

SPIE Medical Imaging

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6913-01, Session 1

Small animal imaging: why we do it, how we do it, and what it tells us (Keynote)

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The mouse provides an essential model for research in the life sciences in that they are biologically and genetically similar to humans, relatively inexpensive, easy to handle and house, and reproduce rapidly. Furthermore, animals now can be bred with characteristics replicated and modeled via genetic manipulations that allow specific traits, including human diseases, to be recapitulated for re-search studies. While animal experimentation traditionally has been performed using tissue and blood sampling where the animal is sacrificed to extract a measurement, small animal imaging systems now are available that allow the animal to survive the experiment. These methods allow the investigator to both visualize and quantify important anatomical and physiological features associated to normal and abnormal biological processes in the intact animal, and to follow disease progression to be followed over time in individual animals. Furthermore, the need to reduce costs and speed development in the pharmaceutical and biotechnological industries has stimulated the adoption of small animal imaging for in vivo measurement of pharmacokinetics and biodistributions in the preclinical steps required for drug discovery. This presentation will describe the development and application of microSPECT and microSPECT/CT as examples for imaging small animal models of cancer, heart disease, and neurological disorders, and for assessing new diagnostic and therapeutic agents at tracer levels in small animal models of disease. These capabilities are expanding use of small animal imaging to understand mammalian biology and disease for studies in modern biological research and development of new diagnostic and therapeutic agents.

6913-02, Session 1

Utility of a prototype liposomal contrast agent for x-ray imaging of breast cancer: a proof of concept using micro-CT in small animals

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Imaging tumor angiogenesis in small animals is extremely challenging due to the size of the tumor vessels. Consequently, both dedicated small animals imaging systems and specialized intravascular contrast agents are required.

The goal of this study was to investigate the use of a liposomal contrast agent for high-resolution micro-CT imaging of tumors in small animals. A liposomal blood pool agent encapsulating iodine with a concentration of 65.5 mg/ml was used with Duke Center for In-Vivo (CIVM) prototype micro-computed tomography (micro-CT) system to image the R3230AC mammary carcinoma implanted in rats. The animals were injected with equivalent volume doses (0.02 ml/kg) of contrast agent. Micro-CT with the liposomal blood pool contrast agent, ensured a signal difference between the blood and the muscle higher than 450 HU allowing the visualization of the tumors 3D vascular architecture in exquisite detail at 100 micron resolution. The micro-CT data correlated well with the hematoxylin and eosin staining. We also studied the ability to detect vascular enhancement with limited angle based reconstruction i.e. tomosynthesis. Tumor volumes and their regional vascular percentage were estimated. This imaging approach could be used to better understand tumor angiogenesis and be the basis for evaluating anti-angiogenic therapies. This work performed at the Duke Center for In Vivo Microscopy, an NCI/NCI National Resource (P41 05959/R24-CA92656), and also supported by NCI (R21 CA124584-01), Komen Foundation (PDF55806), Cancer Research and Prevention Foundation and Neuroradiology Education Research Foundation.

6913-03, Session 1

Respiratory-gated micro-CT of free breathing mice using a carbon nanotube based micro-focus field emission x-ray source

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A four-dimensional (4-D) computed tomography (CT) system for small animal imaging was developed based on a carbon nanotubes (CNT) enabled micro-focus x-ray source recently demonstrated in our laboratory. The x-ray source was switched by electronically switching the gate voltage applied on the carbon nanotube (CNT) cathode through a high voltage pulse generator. The dynamic gating was achieved from a small animal physiological monitor system plus some home made gating electronics. The x-ray pulse firing was gated to the respiratory cycles. The focal spot size of the x-ray source is $\sim 100\mu\text{m}$ \times $100\mu\text{m}$. The current pulse amplitude from the CNT cathode is $\sim 1\text{mA}$. The x-ray pulse duration is 100ms. A two-dimensional (2D) detector with 1024-1024 pixels was used as the image formation device. In our system, the source and detector were fixed and the sample was rotated. The system performance was validated through the in vivo cardiopulmonary imaging of several anesthetized mice.

6913-04, Session 2

HYPR: constrained reconstruction for enhanced SNR in dynamic medical imaging

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During the last eight years our group has developed radial acquisitions with angular undersampling factors of several hundred that accelerate MRI in selected applications. As with all previous acceleration techniques, SNR typically falls at least as fast as the inverse square root of the undersampling factor. This limits the SNR available to support the small voxels which these methods can image over short time intervals in applications like time-resolved contrast-enhanced MR angiography (CE-MRA). Instead of processing each time interval independently, we have developed constrained reconstruction methods that exploit the significant correlation between temporal sampling points. A broad class of methods, termed Highly Constrained Back Projection (HYPR), generalizes this concept to other modalities and sampling dimensions.

HYPR exploits correlations where the index in a series of images represents time, energy, diffusion encoding direction, etc. Composite images formed from a portion or all of the series are used to constrain the information in individual image series frames. The SNR from the composite image is typically fed back into each of the image series frames, providing substantial SNR support for high spatio/temporal resolution acquisitions or permitting substantial radiation, contrast dose reductions or image quality improvements in dynamic X-ray and nuclear applications.

Preliminary results will be presented in phase contrast MRI, where undersampling factors of 1000 have been achieved, as well as CE-MRA, CE breast MRI, diffusion tensor MRI, hyperpolarized ventilation and diffusion MRI, dose-reduced CTA and CT perfusion, dose reduced DSA and X-ray fluoroscopy, dynamic PET/SPECT, photoacoustic tomography and high-resolution ultrasound.

6913-05, Session 2

Technical feasibility of breast cancer screening using ultrasound propagation velocity

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of Western Ontario (Canada)

Both mammography and ultrasound imaging have sub-optimal sensitivity for the detection of solid breast lesions. We investigate the feasibility of detecting occult solid breast lesions using ultrasound propagation velocity differences between malignant lesions and surrounding breast tissue in a phantom study using 3D ultrasound. In this technique, the breast is placed on a flat backplate and imaged using a 3D ultrasound system. The backplate serves as a reference plane in the resulting 3D image. The difference in ultrasound propagation velocity through solid lesions versus surrounding breast tissue produces a shift in the apparent elevation of the backplate in the resulting image. Visible backplate distortion may therefore indicate the presence of an occult solid breast lesion. We provide a mathematical model to predict backplate distortion as a function of lesion thickness, and validate this theory experimentally using multi-compartment agar phantoms with embedded lesions ranging from 2 mm to 16 mm in thickness. Two-dimensional backplate elevation maps were constructed, and visible backplate distortions were observed for lesions of thickness 4 mm and greater. Measured backplate distortions were in excellent agreement with our theoretical predictions for these lesions. This study suggests that ultrasound propagation velocity differences between solid lesions and surrounding tissue may be useful as an additional screening tool for detection and localization of otherwise occult solid breast lesions.

6913-06, Session 2

Experimental proof of an idea for a CT-scanner with dose reduction potential

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Preliminary results for a new CT scanning device with dose-reduction potential were presented at the SPIE Medical Imaging conference 2007. The new device obtains the Radon data after the X-ray beam is collimated through a special mask. This mask is combined with a new geometry that permits an efficient data collection, thus the device has the potential of reducing the dose by a factor of two.

In this work, we report the first complete proof of the idea using the same simplified mask of 197 detectors and in addition a clinical C-arm with a flat panel detector to simulate the gantry. This addition enables the acquisition of data for an independent but complementary reconstruction. Moreover, this clinical set-up enables the acquisition of data for clinically relevant phantoms. Phantom data were acquired using both detector sets and were reconstructed with OPED. Both reconstructions were matched to each other successfully. The performance of the new design was tested through its resolution, noise and artifacts. The results obtained are highly promising, even though the current device acquires only the equivalent to 197 views. Dose comparisons may be now carried out with a more precise prototype, comparable to current devices.

6913-07, Session 2

Imaging with multiprism x-ray lenses

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The multi-prism lens (MPL) is a refractive x-ray lens consisting of two rows of prisms facing each other at an angle. Rays entering the lens at the periphery will encounter a larger number of prisms than will central ones, hence experiencing a greater refraction. The focusing effect of the MPL can be used to gather radiation from a large aperture onto a smaller detector, and accordingly to make better use of the available x-ray flux in medical x-ray imaging. Potential advantages of a better photon economy include shorter acquisition times, a reduced tube loading, or an improved resolution. Since the focusing effect is one-dimensional it matches the design of scanning systems.

In this study we present the first images acquired with an MPL instead of the pre-breast slit collimator in a scanning mammography system.

According to the measurements, the MPL is able to increase the flux 32% at equal resolution compared to the slit collimator, or to improve the resolution 2.4 mm⁻¹ at equal flux. If used with a custom-made absorption filter in a clinical set-up, the gain of flux of the MPL is expected to be at least 45%, and the corresponding improvement in resolution to be 3 mm⁻¹.

6913-08, Session 2

GEANT4 simulation of NSECT for detection of iron overload in the liver

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Neutron stimulated emission computed tomography (NSECT) is being proposed as an experimental technique to diagnose iron overload in humans. The technique uses inelastic scatter interactions between incident neutrons and target nuclei to stimulate characteristic gamma-ray emission that acts as a signature of the emitting target nucleus. Tomographic detection of the emitted gamma-rays yields information about the spatial distribution of the target element in the sample. While early proof-of-concept experiments have suggested that NSECT may have the potential to make a non-invasive diagnosis of iron overload in a clinical system, a tomography application for patient diagnosis has never been tested. This work uses a Monte-Carlo simulation of a clinical NSECT system to investigate the feasibility of detecting iron overload in a simulated human liver. A simulation of a clinical NSECT system is designed in GEANT4 and used to scan a human liver phantom with high-concentration iron lesions through a tomographic scan. The reconstructed image is analyzed for pixel values within regions corresponding to the two high-concentration iron lesions to determine whether a statistically significant difference is observed between the lesions and the background. Analysis results indicate that a wet iron concentration as low as 3 mg/g can be detected in surrounding liver tissue with a p-value ≤ 0.05 through a tomographic scan that delivers only 5.4 mSv of radiation dose to the patient. The research performed here demonstrates that NSECT has the clinical potential for tomographic detection of iron overload in humans.

6913-09, Session 2

Electronic portal imaging using Cherenkov radiation

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Most electronic portal imaging devices (EPIDs) developed so far use a Cu plate/phosphor screen to absorb x rays. The main problem with this approach is that the Cu plate/phosphor screen must be thin (~2 mm) in order to obtain a high spatial resolution, resulting in a low quantum efficiency (QE) for megavoltage (MV) x rays (typically 2-4%). In addition, the phosphor screen contains high atomic number (high-Z) materials, resulting in an over-response of the detector to low energy x rays in dosimetric verification. Our overall goal is to develop a new high QE MV x-ray detector made of a low-Z material for both geometric and dosimetric verification in radiotherapy. Our approach is based on radiation-induced light (Cherenkov radiation) in optical fibers to convert x-ray energy into light. With our approach, a thick (~10-30 cm) fiber-optic taper (FOT) consisting of a matrix of optical fibers aligned with the incident x rays is used to replace the thin Cu plate/phosphor screen to dramatically improve the QE. In this work, we demonstrated that the predominant light source in optical fibers under irradiation of a MV beam is indeed Cherenkov radiation, and thus validated the feasibility of using Cherenkov radiation as the primary light source in our proposed Cherenkov detector. A prototype Cherenkov detector array was also built and images were obtained.

6913-10, Session 3

Photon migration simulator for fluorescence tomography

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Analytically predicting photon paths in high-scattering anisotropic media

is extremely complex, due to significant random scattering events suffered by the light in the tissue and at the boundaries between tissues with different optical properties. A correct optical and anatomical model that statistically predicts the path covered by the photons in tissues of laboratory animals can improve considerably our understanding of how light diffuses within the animals, and therefore help us improving existing experimental setups and reconstruction algorithms for fluorescence mediated tomography (FMT). Here, we present new simulations of photon propagation and fluorescence emission in anisotropic media using realistic models of laboratory animals and a Monte Carlo based approach.

6913-11, Session 3

Computationally efficient perturbative forward modeling for 3D multispectral bioluminescence and fluorescence tomography

J. Dutta, S. Ahn, Univ. of Southern California; C. Li, A. J. Chaudhari, S. R. Cherry, Univ. of California/Davis; R. M. Leahy, Univ. of Southern California

The forward problem of bioluminescence and fluorescence tomography seeks to determine, for a given 3D source distribution, the photon density on the surface of an animal. Photon transport through tissues is commonly modeled by the diffusion equation. The challenge, then, is to accurately and efficiently solve the diffusion equation for a realistic animal geometry and for heterogeneous tissue types.

Fast analytical solvers are available that can be applied to arbitrary geometries but assume homogeneity of tissue optical properties and hence have limited accuracy. The finite element method (FEM) with volume tessellation allows reasonably accurate modeling of both animal geometry and tissue heterogeneity, but this approach is computationally intensive. The computational challenge is heightened when one is working with multispectral data to improve source localization and conditioning of the inverse problem. Here we present a forward model based on the Born approximation that is fast and yet moderately accurate.

Our model introduces tissues heterogeneity as perturbations in diffusion and absorption coefficients at rectangular grid points inside a mouse atlas. These perturbations are accounted for through a correction term added to the homogeneous forward model. The choice of a regular grid with a smaller number of points instead of the tetrahedral tessellations of an FEM model leads to substantial savings. Correlation analyses show that accuracy is preserved to a large degree. Our method allows us to further improve accuracy by iteratively extending it to higher orders with a small overhead cost per iteration.

6913-12, Session 3

3D multispectral light propagation model for subcutaneous vein imaging

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In this paper, we describe a new 3D light propagation model aimed at understanding the effects of various physiological properties on subcutaneous vein imaging. In particular, we will build upon the well known MCML (Monte Carlo Multi Layer) code and present a tissue model that improves upon the current state-of-the-art by: incorporating physiological variation, such as melanin concentration, fat content, and layer thickness; including veins of varying depth and diameter; using curved surfaces from real arm shapes; and modeling the vessel wall interface. We describe our model in detail, present results from the Monte Carlo modeling, and compare these results with those obtained by imaging tissue phantoms.

6913-13, Session 3

Image reconstruction from sparse data samples accounting for variable phase in magnetic resonance imaging

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We present a method for obtaining accurate image reconstruction from sparsely sampled magnetic resonance imaging (MRI) data obtained along Cartesian trajectories. This method minimizes both the total variation (TV) of the estimated image magnitude and the total curvature (TC) of the estimated image phase map, subject to the constraint that the Fourier transform of the complex image matches the known k-space samples. Using this method, we demonstrate accurate image reconstruction from sparse k-space samples using both simulated data and real breast data. By introducing a means of handling the variable phase in MR images, we extend previously presented sparse data reconstruction algorithms to a much broader class of images. Reconstruction from such sparse sampling should reduce scan times allowing more rapid evaluation of time-critical conditions and greater patient comfort during scans.

6913-14, Session 3

A fixed point method for homotopic L0-minimization with application to MR image recovery

J. D. Trzasko, A. Manduca, Mayo Clinic College of Medicine

A novel method for highly-undersampled Magnetic Resonance Image (MRI) reconstruction is presented. One of the principle challenges faced in clinical MR imaging is the fundamental linear relation between net exam duration and admissible spatial resolution. Apart from the diagnostic advantage of higher-resolution studies, increased scan duration diminishes patient comfort while increasing the risk of susceptibility to motion artifact and limits the ability to depict many physiological events at high temporal rates. With the recent development of Compressive Sampling theory, several authors have successfully demonstrated that clinical MR images possessing a sparse representation in some transform domain can be accurately reconstructed even when sampled at rates well below the Nyquist limit by casting the recovery as a convex L1-minimization problem. While L1-based techniques offer a sizeable advantage over Nyquist-limited methods, they nonetheless require a modest degree of over-sampling above the true theoretical minimum sampling rate in order to guarantee the achievability of exact reconstruction. In this work, we present a reconstruction model based on homotopic approximation of the L0 semi-norm and discuss the ability of this technique to reconstruct undersampled MR images at rates even lower than are achievable than with L1-minimization and arbitrarily close to the true minimum sampling rate. A semi-implicit numerical solver is presented for efficient numerical computation of the reconstruction process and several examples depicting the capability for accurate MRI reconstructions from highly-undersampled K-space data are presented.

6913-15, Session 3

Retrospective breathing motion compensation for MRI with continuously moving table

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Breathing motion causes severe artifacts in Magnetic-Resonance Imaging (MRI), which are usually avoided by acquiring data during breathhold or by synchronizing the acquisition with the breathing motion. In MRI with continuously moving table the patient is moved through the magnet during the acquisition to allow for time efficient coverage of arbitrary large body regions. Here standard breathing motion compensation techniques are not applicable: The desired examination region can usually not be covered within one breathhold and synchronization between breathing and table motion requires a variation of table speed, which is technically difficult, sacrifices time efficiency and decreases patient comfort.

In this work a retrospective breathing motion compensation technique for moving table MRI is proposed. Data is acquired during free breathing using multi-shot acquisitions. Thus for each slice position multiple undersampled k-spaces are obtained representing snapshots of the breathing motion. Parallel imaging is used to reconstruct multiple artifact free images for each slice position, each corresponding to a different breathing state. From these images, a motion consistent reference volume is extracted by selecting one out of all available images per slice position, based on the breathing state during acquisition and image

quality criteria. Remaining images are finally mapped onto the reference volume using deformable slice-to-volume registration. Appropriate combination of the reference volume with the deformed images yields a final volume with improved signal-to-noise ratio. Artifacts such as ghosting, blurring or misalignments of organs occurring if data from different breathing states is inconsistently combined are avoided.

6913-16, Session 3

Statistical properties of spin noise in MRI

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Spin noise is inherent in magnetic resonance. It is caused by incomplete cancellation of spin moments when the external static magnetic field is absent or by their small but finite fluctuations when the magnetic field is applied.

Spin noise is viewed as the variation of thermal equilibrium macroscopic magnetization (TEM), and can be described statistically. For MRI, TEM is shown to be characterized by a Binomial distribution and is well approximated by a Gaussian. Parameters of this Gaussian distribution are determined by the spin density and the ratio of population difference over the total population of spins in a unit volume of the sample. Statistics of spin noise not only confirm Bloch's prediction of spin noise in the absence of the external magnetic field, but also give a more accurate account of its behavior under various conditions. These statistics also provide a new insight into the limits of spatial resolution in magnetic resonance microscopy and are consistent with Glover and Mansfield's corresponding conclusions.

6913-17, Session 4

Exploration of the potential performance of polycrystalline silicon-based active matrix flat panel imagers incorporating active pixel sensor architectures

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Conventional active matrix flat-panel imagers (AMFPIs), employing amorphous silicon (a-Si:H) semiconductors, are based on a relatively simple pixel architecture. This consists of a single thin-film transistor (TFT) coupled to a pixel storage capacitor, usually taking the form of a photodiode for indirect detection devices. While this semiconductor-architecture combination has led to the successful creation of imagers for many applications, significant performance limitations have also become apparent. In particular, the high level of additive noise in AMFPIs degrades DQE performance at low x-ray exposures, high spatial frequencies, and fine pixel pitches; the relatively large on-resistance of a-Si:H TFTs limits high-frame-rate operation; and charge trapping in metastable states of a-Si:H photodiodes leads to image lag and memory effects. Intriguingly, progress in the development of large area processes for creating high-quality polycrystalline silicon (poly-Si) TFTs has allowed creation of a first generation of prototype imagers incorporating 1- and 2-stage pixel amplifiers - a circuit architecture referred to as active pixel sensors (APS). From the knowledge and insight gained from empirical evaluations of such prototypes, increasingly sophisticated APS architectures that would largely address the aforementioned limitations are conceivable. In this presentation, a combination of cascaded systems analysis, detailed circuit simulation and achievable design parameters will be used to explore the theoretical performance improvements in readout speed, image lag, and DQE, as a function of pixel pitch, for a number of APS architectures. Finally, prospects for development of such devices will be outlined and the implications of such improvements will be discussed.

6913-18, Session 4

New advances in the development of solid state photomultipliers for medical imaging

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We report the development of a new generation of solid-state photomultipliers for use in medical imaging. The photo-detectors

developed are based on the mechanism of internal discrete amplification that combines high amplification gain and negligible excess noise that in combination surpass the performance parameters of photomultiplier tubes.

Photon detection efficiency is significantly increased over the previous generation of this detector technology and now extends over a wide spectral range of 350 nm to 850 nm. This improvement is combined with the increased dynamic range and subnanosecond timing resolution. These low-voltage robust photo-detectors could be integrated with signal processing electronics, readout circuits and even preprocessing in one silicon chip that creates opportunities for development of highly integrated detector systems for medical imaging.

These improvements overcome the problems that hinder the use of traditional SiPMs and arrays of Geiger-mode APDs in medical imaging.

Advantages of the new detector are described in reference to several medical imaging modalities. The detector could be used with the both blue and green scintillators in PET and other nuclear medicine applications, providing improved energy, spatial and temporal resolution. Because of insensitive to magnetic fields, the use of this detector permits easy combination of PET and MRI modalities in the same imaging system. We outline using this detector technology in fluorescence imaging, including laser scanning fluorescence microscopy where the ability to count a small number of photons in a nanosecond pulse permits non-destructive investigation of live cells. We also discuss the use of this technology in time-resolved fluorescence imaging. We describe potential advantages of employing the detector in optical time-domain brain and breast imaging.

6913-19, Session 4

The solid-state x-ray image intensifier (SSXII): an EMCCD-based x-ray detector

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The solid-state x-ray image intensifier (SSXII) is an EMCCD-based x-ray detector designed to satisfy an increasing need for high-resolution real-time images, while offering significant improvements over current flat panel detectors (FPDs) and x-ray image intensifiers (XII). FPDs are replacing XIIs because they reduce/eliminate veiling glare, pincushion or s-shaped distortions and are physically flat. However, FPDs suffer from excessive lag and ghosting and their performance has been disappointing for low-exposure-per-frame procedures due to excessive instrumentation-noise. XIIs and FPDs both have limited resolution capabilities of ~3 lp/mm. To overcome these limitations a prototype SSXII module has been developed, consisting of a 1k x 1k, 8 μ m pixel EMCCD with a fiber-optic input window, which views a 350 μ m thick CsI(Tl) phosphor via a magnifying fiber-optic-taper (FOT). Arrays of such modules will provide a larger field-of-view. Detector MTF, DQE, and instrumentation-noise equivalent exposure were measured to evaluate the SSXII's performance using a standard x-ray spectrum (IEC RQA5), allowing for comparison with current state-of-the-art detectors. The MTF was 0.31 at 3 lp/mm, double that of standard detectors, and better than 0.05 at 9 lp/mm with FOT magnification ratios as large as 6:1, demonstrating superior resolution capability. DQE curves indicate no degradation from high-angiographic to low-fluoroscopic exposures (<2% deviation in overall DQE from 5 mR to 2.6 μ R), demonstrating negligible instrumentation-noise, even with low input signal intensities. The SSXII is thus shown to provide significant improvements over current FPDs and XIIs, including correctable image distortions, no lag or ghosting, superior resolution and negligible instrumentation-noise.

6913-20, Session 4

Parameter investigation and first results from a digital x-ray flat panel detector with forward bias capability

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Digital flat panel a-Si x-ray detectors can exhibit image lag of several

percent. The image lag can limit the temporal resolution of the detector, and introduce artifacts into CT reconstructions. It is believed that the majority of image lag is due to defect states, or traps, in the a-Si layer. Software methods to characterize and correct for the image lag exist, but they may make assumptions such as the system behaves in a linear time-invariant manner. The proposed method of reducing lag is a hardware solution that makes few additional hardware changes. For pulsed irradiation, the proposed method inserts a new stage in between the readout of the detector and the data collection stages. During this stage the photodiode is operated in a forward bias mode, which fills the defect states with charge. Parameters of importance are current per diode and current duration, which were investigated under light illumination by the following design parameters: 1.) forward bias voltage across the photodiode, 2.) number of rows simultaneously forward biased, and 3.) duration of the forward bias current. From measurements, it appears that good design criteria are 8 or fewer active rows, 4V (or less) forward bias voltage, and a row frequency of 100kHz or less. Overall, the forward bias method has been found to reduce first frame lag by as much as 96%. The panel was also tested under x-ray irradiation. Image lag improved (94% reduction), but the temporal response of the scintillator became evident in the turn-on step response.

6913-21, Session 4

An indirect flat-panel detector with avalanche gain for low dose x-ray imaging: SAPHIRE (scintillator avalanche photoconductor with high resolution emitter readout)

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An indirect flat panel imager with programmable avalanche gain and field emitter array (FEA) readout is being investigated for low-dose x-ray imaging with high resolution. It is made by placing a structured x-ray scintillator CsI (TI) in direct contact with an amorphous selenium (a-Se) avalanche photoconductor called HARP (high-gain avalanche rushing photoconductor). The charge image created by HARP is read out by electron beams generated by the FEA. The proposed detector is called SAPHIRE (Scintillator Avalanche Photoconductor with High Resolution Emitter readout). The avalanche gain of HARP depends on both a-Se thickness and applied electric field E_{Se}. At E_{Se} of > 80 V/μm, the avalanche gain can enhance the signal at low dose (e.g. fluoroscopy) and make the detector x-ray quantum noise limited down to a single x-ray photon. At high exposure (e.g. radiography), the avalanche gain can be turned off by decreasing E_{Se} to < 70 V/μm. The purpose of this paper is to investigate the potential x-ray imaging performance of SAPHIRE including dynamic range, detective quantum efficiency (DQE) as a function of exposure and operational conditions, spatial resolution and temporal performance (e.g. lag). A prototype HARP-FEA sensor with 640 x 480 pixels and 20 x 20 μm pixel size was optically couple to the output of an x-ray imaging intensifier (XRRI) with variable zoom. The use of an XRRI allows the investigation of HARP-FEA with different effective pixel sizes. In the final configuration of SAPHIRE, the CsI layer will be in direct contact with the fiber optic faceplate (FOP) of the HARP-FEA sensor.

6913-22, Session 5

Detective quantum efficiency of an energy resolving photon counting detector

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The output response characteristics of a photon counting detector are measured experimentally and simulated using a Monte Carlo method in order to quantify the loss of statistical information due to pile-up. The analysis is applied to idealize counting detector models, but is adaptable to realistic event processing that is not amenable to analytic solution. In particular, the detective quantum efficiency (DQE) is calculated as a function of flux rate and shown to have an intermediate zero for

the paralyzable case at the maximum periodic rate. The progressive degradation of the spectral response as a function of increasing flux rate is also modeled. Analogous metrics to DQE are defined in regards to the detector's ability to resolve atomic number and enhance image contrast based on atomic number differentiation. Analytic solutions are provided for the output and linearized response statistics and these interpolate well across the Monte Carlo and experimental results.

6913-23, Session 5

An efficient depth- and energy-dependent Monte Carlo model for columnar CsI detector

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We developed an efficient, depth- and energy-dependent Monte Carlo model for indirect columnar CsI detectors. The optical photon, electron/positron Monte Carlo package MANTIS developed by our group, was used to generate optical photon distributions and collection efficiencies as a function of the x-ray/electron interaction depth and deposited energy for a realistic scintillator geometry. The detector geometry we used for the simulations was reported in the past and is based on a 500  1/4m columnar CsI scintillator. The resulting distributions indicated that the width of the optical spread at the scintillator exit surface varies linearly in the range of 6 to 64  1/4m depending on the interaction depth. The peak of the depth-dependent optical spread has a total spatial shift of a 53  1/4m. The optical photon collection efficiency at the photo diode layer follows a power law varying from 90% for interactions at the scintillator exit surface to 20% for interactions at the detector entrance. The distributions we generated were consequently incorporated into penMesh, a PENELOPE based Monte Carlo xray, electron/positron transport simulation package for generating clinically realistic images of triangular mesh phantoms. The resulting detector model is compared against a full simulation using MANTIS.

6913-24, Session 5

CIX: a detector for spectrally enhanced x-ray imaging by simultaneous counting and integrating

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A hybrid pixel detector based on the concept of simultaneous charge integration and photon counting will be presented. The second generation of a counting and integrating X-ray prototype CMOS chip (CIX) has been operated with different direct converting sensor materials (CdZnTe and CdTe) bump bonded to its 8x8 pixel matrix. Photon counting devices give excellent results for low to medium X-ray fluxes but saturate at high rates, while charge integration allows the detection of very high fluxes but is limited at low rates by the finite signal to noise ratio. The combination of both signal processing concepts therefore extends the resolvable dynamic range of the X-ray detection. Moreover, for a large region of the dynamic range, where counter and integrator operate simultaneously, the mean energy of the detected X-ray spectrum can be calculated in each pixel. This additional spectral information can be used to enhance the contrast of the X-ray image. The advantages of the counting and integrating signal processing concept and the performance of the imaging system will be reviewed. The performance of the system with respect to long-term stability, homogeneity and dynamic range will be discussed and examples of imaging with additional spectral information will be presented.

6913-25, Session 5

Characterization of the new co-doped CsI microcolumnar films for high-speed radiographic imaging

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Scintillation detectors are used in wide variety of nuclear and medical

applications. While wide choices of new scintillators are now available, CsI:Tl remains a highly desirable material due to its excellent properties, low cost, and easy availability. However, despite its well-known advantages, CsI:Tl has two characteristic properties that undermine its use in clinical/high speed imaging: an afterglow component in its scintillation decay, and a hysteresis effect that causes non-deterministic change in its scintillation yield after high exposure. We have found that adding a second dopant, Sm^{2+} , to the crystals, suppresses both afterglow and hysteresis, making the material useful for such applications as high-speed radiography and X-ray CT. The addition of Sm^{2+} ions to CsI:Tl crystals suppresses their afterglow by a factor of 50 even when subjected to very high exposure of 120R. Conventional CsI:Tl shows a hysteresis on the order of 10%, compared to only 0.5% for CsI:Tl,Sm. This is a significant result, which shows a factor of 20 improvement in hysteresis compared to the standard CsI:Tl.

Here we report on growth and characterization of microcolumnar films of the co-doped CsI formed by thermal vapor deposition. These films exhibit excellent columnar structure, high resolution and contrast. Specifically, we have fabricated films in the range of 50-250nm thickness, characterized their performance in terms of afterglow, hysteresis, and resolution, and integrated them into a high resolution CCD camera to evaluate the resulting detector's DQE. Implications of this new development for future high-speed X-ray imaging and cone-beam CT applications will be discussed.

6913-26, Session 5

Recent developments in scintillating fiber detection systems in radiation therapy

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Sophisticated radiotherapy techniques lead to more conformal dose distributions but increase treatment complexity. Image guidance allows for varying degrees of accuracy in patient set-up. However, the consequences of inaccurate set-up and/or patient motion during treatment become more serious when treatment doses are increased and treatment margins are decreased. Thus, we need to know if we have delivered the dose as planned. This has driven the development of plastic scintillation detector systems for accurate measurements in real time with high spatial resolution. We have developed a clinical prototype comprising 29 scintillating fiber detectors 1 mm in diameter and 2 mm in length. The detectors are coupled to clear optical fibers that collect the scintillation photons and transport them to a CCD for detection. Open field profiles and depth-dose profiles in Plastic Water were compared to ionization chamber measurements in water. The maximum in-field relative difference was 1.6%. With a standard deviation for in-field measurements smaller than 1 %, this prototype array was found to be accurate, precise and practical. Monte Carlo simulations were also used to evaluate the response of the scintillation detector to proton beams and to optimize the light collection efficiency. The Monte Carlo code Geant4 was used to simulate dose deposition, the production of scintillation photons and the propagation of those photons inside the scintillation detector. Further development of the system will allow thousands of measurement points distributed in a three-dimensional volume per single irradiation, therefore producing a rapid evaluation of complex dose distribution.

6913-27, Session 5

Photon counting readout pixel array in 0.18- μm CMOS technology for on-line gamma-ray imaging of 103-palladium seeds for permanent breast seed implant (PBSI) brachytherapy

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Permanent breast seed implant (PBSI) brachytherapy technique was recently introduced as an alternative to high dose rate (HDR) brachytherapy and involves the permanent implantation of radioactive 103Palladium seeds into the surgical cavity of the breast for cancer

treatment. To enable accurate seed implantation, this research introduces a gamma camera based on a hybrid amorphous selenium detector and CMOS readout pixel architecture for real-time imaging of 103Palladium seeds during the PBSI procedure. A prototype chip was designed and fabricated in 0.18- μm n-well CMOS process. We present the experimental results obtained from this integrated photon counting readout pixel.

6913-28, Session 6

Towards a full-reference, information-theoretic quality assessment method for x-ray images

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The goal of this work is to perform information-theoretic image quality assessment on cardiovascular X-ray images, using a full-reference scheme. With the growth of advanced signal processing in medical imaging, such an approach will enable objective comparison of the quality of processed images. A concept for describing the quality of an image is to express it in terms of its information capacity. Shannon has derived this capacity for noisy channel coding. However, for X-ray images, the noise is signal-dependent and non-additive, so that Shannon's theorem is not directly applicable. To overcome these complications, we exploit the fact that any invertible mapping on a signal does not change its information content. We show that it is possible to transform the images in such a way that the Shannon theorem can be applied. A general method for calculating such a transformation is used, given a known relation between signal mean and noise standard deviation. After making the noise signal-independent, it is possible to assess the information content of an image and to calculate an overall objective quality metric (e.g. information capacity) which includes the effects of sharpness, contrast and noise. We have applied this method on phantom images under different acquisition conditions and computed the information capacity for those images. We aim to show that the results of this assessment are consistent with variations in noise, contrast and sharpness, introduced by system settings and image processing.

6913-29, Session 6

Generalized objective performance assessment of a new high-sensitivity microangiographic fluoroscopic (HSMAF) imaging system

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The generalized objective performance evaluation metrics, termed Generalized Modulation Transfer Function (GMTF), Generalized Noise Power Spectrum (GNPS), Generalized Noise Equivalent Quanta (GNEQ), and Generalized Detective Quantum Efficiency (GDQE), have been developed to incorporate geometric unsharpness due to the finite size of the focal spot and scattered radiation in addition to the detector properties. These metrics were used to assess the total-imaging-system performance of the HSMAF, a custom-built, high-resolution, real-time-acquisition detector with 35 μm pixels, in simulated neurovascular angiographic conditions using a uniform head-equivalent phantom. The HSMAF consists of a 300- μm -thick structured CsI(Tl) scintillator coupled to a 4 cm diameter, variable-gain, Gen2 light image intensifier with dual stage microchannel plate, followed by direct fiber-optic coupling with a 30 fps CCD camera, and is capable of both fluoroscopy and angiography. Effects of focal spot size, geometric magnification, irradiation field-of-view, and air-gap between the phantom and the detector were evaluated. The resulting plots of GMTF and GDQE showed that geometric blurring is the more dominant image degradation factor at high spatial frequencies, whereas scatter dominates at low spatial frequencies, yet the HSMAF maintains substantial capability ($\text{GDQE} > 5\%$) at frequencies above 4 lp/mm where conventional detectors cannot operate. The loss in detector SNR due to scatter or focal-spot unsharpness could be compensated by increasing the exposure by a factor of 2 - 3. This generalized evaluation method may be used to more realistically evaluate and compare total system performance leading to improved and optimized total system

designs. (Partial support: NIH grants R01NS43294, R01EB002873; Toshiba Medical Systems)

6913-30, Session 6

Physical characterization of digital radiological images by use of transmitted information metric

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This paper presents an information-entropy based metric for combined evaluation of resolution and noise properties of radiological images. The metric is expressed by the amount of transmitted information (TI). It is a measure of how much information that one image contains about an object or an input. The amount of TI depends on the distribution of the grayscale pixel values after imaging and it will be low when the image becomes very noisy or blurred. Merits of the proposed method are its simplicity of computation and the experimented setup. Acrylic step wedges were used as test sample objects for experiments. An imaging plate for computed radiography was employed as a detector to record X-ray intensities.

We investigated the effects of noise and resolution degradation on the amount of TI by varying exposure levels and by employing various effective focal spot sizes of the X-ray tube. Experimental results show that the TI value increases with the increase in the exposure dose and decreases when blur is deteriorated. To validate the reasoning and usefulness of the proposed metric, we also calculated and compared the presampling modulation transfer functions and noise power spectra. Results show that the TI has close correlation with both image noise and image blurring, and it may offer the potential to become an alternative and generally applicable measure for quality evaluation of medical images.

6913-31, Session 6

A perfusion phantom for quantitative medical imaging

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Many of the problems in studying and improving quantitative perfusion measurement can be avoided by implementing an artificial model of tissue, a perfusion phantom. Using a well-designed phantom many of the characteristics of real tissues can be simulated. The geometry of the vascular network could be designed in a way that simulates different vascular diseases. Different sources of error in measurements can be studied separately. Perfusion-related parameters can be calculated very precisely using a computational fluid dynamics software and can be used to verify the accuracy of perfusion measurement techniques.

In this research a perfusion phantom, generated using lithography micro-fabrication techniques, is presented. Using this approach we have the capability of creating micro-channels in the same size scale as actual capillaries in tissues. The perfusion phantom can be used in both diffusible and non-diffusible tracers' studies. For non-diffusible tracers both the substrate and the fabricated layer are made of polydimethylsiloxane (PDMS). To study diffusible tracers the substrate would be made of agarose gel since it exchanges water with micro-channels in a similar time scale as it happens in capillaries-tissues. Also our experiments show that the uptake-washout curve in agarose is very similar to that in actual tissues.

Using computational fluid dynamics software, perfusion parameters including the blood volume, flow and the transition time in the micro-channels network were calculated to be in the range of brain perfusion values. The correlation between the calculated and the measured values of perfusion-parameters can be used for calibration or accuracy investigation in quantitative imaging.

6913-32, Session 6

Voxel models representing the male and female ICRP reference adult: a dosimetric tool for medical imaging

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For optimisation in diagnostic medical imaging it is important to consider the relation between diagnostic image quality and patient dose. In the past, schematic representations of the human body were commonly used for dosimetric simulations. During the last two decades, voxel models were introduced as an improvement to these body models. Studies performed by various research groups have shown that the more realistic organ topology of voxel models constructed from medical image data of real persons has an impact on calculated doses for external as well as internal exposures. As a consequence of these findings, the ICRP decided to use voxel models for the forthcoming update of organ dose conversion coefficients. These voxel models should be representative of an average population, i.e. they should resemble the ICRP reference anatomical data with respect to their external dimensions and their organ masses. To meet the ICRP requirements, our group at the GSF constructed voxel models of a male and female adult, based on the voxel models of two individuals whose body height and weight resembled those of the male and female ICRP reference adult. The organ masses of both models were adjusted to the ICRP reference anatomical data, without spoiling their realistic anatomy. The paper describes the method used for this process and the resulting voxel models.

6913-33, Session 7

Optimization of dual energy contrast enhanced breast tomosynthesis for improved mammographic lesion detection and diagnosis

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Dual energy contrast enhanced breast tomosynthesis has been proposed as a technique to improve the detection of early-stage cancer in young, high-risk women. This study focused on optimizing this technique using computer simulations. The computer simulation included analytical calculations that identified the optimal beam qualities, distribution of dose between the two images, and weighting factor for the dual energy subtraction to maximize the subtracted images' contrast-to-noise ratio (SdNR). Importantly, the SdNR included both anatomical and quantum noise sources, as dual energy imaging reduces anatomical noise at the expense of increases in quantum noise. The analytical calculations found that for tomosynthesis projection doses the maximum SdNR occurred for Gaussian beams with mean energy (21 keV, 41 keV). The visibility of the iodinated lesion, as measured by the SdNR, increased from 0.3 and 2.6 for the low and high energy image, respectively, to 120 for the dual energy subtracted image. These analytical calculations were followed by Monte Carlo simulations that included the effects of scattered radiation and detector properties. Finally, the feasibility of this technique was tested in a small animal imaging experiment using a novel iodinated liposomal contrast agent. The results illustrated the utility of dual energy imaging and determined the optimal acquisition parameters for this technique. This work was supported in part by grants from the Komen Foundation (PDF55806), the Cancer Research and Prevention Foundation, and the NIH (NCI R21 CA124584-01). CIVM is a NCCRR/NCI National Resource under P41-05959/U24-CA092656.

6913-34, Session 7

Optimization of beam parameters and iodine quantification in dual-energy contrast enhanced digital breast tomosynthesis

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Dual-Energy Contrast Enhanced Digital Breast Tomosynthesis (DE CEDBT) is a promising technique for breast cancer detection, which combines the strengths of functional and 3D imaging. In the present study, we first focused on the optimization of the acquisition parameters for the low and high-energy projections, which leads to a trade-off between image quality in the recombined slices and the Average Glandular Dose (AGD) delivered to the patient. Optimized parameters were found and experimentally validated on phantom images. Then, we addressed the problem of iodine quantification in the recombined

slices. In DE CEDBT, iodine quantification is limited by the z-resolution, due to the restricted angle acquisition inherent to tomosynthesis. We evaluated the lesion thickness above which determination of iodine volumetric concentration is possible. For lesions below this thickness, estimation of iodine concentration is possible if a priori information or a model on the shape of the lesion is available. Iodine quantification for lesions located near the breast boundary can also be challenging, due to scatter border effects and variation of the breast thickness in this region. A scatter correction algorithm based on a deconvolution scheme and a thickness compensation algorithm were applied on the low and high-energy projections. Corrected images show a more accurate quantification of iodine.

6913-35, Session 7

Multiprism x-ray lenses for dual energy imaging

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Dual-energy subtraction imaging is a method to improve the contrast provided by contrast agents in medical x-ray imaging. Two images, acquired at x-ray energies above and below an absorption edge of the agent material, are logarithmically subtracted, resulting in suppression of the signal from tissue and a relative enhancement of the signal from the agent. Although promising, dual-energy subtraction is still not widely used in clinical practice. One reason thereto is the need for two distinctly separated x-ray spectra that are still close to the absorption edge; obtaining such spectra is not an easy task. In this study, spectra filtered with a multi-prism lens (MPL) are evaluated for dual-energy subtraction imaging. The MPL is a refractive x-ray lens with chromatic properties that offers more efficient energy filtering than absorption filters. An MPL spectrum can be tuned to center on the absorption edge of the agent for electronic splitting with an energy sensitive detector. Alternatively, two MPL-filtered spectra with peaks above and below the absorption edge can be combined in two separate exposures. The potential dose reductions compared to other methods for dual-energy subtraction are calculated for a model mammography system, and experimental data are presented in support of the theoretical results.

6913-36, Session 7

NEQ and task in dual-energy imaging: from cascaded systems analysis to human observer performance

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The relationship between theoretical descriptions of imaging performance (Fourier-based cascaded systems analysis) and the performance of real human observers was investigated for various detection and discrimination tasks. Dual-energy (DE) imaging provided a useful basis for investigating this relationship, because it presents a host of acquisition and processing parameters that can significantly affect NEQ and human observer performance. The detectability index for the Fisher-Hotelling model observer (with and without internal noise) was computed theoretically using: 1) cascaded systems analysis of the modulation transfer function (MTF) and noise-power spectrum (NPS) for DE imaging; and 2) a Fourier description of imaging task. Three idealized tasks were considered: sphere detection, shape discrimination (sphere vs. disk), and texture discrimination (uniform vs. textured disk). Based upon DE images of phantoms acquired on a pre-clinical imaging system, human observer performance was assessed in terms of the area under the ROC curve (Az) estimated from MAFC tests. The degree to which the theoretical detectability index correlated with human observer performance was investigated, and results agreed well over a broad range of imaging conditions, depending on the choice of observer model. Results demonstrated that optimal DE image acquisition and decomposition parameters depend significantly on the imaging task. These studies provide important initial validation that the detectability index derived theoretically by Fourier-based cascaded systems analysis represents a meaningful metric for actual human observer performance.

6913-37, Session 7

Low-dose dual-energy computed tomography for PET attenuation correction with statistical sinogram restoration

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Dual-energy (DE) X-ray computed tomography (CT) has been proposed as an useful tool for quantitative CT in medical diagnosis and material characterization in non-destructive evaluation. One promising application is DE-CT for attenuation correction in positron emission tomography (PET). Conventional DE-CT methods for sinogram decomposition have been mainly based on logarithmic transformation and ignored noise, leading to noisy solutions, especially for low-dose DE-CT. In this paper, we propose two novel methods for DE-CT sinogram restoration based on statistical models: penalized weighted least square (PWLS) and penalized likelihood (PL), restoring component sinograms with more accuracy than the conventional approach. Simulation indicates that the proposed methods provide less noisy sinograms and reconstructed images than the conventional one, showing promise for attenuation correction in emission tomography.

6913-38, Session 7

Analysis of fast kV-switching in dual energy CT using a pre-reconstruction decomposition technique

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Fast-kV-switching dual energy CT alternates the high and low energy data sets with the odd and even views. Its advantage over slow-kV-switching (alternates high and low energy data sets with rotations) is because of the good temporal registration between data sets and its suitability to various source trajectories. The disadvantages are the one view spatial mis-registration between the low and high energies, poor spectrum separation if the switching is more sinusoidal rather than square-wave, and higher noise in the low voltage data if the mA cannot vary counter to the kV. With our recently developed pre-reconstruction decomposition method in dual energy CT, we investigated these issues through a series of numerical simulation studies. It was found that no significant artifacts of view mis-registrations appear in the images from the symmetric match scheme. For 1800 views-per-rotation, the pre-reconstruction decomposition is stable to the inconsistencies of the mis-registration and noise for the square-wave waveform with voltage pairs of 80/135 and 100/135 kV. As the spectrum separation become smaller for voltage pair of 120/135 kV, the decomposition amplifies the inconsistency, which results in strong streak artifacts in the reconstructed images. Other results will be ready for the conference. The tentative conclusion is that it is feasible to perform pre-reconstruction decomposition for fast kV-switching in dual energy CT with a practical view sampling (total views of 1800 per revolution) and a reasonable spectrum separation (low voltage of 100 kV and high voltage of 135 kV).

6913-39, Session 8

Three-dimensional computer generated breast phantom based on empirical data

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The goal of this work is to create a detailed three-dimensional (3D) digital breast phantom based on empirical data and to incorporate it into the four-dimensional (4D) NCAT phantom, a computerized model of the human anatomy widely used in imaging research. Twenty sets of high-resolution breast CT data will be used to create anatomically diverse models. The datasets will be segmented using techniques developed in our laboratory and the breast structures will be defined using a combination of non-uniform rational b-splines (NURBS) and subdivision surfaces (SD). Imaging data from various modalities will be simulated to demonstrate the utility of the new breast phantoms. Finite element techniques will be used to deform the breast models to simulate modalities (mammography and tomosynthesis) that involve compression. Initial studies using one CT dataset indicate that the simulated breast

phantom is capable of providing a realistic and flexible representation of breast tissue and can be used with different acquisition methods to test varying imaging parameters such as dose, resolution, and patient motion. The final model will have a more accurate depiction of the internal breast structures and will be scaleable in terms of size and density. With the ability to simulate realistic, predictive patient imaging data, we believe the phantom will provide a vital tool to investigate current and emerging breast imaging methods and techniques.

6913-40, Session 8

Using mastectomy specimens to develop breast models for breast tomosynthesis and CT breast imaging

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Dedicated x-ray computed tomography (CT) of the breast using a cone-beam flat-panel detector system is a modality under investigation by a number of research teams. As previously reported, we have fabricated a prototype, bench-top flat-panel CT breast imaging (CTBI) system and developed computer simulation software to model such a system. We are developing a methodology to use high resolution, low noise CT reconstructions of fresh mastectomy specimens for generating an ensemble of 3D digital breast phantoms that realistically model 3D compressed and uncompressed breast anatomy. These breast models can be used to simulate realistic projection data for both breast tomosynthesis and CT systems thereby providing a powerful evaluation and optimization mechanism.

6913-41, Session 8

Quantifying breast structure in digital breast tomosynthesis

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Purpose: An advantage of digital breast tomosynthesis (DBT) is that it can reduce the amount of breast structure in a given reconstructed slice compared to a conventional mammogram. This should improve the detectability of breast cancer. Burgess et al. have shown that the power spectrum of a screen-film mammogram follows a power law ($1/f\beta$) and that β can be used to predict the detectability of masses in a mammogram. We hypothesize that β for reconstructed tomosynthesis slices is reduced compared to that of tomosynthesis projection images.

Method and Materials: Following the method of Burgess et al., we measure β for reconstructed slices and the corresponding projection images. Sixty DBT image sets were used, each consisted of 11 projection images and 33-85 reconstructed slices of a normal breast. All images were acquired on a GE prototype system and a maximum-likelihood-expectation-maximization reconstruction was used.

Results: On average, β was reduced from 3.05 for the projections to 2.85 for the reconstructed slices. The average difference between the slices and the projections for a given case was 0.195 with 95% CI of [0.175,0.221]. A two-tailed, paired student t-test showed that this difference was statistically significant at a p-value <0.001 .

Conclusions: Our result confirms that DBT can reduce the amount of breast structure in a mammogram, which should lead to improve detectability of breast masses. We plan to test whether β can be used to optimize DBT in a future study.

6913-42, Session 8

Simulation of mammograms and tomosynthesis with cone beam breast CT images

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Method and Materials: In order to model the attenuating object, cone beam CT images of a mastectomy breast specimen was acquired on a

rotation phantom, stationary gantry bench top system. Re-projection with parallel computation software was developed based on ray summing algorithm and implemented on a general-purpose PC cluster. In order to simulate mammograms and tomosynthesis, CT numbers under 80kVp of cone beam CT images were re-scaled to 30 kVp and thus generate a 3-D breast map of linear attenuation coefficients. And then it was deformed to simulate a compressed breast. A single projection image of this compressed breast was considered as mammogram, and the re-projection images for a stationary detector and a linearly shifted x-ray source can simulate the tomosynthesis imaging. The resulting images were then used to reconstruct tomosynthesis mammograms using various algorithms. Microcalcifications (MCs) were segmented from cone beam CT images and enhanced during re-projection preserve the contrast of MCs in projection images and reconstructed tomosynthesis.

Results: Re-projection software with parallel computation we developed can improve the simulation speed significantly. We have successively use cone beam CT images of mastectomy breast specimens to generate 3-D maps of attenuation coefficients to model compressed breasts and simulate digital mammograms and tomosynthesis images. It was found that MCs clearly visible in cone beam CT images were not visible in regular mammograms but faintly visible in tomosynthesis images. The MCs were clearly visible in both MC enhanced mammograms and tomosynthesis images reconstructed from them.

Conclusions: Cone beam CT images may be used to model a compressed breast for simulating mammograms and tomosynthesis images. MC enhanced re-projection could be useful in displaying the cone beam CT images with the more conventional appearances of regular and tomosynthesis mammograms while maintaining the contrast and visibility of MCs in the CT images.

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6913-43, Session 8

Breast percent density estimation from 3D reconstructed digital breast tomosynthesis images

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Breast density is known to highly correlate with breast cancer risk. Breast density is quantitatively measured as percent density (PD), the percentage of non-fatty (dense) tissue in mammograms. To date, clinical estimates of PD have varied significantly, in part due to the projective nature of mammography. Digital breast tomosynthesis (DBT) is a novel 3D imaging modality in which cross-sectional images are reconstructed from a small number of source projections acquired at different x-ray tube positions. DBT is superior to mammography in tissue visualization. By filtering the superimposed anatomical structures present in mammograms, DBT could provide a more realistic estimation of volumetric PD. In this paper, we propose a method to estimate 3D PD from DBT images. Our method uses a semi-automated thresholding technique; preprocessing steps are applied to exclude the image background and the area of the pectoral muscle. Threshold values are first selected manually from only a small number (3-7) of reconstructed slices; the average of these thresholds is then applied to each tomographic slice throughout the entire reconstructed DBT volume. Our population included women with recently detected abnormalities and previous cancer patients; only contralateral breasts were considered in our analysis. The images were retrospectively collected from an on-going multimodality imaging trial at our department. We computed the correlation between the DBT PD estimate and the corresponding mammographic PD; strong correlation was observed between the two modalities. The tomographic variation of PD was investigated for each case.

6913-44, Session 9

Evaluation of a variable dose acquisition methodology for breast tomosynthesis

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The purpose of this study is to evaluate the recently proposed variable dose (VD) acquisition scheme that has been hypothesized to overcome the limitations of microcalcification detection in breast tomosynthesis (BT). In this acquisition methodology, approximately half of the total dose is used for one central projection. This central projection view is similar to a conventional mammogram and used to detect microcalcifications. The other half of the total dose is split among the rest of the projection views. These variable dose projection data are then reconstructed and the 3D slices are used for detection of masses. This novel acquisition methodology can potentially overcome the current limitations with microcalcification detection in breast tomosynthesis (BT) and may result in faster and more accurate detection of both microcalcifications and masses. Having access to both a conventional mammogram (i.e., the central projection) and tomosynthesis slices would also act as a bridge for radiologists who are used to viewing single projection images. In the current study, a comparison of microcalcification detection accuracy obtained using VD and conventional BT was conducted. A rigorous computer simulation was used to model the realistic noise and blur encountered in BT systems. The simulation used a compressed breast phantom, modeled using CT images of compressed mastectomy specimens. Localization receiver operating characteristic (LROC) analysis was performed for detecting microcalcifications of size ranging from 147 microns to 178 microns. The results suggested higher microcalcification detection and localization accuracy using the VD technique. To the best of our knowledge this is the first time a task based evaluation strategy has been performed to study the previously proposed VD technique.

6913-45, Session 9

Novel gantry-free digital breast tomosynthesis (DBT) system using a stationary multibeam field emission x-ray source array based on carbon nanotubes

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X-ray digital breast tomosynthesis (DBT) allows for digital tomography of the breast with three-dimensional reconstruction and has the potential to allow radiologists to see breast cancers better even in very dense breasts. Preliminary studies have suggested that this technique does reduce structured noise and improve the visibility of subtle breast cancers in women with dense breasts at a similar dose to two-view screen-film mammography. The current commercial DBT scanner utilizes a conventional single-source x-ray tube mounted on a gantry that rotates around the breast to provide the viewing angles required through either a step-and-shoot process or continuous rotation. This design prolongs the scanning time and causes imaging blurring. The purpose of the present study is to develop a stationary DBT scanner that can generate all the projection images without mechanical motion of either the source or the detector. The new design utilizes a newly developed multi-beam field emission x-ray (MBFEX) source array that provides 25 views over 48 degree angles in a geometry that closely resembles that of the conventional systems. The Mo/Mo x-ray source can be operated at 0-100kVp with a peak tube current of 10mA (per pixel) and an isotropic x-ray focal spot size of 200 μ m. The scan time for 25 views at the total dose of 75mAs is 8-11s which can potentially be reduced to 2-4s by using x-ray sources with focal spot size of 300 μ m. Projection and reconstructed images from a standard breast-imaging phantom obtained from this system were analyzed.

6913-46, Session 9

Imaging CDMAM phantom with tomosynthesis

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We studied the use of the mammography contrast detail phantom (CDMAM) with tomosynthesis to evaluate the performance of our system as well as to explore the application of CDMAM in 3D breast imaging. The system was Hologic's 1st generation tomosynthesis machine [SPIE 5745-61]. CDMAM phantom plus PMMA slabs were imaged eight times at each of the 3 cm, 5 cm, 7 cm, and 9 cm PMMA equivalent thickness, with 11 projections acquired per scan over 15 degree angle. CDMAM images were reconstructed using back projection, and were scored with

the CDCOM automatic analysis program, available from the EUREF website. Then, average contrast detail curves at each thickness were obtained with psychometric curve fitting method applied.

We studied factors that affected CDMAM results in 3D tomosynthesis imaging, including the in-plane reconstruction pixel size, the slice-to-slice step size, the location of the CDMAM inside the PMMA slabs, and scatter effects. In addition, we also analyzed the CDMAM image in each of the projection images of a scan and related the results to the reconstructed image.

This paper will present results of CDMAM performance of the system, as well as their dependence on the various factors, and limitations of the study. We will also make proposals to modify the CDMAM analysis methods, to optimize the method for 3D breast tomosynthesis.

6913-47, Session 9

Evaluation of software in reading images of the CDMAM test object to assess digital mammography systems

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European Guidelines for quality control in digital mammography specify minimum and achievable standards of image quality in terms of threshold contrast, based on readings of images of the CDMAM test object by human observers. However this is time-consuming and has large inter- and intra-observer error. To overcome these problems a software program (CDCOM) is available to automatically read CDMAM images. After some further analysis the automated measurements can be used to predict the threshold contrast for a typical observer. The results of threshold contrast determination by human observers at three different centres were compared against automated readings. These data provide a means of predicting average human performance using the automated reading software. The coefficient of variation in automatically determined threshold gold thickness was about 4% for detail sizes from 0.2 to 1.0mm when 8 images were analysed. The coefficient of variation was about 10% at a detail size of 0.1mm due to the reduced number of detectable details at this size. Using larger numbers of images improved reproducibility for all detail sizes. A change in phantom design could greatly improve reproducibility for the smallest detail sizes. Greater consistency of phantom construction would also be desirable as one of the four phantoms tested was significantly different from the other three. Despite some limitations automated reading of CDMAM images can provide a reproducible means of assessing digital mammography systems against European Guidelines.

6913-48, Session 9

Temporal change analysis for improved tumor detection in dedicated CT breast imaging

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Preliminary evidence has suggested that dedicated CT imaging of the breast has great potential for improving detection of early-stage breast cancer. However minimal contrast exists between breast tumor and the surrounding fibro-glandular tissue which might make tumor detection more difficult. Hypothetically, a powerful mechanism for assisting in tumor detection from annual screening breast CT studies would be to examine temporal changes in the breast from year-to-year. In current practice, radiologists request prior mammograms when needed and some studies have been conducted to investigate image registration of these mammograms. Automatically registering 3D breast CT volumes should be a more accurate approach than registering mammograms. In this study, a non-rigid 3D image registration algorithm is developed to automatically register breast CT volumes scanned at different times (e.g., yearly screening exams). To evaluate the algorithm, experiments were performed on a mastectomy specimen imaged on a bench-top, flat-panel CT imager. The mastectomy specimen was imaged at two time points, where the specimen was physically moved between acquisitions

to model the typical motion of the breast during repositioning of the breast in the CT scanner. A synthetic tumor of 5mm diameter was then digitally inserted into the second CT scan at a clinically realistic location (to emulate tumor growth from year-to-year). The difference image after registration of the two datasets shows the tumor clearly. Results from this study suggest that temporal change analysis in 3D breast CT can potentially be a powerful tool in improving the visualization of small lesion growth.

6913-49, Session 9

Feasibility of dual-resolution cone beam breast CT: a simulation study

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Purpose: The feasibility of using the dual-resolution cone beam breast CT technique to obtain high-resolution images inside a selected volume-of-interest (VOI). The spatial resolution improvement, dose saving and scatter reduction with this technique are investigated.

Methods and Materials: With the dual-resolution cone beam CT technique, the breast is first scanned with a low-resolution detector at a lower exposure level. A selected volume-of-interest (VOI) in the breast is then scanned with a small field, high-resolution detector at a higher exposure level. The two image sets are then combined together to reconstruct high-resolution 3-D images for the VOI. The spatial resolution was estimated by computing the MTFs for evaluation as a function of the geometric magnification, detector blurring function and focal spot size. Monte Carlo simulation was used to estimate dose saving and scatter reduction for a breast phantom.

Results: The VOI images generated with the dual-resolution cone beam CT technique demonstrated the same visibility of micro-calcifications as those generated with the full-breast, high resolution image acquisition. The spatial resolution can be increased by a factor of 1.2 with smaller focal spot size and larger magnification. With the exposure level outside the VOI reduced by a factor of 10, scatter components can be reduced by a factor of 6 or greater in and outside the VOI. Dose can be reduced by a factor of 4.5 inside the VOI and up to 6.9 outside the VOI.

Conclusion: We have demonstrated that high spatial resolution inside the VOI may be achieved with a high-resolution detector, small focal spot size, and optimized geometrical magnification. Exposure reduction outside the VOI has been shown to reduce the scatter components and dose level inside and outside the VOI.

6913-50, Session 10

Temporally targeted image reconstruction for gated-computed tomography

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It has been demonstrated that projection data acquired over a smaller angular range (i.e. less than 180° + fan angle) are sufficient for an exact reconstruction of a region of interest within the field of view. This technique is often referred to as a super-short scan in the reconstruction literature. In MDCT the acquisition time dictates the temporal resolution of the images, and therefore, targeted ROI reconstruction methods have the potential to reduce motion artifacts because data acquired over a smaller angular range is required for reconstruction. Temporally targeted reconstruction techniques are presented using a controlled motion phantom to simulate coronary artery motion. This study demonstrates the potential reduction in motion artifacts for gated coronary angiography. Retrospectively gated coronary angiography data from a 64-slice computed tomography system were utilized. Clinically, temporally targeted reconstruction would not change the primary means of reconstructing and evaluating images, but rather would enable region-of-interest (ROI) imaging with improved temporal resolution compared with standard reconstruction (~20-25% smaller temporal scan window). Results show a decrease in motion induced artifacts including motion blur and streak artifacts from contrast enhanced vessels within the targeted ROIs. The fidelity of the reconstructed objects' shape were assessed via fitting of iso-HU curves in the reconstructed images.

6913-51, Session 10

Cardiac C-arm CT: image-based gating

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Image guidance during cardiac interventional procedures (IP) using cardiac C-arm CT systems is desirable for many procedures. Applying the concept of electrocardiogram gating (ECG) during the acquisition of multiple, serial, backward and forward, ECG-triggered rotational acquisitions using a C-arm system allows the 3D+t reconstruction of the heart. The process of retrospective gating is a crucial component of 3-D reconstruction. The gold-standard is still given by the ECG signal. However, the ECG signal is not always available in practice. Therefore an alternative gating method, based on the acquired projection data is required. Our goal is to provide an image-based gating (IBG) method without ECG such that already acquired projection data from a multi-run acquisition can still be used for reconstruction. We formulate the gating problem as a shortest-path optimization problem, where a directed graph is associated with the acquired projection images. The path costs are defined by projection image similarities that are based on image metrics. The objective function is additionally regularized to prefer solutions where the path of consecutive selected projections acquired along one forward or backward C-arm sweep is short. This regularization depends on an estimated average heart rate that is also estimated using an image-based method. We can show that the introduced image-based gating method provides an alternative to ECG-gating. First promising results using in-vivo data are presented and compared to standard ECG gating. We conclude that the presented IBG method provides a reliable gating when an ECG signal is not available.

6913-52, Session 10

Cardiac imaging in diagnostic volumetric CT using multisector data acquisition and image reconstruction: step-and-shoot scan vs. helical scan

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Since the advent of multi-slice CT, helical scan has played an important role in cardiac imaging. With increasing detector dimension provided by volumetric CT, step-and-shoot scan is becoming available. At present, both helical and step-and-shoot scans are conducted in gated sequential-slab-based manner, in which slabs corresponding to different cardiac cycles are stacked together to cover an entire heart. In comparison to helical scan, step-and-shoot scan decouples patient table movement from cardiac gating/triggering. Consequently, the temporal window for data acquisition and image reconstruction can be optimized, resulting in the following major benefits: (a) significantly reduced patient radiation dose; (b) improved tolerance to heart beat rate variation, such as arrhythmia frequently encounter in the clinic; (c) improved capability of handling inter-cycle motion inconsistency. Multi-sector data acquisition and image reconstruction have been extensively utilized in multi-slice helical cardiac imaging to improve temporal resolution, and such strategies can also be exercised by step-and-shoot cardiac scan in volumetric CT, in which all the benefits listed above can be inherited. To take advantage of those benefits appropriately, a multi-sector data acquisition and image reconstruction scheme for step-and-shoot scan is proposed and evaluated here. The scan protocols and their relationship with EKG are studied by analyzing clinical data statistics. The improvement in temporal resolution and suppression of motion artifacts are evaluated and verified using motion phantoms. Based on theoretical analysis and experimental evaluation, it is believed, that the step-and-shoot scan with multi-sector data acquisition and image reconstruction will play an increasingly important role in cardiac CT imaging.

6913-53, Session 10

Frame-by-frame 3D catheter tracking methods for an inverse geometry cardiac interventional x-ray system

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The Scanning-Beam Digital X-ray (SBDX) system performs rapid scanning of a narrow x-ray beam without mechanical motion by employing a magnetically deflected focal spot and inverted beam geometry. SBDX's ability to perform real-time multi-plane tomosynthesis with high dose efficiency is well-suited to interventional procedures such as left atrial ablation, where precise knowledge of catheter positioning is desired and imaging times are long. We describe and evaluate techniques for frame-by-frame 3D localization of multiple catheter electrodes from the stack of tomosynthetic images generated by SBDX. The localization algorithms operate on gradient-filtered versions of the tomosynthetic planes. Small high contrast objects are identified by thresholding the stack of images and applying connected component analysis. The 3D coordinate of each object is the center-of-mass of each connected component. Simulated scans of phantoms containing 1-mm platinum spheres were used to evaluate localization performance with the SBDX prototype (5.5-cm x 5.5-cm detector, 3° tomographic angle) and a new SBDX detector under design (6-cm x 10-cm, 3°x6°). Accuracy was 0.3 to 0.7 mm. Precision with the SBDX prototype was +/-1.3 mm in the z-direction and +/-0.2 mm along x and y (15 frame/sec, 12-mm tomosynthetic plane spacing). Z-precision improved to +/-0.7 mm with the 10-cm wide SBDX detector and 3-mm plane spacing. Dependences on tomographic angle, plane-to-plane spacing, and object velocity are described, and a simulation demonstrating ablation catheter localization within real anatomic background is presented. Results indicate that SBDX is capable of precise real-time 3D tracking of high contrast objects.

6913-54, Session 10

CT blurring induced bias of quantitative in-stent restenosis analyses

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Rationale and Objective: In CT systems, blurring is the main limiting factor for imaging stented arteries and in-stent restenosis. In practice, the measured diameter of a stent is underestimated. The aim of this study is to systematically analyze the effect of blurring related artifacts on the quantitative assessment of in-stent restenosis and to evaluate methods that correct for blurring.

Methods: 3D analytical models of blurred, stented vessel are presented. These models are used to quantify blurring related artifacts in the stent diameter measurement. Two correction methods are presented for an improved stent diameter measurement. We also examine the suitability of deconvolution techniques for correcting blurring artifacts.

Results: Blurring results in a shift of the maximal intensity signal towards the center position of the stent, resulting in an underestimation of the stent diameter. The shift, or underestimation, can be expressed as a function of the stent radius and width of the point spread function. For a 5 mm stent and a 1 mm width point-spread function, this results in an underestimation of the diameter of approximately 20 percent. The correction for this phenomenon reduces the error with 75 percent. Deconvolution reduces the blurring artifacts but introduces a ringing artifact.

Conclusions: The analytical vessel models are well suited to study the influence of various parameters on blurring-induced artifacts. The blurring-related underestimation of the stent diameter can significantly be reduced using the presented corrections. Care should be taken into choosing suitable deconvolution filters since they may introduce new artifacts.

6913-55, Session 11

Dependence of CT attenuation values on scanner type using in vivo measurements

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One of the key measures of response to treatment for patients in multicenter clinical trials is the lung density measured in Hounsfield Units

(HU) from Computer Tomography (CT) scans. The purpose of this work is to determine the dependence of CT attenuation values on scanner type by using in vivo measurements made from homogeneous anatomic areas. In vivo measurements were made in areas within the trachea, aorta, fat and muscle regions of CT scans obtained from subjects scanned as part of a multicenter treatment trial. Scans were selected so that exams from all four major manufacturers were included in the study. For each anatomic region of interest, the mean and standard deviation values were computed to investigate attenuation dependence on scanners. For example, trachea mean (standard deviation) measurements for exams from GE, Siemens, Philips and Toshiba scanners were -986 HU($i, \pm 15$), -993 HU($i, \pm 9$), -988HU($i, \pm 8$), -1046($i, \pm 10$) respectively. Inter-scanner variability was observed for each scanner showing significant differences (all p-values <0.005). Previous work in examining attenuation dependence on scanners has been performed using anthropomorphic phantoms [2, 3]. The novelty of this work is the use of in vivo measurements from homogeneous regions in order to examine scanner effects on CT attenuation values. Our results show that CT attenuation values for the anatomic regions vary between scanners and hence, dependence of CT attenuation values on scanners is observed. This work has not been submitted for publication or presentation elsewhere.

6913-56, Session 11

Towards assessing the diagnostic influence of dose reduction in pediatric CT: a study based on simulated lung nodules

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The purpose of this study is to evaluate the effect of reduced tube current (radiation dose) on lung nodule detection in pediatric chest CT. Normal chest CT images of 13 pediatric patients aged 1 to 7 years old were included in the study. The original tube currents of those images were between 70 mA and 180 mA. Using noise addition software (GE Healthcare, Waukesha, Wis), noise was added to the images to create 13 cases at the lowest common mA (i.e. 70 mA), 13 cases at 35 mA (50% reduction), and 13 cases at 17.5 mA (75% reduction). Three copies of each case were made for a total of 117 series serving as background for nodule simulation. A technique for 3D simulation of small lung nodules was developed, validated through an observer study, and used to add nodules to the 117 series. Care was taken to ensure that each of three lung zones (upper, middle, lower) contained 0 or 1 nodule. The series were randomized and the presence of a nodule in each lung zone was rated independently by three pediatric radiologists on a continuous scale between 0 (definitely absent) and 100 (definitely present). Receiver operating characteristic (ROC) analysis of the data showed no general significant difference in diagnostic accuracy between the reduced mA values and 70 mA, suggesting a potential for dose reduction. To our knowledge, this study is one of the first systematic and task-specific assessments of the influence of dose reduction in pediatric chest CT.

6913-58, Session 11

Measurement of small lesions near metallic implants with mega-voltage cone beam CT

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INTRODUCTION: Metallic objects severely limit diagnostic CT imaging because of their high X-ray attenuation in the diagnostic energy range. In contrast, radiation therapy linear accelerators now offer CT imaging with X-ray energies in the megavolt range where the attenuation coefficients of metals are significantly lower. We hypothesized that Mega-Voltage Cone-Beam CT (MVCB-CT) is of higher diagnostic value than clinical CT for imaging periprosthetic osteolysis, a condition that is associated with small focal bone lesions next to the prosthesis and is of severe concern in hip replacement surgery.

METHODS: Both MVCBCT and (Kilo-Voltage) CT were used to image a phantom containing simulated osteolytic bone lesions centered around a Chrome-Cobalt hip prosthesis stem with hemispherical lesions with sizes and density ranging from 4 to 0.5 mm radius and 0 to 500 mg•cm⁻³, respectively. Images for both modalities were visually graded

to establish lower limits of lesion visibility as a function of their size. Lesion volumes and mean density were determined and compared to reference values.

RESULTS: MVCB-CT images allowed proper visualization of all lesions larger than 2mm, independent of the placement of the lesion, whereas clinical CT could only allow visual discernment down to 4 mm, if the lesion (incidentally) occurred in an area without artifact. Volume determination uncertainty was reduced from 30% when the lesions were visible on CT to 20% for all lesions on MVCB-CT.

CONCLUSIONS: Localization and quantification of lesions is improved with MVCB-CT imaging. MVCB-CT offers a viable alternative to clinical CT in cases where accurate 3D imaging of small features near metallic hardware is critical. These results need to be extended to other metallic objects of different composition and shape.

6913-59, Session 11

Measurement of three-dimensional point spread functions in multidetector-row CT

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The latest generation of multidetector-row CT (MDCT) systems yields high spatial resolution in all directions of volumetric images in clinical routine. The quantitative characterization of the performance of MDCT systems is important for comparing the effects of different scan and reconstruction parameters, for comparing between different CT systems, and for evaluating the accuracy of size and density measurements of fine details in MDCT images. This paper presents a method to characterize the performance of MDCT using a three-dimensional (3D) point spread function (PSF) obtained from MDCT images without knowing the specifics associated with the MDCT scan and volumetric reconstruction algorithm. With separability assumed, the 3D PSF is decomposed into 2D PSF in the scan plane and SSP on the z-axis. The 2D PSF and SSP are modeled on the basis of the symmetric function such as the Gaussian functions. The descriptions of 3D PSF are defined from the Fourier analysis of MDCT images of wire (diameter 0.049mm) and micro-disk (thickness 0.05mm) phantoms. Experimenting with a MDCT system, we demonstrate the method for 3D PSF measurement.

6913-60, Session 11

Correlation identification between internal/external tumor motion signals

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Tumor motion induced by patient breathing decreases the effectiveness of radiation treatment. Image guided radiation treatment (IGRT) is an advanced approach for cancer radiation treatment. The success of IGRT is largely dependent on the accurate localization of tumor in real-time. There are two major imaging approaches currently in use to localize a tumor: internal imaging and external imaging. Internal imaging determines the tumor locations by directly x-ray of the tumor area. It is accurate but radiation dose is a big concern. External imaging derives the internal tumor locations through an external mark on the patient surface. It is radiation dose free but less accurate. Integrating the internal and external signals together is necessary for reliable radiation treatment and acceptable patient radiation exposure. Our work tries to identify the correlation patterns between internal/external signals and the influential factors so that the hybrid signal will give desire accuracy in dose delivery while limiting radiation exposure to the patients. Both theoretical simulation and statistical analysis are performed based on sinusoidal functions and real patient data. The sinusoidal simulation will identify the potential correlation factors while the statistical analysis will identify the influence factors on real patients. The results have demonstrated the various correlation patterns with amplitude various,

frequency changes (duration changes), phase shifts, and baseline drift. The statistical analytical results have identified some dominant factors in real-patients. Our work will be very useful in real-time IGRT to update the internal/external correlation for better cancer patient care.

6913-120, Session 11

Noise properties of low-dose x-ray CT sinogram data in the radon space

Z. Liang, J. Wang, Stony Brook Univ.; H. Lu, Fourth Military Medical Univ. (China)

Computed tomography (CT) has been well established as a diagnostic tool through hardware optimization and data calibration for image reconstruction in the Radon space. For screening purposes, the associated X-ray exposure risk must be minimized. An effective way to minimize the risk is to lower the mAs level or deliver less X-rays to the subject. This work aims to study the noise property of the calibrated or preprocessed sinogram data in Radon space as the mAs level decreases. An anthropomorphic torso phantom was scanned repeatedly by a commercial CT imager at five different mAs levels from 100 down to 17 (the lowest provided by the scanner). The preprocessed sinogram datasets of the CT scanner were extracted to a computer for noise analysis. By the repeated measurements at each mAs level, we first tested the normality of the repeatedly measured samples for each data channel by the Shapiro-Wilk statistical merit. The rejection rate was approximately 6% at 100 mAs level and up to 9% at 17 mAs level for all data channels. Most importantly, we validated a theoretical relationship between the sample mean and variance at each channel and furthermore related the relationship to different mAs levels for different CT scanners and different phantoms. It is hoped that the relationship between the first and second statistical moments and its relation to the mAs level will improve low-dose CT image reconstruction for screening applications.

6913-83, Poster Session

Few-view cone-beam computed tomography for image-guided radiation therapy

S. Cho, E. Y. Sidky, C. A. Pelizzari, X. M. Pan, The Univ. of Chicago

Purpose: The radiation dose delivered to a patient due to daily cone-beam CT before each fractionated treatment in image-guided radiation therapy may pose a challenge in the patient's radiation safety. In order to reduce the patient dose with preserving the quality of the daily CT images, we propose a total-variation minimization algorithm with a priori information for a few-view cone-beam CT.

Methods: Since a patient usually undergoes a CT scanning for treatment planning in image-guided radiation therapy, we can use the planning-CT image as the a priori information to the iterative image reconstruction algorithm we have developed recently. The algorithm iterates seeking for minimized image total-variation. A series of few-view projection data sets of the shifted phantom were tested either with or without the original phantom image as a priori.

Results: A preliminary numerical study has been conducted. The images reconstructed by use of the a priori information from a very few-view projection data appear to be reasonable while the images without a priori have poor quality.

Conclusion: The proposed algorithm is thought to be very interesting and promising since it may be able to reconstruct 3D volume image of the target including soft-tissue such as prostate from a few-view projection data.

6913-84, Poster Session

Tomosynthesis via total variation minimization reconstruction

B. E. Nett, S. Leng, J. V. Velikina, G. Chen, Univ. of Wisconsin/Madison

As research and product development using tomosynthetic image acquisition has seen significant growth in recent years there is a strong desire for improved reconstruction algorithms. For planar tomosynthesis

trajectories (e.g. linear tomosynthesis, circle tomosynthesis, etc.) it has been demonstrated that parallel beam reconstruction techniques may be employed using the concept of a virtual object.

Additionally, image reconstruction by total variation minimization using frequency space constraints has demonstrated improvements in reconstruction image quality over the standard filtered backprojection algorithm. This work describes a total variation minimization procedure where the measured data constraints are enforced in frequency space using the central slice theorem for parallel projections. This iterative procedure utilizes the Non-Uniform Fast Fourier Transform (NUFFT) proposed by Fessler and Sutton (IEEE Trans. Sig. Proc., 51, 2003) to address the non-cartesian acquisition. Simulations are performed utilizing low dose neuro CT-angiography data acquired from a state-of-the-art CT scanner in a canine model.

The new reconstruction framework demonstrates a visible reduction in the correlated noise and shows less variation in image intensity across the image compared with standard filtered backprojection reconstruction for a range of tomographic angles.

6913-85, Poster Session

Efficient extended field of view (FOV) reconstruction techniques for multi-slice helical CT

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Truncation of CT projection data is always coupled with non-complete angular sampling and can lead to severe image artifacts in clinical CT. Extrapolation of projection data is needed to restore CT values inside and outside the scan field of view (SFOV). We present three types of different extrapolation schemes.

The first type (A) is characterized by extrapolation of projection data using a virtual object of constant attenuation. For multi-slice helical CT this extrapolation scheme is applied in a row-wise manner. The second type utilizes consistency conditions of parallel projection data. The conservation of m th order moments of non-truncated projections can be utilized for the extrapolation of truncated projection data by fitting extrapolation functions of variable length. However, due to the helical sampling and the conical shape of projection data the conservation equations are violated and can be applied only in an approximate manner. The third type extrapolates truncated data by sinogram decomposition and completion. For each voxel in image space the corresponding trace in the 3D-sinogram is computed. The minimum signal within each trace is extrapolated to the extended sinogram parts, which represent the extended FOV.

Based on the evaluation of both simulation data and clinical data we evaluate the three different reconstruction techniques. Sinogram decomposition proved to be far better than the other techniques, but is computationally very demanding. It efficiently restores CT Hounsfield values to an accuracy of about 100 HU even for an image field of view (FOV) increased by 50% compared to the SFOV.

6913-86, Poster Session

Expectation maximization SPECT reconstruction with a content adaptive singularity-based mesh-domain image model

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To improve the speed and quality of ordered-subsets expectation-maximization (OSEM) SPECT reconstruction, we implemented a content-adaptive singularity-based mesh-domain image model (CASMIM) with an accurate algorithm for estimation of the mesh-domain system matrix. A preliminary image (starting point for CASMIM reconstruction) was obtained using pixel-domain OSEM, and it provided a mesh-domain representation through application of 2D wavelets followed by Delaunay triangulation in order to obtain joint estimation of nodal locations and their activity values. Digital chest-phantom SPECT was simulated and reconstructed. The quality of images reconstructed with OSEM-CASMIM is comparable to pixel-domain OSEM but at 5-fold higher speed.

6913-87, Poster Session

Chord-based image reconstruction from clinical projection data

M. T. King, D. Xia, X. M. Pan, M. W. Vannier, P. J. La Riviere, E. Y. Sidky, M. L. Giger, The Univ. of Chicago

Two projection datasets were transferred from a Philips Brilliance 64 CT scanner at the University of Chicago. The first was an axial scan of a quality assurance body phantom, and the second was a helical scan of the head. Both projection datasets were processed and then reconstructed with FDK-based algorithms using full-scan (FDK-FS) and half-scan (FDK-HS) data as well as the chord-based backprojection filtration (BPF) algorithm. The three reconstructed image sets were then compared to a fourth image set acquired from the clinical scanner (CLIN). Standard deviations measured within an elliptical ROI placed within the body phantom were 13.3, 18.2, 10.3, and 12.6 HU for the FDK-FS, FDK-HS, BPF, and CLIN images, respectively. This research demonstrates the feasibility of using chord-based algorithms for reconstructing images from clinical projection datasets.

6913-88, Poster Session

Electronic noise compensation in an iterative reconstruction algorithm for x-ray CT

J. Xu, B. M. W. Tsui, Johns Hopkins Univ.

We present a general approach for electronic noise compensation in iterative x-ray CT reconstruction with energy-integrating type detectors. A surrogate function is usually employed to derive a maximum-likelihood reconstruction algorithm for x-ray CT. Using an expectation-maximization formulation, we have shown previously that a conditional expectation of the surrogate function constructed without electronic noise effect is a legitimate surrogate for the log-likelihood with electronic noise incorporated.

Implementation of this approach requires calculation of the conditional expectation of the x-ray transmission signal given the raw detector measurements contaminated by electronic noise.

In many cases, this conditional expectation does not have an analytic expression.

We propose a best affine estimator to approximate this conditional expectation and evaluate its accuracy.

We incorporate this affine estimator in an iterative x-ray CT reconstruction algorithm and perform preliminary studies of the relative importance of electronic noise compensation in x-ray CT. Our results indicate that there was a moderate noise reduction for electronic-noise compensated images as a function of iteration numbers, but very similar noise-resolution trade-off compared with non-compensated images. More extensive studies are needed to better understand the benefit of electronic noise compensation in iterative x-ray CT reconstruction.

6913-89, Poster Session

A rebinned BPF algorithm with a general source trajectory for ROI imaging

J. Bian, D. Xia, The Univ. of Chicago; L. Yu, Mayo Clinic College of Medicine; E. Y. Sidky, X. M. Pan, The Univ. of Chicago

The back-projection filtration (BPF) algorithm is one of the recently developed algorithms for exact image reconstruction from cone-beam projections. The BPF algorithm can be applied to reconstruct images for a wide class of general scanning trajectories and is capable of reconstructing an image within a region of interest (ROI) from projection data containing truncations. The original BPF algorithm involves the computation of a spatially varying weighting factor in its backprojection step. This weighting factor not only increases the computation load, but also leads to amplified and non-uniform noise in reconstructed images. Therefore, it is desirable to eliminate the weighting factor in the BPF algorithm. In this work, we reformulate the BPF algorithm in terms of a rebinned geometry for a general scanning trajectory. The use of the rebinned geometry can, on one hand, eliminate the spatially varying weighting factor, thus improving the noise properties

of BPF reconstructions, and, on the other hand, can retain the unique properties of the original BPF algorithm. We also apply the rebinned BPF algorithm to reconstruct ROI images from truncated cone-beam data collected from general trajectories. The proposed algorithm has been validated and evaluated in numerical studies. The improved noise properties in reconstructed images may have significant implications for CT-image-based detection and/or estimation tasks.

6913-90, Poster Session

An FBP image reconstruction algorithm for x-ray differential phase contrast CT

Z. Qi, G. Chen, Univ. of Wisconsin/Madison

Most recently, a novel data acquisition method has been proposed and experimentally implemented for x-ray differential phase contrast computed tomography (DPC-CT), in which a conventional x-ray tube and a Talbot-Lau type interferometer were utilized in data acquisition. The divergent nature of the data acquisition system requires a divergent-beam image reconstruction algorithm for DPC-CT. This paper focuses on addressing this image reconstruction issue. We developed a filtered backprojection algorithm to directly reconstruct the DPC-CT images from acquired projection data. The developed algorithm allows one to directly reconstruct the decrement of the real part of the refractive index from the measured data. In order to accurately reconstruct an image, the data need to be acquired over an angular range of at least 180 degree plus the fan-angle. Different from the parallel beam data acquisition and reconstruction methods, a 180 degree rotation angle for data acquisition system does not provide sufficient data for an accurate reconstruction of the entire field of view. Numerical simulations have been conducted to validate the image reconstruction algorithm.

6913-91, Poster Session

Development of a fully 3D adaptive system model for cone-beam SPECT expectation-maximization reconstruction

H. Ye, Syracuse Univ.; D. H. Feiglin, Upstate Medical Univ./SUNY; E. D. Lipson, Syracuse Univ.; A. Krol, Upstate Medical Univ./SUNY

To improve cone-beam collimator (CBC) SPECT a fully 3D reconstruction, ordered-subsets expectation-maximization (OSEM) algorithm with an adaptive cone-volume system model (CVSM) has been developed. Monte Carlo package SimSET was used to simulate scatter-free SPECT projections with Poisson noise for numerical DeFrise (disk) phantoms with axial and transaxial spatial frequencies (f) in 0 - 0.52 cm⁻¹ range. These data were reconstructed using OSEM-CVSM and OSEM with line-length system model (LLSM). Quantitative analysis of the obtained images indicates that OSEM-CVSM yields superior image quality, lower noise, lower bias, and higher contrast-to-noise ratio and both algorithms imaging performance worsen with increasing f .

6913-92, Poster Session

Mesh model 2D reconstruction operator for SPECT

R. Delgado-Gonzalo, J. G. Brankov, Illinois Institute of Technology

In this paper we extend our previous approach of 2D tomographic image reconstruction using a content-adaptive mesh model (CMM) for emission tomography (EM). Here we present a model for the projection operator calculation using a ray-tracing algorithm. The proposed approach allows us to incorporate a non-uniform attenuation and distance-dependent spatial resolution of the imaging system. This approach was tested using realistic simulations with the NCAT phantom and SIMIND Monte Carlo simulation of a SPECT system. The research described in this paper establishes a method for the future development of 3D reconstruction images and spatio-temporal processing using deformable mesh modeling.

6913-93, Poster Session

Generic iterative reconstruction of multipinhole SPECT

W. J. Ryder, M. Brennan, A. J. Sinusas, Y. Liu, Yale Univ.

Single photon emission computerized tomographic (SPECT) images often suffer from low resolution and low count density. To improve spatial resolution of SPECT it is possible to use a pinhole collimator; however, this further reduces the system sensitivity. A potential solution to this problem is to use coded apertures which offers increased sensitivity by using multiple pinholes, at the cost of increased image reconstruction time.

A generic reconstruction algorithm has been developed which allows for arbitrary acquisition geometry via affine transforms (translation and rotation). The reconstruction process uses a (Siddon) ray projector, the expectation maximization (EM) algorithm and a 1 to n pinhole position matrix. Iteration times scale as a function of the number of pinholes in the collimator. Resolution recovery has also been incorporated into the reconstruction algorithm.

The algorithm developed allows for the investigation of optimal imaging settings for small animal imaging. Simulated acquisitions of a rat heart with 1, 5 and 8 pinholes, over 360 degree acquisition, showing that multi-pinhole imaging can be successfully applied to rat cardiac imaging. Further refinement of the acquisition parameters, such as image overlap, collimator pinhole configuration and geometrical imaging configuration, will predict the theoretical settings for quantitative cardiac multi-pinhole SPECT imaging.

6913-94, Poster Session

A blob-based tomographic reconstruction of 3D coronary trees from rotational x-ray angiography

J. Zhou, A. Bousse, J. Bellanger, Univ. de Rennes I (France); L. Luo, Southeast Univ. (China); J. Coatrieux, Univ. de Rennes I (France)

A method is proposed for a 3D reconstruction of coronary networks from rotational projections that departs from motion-compensated approaches. It deals with multiple views extracted from a time-stamped image sequence through ECG gating. This statistics-based vessel reconstruction method relies on a new imaging model by considering both the effect of background tissues and the image representation using spherically-symmetric basis functions, also called 'blobs'. These blobs have a closed and spherically symmetric analytical expression for the X-ray transform, which makes it easier to compute a cone-beam projection than a voxel-based description. A Bayesian maximum a posteriori (MAP) estimation is used with a Poisson distributed projection data instead of the Gaussian approximation often used in tomography reconstruction. A heavy-tailed distribution is proposed as image prior to take into account the sparse nature of the object of interest. The optimization is performed by an expectation-maximization like (EM) block iterative algorithm which offers a fast convergence and a sound introduction of the non-negativity constraint for vessel attenuation coefficients. Simulations are performed using a model of coronary tree extracted from multidetector CT scanner and a performance study with a comparison to other methods is conducted. They point out that, even with severe angular undersampling (6 projections over 110 degrees for instance) and without introducing a prior model of the object, significant results can be achieved.

6913-95, Poster Session

A hardware projector/backprojector pair for 3D PET reconstruction

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Forward and Backward projections are two computational costly steps in tomography image reconstruction such as Positron Emission Tomography (PET). To speed-up reconstruction time, a hardware projection/backprojection pair have been built following algorithm architecture adequacy principles. Thanks to an original memory access strategy based on an 3D adaptive and predictive memory cache, the external memory wall have been overcome. Thus, for both projector architectures several units run efficiently. Each unit reaches a computational throughput close to 1 operation per cycle.

In this paper, we present how from our hardware projection/backprojection

pair, an analytic (3D-RP) and an iterative (3D-EM) reconstruction algorithms can be implemented on a System on Programmable Chip (SoPC). First, a hardware/software partitioning is done based on the different steps of each algorithm. Then the reconstruction system is composed of two hardware configurations of the programmable logic resources (FPGA). Each one corresponding mainly to the projection and backprojection step.

Our projector/backprojector has been validated with a software 3D-RP and 3D-EM reconstruction on simulated PET-SORTEO data. A reconstruction time evaluation of these reconstruction systems are done based on the measured performances of our projectors IPs and the estimated performances of the additional simple hardware IPs. The expected reconstruction time is compared with the software tomography distribution STIR. A speed-up of 7 can be expected for the 3D-RP algorithm and a speed-up of 3.5 for the 3D-EM algorithm. For both algorithms, the architecture cycle efficiency expected is largely greater than the software implementation : 120 times for 3D-RP and 60 times for 3D-EM.

6913-96, Poster Session

Automatic local thresholding of tomographic reconstructions based on the projection data

K. J. Batenburg, J. Sijbers, Univ. Antwerpen (Belgium)

Segmentation is an important step to obtain quantitative information from tomographic datasets. Thresholding schemes are often used in practice, as they are easy to implement and use. However, if the tomogram exhibits variations in the intensity of certain image features, it is not possible to obtain an accurate segmentation using a single, global threshold. Instead, local thresholding schemes can be applied that use a varying threshold, depending on local characteristics of the tomogram. Selecting the best local thresholds is not a straightforward task, as local image features (such as the local histogram) often do not provide sufficient information for choosing a proper threshold. In this paper, we propose a new criterion for selecting local thresholds, based on the available projection data, from which the tomogram was initially computed. By computing simulated projection images of the segmented tomogram, a comparison can be made with the measured projection data. This yields a quantitative measure of the quality of the segmentation. By minimizing the difference between the computed and measured projections, optimal local thresholds can be computed. Simulation experiments have been performed, comparing the result of our local thresholding approach with global thresholding. Our results demonstrate that the local thresholding approach yields segmentations that are significantly more accurate, in particular when the tomogram contains artifacts.

6913-97, Poster Session

Cone-beam reconstruction using retrieved phase projections of in-line holography for breast imaging

W. Cai, R. Ning, Univ. of Rochester

This work is a feasibility study of a phase-contrast cone-beam CT system for ROI (region of interest) reconstruction in breast imaging that incorporates the in-line holography technique into a cone-beam CT system. The in-line holographic images are generated using Fresnel theory through computer simulation, and the projected phase maps, as line integrals of the phase coefficient of the scanned breast, are retrieved using phase-attenuation duality theory. In this way the object's phase coefficient, as the object function, can be reconstructed using these projected phase maps. However, because of the small angle assumption of Fresnel diffraction, a limited field of view is available to expose the breast, which results in a transverse truncation problem in phase projections. These truncated projections are extended based on a prior knowledge about the shape and compositions of the breast, and then are processed using the FDK algorithm to compute the reconstruction. The reconstruction error is calculated to evaluate the accuracy of this approach. The noise property of this approach is investigated as well by adding Poisson noise to the holographic images. The projected phase maps are retrieved and the object function is reconstructed in the presence of noise. The results show that the object's phase coefficient can be reconstructed with very small reconstruction error,

and the noise level can be greatly reduced compared to the conventional CBCT system. In conclusion, the phase-contrast CBCT breast imaging approach is very promising to provide better image quality and to lower x-ray dose level.

6913-98, Poster Session

SPECT reconstruction on the GPU

C. P. Vetter, Siemens Corporate Research; R. Westermann, Technische Univ. München (Germany)

With the increasing reliance of doctors on the imaging procedures, not only the visualization needs to be optimized, but the reconstruction of the volumes from the scanner output is another bottleneck. Accelerating the computationally intensive reconstruction process improves the medical work flow, matches the reconstruction speed to the acquisition speed, and allows fast batch processing and interactive or near-interactive parameter tuning.

Recently, much effort has been focused on using the computational power of graphics processing units (GPUs) for general purpose computations. This paper presents a GPU-accelerated implementation of single photon emission computed tomographic (SPECT) volume reconstruction based on an ordered-subset expectation maximization algorithm.

The algorithm uses models for the point-spread-function (PSF) to improve spatial resolution in the reconstruction images. Instead of computing the PSF directly, it is modeled as efficient blurring of slabs on the GPU in order to accelerate the process.

An optimized algorithm for the calculation of accumulated attenuation factors that allow correcting the generated volume according to the attenuation properties of the volume is presented. Since these factors can be reused between different iterations a cache is used that is adapted to different sizes of the video memory so that only those factors have to be recomputed that do not fit onto graphics memory.

These improvements make the reconstruction of typical SPECT volume near interactive.

6913-99, Poster Session

Mojette and FRT tomographs

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The tomographic acquisition uses angles well dispatched around 2π . The Mojette transform as well as the Discrete Radon Transform (DRT) are using discrete geometry to solve the ill posedness inverse Radon transform. This paper focus on the transformation of acquired tomographic projections to discrete projections. Mojette and FRT are then used concurrently for reconstruction. The impact of physical acquisition (uncertainties of the detection process) is also analysed in terms of possible useful interpolations according to angle acquisitions and null space of the transform. MSE results on analytical phantoms always show the superiority of our approach compared to classical FBP.

6913-100, Poster Session

Accelerate helical cone-beam CT with graphics hardware

W. Bi, Z. Chen, L. Zhang, Y. Xing, Tsinghua Univ. (China)

Helical cone-beam CT is used widely nowadays because of its rapid scan speed and efficient utilization of x-ray dose. Filter and back projection algorithm for helical scanning (H-FDK) is an effective reconstruction algorithm on Helical CT. But like other 3D reconstruction algorithms, H-FDK is time consuming because of its large amount of data processing, including the convolution and 3D-3D back projection. Recently, GPU is widely used to parallel many reconstruction algorithms. The latest GPU has some nice features, like large memory, lots of processors, fast 3D texture mapping, and flexible frame buffer object. All these features help the reconstruction a lot. In this paper, we present a whole solution to this problem with GPU. First, we bring a lookup table into H-FDK. Then both the convolution and back projection are implemented on GPU.

At last, the reconstruction result is directly smoothed and visualized by GPU. Experimental results are given to compare among CPU and two generations of GPU: Geforce 6800GT and Geforce 8800GTX. The comparison was applied both on simulation data and real data. We have shown that, GPU-accelerated H-FDK gets result with similar levels of noise and clarity, but gains a performance increase about 10-100 times faster than CPU. With the newer feature, 8800 can get a better quality than 6800 and about 20 times faster.

6913-101, Poster Session

A projection-driven pre-correction technique for iterative reconstruction of helical cone-beam CT images

S. Do, Massachusetts General Hospital; Z. Liang, W. C. Karl, Boston Univ.; M. K. Kalra, T. J. Brady, H. H. Pien, Massachusetts General Hospital

Capabilities of the modern clinical computed tomography (CT) systems are advancing at a rapid pace; these advances are in part due to the desire for larger area-of-coverage systems, as well as the desire to see smaller anatomic structures. Conventional filtered-backprojection approaches are limited in image quality by the approximations and interpolations they make; this issue is particularly acute when the structure of interest is near the resolution-limit of the CT system. In this study we demonstrate the ability to improve image quality using a novel approach based on algebraic reconstructions on both ex vivo and in vivo data, and demonstrate the results using coronary calcium and stent.

Algebraic reconstruction techniques have historically found only limited commercial application because of their computationally intensive nature. We have developed a compromise solution in which we exploit the computational advantages of filtered-backprojection where the soft tissue image reconstruction quality is sufficient, but utilize algebraic reconstructions when high attenuation objects or features which are resolution-limited are of interest. This pre-correction methodology allows us to achieve improved image quality over particular regions of interest without unduly suffering from the computational burden of algebraic techniques in helical cone-beam geometry. This pre-correction algorithm produces a smooth transition between the two regions. Our approach subtracts the background sinogram from the complete sinogram to create the sinogram of the region-of-interest; we then utilize an energy functional to generate the desired solution at a higher-resolution than the original acquisition. We demonstrate our super-resolution approach using the Siemens Sensation-64 MDCT system.

6913-102, Poster Session

Hardware accelerated C-arm fluoroscopy and CT: a pilot study

D. Riabkov, A. Cheryauka, A. Tokhtuev, T. Brown, GE Healthcare

Clinical demands of image-guided procedures present technical challenges in doing 1Kx1K fluoroscopy and cone-beam CT on a mobile C-arm.

Performance-per-watt and performance-per-dollar are other major considerations in a search for an optimal computational platform.

Real-time constraints of processing high resolution fluoroscopic images typically necessitate use of highly specialized proprietary image processing hardware, which cannot be easily repurposed for acceleration of other computing tasks. In our previous studies, we have been looking for a heterogeneous computing architecture and suitable hardware / software components to assist in time-critical surgical applications. It has been shown that Graphics Processing Units (GPUs) can provide the exceptional levels of computational power utilizing the Single Instruction Multiple Data (SIMD) programming model. In the present study, we expand our research in the domain of real-time processing and continue to explore feasibility of GPU acceleration for both fluoroscopic and tomographic imaging. The current emphasis is being placed on applicability of NVIDIA's novel Tesla GPU computing solutions and Compute Unified Device Architecture (CUDA). The results of this pilot project comprise the Cg/OpenGL and CUDA algorithm implementations, benchmark evaluations, and examples of processing image data acquired with the use of anthropomorphic phantoms.

6913-103, Poster Session

A study on projection distribution of few-view reconstruction with total variation constraint

X. Duan, L. Zhang, Y. Xing, Z. Chen, J. Cheng, Tsinghua Univ. (China)

In today's tomographic imaging, there are more incomplete data systems, such as few-view system. The advantage of few-view tomography is less x-ray dose and reduced scanning time. In this work, we investigate the reconstruction algorithm with total variation (TV) constraint in few-view fan-beam CT in the form of ART-TV approached by E. Sidky et al in 2006. In few-view reconstruction, projection data are much less than the regular fan-beam CT, so redundant data of projection have great impact on reconstructed images. Additionally, fan-beam projection data have inherent symmetry to result in redundancy and ART-TV form iteration may require more independent data than the compact form of FT-TV proposed by Candes. It becomes important in the few-view reconstruction that how projections distribute to reduce data redundancy. Study of this problem is performed with simulated and real experimental data on a fan-beam x-ray CT. We choose five typical distribution schemes to seek the best one. The results show that short-scan type distribution produces the most accurate image. This scheme greatly reduces data redundancy and avoids more data singularity.

6913-104, Poster Session

PDE regularization for Bayesian reconstruction of emission tomography

Z. Wang, L. Zhang, Y. Xing, Z. Zhao, Tsinghua Univ. (China)

The aim of the present study is to investigate a type of Bayesian reconstruction which utilizes partial differential equations (PDE) image models as regularization. PDE image models are widely used in image restoration and segmentation. In a PDE model, the image can be viewed as the solution of an evolutionary differential equation. The variation of the image can be regarded as a descent of an energy function, which entitles us to use PDE models in Bayesian reconstruction. In this paper, two PDE models called anisotropic diffusion are studied. Both of them have the characteristics of edge-preserving and denoising like the popular median root prior (MRP). We use PDE regularization with an Ordered Subsets accelerated Bayesian one step late (OSL) reconstruction algorithm for emission tomography. The OS accelerated OSL algorithm is more practical than a non-accelerated one. The proposed algorithm is called OSEM-PDE. We validated the OSEM-PDE using a Zubal phantom in numerical experiments with attenuation correction and quantum noise considered, and the results are compared with OSEM and an OS version of MRP (OSEM-MRP) reconstruction. OSEM-PDE shows better results both in bias and variance. The reconstruction images are smoother and have sharper edges, thus are more applicable for post processing such as segmentation. We validate this using a k-means segmentation algorithm. The classic OSEM is not convergent especially in noisy condition. However, in our experiment, OSEM-PDE can benefit from OS acceleration and keep stable and convergent while OSEM-MRP failed to converge.

6913-105, Poster Session

Truncation artifact and boundary artifact reduction in breast tomosynthesis reconstruction

Y. Zhang, H. Chan, Y. Wu, B. Sahiner, C. Zhou, J. Wei, J. Ge, L. M. Hadjiiski, J. Shi, Univ. of Michigan

Digital Tomosynthesis Mammography (DTM) is an emerging technique that has the potential to improve breast cancer detection. DTM acquires low-dose mammograms at a number of projection angles over a limited angular range and reconstructs the 3D breast volume. Due to the limited number of projections within a limited angular range, and the finite size of the detector, DTM reconstruction contains boundary and truncation artifacts that degrade the image quality of the tomosynthesized slices, especially that of the boundary and truncated regions. In this work, we developed artifact reduction methods that use both 2D and 3D breast boundary information, and include a local smoothing method and a tissue compensation method. A breast phantom containing test objects

and selected DTM patient cases were used to evaluate the effects of artifact reduction. The contrast-to-noise ratio (CNR), the normalized profiles of line objects, and a non-uniformity error index were used as performance measures. A GE prototype DTM system was used to acquire 21 PVs in 3° increments over a $\pm 30^\circ$ angular range. The Simultaneous Algebraic Reconstruction Technique (SART) was used for DTM reconstruction. Preliminary results demonstrated that the proposed methods can improve the image quality both qualitatively and quantitatively, resulting in increased CNR values, and an overall reconstruction quality comparable to that without truncation. For DTM patient cases, the obscured breast structural information near the truncated regions was essentially recovered. In addition, restricting SART reconstruction to be performed within the estimated 3D breast volume increased the computation efficiency.

6913-106, Poster Session

A new reconstruction method to improve SNR for an inverse geometry CT system

J. Baek, N. J. Pelc, Stanford Univ.

The inverse-geometry CT (IGCT) system uses a large-area scanned source and a 2D detector array with a smaller extent in the transverse direction. The acquired IGCT data can be significantly oversampled and the samples are not equally spaced in radial distance or angle. Previously proposed reconstruction algorithm used a modified gridding method to rebin the normalized and logged projection data into the parallel projection data. This approach can be suboptimal if the measured rays contributing to an output sample do not have the same signal-to-noise ratio (SNR). Since each ray can have a different SNR depending on the detected number of photons due to different incident intensities, reconstructed images may have better SNR if we consider the SNR of each ray in rebinning step. In this paper, we propose a new method to improve the SNR in the reconstructed image. In this method, input rays with different SNR were combined in the rebinning step by using weighted-least square fitting to produce SNR efficient output projection data. We simulated two cases: uniform, and triangular profiles of the detected number of photons across the detector array. SNR improvements of 6% (uniform) and 37% (triangular) were observed. Experiments were also performed with real flat field data acquired from a C-arm system (NovaRay, Inc., Palo Alto, CA). In this case, we observed SNR improvement as high as 42%, depending on the intensity nonuniformity across the detector.

6913-107, Poster Session

Tomographic reconstruction of band-limited Hermite expansions

W. Park, G. S. Chirikjian, The Johns Hopkins Univ.

The Fourier slice theorem states that the Fourier transform of a projection of a 2D function is equal to the slice of the 2D Fourier transform of the function along a line through the origin in the frequency domain and tilted by the angle with which the projection is taken. While the 2D Fourier transform can be obtained by filling the frequency domain with slices, and its inverse Fourier transform gives the original 2D function, this direct scheme has not been adopted, since the slices form the samples of the Fourier transform on a polar grid and samples on a Cartesian grid are needed in traditional reconstructions. This means that a complete polar-Cartesian coordinate conversion is required.

In this work, we investigate the parallel-beam projection and reconstruction of band-limited Hermite expansions. Using a recently developed coordinate conversion technique, we show how the Fourier slice theorem can be directly applied. In our new approach, we don't introduce a filter like the one that appears in the filtered backprojection method. Since a projection of a 2D bandlimited Hermite expansion is a 1D band-limited Hermite expansion and the coordinate conversion technique is lossless with this special expansion, we can avoid a series of approximations that the classical tomography techniques make.

6913-108, Poster Session

MLSD-OSEM reconstruction algorithm for cosmic ray muon radiography

Y. Liu, Z. Zhao, Z. Chen, L. Zhang, Y. Xing, Tsinghua Univ. (China)

Cosmic ray muon radiography which has a good penetrability and sensitivity to high-Z materials is an effective way for detecting shielded nuclear materials. Reconstruction algorithm is the key point of this technique. Now, there are two main algorithms about this technique. One is the Point of Closest Approach (POCA) reconstruction algorithm which is using the track information to reconstruct; the other is to solve the Maximum Likelihood estimation, such as the Maximum Likelihood Scattering (MLS) and the Maximum Likelihood Scattering and Displacement (MLSD) reconstruction algorithms which are proposed by the Los Alamos National Laboratory (LANL). The performance of MLSD is always better than MLS. For MLSD reconstruction algorithm includes scattering and displacement information while MLS reconstruction algorithm is only including scattering information. In order to solve this Maximum Likelihood estimation, they select f_{mincon} which is a function in MATLAB. In this paper, we propose to use EM method to get the estimation (MLS-EM and MLSD-EM). Then, in order to solve the problem of reconstruction time we use the OS method to accelerate MLS and MLSD reconstruction algorithm with the initial value of the EM which is the result of the POCA reconstruction algorithm. That is, the Maximum Likelihood Scattering-OSEM (MLS-OSEM) and the Maximum Likelihood Scattering and Displacement-OSEM (MLSD-OSEM). Numerical simulations show that the performance of MLSD-OSEM is better than MLS-OSEM and the MLSD-OSEM is effective.

6913-109, Poster Session

Lossy raw data compression in computed tomography with noise shaping to control image effects

Y. Xie, A. S. Wang, N. J. Pelc, Stanford Univ.

The data rate requirements for raw data transmission through the slip ring of a CT scanner can be quite challenging, especially as the scanning speed and number of detector channels increase. Compression can be used to reduce the size of the data rate array, and therefore the data rate requirements. Compression can also be applied to raw data storage and transmission through the computation system. Currently, raw data are stored only for a short period. Compression may encourage longer-term storage of raw data, increasing the flexibility for retrospective reconstructions.

While lossy compression can offer a significant reduction in data set size, it introduces errors to the measurements. The design and evaluation of compression methods need to take into account the nature of the sinogram and how errors in the sinogram contribute to noise in the reconstructed image. Further, it is possible to control the relative distribution of errors in the reconstructed image. This may be important to ensure higher image quality in some region of the image (e.g., the center of the field of view). We found that low frequency errors in the angular direction of the dominate the errors in the central ROI, whereas the high frequency error contributes more to the peripheral region of the image.

In this paper, we present two noise shaping methods for fixed rate lossy compression of CT raw data that achieve a lower error level in the center region of the reconstructed image: error feedback filters and sub-band coding with bit allocation. Our preliminary numerical examples show the effectiveness of both methods.

6913-110, Poster Session

Beam hardening correction based on HL consistency in polychromatic transmission tomography

X. Mou, S. Tang, T. Luo, Y. Zhang, Xi'an Jiaotong Univ. (China); H. Yu, Virginia Polytechnic Institute and State Univ.

In this paper, we propose a novel method for beam hardening correction in polychromatic transmission tomography. A family of polynomials is firstly determined in a training stage, which forms a complete set in the sense of X-ray physics of medical diagnostic imaging. In particular,

every polynomial in the set is indexed by a beam hardening factor, i.e. effective atomic number, which is further assigned to specific X-ray penetrating path. In order to successfully accomplish the assignment in an imaging stage, another polynomial is adopted to formulize the mapping relationship between the index of polynomial family and the area density ratio of bone tissue. Here, the area density ratio of bone tissue is calculated after the pre reconstructed image being segmented into soft tissue and bone regions. The mapping polynomial is iteratively approximated by a specialized HL Consistency (HLC) based nonlinear algorithm. The key characteristics of this method include that the polynomial family can cover the variations of both high potential and effective filter of X-ray tube, the beam hardening correction in the imaging stage can adapt the content variations of objects being imaged, and the correction effect is also well while bowtie filter exists. Performance analysis and related computer simulation show that HLC based correction is much robust than traditional bone correction to the variants of scale factor .

6913-111, Poster Session

Effect of the frequency content and spatial location of raw data errors on CT images

A. S. Wang, Y. Xie, N. J. Pelc, Stanford Univ.

As CT scanners continue to collect more data per scan, transmitting raw data across the slip ring and storing raw data can be very challenging. While lossy compression can offer a significant reduction in data set size, it introduces errors to the measurements. Thus, it is important to characterize how these errors present themselves in the final reconstructed image. Since these compression errors can be considered as a source of noise, our results are relevant to other sources of noise, such as electronic noise.

In this paper, quantization combined with companders serves as an elementary form of compression to illustrate various effects. We examined the effect of noise of different frequencies in the view (time) direction as well as at different locations in the detector arc. Our research showed that only low temporal frequency errors in the center detectors can contribute to errors in the center of the reconstructed field-of-view (FOV). On the other hand, high temporal frequency errors only contribute to errors in the periphery of the reconstructed FOV. The image errors can also be object-dependent since they depend on the transmitted intensity.

Whether image errors arise from compression or electronic noise, their relative sensitivity to different frequencies and detectors is an important consideration for applications such as cardiac CT, where the center of the FOV may be considered the most critical region. Therefore, when limiting data rate is essential, detectors could be allocated different bit-rates for compression based on the frequency content of their errors and their spatial location.

6913-112, Poster Session

A 3D metal artifact correction method in cone-beam CT bone imaging by using an implant image library

Y. Zhang, R. Ning, D. L. Conover, Univ. of Rochester

A three-dimensional metal artifact correction method has been previously developed to correct the streaking artifacts generated by titanium implants in cone-beam CT bone imaging. In the method, the implants' mathematic boundaries were generated to help to segment the metal from the reconstructed images. The segmented metal implants were then re-projected onto the detector to create metal-only projections to compensate for the beam-hardening effect. This method had been proved very effective with the metal implants of regular shape which can be simulated by simple 3D primitives, such as cuboid, cylinder and cone. However, for the metal implant of arbitrary shape, its boundary is difficult to define mathematically. To solve this problem, this paper proposes a way to acquire the implants' shape information by setting up an implant image library. The metal implants were acquired and scanned before the surgery and their images were reconstructed and stored in a library. During the metal artifacts correction, the library was called to provide the shape information of the implants to help to do the segmentation. The segmented metal images were re-projected to generate metal-

only projections by a cone-beam re-projection technique. The beam-hardening effect in the original projections was then compensated by high polynomial orders of metal projections. Finally, the corrected projections were back-projected to produce artifacts-reduced images. Both phantom studies and patient studies were conducted to test this correction method. Results from both studies are presented in the paper.

6913-113, Poster Session

Accurate measurement of respiratory airway wall thickness in CT images using a signal restoration technique

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Airway wall thickness (AWT) is an important bio-marker for evaluation of pulmonary diseases such as stenosis, bronchiectasis. While an image-based analysis of the airway tree can provide precise and valuable airway size information, quantitative measurement of AWT in MDCT images involves various sources of error and uncertainty. So we have developed an accurate AWT measurement technique for small airways with three-dimensional (3-D) approach. To evaluate performance of these techniques, we used a set of acrylic tube phantom was made to mimic small airways to have three different sizes of wall diameter (4.20, 1.79, 1.24 mm) and wall thickness (1.84, 1.22, 0.67 mm). The phantom was imaged with MDCT using standard reconstruction kernel (Sensation 16, Siemens, Erlangen). The pixel size was 0.488 mm x 0.488 mm x 0.75 mm in x, y, and z direction respectively. The images were magnified in 5 times using cubic B-spline interpolation, and line profiles were obtained for each tube. To recover faithful line profile from the blurred images, the line profiles were deconvolved with a point spread kernel of the MDCT which was estimated using the ideal tube profile and image line profile. The inner diameter, outer diameter, and wall thickness of each tube were obtained with full-width-half-maximum (FWHM) method for the line profiles before and after deconvolution processing. Results show that significant improvement was achieved over the conventional FWHM method in the measurement of lumen area and AWT.

6913-114, Poster Session

Reconstruction artifacts in VRX CT scanner images

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Variable Resolution X-ray (VRX) CT scanners allow imaging of different sized anatomy at the same proportional level of detail using the same device. This is achieved by tilting the x-ray detectors so that the projected size of the detecting elements is varied producing reconstructions of smaller fields of view with higher spatial resolution. As with regular CT scanners, the images obtained with VRX scanners are affected by different kinds of artifacts. Some artifacts are due to phenomena inherent to x-ray imaging such as beam hardening. Others are specific to the x-ray detector technology used. Still others are due to the image acquisition protocol and the reconstruction algorithm. This work studies some of these artifacts and the impact that the VRX effect has on them. For this, a single-arm single-slice VRX scanner is used to produce images with artifacts commonly found in routine use, for example streak artifacts produced by highly absorbent objects such as bones, needles and calibration pins. These images and artifacts are replicated using our VRX CT scanner simulator, which allows us to isolate the system parameters that have a greater effect on the artifacts. A study of the behavior of the artifacts at varying VRX opening angles is also presented. The information gathered through these virtual and physical experiments allows us to identify elements in the VRX system that play the major roles in the generation of artifacts, and is therefore valuable in designing changes to the acquisition protocols and the reconstruction process that will minimize those artifacts.

6913-115, Poster Session

Quantification and elimination of windmill artifacts in multislice CT

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In multi slice cone beam CT imaging, there are artifacts known as “windmill” artifacts. These artifacts are due to not satisfying the Nyquist criteria in the patient longitudinal direction. This paper quantifies and compares these artifacts as a function of the number of rows, pitch, collimation, and image thickness of the CT scanner. Scanners with rows of 16, 64 and 128 are measured and compared with simulated data, using both Helical and Axial scanning modes. In addition three focal spot switching modes are compared: the traditional within image plane mode; diagonal mode; and quad mode. All images are compared via four criteria: artifacts, MTF, SSP and noise.

Results show that the frequency of the artifact, or number of blades on the windmill and magnitude of each blade, is dependent on the rate at which the rows are crossed for an image. For example, for a given pitch, doubling the rows doubles the frequency of the artifact, with each artifact approximately 1/2 the magnitude. A similar result can be obtained by keeping the number of rows constant and varying the pitch. The artifact disappears as the Nyquist criteria is satisfied by either increasing the slice thickness or incorporating one of the focal spot switching modes that switch in the patient longitudinal direction. For a given MTF and SSP, the diagonal focal spot switching mode has slightly more noise while the other two are approximately equal. The artifact varies with the quad mode being the best and traditional mode being the worse.

6913-116, Poster Session

Three-dimensional vessel sizing and PSF estimation in CT volumes using Fourier analysis

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PURPOSE: In neuro-ensodvascular procedures, 3D vessel analysis (such as vessel sizes) using Computed Tomography (CT) reconstruction relies on segmentation, edge-detection, or window-level as an important first step. These procedures almost never involve the deconvolution of the reconstructed volume from the blur function of the x-ray imaging system or the specific CT reconstruction technique employed. This may result in inaccurate vessel sizing information. We propose a simple method for calculating the vessel sizes and point spread function from the CT volumes using Fourier analysis.

METHODS: Our technique is based on extracting vessel profiles using a plane perpendicular to the vessel. This profile is the result of the convolution between the ideal vessel profile and the blur function (system and reconstruction algorithm). The vessel parameters are found by (1) finding the first zero crossing of the fourier transform of the observed profile, (2) Using the model for the blur function, fitting in Fourier space will further improve the calculated vessel radius and sigma parameter of the blur function. This also yields the point spread function at any point in the CT volume.

RESULTS: We perform experiments on simulation and phantom data. For both categories, we report on promising results. Apart from observing that the model is in fact a good approximation for the real data, we can obtain vessel sizes within 0.2 voxels of the real sizes.

CONCLUSION: We have proposed a method for calculating vessel sizes and point spread function in CT volumes.

6913-117, Poster Session

Effects of scanning orbit wobbling and detector tilting on cone-beam tomography

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Cone-beam scanning and volume tomographic reconstruction is being accepted by medical imaging community. The cone-beam scanning involves a circular orbit and rotational pyramidal projections. In practice, the manufacturing error may produce a non-circular orbit (either in the orbit plane or out of the orbit plane). The positioning error may cause the detector plane not to be perpendicular to the central source-to-detector ray (called isoray). All these mechanical errors will degrade the volume imaging performance of cone-beam tomography. In this paper, we will study on the effects of orbit wobbling and detector tilting through the use of 3D point spread function (PSF). In general, the orbit wobbling deteriorates the spatial variance of the cone-beam volume imaging in terms of edge blurring. The detector tilting will cause asymmetry of 3D PSF because of the fact that: one side locates away from the source further than the other side due to the obliqueness. By quantitative measurement of the asymmetrical PSFs, it is expected to characterize the orientation and angle of the obliqueness therefrom. The PSF measurement can also be used for calibrations for detector tilting and orbit wobbling. Computer simulation and phantom experiment will be reported.

6913-118, Poster Session

Quantitative comparison of weighted Feldkamp FBP full-scan and half-scan algorithms for contrast-enhanced CT breast imaging

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Dedicated CT breast imaging using a flat-panel detector system holds great promise for improving the detection and diagnosis of early stage breast cancer. It is currently unclear whether dedicated CTBI systems will be useful for screening of the general population. Possibly a more realistic goal will be contrast-enhanced, flat-panel CTBI to assist in the diagnostic workup of suspected breast cancer patients. It has been suggested that the specificity of CECTBI can be improved by acquiring a dynamic sequence of CT images, characterizing the lesion enhancement pattern. To make dynamic CE-CTBI feasible, it is important to perform very fast CT acquisitions, with minimal radiation dose. One technique for reducing the time required for CT acquisitions, is to use a half-scan cone-beam acquisition, requiring a scan of 180° plus the detector width. In addition to achieving a shorter CT scan, half-scan acquisition can provide a number of benefits in CTBI system design. This study compares different half-scan reconstruction methods with a focus on evaluating the quantitative performance in estimating the CT number of iodinated contrast enhanced lesions. Results indicate that half-scan cone-beam acquisition can be used with little loss in quantitative accuracy.

6913-119, Poster Session

Landmark based compensation of patient motion artifacts in computed tomography

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We propose a new method for compensating patient motion in computed tomography. The method consists of analyzing the frequency spectrum of tracked landmark points in the acquired sinogram. These landmarks are either physically attached to the patient prior scanning, or coincide with anatomical points traceable in the sinogram. Without motion present, these extracted landmark curves represent one period of a sine wave in full-rotation tomography. Motion compensation is achieved by calculating the fundamental frequency component of the extracted landmark curves with motion in order to obtain the motion compensated landmark curve. The extracted and compensated landmark curve pairs serve for constructing a motion map, and these are utilized to re-sort the acquired sinogram to obtain a motion compensated sinogram. Reconstructing the motion compensated sinogram with any existing reconstruction algorithm yields the motion compensated image. The proposed method

is compared to a previously published motion artifact reduction method. The results show equal or improved motion compensation capabilities of the proposed method for three different types of computer simulated in-plane motion in synthetic 2D parallel-beam sinograms. The influence of inaccurate curve extraction has been simulated and results are included. Experiments aimed at demonstrating the compensation of motion artifacts in micro-computed tomography patient images are currently under way. In addition to compensation, future work will explore detection and quantification of patient motion based on frequency spectrum analysis of landmark curves, potentially providing a comprehensive tool for understanding and managing motion artifacts.

6913-121, Poster Session

Temporal-noise measurements of a CMOS camera used for image quality measurements

H. Roehrig, W. J. Dallas, The Univ. of Arizona; G. R. Redford, Optic Valley Photonics

We have used a CMOS camera as multi-purpose instrument for measuring image quality of high-resolution LCD displays for use in medical diagnosis. The camera uses a Foveon sensor so that the RGB pixels are co-located making for simplified spatial sampling. In this presentation we examine the temporal-noise characteristics of the CMOS camera.

We are using one of several LED's in an integrating sphere as the light source to provide the nominally uniform illumination for each experiment. In first experiments we place the camera sensor near to the opening of the integrating sphere without introducing an imaging lens in order to initially eliminate the characteristics of the lens. The capture parameters for the camera control software are set to give us as nearly raw data as possible. We suppress the native processing because our application is much different than the usual image-reproduction function. We capture sequences of images with the same illumination and same capture parameters and write them to TIFF files.

The Matlab-based software we've written first pre-processes the images then calculates the pixel-wise mean and standard deviation over the sequence of frames. The calculation is repeated for each of the three (RGB) channels of the CMOS camera. These statistics are displayed as graytone images in three windows with the maxima and minima displayed in the title-bars.

The short-term goal of experiments is to prepare the way to compare the performance of cooled and un-cooled versions of the camera.

6913-122, Poster Session

New automatic quality control methods for geometrical treatment planning system tools in external conformal radiotherapy

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Quality control of external conformal radiotherapy treatment planning systems softwares is a crucial issue. Indeed, the treatment quality depends directly on the quality of treatment planning systems (TPS). Radiotherapists need to be sure that the softwares compute accurately every parameter of the treatment. This paper focuses on the quality control of geometrical treatment planning systems. These TPS compute the geometrical part of the treatment. They define the targets and shapes of the irradiation beams. Four operations done by these TPS are examined in this work. The quality control of the auto-contouring, auto-margin, isocenter computation and collimator conformation tool is treated with a new method based on digital test objects (DTO). Standard methods for this quality control have been set up from the development of some physical test objects (PTO). These methods are time-consuming and inaccurate. Results are biased by the CT-scan acquisition and error evaluation is done with the graphic tools of the TPS. Our method uses DTOs and allows an automatic qualitative error evaluation. DTOs present many advantages for TPS quality control. They lead to a fast, accurate, complete and automatic quality assessment. Special DTOs have been

developed to control the TPS tools mentioned previously as well as their automatic result analysis methods. A TPS has been controlled with these test objects. The quality assessment shows some errors and highlights some particularities in the TPS tools' functioning. This quality control was then compared with the standard quality control.

6913-123, Poster Session

Digital phantoms for an evaluation of software used for an automatic analysis of the Winston-Lutz test in image guided radiation therapy

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Accurate isocenter positioning of the treatment machine is essential for the radiation therapy process, especially in stereotactic radio surgery and in image guided radiation therapy.

We present in this paper a new method to evaluate a software which is used to perform an automatic analysis of the Winston-Lutz1 test used in order to determine the position and the size of the isocenter. The method consists of developing digital phantoms that simulate mechanical distortions and isocenter misalignments of the treatment machine. These Digital Test Objects (DTO) offer a detailed and profound evaluation of the software, and allow determining the necessary adjustments which lead to high precision and therefore better treatment results.

6913-124, Poster Session

A simulation framework for pre-clinical studies on dose and image quality: concept and first validation

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Purpose: The purposes of the study were to set-up and validate a simulation framework for dose and image quality optimization studies. In a first phase we have evaluated whether CDRAD images as obtained with 2 computed radiography plates could be simulated.

Material and Methods: The Monte Carlo method is a numerical method that can be used to simulate radiation transport. It is often used in dosimetry, but in present study it is used to simulate X-ray images. With the Monte Carlo software, MCNPX, the successive steps in the imaging chain were simulated: the x-ray beam, the attenuation and scatter process in a test object and image generation by an ideal detector.

Those simulated images were further modified for specific properties of CR imaging systems. The signaltransfer-properties were used to convert the simulated images into the proper grey scale. To account for resolution properties the simulated images were convolved with the point spread function of the CR systems. In a last phase noise, based on noise power spectrum (NPS) measurements, was added to the image.

In this study, we simulated X-ray images of the CDRAD contrast-detail phantom. Those simulated images, modified for the CR-system, were compared with real X-ray images of the CDRAD phantom.

Results: First results confirm that realistic CDRAD images can be simulated and that reading results of series of simulated and real images have the same tendency.

6913-125, Poster Session

Validation of a GEANT4 simulation of neutron stimulated emission computed tomography

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Neutron stimulated emission computed tomography (NSECT) is being proposed as a non-invasive technique to detect concentrations of elements in the body to diagnose iron overload in the liver. Several

experiments have been conducted to test NSECT's feasibility in determining iron concentration in liver tissue and determine the detection sensitivity of the system. While these experiments have generally demonstrated excellent potential for NSECT, they have been prohibitively time consuming and difficult to implement for different combinations of acquisition parameters under consideration. To overcome these difficulties, GEANT4 simulations are being developed as an alternative to investigate system optimization and aid further progress of the experimental technique. This work presents results that validate a GEANT4 simulation of NSECT by comparing simulated data with corresponding experimental results from a sample of natural iron scanned with identical source-detector configuration as the experimental acquisition system. A sample of natural iron is scanned with a 7.5 MeV neutron beam to stimulate gamma emission from iron nuclei. The resulting gamma spectrum is reconstructed using high-purity germanium detectors and analyzed for energy peaks corresponding to iron. Four peaks are detected corresponding to gamma lines from ^{56}Fe in both, the experimental and simulated spectra, with relative errors ranging from 4.5% to 11.5%. This result validates the GEANT4 simulation as a feasible alternative to perform simulated NSECT experiments using only computational resources.

6913-126, Poster Session

Use of the detective quantum efficiency in a quality assurance program

I. A. Cunningham, Robarts Research Institute (Canada)

X-ray imaging facilities use quality assurance (QA) programs to help ensure images are obtained with the highest possible quality for acceptable patient exposure levels. While the measurement of patient exposure is straightforward, measuring and specifying image quality in these QA programs is subjective, non-quantitative, and depends on specific test phantoms. The detective quantum efficiency (DQE), expressed as a function of spatial frequency, is a direct measure of system performance and "dose efficiency" that is objective, quantitative, and widely accepted by the scientific community. We have implemented a QA program in a tertiary care hospital in which both the DQE and modulation transfer function (MTF) are measured as part of a routine QA program.

The DQE and MTF are measured using a prototype device that automates the measurement and analysis. Each measurement is completed in 15 min, requires no system modification or disassembly, and is compliant with IEC 62220. Digital chest, general radiography and mammographic systems are included. In the past year, no significant deterioration in DQE or MTF of any system has been observed. However, large differences in DQE and MTF are observed between different detector technologies. While the MTF correlates well with analyses of images of resolution-test bar patterns at relatively high detector exposures used in QA programs, it overstates detectability of small detail at normal clinical exposure levels where the DQE correlates well with actual low-contrast detection tasks. It is anticipated that routine monitoring of DQE will provide early warning of system failures that will require service interventions.

6913-127, Poster Session

Radiation dose measurement for various parameters in MDCT

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Due to increasing demand for high quality diagnostic studies, the use of MDCT has been rapidly increased and raised the important issues of patient dose of radiation. The MDCT parameters affecting radiation dose include tube voltage, tube current, pitch, change of beam collimation, and size of the human body. The purpose of this study was to measure and evaluate radiation dose for MDCT parameters. Patient dose for various combination of MDCT parameters were experimentally measured, using MDCT (GE light speed plus 4 slice, USA), model 2026C electrometer (RADICAL 2026C, USA), standard Polymethylmethacrylate (PMMA) head and body CT dosimetry phantom. CTDI_{free} air was measured free in air and CTDI_w was measured using head and body phantoms.

The CTDI_w was determined as a function of x-ray tube voltage (80, 100, 120, 140 kVp), tube current (100, 150, 200, 250, 340 mA), beam collimation (1.25, 5, 10, 15, 20 mm), pitch (0.75, 1.5), and tube rotation time was 1 second.

For both phantoms, the CTDI_w values (6.15 mGy to 44.33 mGy) linearly increased as tube voltage increased, and the CTDI_w values (8.09 mGy to 53.39 mGy) linearly increased as tube current increased, and the CTDI_w values (43.32 mGy to 13.40 mGy) nonlinearly decreased, as beam collimation increased and the CTDI_w values (head: 60.34 mGy to 40.72 mGy, body: 19.76 mGy to 11.25 mGy) decreased, as pitch values increased.

In conclusion, the patient dose which was CTDI_w values linearly increased for tube voltage and current increased, nonlinearly decreased for beam collimation increased, and decreased for pitch value increased.

6913-128, Poster Session

Dosimetric measurements and comparison studies in digital imaging system

J. Jung, H. Kim, H. Cho, C. Lee, S. Nam, Yonsei Univ. (South Korea)

Number of radiologic exams using digital imaging systems has rapidly increased with advanced imaging technologies. However, it has not been paid attention to the radiation dose in clinical situations. It was the motivation to study radiation dosimetry in the DR system. The objective of this study was to measure beam quality and patient's dose using DR system and to compare them to both IEC standard and IAEA guidelines. The measured beam quality was 50% of the IEC standard. The measured average dose for chest and abdomen was 1.376mGy and 9.501mGy, respectively, compared to 0.4mGy and 10.0mGy in IAEA guidelines. The results showed that the patients may be exposed higher radiation for chest exams and lower radiation for abdomen exams using DR system. IAEA Guidelines were prepared based on western people which may be different weight and height for patients compared them to Korean. In conclusion, a new guideline for acceptable DR dosimetry for Korean patients may need to be developed with further studies for large populations

6913-129, Poster Session

Estimation of x-ray parameters in digital coronary angiography for compensation of myocardial perfusion measurements

C. H. Slump, Univ. Twente (Netherlands); C. J. Storm, Ziekenhuis Walcheren (Netherlands)

In this paper we present a method for the estimation of the X-ray exposure parameters from the acquired images. All images are acquired with a Siemens Medical Axiom Artis dFC single plane C-arm with digital dynamic flat detector. The application of the method is in digital coronary angiography where we need it for the compensation of X-ray parameter differences between a normal image sequence and a hyperemic induced run. This comparison is the basis of the assessment of a Coronary Flow Reserve (CFR) measure indicating the physiological relevance of lesions in coronary angiograms. We have setup a phantom study to obtain measurements of the X-ray parameters in order to compare the estimates with measured values. A side result of our phantom study is a reverse engineering analysis of the Automatic Exposure Control (AEC) unit of the digital cath. lab. with flat detector. The AEC is a system unit with the task to ensure a constant dose rate at the entrance of the detector and making the appropriate adaptations in X-ray factor settings for patients which range from slim to more obese. We present several of the developed phantoms together with the measurement strategy. The basis consists of 20 cm water and static and dynamical phantoms are used in addition to reveal the AEC response for the various cardiac acquisition protocols installed in the system. In addition the X-ray dose is measured separately at the entrance of the detector. Based on the acquired images the X-ray factors are estimated, which are compared with the measured values.

6913-130, Poster Session

Computational method for automatic determination of radiographic equipment anode angle

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There are several parameters related to the radiographic equipment that must be evaluated to guarantee the efficiency of a radiological examination. Most of them are directly related to the quality of the radiographic image. The anode angle of an x-ray tube is an important parameter that must be evaluated as it is associated to the focal spot size, heel effect, anode heat dissipation and can determine the useful life of the x-ray tube. However, it is very difficult to be measured experimentally and rarely is provided by the manufacturer. Thus, this work presents a computational technique for automatic determination of the anode angle of any radiographic equipment using a non-invasive method. First, it was built a pinhole matrix made by lead, which contains 33 radial 50 μ m diameter holes. This pinhole matrix is used to obtain a radiographic image of focal spot projections along the radiation field. The computer algorithm calculates the point spread function of each focal spot projection as well as the distance between them. Thus, anode angle can be determined automatically by using the field characteristic equations, as the geometric unsharpness at any arbitrary field position can be derived from those at the central beam position. Results showed good accuracy compared to nominal values and also a methodology was developed to validate the computational algorithm. Determination of anode angle of any radiographic equipment (including mammographic ones) which great precision can be easily done by using the method proposed in this work.

6913-131, Poster Session

Performance assessment of a simple and accurate grid alignment aid for portable chest imaging

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Portable chest radiography is one of the most widely performed radiographic exams. However, they usually have less image quality than standard chest exams because antiscatter grids are often not used to reduce the excessive x-ray scatter. Studies have demonstrated the benefit of using grids for image quality improvement, but grids are not often being applied because of the challenge of an operator's ability to visually align the x-ray focal spot to the grid focal axis. A grid alignment aid has been developed and its performance evaluated. The grid alignment aid consists of one line laser and one cross-hair laser symmetrically mounted on either end of a supporting frame. During an x-ray exam, the alignment aid is attached to the top of a standard 35 x 43 cm radiographic cassette. The two lasers generate a predetermined light pattern on the mobile x-ray collimator surface to indicate the optimal x-ray source position in the Cartesian coordinate system. Two grids commonly used in portable chest exams (103 lp/in. resolution, 6:1 and 8:1 ratio) were characterized in term of the signal-to-noise ratio improvement factor and the grid cut-off artifact as a function of the x-ray focal-spot off-focus distance, from which the optimal grid operating range was determined. The geometric accuracy that could be achieved with the grid alignment aid was analyzed and compared against the optimal grid operating range. Data indicate the optimal grid operating range is within $\pm 2.5^\circ$ off-grid focal axis, in order to realize the benefit of using a grid. The grid alignment aid is able to provide sufficient accuracy for positioning the x-ray tube to achieve optimal image capture. This method can be used with any mobile x-ray unit without involving hardware modification. Further, it can be integrated with a grid to provide a complete solution for portable chest radiography.

6913-133, Poster Session

Comparison of MTFs in X-ray CT images between measured by current method and considered linearity in low contrast

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Generally, modulation transfer function (MTF) of computed tomography (CT) is calculated based on CT values. However, it is impossible to measure MTF strictly because the CT value is defined as non-linear function of X-ray intensity. Due to this characteristic, MTF changes according to subject's contrast. Therefore, we measured MTFs of CT with the high and low contrast wire phantoms. In the measurement, we selected thick copper wire in water as high contrast subject and thin copper wire in water as low contrast subject respectively. As compared with MTF measured with the high contrast subject, MTF measured with the low contrast subject was decreased. This was caused, because CT value was nonlinear. To evaluate the spatial resolution in the low contrast subject like human body, we should measure MTFs with the low contrast wire phantom. By using low contrast subjects, we can consider CT value approximately as linear function.

6913-134, Poster Session

An analysis of Field II simulation

L. Candemir, TÜBITAK (Turkey); I. F. Cilesiz, Istanbul Teknik Univ. (Turkey)

Factors like, (i) noise and (ii) artifacts, that occur depending on acoustical properties of tissues, (iii) wrong selection of system variables, like (a) wrong operation frequency, (b) poor calibration, and (c) improper location of focal points, may cause high amount of image degradation during ultrasound imaging. This, in return, may lead to misdiagnoses, making correct diagnosis of uncommon cases impossible. These misdiagnoses may be avoided by enhanced training of physicians. Commercially available phantoms are limited in content and relatively expensive, which makes the simulation of ultrasound imaging a mandatory component in diagnostic ultrasound training. The aim of this study was to investigate the feasibility of the simulation of ultrasound imaging. Under the scope of this work, ultrasound imaging was simulated by using FIELD II program set developed by J.A. Jensen by for various settings. In order to compare the results a selected cyst phantom was used and the effects of simulation frequency and sampling frequency on visibility and simulation times were observed. The quality of generated images was evaluated by measuring the visibility of the cyst phantom. Identification of cysts was accomplished by detection of the cysts with an algorithm to perform a series of image processing operations. Located objects were classified manually and errors (with respect to size and position of cysts) were calculated. Our observations indicated that to obtain a good image quality, interdependent simulation and sampling frequencies should be selected carefully, which in return requires longer simulation times at higher frequencies.

6913-135, Poster Session

Experimental validation of a Monte Carlo-based kV x-ray projection model for the Varian linac-mounted cone-beam CT imaging system

D. Lazos, D. Pokhrel, Z. Su, J. Lu, J. F. Williamson, Virginia Commonwealth Univ.

Fast and accurate modeling of cone-beam CT (CBCT) x-ray projection data can improve cone-beam CT (CBCT) image quality either by linearizing projection data for each patient prior to image reconstruction (thereby mitigating detector blur/lag, spectral hardening, and scatter artifacts) or indirectly by supporting rigorous comparative simulation studies of competing image reconstruction and processing algorithms. In this study, we compare Monte Carlo-computed x-ray projections with projections experimentally acquired from our Varian Trilogy CBCT imaging system for phantoms of known design. Our recently developed Monte Carlo photon-transport code, PTRAN, was used to compute primary and scatter projections for cylindrical phantoms of known diameter (CatPhan and NA model 76-410) with and without bow-tie filter and antiscatter grid for both full- and half-fan geometries. These simulations were based upon measured 120 kVp spectra, beam profiles, and flat-panel detector (4030CB) point-spread function. Compound Poisson- process noise was simulated based upon measured beam output. Computed projections were compared to flat- and dark-field corrected 4030CB images where

scatter profiles were estimated by subtracting narrow axial- from full axial width 4030CB profiles. In agreement with the literature, the difference between simulated and measured projection data is of the order of 6-8%. The measurement of the scatter profiles is affected by the long tails of the detector PSF. Higher accuracy can be achieved mainly by improving the beam modeling and correcting the non linearities induced by the detector PSF.

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6913-136, Poster Session

High resolution amplified pixel sensor architecture for large area digital mammography tomosynthesis

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We introduce a novel architecture for amplified pixel sensor (APS) arrays with only two thin film transistors (TFTs), and present results on in-house fabricated test arrays with a pixel pitch of 100 μm . We also discuss a new driving scheme for the array which minimizes the threshold voltage metastability problem inherent to hydrogenated amorphous silicon (a-Si) TFTs, and provides a faster frame rate. The fewer number of on-pixel elements, and reduced pixel complexity, results in a smaller pixel pitch and increased image resolution, making the APS architecture promising for high resolution, high speed imaging modalities such as digital mammography tomosynthesis.

Pixel transconductance gain of 0.3 $\mu\text{A/V}$, and pixel charge gain of 9 were measured from fabricated test arrays prior to deposition of amorphous selenium x-ray detector. Our in-house fabrication resulted in field effect mobility of $\sim 0.5 \text{ cm}^2/\text{Vs}$; better pixel performance is expected from state-of-the-art a-Si TFT fabrication.

This research extends the application of a-Si on-pixel amplifiers to emerging high resolution, fast readout, low noise large area digital imaging applications such as digital mammography tomosynthesis. Two-transistor on-pixel APS architecture in a-Si technology, coupled with a well established x-ray detection technology such as amorphous selenium (a-Se) can enable large area mammography tomosynthesis.

6913-137, Poster Session

Photodiode forward bias to reduce temporal effects in a-Si-based flat panel detectors

I. Mollov, C. A. Tognina, R. E. Colbeth, Varian Medical Systems, Inc.

Lag and gain modulation are well known temporal artifacts of a-Si based flat panel detectors. Both effects are caused by charge carriers being trapped in the semiconductor. Trapping and releasing of these carriers is a statistical process with time constants much longer than the frame time of flat panel detectors. One way to reduce these temporal artifacts is to keep the traps filled by applying a pulse of light over the entire detector area every frame before the x-ray exposure. This paper describes an alternative method, forward biasing the a-Si photo diodes and supplying free carriers to fill the traps. Photodiodes are forward biased and then reversed biased again every frame between the panel readout and x-ray exposure. The method requires no change of the mechanical construction of the detector, only minor modifications of the detector electronics and no image post processing. An existing flat panel detector was modified and evaluated for lag and gain modulation. The required changes of the panel configuration, readout scheme and readout timing are presented in this paper. The results of applying the new technique are presented and compared to the standard mode of operation. The improvements are better than an order of magnitude for both gain modulation and lag; lowering their values to levels comparable to the scintillator afterglow. To differentiate the contribution of the electronics, from that of the scintillator, a large area light source was used in addition to the standard x-ray exposure. Possible implementations and applications of the method are discussed.

6913-138, Poster Session

Distortion, orientation and translation corrections of tiled EMCCD detectors for the new solid state x-ray image intensifier (SSXII)

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We report our design considerations for a new detector system, the solid state x-ray image intensifier (SSXII), with enhanced resolution and fluoroscopic imaging capabilities, made of a mosaic of modules each consisting of CsI(Tl) phosphor coupled using a fiber-optic taper or minifier to an electron multiplier charge coupled device (EMCCD). Generating high quality images using this EMCCD tiled-array system requires the determination and correction of the individual EMCCD sub-images with respect to relative rotations and translations as well as optical distortions due to the fiber optic tapers. Image corrections are based on images of a wire mesh phantom. The mesh crossing point positions in each sub-image are automatically identified. With the crossing points identified, the mapping between distorted and undistorted arrays is determined. For each pixel in the distortion-corrected image, the corresponding location in the undistorted image is calculated and the pixel value at that location is obtained using bilinear interpolation. For the rotation correction, the orientation of the vectors between respective mesh crossing points in the various sub-images are determined and each sub-image is appropriately rotated with the pixel values again determined using bilinear interpolation. Image translation correction is performed using reference structures at known locations. Distortion corrections are accurate to within 1%. Rotations are determined to within 0.1 degree. Translation corrections are accurate to within 1 pixel. This approach will provide the basis for generating single images from tiled-image configurations of the SSXII regardless of how many modules are used to form the images.

6913-139, Poster Session

Modeling of dark current and ghosting in multilayer amorphous selenium x-ray detectors

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A theoretical model is developed to describe bias-dependent transient behavior of dark current in multilayer amorphous selenium (a-Se) detectors by solving Poisson's equation, and the trapping and release rate equations in the a-Se layer. The transient behavior of the dark current is studied under different applied biases and is fitted with experimental data. The proposed theoretical model shows a very good agreement with experimental results. The initial high dark current decays with time and stabilizes at a much lower value within the time range of $\sim 3/4$ 100-1000 seconds. It has been found that the electric fields at the metal contacts reduces to 20-30% of the applied field (applied voltage/thickness). The dark current is mainly controlled by the hole injection and trapped hole concentration in the thin n-layer of the p-i-n or n-i-p type detector structure (commonly referred to as the multilayer structure). It has been found that the dark current in a-Se detectors can be described by the thermionic emission-diffusion current. The dependence of the X-ray sensitivity of multilayer a-Se X-ray imaging detectors on repeated X-ray exposures is studied by considering accumulated trapped charges and their effects (trap filling, recombination, electric field profile, electric field dependent electron-hole pair creation), the carrier transport in the blocking layers, X-ray induced metastable deep trap center generations, and the effects of dark current. We simultaneously solve the continuity equations for both holes and electrons, trapping rate equations, and the Poisson's equation across the photoconductor for a step X-ray exposure by the Backward Euler finite difference method. It has been found that the electric field at the metal and the n-layer contact increases several times (as high as 5 times as compared to the steady values before any exposure) with increasing accumulated X-ray exposures. The theoretical model shows a very good agreement with the experimental relative sensitivity versus cumulative X-ray exposure characteristics.

6913-140, Poster Session**The study of I-V response characterization about top-electrode type on mercury-iodide(Hgl2) film for application of x-ray image detectors**

C. Kwon, S. Heo, C. Choi, Inje Univ. (South Korea); Y. Kim, Inha Univ. (South Korea); B. Y. Cha, S. Kang, S. Nam, Inje Univ. (South Korea)

The purpose of this study is to develop a new direct-method digital radiation detector on Mercury Iodide. In this study, high electrical signals generated in Mercury-Iodide (Hgl2) are analyzed, it's analyzed how types of top electrode influence on leakage current and SNR (signal to noise ratio). In order to quantitatively measured and analyze electrical characteristics. Samples were fabricated using Screen printing method. Sample thickness was 100um. And ITO (Indium Tin Oxide) was used as a bottom electrode and ITO, Au, In was used as top electrodes. Leakage-current was examined to x-ray dose and applied voltages, and SNR of x-ray was also measured. Applied voltages were 50, 100, 150 and 200V measured for 10minute. As a result, types of top electrodes don't influence on leakage current, rather the condition of interface influences on leakage current much more.

6913-141, Poster Session**The study of multilayer for increasing semiconductor efficiency by decreasing dark current with oxidized substance for x-ray imaging**

D. Son, S. Kang, S. Jo, C. Choi, M. Yoon, M. Kim, S. Nam, Inje Univ. (South Korea)

Various semiconductor materials as X-ray detector have been studied for Digital X-ray imaging. In this paper, the multi-layer deposited with PbO layer on Hgl2 film was fabricated to decrease the dark current of Hgl2 with high conversion efficiency. Sample film was grown by a particle-in-binder (PIB) method, onto glass substrates 3Å" x3Å" in size, with ITO deposited as bottom electrode. Film thickness was measured about 250Å_ (Å±5%) and top electrode is deposited ITO with sputtering system. The structural and morphological properties of film sample were investigated by using scanning electron microscopy (SEM) to observe a layer structure as reported previous literature. Also, electrical properties such as dark current, sensitivity, signal to noise ratio (SNR) and lag were verified with x-ray evaluation system for efficiency performance of semiconductor. As a result, the dark current of multi-layer film was shown in decreasing tendency about three times from 2.0nA to 0.7nA. But, the sensitivity of multi-layer did not decrease so much as like the dark current. It is thought that dark current due to using PbO layer as blocking layer was decreased, as shown in P-N junction semiconductor.

6913-142, Poster Session**X-ray detector using liquid crystal modulator**

S. Heo, S. Kang, B. Y. Cha, S. Cho, S. Kim, C. Kwon, S. Nam, Inje Univ. (South Korea)

The study of Digital X-ray Detector has been focused on high resolution image acquisition. However, indirect system has a low resolution due to blurring of light from scintillator, the other hand, though direct system has higher resolution comparing with indirect system, it is expensive and difficult to fabricate in large size by using TFT array. This study suggested new structure of Digital X-ray Detector by combining Photoconductor Material and LC (Liquid Crystal). In the experiment, the linear range of LC twisting was acquired by measure of T-V (Transmittance-Voltage) Curve. The voltage generated from Photoconductor was acquired by changing the glass thickness and the voltage enable LC to twist over 90%. Combining Photoconductor on LC, the feasibility of new structure detector was evaluated as X-ray detector by using Back Light Unit and X-ray film. In the result of this study, new structure detector showed enough feasibility as X-ray detector.

6913-143, Poster Session**X-ray properties measurement of flat panel gas detector**

M. Yun, Inje Univ. (South Korea)

Recently, large area matrix-addressed image detectors are investigated for X-ray imaging with medical diagnostic and other applications. In this paper, a new flat panel gas detector for diagnostic X-ray imaging is proposed, and its characteristics are investigated. To estimate the X-ray signal of gas detector, we simulated the space distribution of the X-ray induced charges by Monte Carlo simulations. Most simulations of such detectors simplify the setup by only taking the conversion layer into account neglecting behind. The Monte Carlo code MCNPX has been used to simulate the complete interaction and subsequent charge transport of X-ray radiation. The experimental measurements, the transparent electrodes, dielectric layer, and the MgO protection layer were formed in front glass. And, the X-ray phosphor layer and address electrodes are formed in the rare glass. The dark current, the x-ray sensitivity and linearity as a function of electric field were measured to investigate the electrical properties. From the results, the stabilized dark current density and the significant x-ray sensitivity were obtained. And the good linearity as a function of exposure dose was showed in wide diagnostic energy range. These results means that the passive matrix-addressed flat panel gas detector can be used for digital x-ray imaging.

6913-144, Poster Session**Soft tissue small avascular tumor imaging with x-ray phase-contrast micro-CT in in-line holography setup**

Y. I. Nesterets, T. E. Gureyev, A. W. Stevenson, A. Pogany, S. W. Wilkins, Commonwealth Scientific and Industrial Research Organisation (Australia); R. E. Kincaid, H. Ye, L. Vogelsang, E. D. Lipson, Syracuse Univ.; I. L. Coman, Upstate Medical Univ./SUNY; S. Fourmaux, J. Kieffer, Institut National de la Recherche Scientifique (Canada); A. Krol, Upstate Medical Univ./SUNY

To assess feasibility of small soft tissue avascular tumor micro-CT imaging with x-ray phase-contrast in in-line holography setup we studied micro-CT imaging with in-line geometry of small spheroidal avascular tumor models with quiescent cells core (< 250 µm) and various distributions of the proliferating cell density (PCD) forming the outer shell. We simulated images and performed experiments with ultrafast laser-based x-ray source with Mo target. We observe phase-contrast enhancement of the boundaries of the tumor in the reconstructed transaxial images resulting in improved detection of small soft tissue tumors providing that PCD density gradient is sufficiently large.

6913-145, Poster Session**A predictive software tool for optimal timing in contrast enhanced carotid MR angiography**

A. N. Moghaddam, David Geffen School of Medicine at UCLA and California Institute of Technology; T. Balawi, R. Habibi, David Geffen School of Medicine at UCLA; C. Panknin, G. Laub, Siemens Medical Solutions, Inc.; S. G. Ruehm, P. Finn, David Geffen School of Medicine at UCLA

A clear understanding of the dynamics of contrast agents is crucial in synchronizing data acquisition of 3D MR angiography (MRA) with arrival of the contrast bolus in the vessels of interest. We implemented a computational model to simulate contrast dynamics in the vessels using the theory of linear time invariant systems. The algorithm calculates an impulse response for the contrast concentration from time resolved images. The method was validated on time resolved contrast enhancement in CT angiography. This algorithm can be used as a clinical tool to replace empiric formulae by computation of patient-specific timing of data acquisition for MRA.

6913-146, Poster Session

A feasibility study of the 3D fluorescent image reconstruction for the simultaneous PET and fluorescent CT imaging system using depth of interaction PET detector

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Multimodal molecular imaging is emerging technology for bioscience. The simultaneous imaging system of PET (Positron Emission Tomography) and Fluorescent CT (Computed Tomography) is being developed in the National Institute of Radiological Science in Japan. To reconstruct 3D fluorescent image, it is necessary to use NIR (Near Infrared) probes, which can deeply penetrate biological tissues. We are considering using the PET-DOI (Depth of Interaction) detectors as simultaneous detectors of the gamma ray for PET and NIR light for fluorescence by changing the upper reflectors to the dichroic mirrors. Here, PET-DOI detector has very low spatial resolution to the NIR signals compared to basically used CCD cameras. However, NIR light is scattered by biological tissues. In such a case, it can be possible to reconstruct valuable image from the data which acquired from low resolution devices.

In this study, we conducted a computer simulation to evaluate it. In the simulation, we use a cubic phantom and square shaped detector geometry and diffusion equation to approximate the light propagation. The system matrices of the Fluorescent CT geometries having different detector resolutions are calculated and we evaluated the singular values of the matrices. Using the system matrices, we simulated the image reconstruction from observed data which is generated by simulation and noise added. As a result, the reconstructed image from low resolution detectors is as same level as one from higher resolution detectors using ML-EM image reconstruction algorithm.

6913-147, Poster Session

A dual micro-CT system for small animal imaging

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Micro-CT is a non-invasive imaging modality used usually to assess morphology in small animals. In our previous work, we have proved that also functional micro-CT imaging is possible. This paper describes a dual micro-CT system with fixed x-ray/detectors developed to address better such challenging tasks as cardiac or perfusion studies. A two tubes/detectors system ensures simultaneous acquisition of two projections, thus reducing scanning time and the number of contrast injections in perfusion studies by a factor of two. The system is integrated with in house developed software for cardio respiratory gating. The sampling geometry was optimized for 88 microns in such a way that the geometric blur of the focal spot that matches the Nyquist sample at the detector. A geometric calibration procedure allows combining projection data from the two chains in a single reconstructed volume. Image quality was estimated in terms of spatial resolution, uniformity and noise and linearity. The MTF at 10% appears to be 3.4 lp/mm for single detector reconstructions and 2.3 lp/mm for dual tube/detector reconstructions. We suspect that this loss in spatial resolution is due to the compounding of slight errors in the separate single chain calibrations.

The dual micro-CT system is currently used in studies for morphological and functional imaging of both rats and mice. This work was performed at the Duke Center for In Vivo Microscopy, an NCR/NCI National Resource (P41 05959/R24-CA92656), and also supported by NCI R21 CA124584-01.

6913-148, Poster Session

CT number variations in micro CT imaging systems

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CT numbers can be directly computed from the linear attenuation coefficients in the reconstructed CT images and are correlated to the electron densities of chemical elements with specific atomic numbers.

However, the computed CT numbers can be varied when different imaging parameters are used. Phantoms composed of clinically relevant and tissue-equivalent materials (lung, bone, muscle, and adipose) were scanned with two different micro CT imaging systems (one is charged-coupled device detector based with circular scanning geometry and the other one is flat-panel detector based with helical scanning geometry). The mean CT numbers and the corresponding standard deviations in terms of Hounsfield units were then computed from a pre-defined region of interest located within the reconstructed volumetric images. The variations of CT number were then identified from a series of imaging parameters. Those parameters include imaging acquisition modes (e.g., the number of projections and metal filter in the x-ray tube), reconstruction methods (e.g., Feldkamp, total volume minimization, circle-and line, and iterative algorithm), and post-image processing techniques (e.g., cupping artifact, beam-hardening artifact, and photon scatter correction). These variations of CT numbers are useful and important in tissue characterization, quantitative bone structure analysis, bone marrow density evaluation, and Monte Carlo dose calculations for the pilot small animal study when micro CT imaging systems are employed.

6913-149, Poster Session

Contrast imaging with a monochromatic x-ray system

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We are currently developing a monochromatic x-ray source for small animal tomographic imaging. This source currently consists of a conventional cone beam microfocus x-ray tube coupled to a filter that uses Bragg diffraction to transmit only x-rays within a narrow energy range (~10% FWHM). The filter used in this work is designed so that spectral peaks centered between 25 and 35 keV can be obtained by adjusting the angle between the incident x-rays and diffraction planes. A tissue-equivalent mouse phantom was used to a) evaluate how clearly CT imaging using the quasimonoenergetic beam is able to differentiate tissue types compared to conventional polyenergetic CT, and b) to test the ability of the source to perform dual energy, iodine contrast enhanced imaging. The phantom contains rods of various materials whose linear attenuation coefficients approximate those of bone, muscle tissue, and fat. The first set was with an acrylic phantom containing rods of various tissue approximates. Two single slice CT scans were obtained with polyenergetic and 35 keV x-rays. Pixel value fluctuations were reduced in the 35 keV case compared to the polyenergetic case. The second set was with an iodine contrast phantom containing varying concentrations of potassium iodide. Two single slice CT scans were obtained using spectra with maximum values at 30 and 35 keV, respectively. A subtracted CT slice of this phantom (35 keV image - 30 keV image) reveals that the two highest concentrations of potassium iodide remain visible.

6913-150, Poster Session

Noise evaluations of accurate image reconstructions for a dual-head small-animal PET scanner

C. Kao, The Univ. of Chicago; Y. Dong, Illinois Institute of Technology; Q. Xie, The Univ. of Chicago

We are developing high-sensitivity small-animal PET systems by employing large-area detector panels and compact geometry. While our prototype provides high sensitivity, it exhibits significant parallax errors and hence limited resolution. Although parallax errors can be removed when the detector response functions (DRFs) of the scanner are known, in practice accurate calculation of the DRFs and its use in reconstruction are generally infeasible due to the enormous dimension of the resulting mathematical model describing the imaging process. We have exploited the symmetry properties of our scanner to overcome this obstacle and evaluate the noise properties of the resulting reconstruction methods. We generate noise-free and noisy datasets for a numerical micro-Derenzo phantom and reconstruct them by using OSEM algorithms that employ either the accurate DRFs generated by Monte-Carlo (MC) calculations or the approximate DRFs generated by the Siddon ray-tracing method (the common practice). Our results indicate that the MC method can resolve structures as small as 1.2mm while the ray-tracing method produces noticeable image artifacts. For noisy datasets, the MC method also

generates images having superior visual quality. Additionally, the MC method improves the signal-to-noise ratios of several ROIs defined on the phantom. We observe that this improvement is more significant for ROIs containing smaller structures and datasets containing more noise. In conclusion, by incorporating accurate DRFs for reconstructing datasets generated by our scanner, we are able to generate high-resolution small-animal images (~1.2 mm resolution) at high sensitivity (~30% sensitivity in simulation), making our system particularly attractive for low-dose and short-scan imaging.

6913-152, Poster Session

Ordered k-space acquisition in contrast enhanced magnetic resonance angiography (CE-MRA)

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A new way of performing contrast enhanced magnetic resonance angiography (CE-MRA) is presented, in which the entire k-space is decomposed into interlaced subsets that are acquired sequentially. Based on a new parallel imaging technique, Generalized Unaliasing Incorporating object Support constraint and sensitivity Encoding (GUISE), reconstructions can be made using different subsets of k-space to reveal the level of contrast agent in the corresponding data acquisition time period. A proof-of-concept study using a customized phantom was carried out to examine the utility of the new method. A quantity of contrast agent (copper sulfate solution) was injected while data was acquired using an 8-coil receiver and the modified MRI sequence. A sequence of images was successfully reconstructed at high temporal resolution. This eliminated the need to precisely synchronize data acquisition with contrast arrival. With this new method, it is possible to choose a temporal resolution that gives the best vessel contrast and SNR in the post-processing stage. Furthermore, subtraction of a pre-contrast data set prior to reconstruction, which eliminates the need for recovering the stationary background signal, has proven to be an effective way to improve the SNR and allow a higher temporal resolution to be achieved. Acceptably good reconstruction results were obtained at a temporal resolution equivalent to a 16-fold speed up compared to the time taken to fully sample k-space.

6913-153, Poster Session

Development of an MR compatible rotating anode x-ray tube

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In order to achieve a truly hybrid, high quality X-ray/MR system one must have a rotating anode x-ray source as close as possible to the bore of the high-field MR magnet. Full integration between a closed bore MR system and an x-ray fluoroscopy system presents two main challenges that must be addressed: x-ray tube motor operation and efficiency in an external field, and focal spot deflection. Regarding the first challenge our results have shown that an AC induction motor operating in external fields will experience a drop off in efficiency. Specifically, fields on the order of 100 Gauss perpendicular to the rotor decrease the rotation speed from 2450 RPM to below 1800 RPM. We are currently analyzing an alternate brushless DC motor design that would exploit the presence of the external MR fringe field and our initial finite element results indicate that the necessary amount of torque is produced. Regarding the second challenge our results show that an external field of 195 Gauss perpendicular to the anode-cathode axis (BR direction) produces a focal spot deflection of 5 mm. For the fields at which we want to operate the x-ray tube (~to 0.1T along BR) this deflection will be larger than 5 mm and must be corrected for. We propose a design that includes active deflection coils which serve to counteract the presence of the external field and reduce the focal spot deflection to less than 1 mm in our simulations.

6913-154, Poster Session

Parameter optimization for a grating-based phase contrast x-ray system

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Differential Phase Contrast Imaging (DPCI) has the potential to vastly increase soft tissue contrast. DPCI requires spatial and temporal coherence as generated by a synchrotron or a micro-focus X-ray source; however, recent research demonstrates DPCI can be implemented using a conventional X-ray source with three transmission gratings (Pfeiffer et al., Nature 2006). This paper describes the optimization of the essential system parameters (system size, delivered dose, spatial resolution) of this implementation from a theoretical perspective. The optimization of these parameters is an essential step in practical application of DPCI. We conclude that the minimum size of the system is approximately 700 mm, the minimum resolution is 100 μm , and the dose is 1/1000 that of conventional absorption CT.

6913-155, Poster Session

A numerical analysis of the Born approximation for image formation modeling of differential interference contrast microscopy for human embryos

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The differential interference contrast (DIC) microscope is commonly used for the visualization of live biological specimens. It enables the view of the transparent specimens while preserving their viability, being a non-invasive modality. Fertility clinics often use the DIC microscope for evaluation of human embryos quality. Towards quantification and reconstruction of the visualized specimens, an image formation model for DIC imaging is sought and the interaction of light waves with biological matter is examined. In many image formation models the light-matter interaction is expressed via the first Born approximation. The validity region of this approximation is defined in a theoretical bound which limits its use to very small specimens with low dielectric contrast. In this work the Born approximation is investigated via the Helmholtz equation, which describes the interaction between the specimen and light. A solution on the lens field is derived using the Gaussian Legendre quadrature formulation. This numerical scheme is considered both accurate and efficient and has shortened significantly the computation time compared to integration methods that required a great amount of sampling for satisfying the Whittaker-Shannon sampling theorem. By comparing the numerical results with the theoretical values it is shown that the theoretical bound is not directly relevant to microscopic imaging and is far too limiting. The numerical exhaustive experiments show that the Born approximation is inappropriate for modeling the visualization of thick human embryos.

6913-156, Poster Session

A study of respiratory motion effects affecting PET/CT reconstruction for lung cancer diagnosis

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In recent years, the clinical utility of PET/CT in achieving more accurate staging of lung cancers has been established and the technology has been enthusiastically received by the medical community. However, its power in chest imaging is still limited by a multitude of physical factors. As result of a typical PET/CT imaging protocol, respiration-averaged PET data and respiration-free CT data are generated in a PET/CT scanning. In this work, we investigate the effects of respiratory motion. We develop computer programs and employ Monte-Carlo simulation for generating PET/CT data. For validating simulation results by experimental measurements in the future, this data generation will be made in accordance with the geometry of the GE Discovery LS PET/CT

scanner installed at PET center of the Huazhong University of Science and Technology. We scale a Zubal phantom to generate 30 phantoms having various sizes to represent "snapshots" of the torso anatomy during respiration. Images reconstructed from selected scaling PET datasets using the respective scaling PET attenuation maps serve as baseline results. We also reconstruct PET images from respiratory-averaged PET datasets by using respiration-averaged PET attenuation maps, which simulates a conventional PET imaging protocol. PET/CT imaging process is simulated by achieving reconstruction from respiration-averaged PET datasets with a selected PET attenuation map. We compare the reconstructed images generated from the above-mentioned approaches to evaluate the effects of respiratory motion to PET/CT images.

6913-157, Poster Session

An investigation of digital signal processing for shaped pulses for all-digital PET

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The recent development of Positron Emission Tomography~(PET) imaging has elevated the needs for quick, need-based and application-specific calibration, as well as extension of event-processing technologies for specific applications. However, proper calibration is a challenging task due to the huge number of channels and multiplexing of input signals in the mixed-signal front end of modern PET system. It's also difficult to extend event-processing because it would involve making changes to the circuitry. We have proposed a simple all-digital PET system to alleviate such limitations by applying digital signal processing~(DSP) technologies for analyzing event pulses generated in PET. We present our work on implementing pulse shaping, followed by a moderate sample rate Analog-to-Digital Converter~(ADC). We also evaluate two DSP algorithms for extracting event information from the digitized pulse samples. Our preliminary results show that a standard deviation of less than or equal to 60ps for peak-time error and < 0.1% for peak-value error can be achieved for ~87 scintillation pulses generated from Na-22 point source with an HRRT detector module. We will extend our work to measure energy resolution and timing resolution for a pair of scintillator/PMT detectors.

6913-158, Poster Session

Evaluation of the partial flip angle spin echo method to improve non-uniformity in T1-weighted imaging with the 3-tesla MRI

Y. Watanabe, M. Tsuzaka, K. Ishibashi, Y. Sakurai, Nagoya Univ. (Japan)

The advantage of the higher signal-to-noise ratio (SNR) of 3- Tesla magnetic resonance imaging (3TMRI) contributes to the improvement of spatial and temporal resolution. However, T1- weighted images of the brain obtained by the spin-echo (SE) method with 3T MR are not satisfactory for clinical use because of radio frequency (RF) field inhomogeneity. It was called B1 non-uniformity. And it is clear by SE method. In addition, prolongation of the longitudinal relaxation time (T1) of most tissues decreases T1 contrast. Therefore, many hospitals that possess 3TMRI are using GRE method to obtain adequate T1 contrast and high uniformity of images instead of the SE method. Although, high intensity of the influence in susceptibility places, signal deficits, and distortion, break out conspicuously with GRE method. So we obtained T1-weighted images using the partial flip angle SE method instead of GRE method or SE method.

We tried to improve image non-uniformity with partial flip angle SE method. Using partial flip angle SE method we could improve uniformity of images and T1 contrast was adequate.

As a result, uniformity improved by 6i1/4... and became 82.6i1/4... in 110 degree.

These studies indicated that using partial flip angle SE for obtaining the adequate uniformity in T1-weighted image of the brain was effective.

6913-159, Poster Session

Motion gated small animal imaging with a flat-panel CT

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Small animal CT gains increasing interest in preclinical research. Physiological motion compensation like in clinical CT has seldom been employed so far.

We present two different methods of retrospective motion correction for small animal imaging even at high respiratory rate and heart rate. Also the combination of respiratory and simultaneous heart gated imaging is shown. In vivo data are acquired with an experimental flat-panel based CT scanner (Siemens Medical Solutions, Forchheim Germany). Whole mice or rats fit in the available FOV of 25 * 25 * 4 cm³, while acquisition rate was 100fps. Extrinsic gating is realized by collecting the physiological data from a small animal monitoring system with a pneumatic pillow for respiratory motion and ECG for heart motion. The alternative intrinsic method is correlating the lung motion directly to the movement of the center of gravity in the acquired projection data. As an advantage of the second method the even low preparation effort per scan is reduced. As long as the rotation time of the gantry is far below the cycle time of heart or the lung a multi-segment reconstruction was used in both methods. Motion artefacts were largely suppressed after gating. While in non gated images, the diaphragm, heart contours, bronchi and lung vessels were already visible, they were more sharply defined in the gated datasets. Four-dimensional assessment of lung movements was possible and lung volume in several phases such as peak inspiration and expiration could be segmented, quantified and compared.

6913-160, Poster Session

Frequency diversity in breast ultrasound tomography

F. Simonetti, Imperial College London (United Kingdom); L. Huang, Los Alamos National Lab.; N. Duric, Karmanos Cancer Institute

Ultrasound tomography is becoming a very attractive imaging modality for the diagnosis of breast cancer as it is intrinsically safe compared to mammography and it can detect some cancers that are invisible on mammograms. Recent progress in solid state electronics and increased computational power have reinvigorated interest in this area and much effort is now being devoted to the development of array systems insonifying the breast from all possible directions along a prescribed tomographic plane. This full view configuration can be used to perform transmission measurements through the breast tissue in addition to the more conventional backscattering measurements obtained with linear array probes. The combination of backscattering and transmission measurements can then be used to extract accurate information about the speed of sound and density distribution within the breast. A number of algorithms have been proposed to reconstruct these maps using continuous wave (CW) or wideband (WB) insonification. Although, the two types of insonification are related by Fourier analysis the random nature of the fine structure of breast tissue leads to very different results depending on how the breast is insonified. In this paper we present a comparison between CW and WB reconstructions obtained from in-vivo breast data acquired with a prototype ultrasound ring array. We investigate the statistical averaging effect due to frequency diversity and the resulting reduction in speckle noise. Thanks to the full view configuration, we are able to isolate the effects of the tissue structure from the transducer geometry, which has biased similar analysis performed in the past with conventional linear arrays.

6913-161, Poster Session

Screen optics effects on DQE in digital radiography: spatial frequency effects

A. R. Lubinsky, W. Zhao, Stony Brook Univ.; K. Suzuki, Hamamatsu Photonics K.K. (Japan)

The effect of screen optics on the spatial-frequency-dependent DQE of digital radiographic systems, expressed as the Lubberts factor L(f), is studied for both isotropic powder and structured columnar (Csl) x-ray

screens. Analytical models for $L(f)$ were derived from diffusion theory for isotropic screens with both reflective and non-reflective backings. Optical ray tracing simulation methods were used to obtain the depth-dependent line spread function (LSF), modulation transfer function (MTF), and Lubberts factors for both isotropic and columnar screens. The simulation results for powder screens were compared with calculations based on the Swank model and the analytical model for $L(f)$. An extension of the analytic model to columnar screens is proposed. The theoretical methods were used to investigate the dependence of $L(f)$ on backing reflectance, thickness, x-ray energy, and screen type. An experimental method to estimate $L(f)$, in which an electron multiplying charge coupled device (EMCCD) is used to image individual optical bursts generated by single x-ray photons, is described. Preliminary results are obtained from data on sample screens, and are compared with the theory.

6913-162, Poster Session

Non-circular scans and image reconstruction for breast CT

J. Bian, The Univ. of Chicago; N. J. Packard, K. Yang, Univ. of California/Davis; D. Xia, The Univ. of Chicago; J. M. Boone, Univ. of California/Davis; X. Pan, The Univ. of Chicago

There has recently been a renewed interest in developing dedicated breast CT because of its potential to provide 3D images of high quality, leading to improved sensitivity and specificity in breast cancer detection. Current dedicated, cone-beam breast CT scanners use a circular scanning configuration for data acquisition. It is well-known, however, that a circular scanning configuration cannot yield cone-beam data sufficient for reconstructing accurate 3D images of the breast. We hypothesize that advanced, non-circular scanning configurations and appropriate reconstruction algorithms can yield images with quality higher than that obtained with a circular scanning configuration and the approximate FDK algorithm. In this work, we investigate and develop advanced, non-circular scanning configurations for data acquisition in dedicated breast CT, and we also develop algorithms for reconstructing accurate 3D images from the acquired data. A dedicated, cone-beam breast CT scanner capable of performing non-circular scanning configurations was used in this research. We have investigated different scanning configurations, including helical and saddle configurations. A Defrise disk phantom and a dead mouse were scanned by use of these configurations. For each configuration, cone-beam data were acquired at 501 views over each turn. We have reconstructed images using our BPF algorithm from data acquired with different scanning configurations. Results of our study suggest that non-circular scanning configurations can be developed for acquiring data sufficient for accurate 3D reconstruction of breast images.

6913-163, Poster Session

A multiple component geometric breast phantom

K. G. Baum, Rochester Institute of Technology and KGB Technologies; K. McNamara, M. Helguera, Rochester Institute of Technology

The quality and realism of simulated images is currently limited by the quality of the digital phantoms used for the simulations. The transition from simple raster based phantoms to more detailed geometric (mesh) based phantoms has the potential to increase the usefulness of the simulated data. A preliminary breast phantom which contains 12 distinct tissue classes along with the tissue properties necessary for the simulation of dynamic positron emission tomography scans was created (activity and attenuation). The phantom contains multiple components which can be separately manipulated, utilizing geometric transformations, to represent populations or a single individual being imaged in multiple positions. A new relational descriptive language is presented which conveys the relationships between individual mesh components. This language, which defines how the individual mesh components are composed into the phantom, aids in phantom development by enabling the addition and removal of components without modification of the other components, and simplifying the definition of complex interfaces.

6913-164, Poster Session

Impact of heel effect and ROI size on the determination of contrast-to-noise ratio for digital mammography systems

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The European Guidelines for quality control in digital mammography specify a procedure for measuring contrast-to-noise ratio (CNR) using a 0.2mm thickness of aluminium with different thicknesses of Plexiglas. The relationship between ROI size and heel effect and how this affects CNR measurement is investigated in this work for DR and CR systems. The measured relative noise for the CR images was found to be strongly dependant on the ROI size due to the heel effect. After applying heel effect correction there was very little dependence on ROI size. The relative noise in the images from the DR system showed very little dependence on ROI size. The heel effect also distorted the CNR measurement on CR images when larger ROI were used. However the use of multiple small ROI led to a result that was essentially the same as if a heel effect correction had been applied. The appropriate ROI size which should be used for CNR measurement was found to be 0.25 ± 0.25 cm. Using this size the heel effect had an insignificant impact on the measurement of relative noise and CNR. This approach has the advantage that only a single image is required for each measurement. The application of heel effect correction with CR systems requires two images and complex image processing. The current suggestion in the European guidelines to use a 2cm x 2cm ROI is inappropriate for CR systems and leads to an error of 8% to 18% in CNR determination due to the heel effect.

6913-165, Poster Session

Optimization of dose in digital breast tomosynthesis using breast specimens

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The purpose of this study was to determine how image quality in breast tomosynthesis (BT) was affected when dose level was varied, using human breast specimens containing tumors and/or microcalcifications. Images of thirty breast lumpectomy and mastectomy specimens were acquired on a BT prototype based on a Mammomat Novation (Siemens) full-field digital mammography (FFDM) system. Two detector modes - binned ($2'1$ in the scan direction) and full resolution - and four BT exposure levels - $2'$, $1.5'$, $1'$, and $0.5'$ the total mAs used in a single FFDM view under automatic exposure control (AEC) conditions - were examined, yielding eight test conditions. The exposure for all BT scans was equally divided among 25 projections. An enhanced filtered back projection reconstruction method was applied with constant settings of spectral and slice-thickness filters. Image quality was evaluated and rated via visual grading analysis (VGA) human observer experiments using criteria; sharpness of structures, lesion visibility, level of noise and overall image quality. The subtle variations of image quality between the dose levels indicates that less than 2 times the exposure of a single-view FFDM acquisition (in the BT case an average glandular dose of approximately 1.6 mGy for a 50 mm thick standard breast) could provide adequate image quality for a single view BT exam. Tumor visibility was only minorly affected by the image noise at the lower dose levels, whereas microcalcification visibility was more affected. The relative difference in VGA score between full resolution and binned detector modes was not statistically significant.

6913-166, Poster Session

Optimizing the anode-filter combination in the sense of image quality and average glandular dose in digital mammography

M. J. Varjonen, P. Strömmer, Planned Oy (Finland)

Purpose: To optimize image quality and average glandular dose in digital mammography, and to provide recommendations concerning anode-filter

combinations in digital mammography which is based on amorphous selenium (a-Se) detector technology.

Method and materials: The full field digital mammography (FFDM) system based on a-Se technology, which is also a platform of tomosynthesis prototype, was used in this study. X-ray tube filter-anode combinations, which were studied, were tungsten (W) - rhodium (Rh) and tungsten (W) - silver (Ag). Anatomically adaptable fully automatic exposure control (AEC) was used. The average glandular doses (AGD) were calculated using a specific program developed by Planmed, which automates the method described by Dance et al. Image quality was evaluated in two different ways: a subjective image quality evaluation, and contrast and noise analysis.

Results: By using W-Rh and W-Ag anode-filter combinations can be achieved a significantly lower average glandular dose compared with Molybdenum (Mo) - Molybdenum (Mo) or Mo-Rh. The average glandular dose reduction was achieved from 20 % to 65 %.

Conclusion: In the future the evaluation will concentrate to study the effect of higher kV (>35 kV) values and other additional filter materials, which might be useful while optimizing the dose in digital mammography.

6913-167, Poster Session

Microcalcification detectability in tomosynthesis

I. S. Reiser, B. A. Lau, R. M. Nishikawa, The Univ. of Chicago

Microcalcifications (MC) are an important early sign of breast cancer. In projection mammography, MC detectability is limited primarily by quantum noise. In tomosynthesis, a dose similar to that delivered in one projection mammogram is divided across a number of projection views (typically ranging between 10 and 30). The purpose of this investigation was to explore the relationship between MC detectability in the projection views and in the reconstructed image.

We simulated projection images for a MC phantom consisting of a uniform 5cm slab containing spheres of 150, 280 and 400 micron diameters. 11 projection views were acquired over an x-ray source arc of 50 degrees. The projections contained quantum noise only. Volume images were reconstructed through backprojection. MC detectability was computed through template matching from 1000 (projections) and 500 (reconstruction) noise realizations. For the reconstructed data, we explored three lesion templates, (a) the 3D region (b) the center slice, (c) a maximum-intensity projection (MIP) of the lesion.

For all MC sizes, detectability in the reconstructed image was increased about twofold, compared to one projection view. In the projection views, spatial variation of detectability could be observed, but not in the reconstructed image, within the data noise. For the reconstructed data, detectability was highest for the 3D template, and lowest for the MIP template.

We plan to further explore other acquisition geometries, as well as reconstruction algorithms.

6913-168, Poster Session

Monte Carlo investigation of cupping artifacts in cone beam mammatomography

D. K. Joseph, P. Madhav, R. L. McKinley III, M. P. Tornai, Duke Univ. Medical Ctr.

A hybrid SPECT-CT prototype system for dedicated fully-3D breast imaging has been developed. The SPECT system retains the capability to execute arbitrary, fully-3D acquisition trajectories, while the CT system has a fixed polar tilt angle over a 360° azimuthal motion about a pendant uncompressed breast. This allows for maximal breast volume and anterior chest wall imaging. Beam hardening and scatter are known to cause cupping artifacts in reconstructed CT images. Our system uses a quasi-monochromatic beam which provides for maximal dose efficiency while minimizing beam hardening and the resulting degradative effect on reconstructed image volumes. We have recently shown empirically that undersampled cone beam projection data may be another contributor to cupping artifacts. To systematically investigate and quantify the relative contribution of beam hardening, scatter, and undersampling to the cupping artifacts in dedicated computed mammatomography, a Penelope Monte Carlo model of our system was implemented, after first

validating the code with others' published data. Acrylic bead phantoms as well as cylindrical breast phantoms of varying size and composition were modeled. Simulations confirm that beam hardening is minimal for the quasi-monochromatic beam. However, scatter was found to be a significant contributing factor in image degradation, and is influenced greatly by breast tissue composition and size. Preliminary Monte Carlo simulated projection data is being generated for reconstruction with an iterative statistical algorithm in order to further investigate and quantify the various contributions toward cupping. Results of different sampling geometries implemented within the Monte Carlo framework are also assessed.

6913-169, Poster Session

Improvement in image quality of computed radiography systems for mammography

C. J. Yang, W. Huang, Carestream Health, Inc.

Computed radiography (CR) is one of the technology choices for digital mammography. For a clinical facility transitioning from analog screen/film systems to digital, CR has the advantage of ease of integration to existing x-ray systems without changing workflow. Continued improvement in image quality of CR mammography benefits the overall quality of patient care.

The previous generation of Kodak CR mammography systems comprised a high-resolution storage phosphor plate and a scanner capable of 50 µm pixel scanning. Since then, efforts have been made to improve the storage phosphor plate through changes in phosphor particle morphology, particle size distribution, phosphor binder ratio and stabilizers. The scanner has been improved, as well, by the optimization of laser power, scanning speed, and filter design. This study investigates the relative changes in image quality metrics, such as modulation transfer function (MTF) and detective quantum efficiency (DQE) under mammography conditions between an improved experimental CR system and the earlier system. Averaging measurements in the plate and laser scanning directions, the MTF improvements range from near 10% at 1 lp/mm to over 400% at Nyquist frequency, and the DQE improvement ranges from 20% at 1 lp/mm to 700% at Nyquist frequency for the experimental system compared to the earlier system. In conclusion, through these design changes and optimization processes, the image quality of the experimental CR mammography system is significantly improved over the earlier system.

6913-170, Poster Session

Toward quantification breast tomosynthesis imaging

C. M. Shafer, E. Samei, R. S. Saunders, J. Y. Lo, Duke Univ. Medical Ctr.

In CT imaging, the pixel values (Hounsfield Units) indicate attenuation coefficient of the tissue; i.e. the pixel values have a physical meaning. In breast tomosynthesis, an ideal resulting image would likewise have meaningful values, which is possible if the grayscale values in the image are related to the x-ray attenuation of the tissue being imaged. Having a suitable tomosynthesis look-up table (LUT) to estimate of the actual composition of tissue in each region of the image may also lead to more accurate cancer diagnoses. To achieve such an LUT, two simple breast phantoms were imaged using the Siemens prototype breast tomosynthesis imaging system. The phantoms contained 6mm-thick cuboid lesions of 5 varying densities sandwiched between two 2cm-thick slabs of either 0% or 100% glandular-equivalent plastic. Tomosynthesis images were acquired using the same radiographic techniques as human subjects. Filtered backprojection yielded reconstructed 3D images, and from the lesion-containing slice images, the lesion grayscale voxel values are plotted against the percent glandularity, resulting in the same linear relationship independent of the sandwiching materials. This result led to a very simple LUT for that particular setup, and the LUT was validated against a separate commercial QA phantom with 5 lesions embedded in 50% glandular-equivalent plastic. After DC bias adjustment, the LUT produced the same linear measurements of glandular fractions. On-going work will further investigate effects of overlying tissue, radiographic technique, scatter compensation, and reconstruction artifacts on quantitative accuracy.

6913-171, Poster Session

Digital tomosynthesis mammography: improvement of artifact reduction method for high-attenuation objects on reconstructed slices

J. Ge, H. Chan, B. Sahiner, Y. Zhang, J. Wei, L. M. Hadjiiski, C. Zhou, Y. Wu, J. Shi, Univ. of Michigan

One major image quality problem in digital tomosynthesis mammography (DTM) is the poor depth-resolution caused by the inherent incomplete sampling. This problem is more pronounced if high-attenuation objects, such as metallic markers and dense calcifications, are present in the breast which results in strong ghosting artifacts in the depth direction. These artifacts may interfere with radiologists' visual assessment and computerized analysis of subtle mammographic features. We previously developed an artifact reduction method by using 3D geometrical information of the objects estimated from the reconstructed slices. In this study, we examined the effect of imaging system blurring in DTM caused by the focal spot and the detector modulation transformation function (MTF). The focal spot was simulated as a 0.3 mm square array of x-ray point sources. The detector MTF was simulated using the Burgess model with parameters derived from published data of a GE FFDM detector. The spatial-variant impulse responses for the DTM imaging system, which are required in our artifact reduction method, were then computed from the DTM imaging model and a given reconstruction technique. Our results demonstrated that inclusion of imaging system blurring improved the performance of our artifact reduction method. The detector MTF had stronger effects than focal spot blurring on artifact reduction. Further work is underway to investigate the effects from other DTM imaging parameters, such as x-ray scattering, different polyenergetic x-ray spectra, and different configurations of angular range and angular sampling interval.

6913-172, Poster Session

On the angular dependence of Bremsstrahlung x-ray emission

A. Ganguly, N. J. Pelc, Stanford Univ.

We have analyzed the angular dependence of Bremsstrahlung x-rays resulting from 120keV energy electrons hitting a tungsten(W) target. This is important in optimizing x-ray tube design for increased x-ray flux. Novel imaging technologies using carbon nanotubes or scanning electron beams are being reported. While these have advantages, there is a need to maximize the efficiency of x-ray production.

The angular distribution of x-rays resulting from single interaction of an electron with a single-atom target is a function of the incident-electron energy, direction and target material. We performed Monte Carlo(MC) simulations for studying how this angular distribution is affected by interactions of the electrons and photons in thick targets. The theoretical distribution for single-atom interaction was verified using a 4nm tungsten spheres. Contributions of the various processes undergone by the electrons and x-ray photons were analyzed individually. The angular distribution of x-rays incident normally and at a grazing angle of 20deg from the surface of a 4mm thick target was calculated. The results for a 12micron transmission target were also simulated.

For single interactions, the theoretical peak for 120keV electrons occurs at 28deg and is 3 times higher than the minimum value. Corresponding values from MC simulations was 7deg. For the solid target, the output is maximum at 180deg to the electron beam which is incident at 90deg to the target, with the peak location remaining unchanged with angulations. This is 122% higher than photons collected at 100deg. The angular distribution is essentially dominated by self absorption in the target.

6913-173, Poster Session

Separation of bone from iodine- and gadolinium-based contrast agents using dual energy CT

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This study aims to evaluate the separability of bone from iodine- and gadolinium-based intravenous contrast agents using dual energy CT techniques in phantom.

A phantom was prepared containing varying concentrations of iodine-based contrast, gadolinium-based contrast, and calcium hydroxyapatite (to simulate bone). Thirteen iodine concentrations from 0.1 to 12 mg/mL, twelve gadolinium concentrations from 0.72 to 34.42 mg/mL, and four calcium concentrations from 0 to 200 mg/mL were used. These phantoms were scanned on a dual source CT using two different source spectra, producing one set of data at 80 kVp and another at 140 kVp. On each resulting image, the mean HU was measured at every concentration level for iodine, gadolinium, and calcium, and plotted on a graph of HU value at 80 versus 140 kVp.

Linear regression was used to produce a best-fit line for each material. These lines were compared to test for a difference of slopes between calcium and iodine as well as between calcium and gadolinium.

Each material exhibited a linear relationship between the HU values at 140 and 80 kVp ($R^2 = 0.99$) and demonstrated a unique slope to this line. The slope for iodine was 2.00, for gadolinium was 1.63, and for calcium was 1.55. The slopes of the calcium and iodine lines were significantly different ($p < 0.05$), while the slopes of the calcium and gadolinium lines were not significantly different ($p > 0.05$).

Our results suggest that while it is technically feasible to separate iodine from bone, gadolinium-based contrast does not appear to be as readily separable from bone as iodine. This result is surprising as the atomic number and k-edge of calcium ($Z = 20$, k-edge = 4 keV) are closer to iodine ($Z = 53$, k-edge = 33 keV) than to gadolinium ($Z = 64$, k-edge = 50 keV).

6913-174, Poster Session

Evaluation of the contrast-detail response of a cardiovascular angiography system and the influence of equipment variables on image quality

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Modern cardiac catheterization laboratories use x-ray flat panel detectors (FPD). The purpose of this study is to assess the influence of physician-selectable equipment variables on image quality (IQ).

CDRAD and Leeds TO10 test objects were used to subjectively assess IQ of cardiac angiograms on a Siemens Artis dBC system. Threshold contrast detail detectability (TCDD) data are presented graphically as a contrast resolution diagram or as threshold detection index. The experimental set-up included the acquisition of images under different entrance dose of FPD (0.10, 0.12, 0.14, 0.17, 0.20 and 0.24 $\mu\text{Gy}/\text{image}$) and for different thicknesses of patient simulated tissue material. Five independent observers evaluated the images. The contrast-detail response depends on the detector entrance dose. An alternative, objective method to assess IQ was also used. It consists of the calculation of a parameter named "figure of merit" based on signal-to-noise data and detector entrance doses.

Our results indicate the potential of all three methods as a quantitative IQ analysis tool. Measurement of threshold contrast over a range of FPD doses show optimal working points. This should lead to a better management of patient radiation dose.

6913-175, Poster Session

Evaluation of exposure dose reduction in coronary CT angiography with prospective ECG-gated helical scanning

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A novel low-dose ECG gated helical scan method to investigate coronary artery diseases was developed. This method uses a high pitch-factor scanning (based on the patient's heart rate) and X-rays generation only during the optimal cardiac phases. The dose reduction was obtained

with a two level approach. A 64-slice CT scanner (Aquilion, Toshiba, Otawarta, Tochigi, Japan) with a scan speed of 0.35 s/rot. was used to helically scan the heart with a high pitch-factor based on the patient's heart rate. By changing the pitch-factor from the conventional 0.175 to 0.267 for a heart rate of 60 bpm, the exposure dose was reduced by 30%. The second was the tube current gating that predicts the timing of optimal cardiac phases from the previous cardiac cycle and generating X-rays in only the required cardiac phases. The combination of a high speed scanning with a high pitch-factor and appropriate X-ray generation in only the cardiac phases from 65% to 85% allows the exposure dose to be reduced to 5 mSv for patients with a heart rate of 60 bpm or lower. This is about a 70% dose reduction compared to conventional scanning method recommended by the manufacturer when segmental reconstruction is considered. This low-dose approach seamlessly allows for wide scan ranges (e.g., aortic dissection) with the benefits of ECG-gated helical scanning: continuous couch movement and data from all cardiac cycles.

6913-176, Poster Session

Comparison of the performances between anti-scatter grid and slot scanning technique for digital chest radiography: effect of anatomical background

C. Lai, C. C. Shaw, X. Liu, L. Chen, T. Han, T. Wang, The Univ. of Texas M.D. Anderson Cancer Ctr.

To investigate and compare the nodule detection in digital chest imaging between anti-scatter grid and slot scanning methods. Anthropomorphic chest phantom was imaged with a flat-panel based digital radiography system. The system was operated in both the slot scanning and full-field modes with and without anti-scatter grid. Imaging technique was 120 kVp and 1 to 16 mAs for both modes. 10-mm in diameter computer-simulated nodules with a nominal peak contrast ratio of 5% were inserted at hilum and mediastinum locations by applying SPR values. 4-AFC experiment was conducted to measure the ratio of correct observations as a function of the exposure level for various imaging conditions and locations. These images were displayed randomly on a review workstation and reviewed by three observers. The average ratios of correct observations were computed across over the readers. The statistical significance of the differences in fractions between imaging techniques was computed by the Student t-test. Nodule detection was not significantly improved by raising the exposure level in the hilum and mediastinum regions. Slot scan without grid and with grid received the highest and next highest fractions of correct response, followed in order by full-field without and with grid for the hilum region, and full-field with and without grid for the mediastinum region. Statistical significant difference was found for most comparisons between slot scan with or without grid and full-field with or without grid (this work was supported in part by a grant CA104759 from the NCI and a research grant EB00117 from the NIBIB).

6913-177, Poster Session

C-arm based cone-beam CT using a two-concentric-arc source trajectory: system evaluation

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The current x-ray source trajectory for C-arm based cone-beam CT is a single arc. Reconstruction from data acquired with this trajectory yields cone-beam artifacts for regions other than the central slice. In this work we present the preliminary evaluation of reconstruction from a source trajectory of two concentric arcs using a flat-panel detector equipped C-arm gantry (GE Healthcare Innova 4100 system, Waukesha, Wisconsin). The reconstruction method employed is a summation of FDK-type reconstructions from the two individual arcs. For the angle between arcs studied here, 30 degrees, this method offers a significant reduction in the visibility of cone-beam artifacts, with the additional advantages of simplicity and ease of implementation due to the fact that it is a direct extension of the reconstruction method currently implemented on commercial systems. Reconstructed images from data acquired from the two arc trajectory are compared to those reconstructed from a single arc trajectory and evaluated in terms of spatial resolution, low contrast resolution, noise, and artifact level.

6913-178, Poster Session

Dose saving and scatter reduction in Volume-of-Interest (VOI) cone beam CT: work in progress

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To estimate the dose saving and scatter reduction properties for the VOI cone beam CT technique. The CBCT system employed a flat-panel (FP) detector with pixel size of 194 μm . The matrix of the FP detector is 1536-2048 pixels. The image acquisition speed was 7.5 frames/sec. The source-to-isocenter and source-to-detector distances were 75cm and 100 cm, respectively. A 11-cm in diameter cylindrical water-equivalent phantom was used to simulate breasts. To implement the VOI scanning technique, a lead filter with a rectangular opening was placed between the x-ray source and the breast phantom. The projection images were acquired at 80 kVp without and with the VOI filter to obtain full-field and VOI images, respectively for scatter-to-primary ratio (SPR) measurement at the detector plane. To determine primary x-ray beam, slot scanning technique was performed by varying slot width. Scattered radiations and SPR values were estimated within the VOI for the VOI technique and compared to these for full field CBCT. Dose measurement has been performed using TLD under the same experimental setup. The results showed that scatter intensities at the detector plane decreased significantly both inside and outside the VOI in the projection images. The results also showed that the SPR values at the detector plane decreased significantly within the VOI (this work was supported in part by a grant CA104759 from the NCI and a research grant EB00117 from the NIBIB).

6913-179, Poster Session

BRAGA: an easy to use and accurate grid alignment system to control scatter and improve image quality in bedside radiography

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Bedside radiography is one of the most commonly performed imaging exams. However, due to the difficulty in aligning the focal spot with an anti-scatter grid, grids are often not used. When grids are employed, misalignment issues dictate the use of low grid ratios. As a result, scatter compromises image quality.

BRAGA (Bedside Radiography Automatic Grid Alignment) is a means of easily and automatically aligning the x-ray tube and grid. BRAGA permits the use of high ratio (12:1 or 15:1) grids, which results in portable radiographs with markedly improved image contrast. Described are the modifications to a commercially available mobile radiographic unit, including an optical position sensing system and a motion control system. Presented is a video of BRAGA in simulated clinical use showing how the technologist can achieve virtually perfect alignment with the grid in less than 10 seconds.

Presented are comparison clinical images employing a 15:1 ratio grid and no grid or a poorly aligned 8:1 grid; and data demonstrating that the x-ray tube focal spot is aligned with the center of the grid focal axis to within 3 mm.

It is concluded that BRAGA is easy to use and permits the virtually perfect alignment of high ratio grids in bedside radiography, providing markedly improved image quality with no increase in patient dose. It is speculated that BRAGA along the other recent improvements in mobile radiographic units will change the current radiography paradigm and increase the percentage of hospital bedside exams.

6913-180, Poster Session

Effect of spatial direction and acquisition techniques on noise power spectra in x-ray CT

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The spatial characteristics of noise in X-ray CT can influence object detectability. Now as three dimensional image reformations become

more clinically common, it has become vital to understand the structure of noise in the x, y, and z directions independently. The purpose of this paper is to study noise structure in the radial direction and tangential direction, under varying conditions, including the use of a wedge filter and varying acquisition technique (i.e. half scan vs full scan). Because the effect of the reconstruction algorithm on an image is highly dependent on spatial location within the field of view, the effect of off-center vs centered positioning in each direction is also examined. The noise spatial frequency distribution was investigated via calculation of the noise power spectrum (NPS) through Fourier methods on simulated water images. As expected, noise structure at center was equivalent in both the radial and tangential directions. Towards the periphery, overall noise power was muted. However, in the tangential direction high frequency noise power was preserved more than twice as much as in the radial direction. Towards the periphery noise becomes more low-frequency in the radial direction, while in the tangential direction it becomes more high-frequency. The half scan increased both noise magnitude and low-mid spatial correlation in the NPS compared to full scan. In conclusion, noise spatial structure is directionally dependent off-center and this may have an impact on object detectability in directional reformations.

6913-181, Poster Session

Analysis of axial spatial resolution in a variable resolution x-ray cone beam CT (VRX-CBCT) system

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The Variable Resolution X-ray (VRX) technique has been successfully used in a Cone-Beam CT (CBCT) system to increase the spatial resolution of CT images in the transverse plane. This was achieved by tilting the Flat Panel Detector (FPD) about its y-axis in a VRX Cone Beam CT (VRX-CBCT) system. In this paper, the effect on the axial spatial resolution of CBCT images caused by tilting the FPD about its x-axis is examined. An amorphous silicon FPD with a CsI scintillator is coupled with a micro-focus x-ray tube to form a CBCT. The FPD is installed on a rotating frame that allows a rotation of up to 90° about x and y axes of the FPD. There is no rotation about the z-axis (i.e. normal to the imaging surface.) The angle between the normal vector of the FPD and the line that passes through the x-ray source and the center of the imaging plane is called a spatial VRX angle and has two components of VRX_x (formerly the VRX angle) and VRX_y. Tilting the FPD about its x-axis decreases the VRX_y angle and reduces both the width of the line-spread function and the sampling distance by a factor of sin(VRX_y), thereby increasing detector spatial resolution proportionately. This results in thinner CT slices that in turn help increase the axial spatial resolution of the CT images. An in-house phantom is used to measure the MTF of the reconstructed CT images using different VRX_y angles.

6913-182, Poster Session

Quantitative imaging of chemical composition using dual-energy, dual-source CT

X. Liu, O. Dzyubak, A. N. Primak, L. Yu, C. H. McCollough, Mayo Clinic; R. L. Morin, Mayo Clinic Jacksonville

Dual-energy x-ray material decomposition has been proposed as a noninvasive quantitative imaging technique for more than 20 years. However, despite its success in some applications, such as bone mineral density quantification, the potential of this technique in other clinical applications has not been fully achieved due to the relatively low spatial and temporal resolutions of earlier computed tomography (CT) systems. With dual source CT, quantitative x-ray imaging of chemical composition using dual-energy techniques may be useful in additional applications. In this paper, we summarize previously developed dual-energy material decomposition methods and propose a simple yet accurate method for quantitatively measuring chemical composition *in vivo*. In order to take advantage of the design of dual-source CT, the proposed method is based upon post reconstruction (image space) data. Different from other post reconstruction methods, this method is designed to directly measure element composition (mass percent) in a tissue by a simple table lookup procedure. The method has been tested in phantom studies. The results showed that 1) this method is

capable of accurately measuring elemental concentrations, such as iron in tissue, under low noise imaging conditions, and 2) noise is the major source of inaccuracy for this method. The advantage of this method lies in its simplicity and fast processing times. We believe that this method can be applied clinically, such as to measure iron overload in the liver (hemochromatosis). Further investigations on de-noising techniques, as well as clinical validation, are merited.

6913-183, Poster Session

Effects of digital geometry and phantom size on cone-beam CT point spread function measurement

Z. Chen, Northeastern Univ. (China); Y. Tao, Univ. of Maryland/College Park

The three-dimensional point spread function (3D PSF) of cone-beam computed tomography (CBCT) can be measured through the use of point phantom or edge phantom. In cone-beam tomography theory, an input of delta impulse function will produce an output of a delta function (except a scale factor) under the assumption of continuous geometry, thus manifesting spatial shift invariance over the scan field of view (SFOV). For a practical CBCT system, its 3D PSF is of spatial variant distribution over the SFOV, due to the digital geometry in discrete projection detection and gridded volume reconstruction. In principle, the 3D PSF of a CBCT system can be measured either by a micro point-like phantom (<1mm) by approaching a delta impulse function, or by a macro edge phantom (>1mm) by analyzing the edge blurring mechanism. We found that there exists ambiguity and controversy among the 3D PSF measurement and characterization, varying with the size of the phantom. In this work, we will investigate the effects of digital geometry and phantom size on the 3D PSF measurement. In the results, we will propose an experimental protocol for eliminating the uncertainty associated with the 3D PSF characterization of a CBCT system.

6913-184, Poster Session

A comparison of three CT voltage optimization strategies

K. M. Ogden, M. R. Khorasani, E. M. Scalzetti, Upstate Medical Univ./SUNY; W. Huda, Medical Univ. of South Carolina

We evaluated three strategies for optimizing the x-ray tube voltage in chest CT examinations: (1) keeping patient dose constant and maximizing contrast to noise ratios (CNR); (2) keeping image quality constant and minimizing patient dose; (3) maximizing (CNR²/Dose). Lung and soft tissue attenuation coefficients relative to water, together with the corresponding image noise, were measured in a Rando phantom at x-ray tube voltages between 80 and 140 kV. A CT dosimetry software package (ImPACT) was used to compute effective doses as a function of CT x-ray tube voltage for adult patients undergoing chest CT examinations. CNR and patient dose in chest CT examinations both increase with increasing x-ray tube voltage. All optimization strategies provided similar qualitative results, which showed the best imaging performance was achieved at the lowest x-ray tube voltage (80 kV). A given change in x-ray tube voltage showed quantitative differences in the optimization parameter (i.e., CNR, E, FOM), as well as differences for detection of soft tissue and lung type lesions in a water background. Optimization using constant CNR, or constant dose, is preferred since this provides explicit choices of optimal kV/mAs combinations as well as quantitative data on how changing kV would modify CNR and/or patient dose. The CNR²/Dose figure of merit does not offer explicit choices of kV/mAs for performing CT examinations, and changes in FOM value cannot be related to changes in imaging performance or patient dose.

6913-185, Poster Session

The built-in capacity of CT D'Or's static ring for scatter correction

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The new scanner geometry CT D'Or, developed at GSF, consists of a discontinuous ring of detectors facing toward the ring center, which

are fixated on an x-ray absorbing material. The x-ray source and an additional outer detector are mounted on a gantry which rotates around the inner static detector and thus the patient. When the source is moving, the detectors are alternately exposed and shielded from the source. Data recorded during periods of direct exposure can be combined and are used for the reconstruction of the image. When the detectors are shielded, their signal is solely caused by scatter. Therefore, direct scatter correction is possible. This can be used to considerably improve the image quality, when scatter radiation yields a strong deterioration of the reconstructed image. The advantage of CT D'Or is thus, that information about scatter radiation is obtained without additional effort or exposure. This property of CT D'Or is investigated and its feasibility is demonstrated by the use of Monte Carlo simulations.

6913-186, Poster Session

Analysis of in-plane signal-to-noise ratios (SNRs) in computed tomography (CT)

T. Hara, Nakatsugawa Municipal General Hospital (Japan); K. Ichikawa, Kanazawa Univ. (Japan); Y. Ida, Fujita Health Univ. (Japan)

The purposes of this study are to analyze signal-to-noise ratio (SNR) changes for in-plane position and direction in computed tomography (CT) system and to verify those visual effects by using simulated small low-contrast disc objects. Three models of multi detector-row CT, SOMATOM Volume Zoom, SOMATOM Emotion6 and Aquilion16 were employed. Modulation transfer functions (MTFs) were obtained using a thin metal wire. Noise power spectra (NPS) were obtained using a water phantom. The measured positions were set to center and off-centers (64mm, 128mm and 192mm) in in-plane. One-dimensional MTFs and NPSs for the x-direction and y-direction were calculated by the numerical slit scanning method. SNRs were then calculated from these MTFs and NPSs. The simulated small low-contrast disc objects with diameters of 2-10mm and some contrast differences (1.5%, 3.0% and 4.5%) were superimposed on the water phantom image. Finally we examined the validity of the resultant SNRs by observing the simulation images. In-plane SNR(s) differed in the center and off-centers and indicated a trend that they increase as the distance from center. The trend changed for the direction, and also the change degrees varied with the CT systems. Also from the simulated images, it was suggested that the peripheral (off-centers) region has higher detectability than the center. The properties derived in this study mean that the depiction abilities at various in-plane positions are not uniform in clinical CT images, and indicated that the region detectability may be influenced.

6913-189, Poster Session

Influence of motion on image quality with a 64-channel CT scanner

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Physiological motions can occur during a Computed Tomography (CT) exam. While the impact of some motions on CT imaging can be reduced, other physiological motions are unavoidable. To attempt correcting the resulting images, it is necessary to understand how the artifacts are formed and their influence on the image quality.

Using a cardiac phantom and a dynamic platform, we have studied the influence of a translation in the z-axis associated with a rotation in the z-axis (at different speeds) on the quality of axial images using a 64-channel scanner.

The results show that, the deformation, the detectability and the contrast of the calcifications are of course dependent on the density and the size of the calcification but also on the movement they undergo. The noise in the image is also affected by the motion.

The influence of the motion on the image quality depends on the examined object and cannot be predicted. The corruption of the data results in the loss of information about the form, the contrast and/or the size of the scanned object. This corruption can lead to diagnosis errors by mimicking diseases or by masking physiologic details.

6913-190, Poster Session

Geometry calibration for x-ray equipment in radiation treatment devices and estimation of remaining patient alignment errors

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Positioning a patient accurately in the treatment device is crucial for radiological tumor treatment, especially if the accuracy advantages of particle beam treatment are exploited. To avoid sub-millimeter misalignments, X-ray images acquired from within the treatment device can be compared to a planning CT to compute a respective alignment correction. Slight deviations of the underlying geometry model for the imaging system that may arise with movements of the dynamic parts of the treatment device degrade the patient alignment accuracy. To solve this problem, we suppose an automatic calibration routine, which bases on the geometry of a calibration phantom and its automatic detection in DRs acquired for various geometric treatment device settings during the calibration. The results from the registration of the phantom's X-ray projections and its known geometry are used to update the geometric model of the respective beamlines, which is used to compute an alignment correction and therewith to enhance patient set-up accuracy. The geometric calibration of a beamline takes all nine relevant degrees of freedom into account, including detector translations in three directions, detector tilt by three axes and three possible translations for the X-ray tube. Introducing a stochastic model for the automatic calibration we are able to predict the patient alignment deviations resulting from inaccuracies inherent to the phantom design and the calibration process. A comparison of the alignment results for a treatment device without calibrated imaging systems and a device where the imagers have been calibrated shows that an accurate calibration can dramatically enhance patient alignment accuracy.

6913-191, Poster Session

Development of a quality control program for a cone beam CT imaging system

R. Betancourt-Benitez, R. Ning, D. L. Conover, W. Cai, Y. Zhang, Univ. of Rochester

Routine quality control assessments of medical equipment are crucial for an accurate patient medical treatment as well as for the safety of the patient and staff involved. These regular evaluations become especially important when dealing with radiation-emitting equipment. Therefore, a quality control (QC) program has been developed to quantitatively evaluate imaging systems by measuring standard parameters related to image quality such as the Modulation Transfer Function (MTF), the Noise Power Spectrum (NPS), uniformity and CNR. First, the methods of evaluating the aforementioned parameters have been investigated using a cone beam CT imaging system. Different exposure techniques, phantoms, acquisition modes of the flat panel detectors (FPD) and reconstruction algorithms relevant to a clinical environment were all included in this investigation. Second, using the results of the first part of this study, a set of parameters for the QC program were established that yields both, an accurate depiction of the system image quality and an integrated program for easy and practical implementation. Third, a QC phantom has been developed by combining and refining all phantoms used during the first two parts of the study. This phantom allows a technician to accurately evaluate the system image quality with an easy to handle phantom. Lastly, this QC program has been implemented and practiced in our cone beam CT imaging system. The results demonstrate that the QC program is adequate to evaluate stability, image quality and overall quality of this system since it provides comparable parameters to other QC programs.

6913-192, Poster Session**Reduced inter-exposure time in dual-energy imaging: a technological and image processing cooperative approach**

C. Coello, M. Arques, Lab. d'Electronique de Technologie de l'Information (France); P. Rohr, Trixell (France); J. Dinten, Lab. d'Electronique de Technologie de l'Information (France); C. Odet, Ctr. de Recherche et d'Applications en Traitement de l'Image et du Signal (France)

Dual-energy imaging increases the possibility of pulmonary nodule detection by reducing the bone structure noise. Dual-shot techniques are limited by structural artefacts due to patient and natural movement during the switch of voltage between energies. A new acquisition approach for dual-energy imaging was envisioned in order to reduce this inter-exposure time. The idea is to keep the tube voltage constant, switch a filter in front of the patient and thus modulate the outgoing x-ray spectrum. The drawback of this method is a poorer spectral separation between low and high energy images leading to a higher sensitivity to noise. On the other hand, noise in the reconstructed image is mainly controlled by high-energy image noise, allowing the use of noise suppression algorithms without losing high-frequency information present in the low-energy image.

The first part is a simulation study presenting system optimisation that includes noise reduction in the HE image. Exposure times and filter thickness are chosen when optimising the signal difference to noise ratio (SDNR) and dose. Results show better SDNR (9 %) for similar dose than state-of-art dual-shot switching voltage technique. Thicker filters could lead to better results, but would demand more tube charge. Experimental validation has been done and several noise suppression algorithms implemented. As radiographs of anatomical phantoms are structured, anisotropic algorithm have been considered. Nodule and anthropomorphic phantoms were used to measure detail suppression after image processing. Results are shown in terms of noise suppression in the reconstructed image as well as in detail preservation.

6913-193, Poster Session**Bone mineral imaging using a digital magnification mammography system**

F. Toyofuku, K. Tokumori, Y. Higashida, H. Arimura, J. Morishita, M. Ohki, Kyushu Univ. (Japan)

The measurement of bone mineral content is important for diagnosis of demineralization diseases such as osteoporosis. A reliable method of obtaining bone mineral images using a digital magnification mammography system has been developed. The full-field digital phase contrast mammography (PCM) system, which has a molybdenum target of 0.1mm focal spot size, was used with 1.75 x magnification. We have performed several phantom experiments using aluminum step wedges (0.2 mm - 6.0 mm in thickness) and a bone mineral standard phantom composed of calcium carbonate and polyurethane (CaCO_3 concentration: 26.7 - 939.0 mg/cm³) within a water or Lucite phantom. X-ray spectra on the exposure field are measured using a CdTe detector for evaluation of heels effect. From the equations of x-ray attenuation and the thickness of the subjects, quantitative images of both components were obtained.

The quantitative images of the two components were obtained for different tube voltages of 24 kV to 39 kV. The relative accuracy was less than 2.5% for the entire aluminum thickness of 0.5 to 6.0 mm at 5 cm water thickness. Accuracy of bone mineral thickness was within 3.5% for 5cm water phantom. The magnified quantitative images of a hand phantom significantly increased the visibility of fine structures of bones.

The digital magnification mammography system is useful not only for measurement of bone mineral content, but also high-resolution quantitative imaging of trabecular structure.

6913-194, Poster Session**In-vivo tracking of implanted mammalian cells using synchrotron x-ray computed tomography**

C. J. Hall, Monash Univ. (Australia); E. Schultke, Univ. of Saskatchewan (Canada); R. H. Menk, Sincrotrone Trieste S.C.p.A. (Italy); F. Arfelli, Univ. degli Studi di Trieste (Italy); S. Ringley-Macdonald, Univ. of Saskatchewan (Canada); L. Rigon, The Abdus Salam International Ctr. for Theoretical Physics (Italy); B. Juurlink, Univ. of Saskatchewan (Canada)

One of the challenges in contemporary biomedical imaging is to visualise the position of small clusters of cells within a host organism and in 3-D. The ability to track targeted cells as they grow or metastasise in a natural environment will be invaluable for many areas of biomedical research. We report work on a protocol which we believe will eventually lead to this ability. Using aggressive brain tumour (C6 glioma) as a model we have embarked on developing imaging techniques using synchrotron facilities. The modality will potentially provide few cell sensitive CT imaging at the micron resolutions, and with low enough dose for small animal testing. A series of experiments at the Elettra synchrotron in Trieste Italy have provided encouraging results. This presentation will show the latest images from synchrotron CT encephalography on some animal models. We will discuss the shortcomings of the technique and implications for future work.

6913-195, Poster Session**Two-dimensional anti-scatter-grids for computed tomography detectors**

G. Vogtmeier, R. Dorscheid, K. Engel, Philips Research Europe Aachen (Germany); R. Luhta, R. A. Mattson, B. Harwood, Philips Medical Systems; M. Appleby, B. Randolph, J. Klinger, MIKRO, Inc.

The use of two-dimensional, focussed, anti-scatter-grids in computed tomography is one essential solution to reduce the scatter radiation for large area detectors.

A detailed analysis of the requirements and related image quality aspects lead to the specification of the two-dimensional focussed geometry of the X-ray absorbing grids. Scatter simulations show trade-off conditions and give estimations for the expected scatter reduction performance.

Different production technologies for focussed two-dimensional structures have been evaluated. The presented technology of Tomo Lithographic Molding (Tomo(tm)) shows good fulfilment of the specifications. Tomo(tm) is a synthesis of lithographic micromachining, precision stack lamination, molding, and casting processes with application-specific material systems. Geometry, material properties, and scatter performance have been investigated. Different analysis methods will be presented and results of the investigations show the performance of current grid technology.

Besides the material composition of the tungsten-polymer composite, the homogeneity of wall thickness and the precision of the focussing have the biggest influence on the X-ray behaviour. Dynamic forces on the anti-scatter-grid during CT operations should not lead to dynamic shadowing or intensity modulation on the active pixel area. Simulations of the wall deformation have been done to estimate the maximum position deviation.

First prototypes are available. The samples have been characterized and show promising results.

6913-196, Poster Session**LabVIEW graphical user interface for a new high sensitivity, high resolution micro-angio-fluoroscopic system**

C. M. Keleshis, C. N. Ionita, G. K. Yadava, D. R. Bednarek, K. R. Hoffmann, A. Verevkin, S. Rudin, Univ. at Buffalo

A graphical user interface based on LabVIEW software was developed to enable clinical evaluation of a new High-Sensitivity Micro-Angio-Fluoroscopic (HSMFAF) system for real-time acquisition, display and rapid frame transfer of high-resolution region-of-interest images. The HSMFAF

detector consists of a CsI(Tl) phosphor, a light image intensifier (LII), and a fiber-optic taper coupled to a progressive scan, frame-transfer, charged-coupled device (CCD) camera which provides real-time 12 bit, 1k x 1k images capable of greater than 10 lp/mm resolution. Images can be captured in continuous or triggered mode, and the camera can be programmed by a computer using Camera Link serial communication. A graphical user interface was developed to control the camera modes such as gain and pixel binning as well as to acquire, store, display, and process the images. The program, written in LabVIEW, has the following capabilities: camera initialization, synchronized image acquisition with the x-ray pulses, roadmap and digital subtraction angiography acquisition (DSA), flat field correction, brightness and contrast control, last frame hold in fluoroscopy, looped play-back of the acquired images in angiography, recursive temporal filtering and LII gain control. Frame rates can be up to 30 fps in full-resolution mode. The user friendly implementation of the interface along with the high frame-rate acquisition and display for this unique high-resolution detector should provide angiographers and interventionalists with a new capability for visualizing details of small vessels and endovascular devices such as stents and hence enable more accurate diagnoses and image guided interventions. (Support: NIH Grants R01NS43924, R01EB002873)

6913-197, Poster Session

Impact on image quality when a variety of x-ray source detector distances are considered for the arthritic cervical spine

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One of the limitations associated with examination of the cervical spine is the unavoidable distance between the neck and the image receptor which presents measurable levels of geometric unsharpness. This reduces image quality and can hinder arthritic scoring. The objective of the current study was to establish the impact on important arthritic indicators by increasing the distance between the X-ray source and image detector (SID) from the commonly employed levels. Lateral cervical spine images were acquired using a human cadaver with evidence of osteoarthritic change using a DR imaging system. All exposures were taken at 65kVp using automatic exposure control and a variety of SID distances from 150 to 210cm. The radiation dose for each exposure was monitored using a dose area product meter. An evaluation panel of four experienced clinicians assessed the images by means of visual grading analysis, using objective criteria based on normal anatomic features and arthritic indicators. The results revealed a statistically significant improvement in image quality with images acquired at 210cm compared with those acquired at 150cm and 180cm ($p < 0.05$), with values of 56.0 (SE=1.105), 50.85 (SE=1.415) and 65.35 (SE=0.737) respectively. All images with a SID of 210cm scored higher for visually sharp reproduction of the spinous processes, facet joints, intervertebral disc spaces and trabecular bone pattern compared with both 180cm and 150cm. This indicates that total image quality and visualisation of specific anatomical features is improved in cervical spine radiographs for arthritic patients when traditionally employed SID distances are increased.

6913-198, Poster Session

CT imaging with a mobile C-arm prototype

A. Cheryauka, D. Tubbs, V. Langille, P. Kalya, B. Smith, R. Cherone, GE Healthcare

Mobile X-ray imagery is an omnipresent tool in conventional musculoskeletal and soft tissue applications. The next generation of mobile C-arm systems will provide clinicians for minimally-invasive surgery and pain management procedures with both real-time high-resolution fluoroscopy and intra-operative CT imaging modalities.

In this work, we research two C-arm CT experimental system configurations and evaluate their imaging capabilities. In the NDE-type configuration, the X-ray Tube - Detector assembly is stationary while an imaging object is placed on a rotating table. In a medical imaging configuration, the C-arm gantry moves around the patient and the table.

In our research setting, we connect the participating devices through the Mobile X-Ray Imaging Environment known as MOXIE. MOXIE is a set of software applications for internal research in GE Healthcare - Surgery used to examine the system imaging performance. Volume renderings and MPR slices of the reconstructed images of the anthropomorphic phantoms are evaluated. The experimental results show CT-like image quality that may be suitable for interventional procedures, 'on-the-fly' data management capability, and the potential for effective acceptance on the clinical floor.

6913-61, Session 12

Analysis of image noise in 3D cone-beam CT: spatial and Fourier domain approaches under conditions of varying stationarity

A. R. Pineda, California State Univ./Fullerton; J. H. Siewerdsen, Princess Margaret Hospital (Canada); D. J. Tward, Univ. of Toronto (Canada)

The statistical properties of medical images are central in characterizing the performance of imaging systems. Cone-beam CT (CBCT) is a promising modality with considerable activity aimed at characterizing 3D imaging performance in terms of Fourier-based metrics, such as the noise-power spectrum (NPS). Under assumptions of stationarity, the NPS provides a complete measure of the second-order statistics of the images, since the covariance matrix of the Fourier transform of the image is diagonal. In practice, such assumptions are obeyed to varying degrees. The objective of this work is to investigate the degree to which such assumptions apply in CBCT and to experimentally characterize the NPS and off-diagonal elements under a range of conditions. A benchtop CBCT system provided 3D reconstructions of various objects (air and water cylinders) across a broad range of experimental conditions that affect stationarity - e.g., field of view (x-ray scatter), bowtie filter, reconstruction filter, voxel size, and dose. For the most stationary conditions (e.g., air scan), the mean of the off-diagonal elements was 0.11% of the mean of NPS, but the maximum was 22% of the maximum of the NPS. In the least stationary situation (e.g., water cylinder imaged without a bowtie filter under conditions of high x-ray scatter), the ratio of means and maxima was 0.63% and 27%, respectively. Our studies of stationarity suggest that under some imaging conditions local descriptions of the noise need to be developed to appropriately describe CBCT images and that the off-diagonal elements of the DFT covariance matrix cannot always be ignored.

6913-62, Session 12

Spectral analysis of scattered radiation in CT

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In the framework of spectral Computed Tomography ("spectral CT"), scattered X-ray radiation is examined for its spectral composition and spatial distribution by means of Monte Carlo simulations. A reliable material (i.e. bone / contrast agent) separation and quantification requires a precise knowledge of the transmitted X-ray spectrum especially for low energy photons. Unfortunately, for lower energies the primary intensity is increasingly covered by scattered radiation. The detected scattered radiation can be classified into two main categories with respect to their scattering history. One category contains purely elastically (Rayleigh) scattered photons, which typically have small scattering angles and an energy spectrum similar to that of the transmitted primary radiation. The second category contains multiple Compton scattered photons with a spectral composition, which is typically softer than that of the transmitted primary photons. In regions of strong beam attenuation (i.e. in the X-ray shadow of a scanned object), the scattered radiation is mainly composed of multiple Compton scattered photons. As a consequence, the spectrally resolved scatter-to-primary ratios strongly increase for low energies. High-quality anti-scatter collimators can be used to reduce especially the detection of multiple Compton-scattered photons. A quantitative evaluation of transmitted radiation below 40 keV is challenging, since primary photons are superposed by a significantly higher number of scattered photons.

6913-63, Session 12**Cascaded systems analysis of the 3D NEQ for cone-beam CT and tomosynthesis**

D. J. Tward, Univ. of Toronto (Canada); J. H. Siewerdsen, Princess Margaret Hospital (Canada) and Univ. of Toronto (Canada); R. A. Fahrig, Stanford Univ.; A. R. Pineda, California State Univ./Fullerton

Crucial to understanding the factors that govern imaging performance is a rigorous analysis of signal and noise transfer characteristics (e.g., MTF, NPS, and NEQ) applied to a task-based performance metric (e.g., detectability index). This paper advances a theoretical framework for calculation of the NPS, NEQ, and DQE of cone-beam CT (CBCT) and tomosynthesis based on cascaded systems analysis. The model considers the 2D projection NPS propagated through a series of reconstruction stages to yield the 3D NPS. Factors considered in the cascade include: system geometry; angular extent of source-detector orbit; finite number of projection views; non-linear log-scaling; application of ramp, apodization, and interpolation filters; backprojection; and 3D noise aliasing - all of which have a direct impact on the 3D NEQ and DQE. The model reveals a continuum (from 2D projection radiography, through limited-angle tomosynthesis, to fully 3D CBCT) for which NEQ and detectability index may be investigated as a function of any system parameter. Calculations of the 3D NPS were found to agree with experimental measurements across a broad range of imaging conditions. Studies were performed to examine the dependence (and optimization) of detectability index on: 1.) acquisition angle (in relation to the number of projections and total dose), 2.) reconstruction filter, and 3.) voxel size in tomosynthesis and CBCT. The model presents a theoretical framework that unifies 3D Fourier-based performance metrology in tomosynthesis and CBCT, providing a guide to optimization that rigorously considers the system configuration, reconstruction parameters, and imaging task.

6913-64, Session 12**Hadamard multiplexing radiography based on carbon nanotube field emission multipixel x-ray technology**

J. Zhang, G. Yang, S. Chang, J. Lu, O. Zhou, The Univ. of North Carolina at Chapel Hill

Currently all CT scanners collect the projection images sequentially, one at a time. The serial approach demands fast gantry rotation and high x-ray peak power which in turn limits the scanning speed of the CT scanners. To overcome the limitations of the current CT scanners, we have proposed and demonstrated the concept of stationary CT scanners that completely eliminate the need for gantry rotation. In such multi-pixel x-ray imaging system, multiple carbon nanotube field emission x-ray sources are spatially distributed along the CT scanning path. By generating scanning x-ray beams electronically, it's capable of performing CT scanning without mechanical movement. Based on this multi-pixel x-ray technology and so called multiplexing principle, which has been widely used in analytical instruments and communication areas to improve data throughput, we have recently developed multiplexing radiography technique that enables simultaneous collection of multiple projection images through multiplexing. A drastic increase of the imaging speed and reduction of the x-ray peak power can be achieved without compromising the imaging quality. In this paper we demonstrated a novel Hadamard multiplexing radiography technique based on Hadamard transform principle using a carbon nanotube based multi-pixel x-ray source. The combination of the multi-pixel x-ray technology and multiplexing principle has the potential to lead to a new generation of stationary multiplexing CT scanners that have drastically increased data throughput at reduced cost.

6913-65, Session 12**Propagation of quantum noise in multiplexed x-ray imaging**

B. De Man, GE Global Research; N. J. Pelc, Stanford Univ.; T. Bernstein, GE Healthcare

Multiplexed x-ray imaging was recently proposed as a way to possibly reduce x-ray source power requirements while maintaining temporal

resolution and imaging speed. Rather than measuring projections sequentially, with multiplexing, multiple sources send photons to the same detector corresponding to different projections. Data for the multiple projections that are measured by the same detector are separated by energizing the sources with different temporal sequences. This concept could be used for radiography, tomosynthesis, or CT imaging. Multiplexed measurements are used very successfully in other modalities. For example, in magnetic resonance imaging (MRI) we can measure data for multiple voxels, perhaps even the entire object, through a single channel. In MRI, this huge increase in the number of regions interrogated simultaneously has no SNR impact. It is important to examine the noise impact of multiplexing/demultiplexing in x-ray imaging. We examined the propagation of noise due to the quantum statistics of the measured x-rays. The analysis showed that for quantum limited acquisitions, the noise penalty of multiplexing can be severe. Indeed, if both the multiplexed and sequential methods can be quantum limited, the simpler sequential method always outperforms multiplexing.

6913-66, Session 13**A simple motion tracking backprojection for a class of affine transformation**

K. Taguchi, Johns Hopkins Univ.; H. Kudo, Univ. of Tsukuba (Japan)

Image reconstruction of dynamically deforming objects from projections and known time-dependent motion field is of interest for x-ray computed tomography. Recently, three analytical exact methods have been developed based on DFBP or DBPF algorithms which compensates for time-dependent standard affine or relaxed affine transformation (Desbat, et al., TMI 2007; Roux, et al., PMB 2004; and Taguchi, et al., 3D07). In contrast, an empirical algorithm has been proposed by Schafer, et al., which merely "trace" the motion of each voxel during backprojection process (Schafer, et al., TMI 2006; van Stevendaal, et al., 3D07). The method is known to be an approximation; however, it has not been discussed how good or bad the level of approximation is. In this paper, we present that a slightly modified Schafer's method is exact if the motion of the object can be described by a class of time-dependent affine transformation-isotropic scaling (contraction and expansion) and rotation. If the motion includes translation, the method is reduced to an approximation; yet it remains a good approximation.

6913-67, Session 13**Correction of cross-scatter in next generation dual source CT scanners**

H. K. Bruder, K. Stierstorfer, M. Petersilka, C. Suess, Siemens Medical Solutions (Germany)

In dual source CT (DSCT) with two x-ray sources and two data measurement systems mounted 90 deg ahead of each other, cross scatter radiation, (essentially 90 deg Compton scatter) is added the detector signals. In current DSCT scanners the cross scatter correction is model based: the idea is to describe the scattering surface in terms of its tangents. The positions of these tangent lines are used to characterize the shape of the scattering object. The tangent line positions found can be used for a lookup into a table where scatter distributions for all of these tangent line positions are stored. In certain clinical situations the model based correction will not perfectly remove the scatter signal in the detector readings: scatter artifacts in dual sources scan modes can be expected. These shortcomings can be circumvented by utilizing the non-diagnostic time windows in cardiac scan modes to measure cross scatter online. The x-ray generators of both systems can be alternately switched on and off. If one x-ray source is switched off, cross scatter deposited in the respective other detector can be recorded and processed to be used for efficient cross scatter correction. The procedure will be demonstrated for cardiac step&shoot as well as for spiral acquisitions. Full rotation reconstructions are less sensitive to cross scatter radiation, hence in non-cardiac case the model-based approach is applied. Based on measurements of physical and anthropomorphic phantoms we present image data for a DSCT scanner with various collimator openings demonstrating the efficacy of the proposed methods.

6913-68, Session 13**Cardiac CT artifact mitigation through decomposition-based image reconstruction**

Z. Liang, Boston Univ.; S. Do, Massachusetts General Hospital; W. C. Karl, Boston Univ.; T. J. Brady, H. H. Pien, Massachusetts General Hospital

A common problem arising in medical imaging is the suppression of undesired image artifacts with the simultaneous preservation of salient clinical information. Often the proposed processing ‘cure’ introduces its own artifacts in other parts of the image that confound reliable diagnosis. A canonical example is the suppression of artifacts from hyperdense objects, such as metal and calcium. In this paper we propose a new decomposition-based approach to the combined image formation and the suppression of localized image artifacts which is motivated by recent results on image inpainting. The approach, which we term Model-Based Algebraic Iteration (MBAI) processing, decomposes an image into a collection of homogeneous components, each of which can be reconstructed in the manner most appropriate to its underlying nature. Because each component is localized, the effects of processing on that component do not contaminate other areas of the image. Our specific motivation is the mitigation of artifacts in cardiac multi-detector computed tomography (MDCT) images.

Recently, MDCT has offered the promise of a non-invasive alternative to invasive coronary angiography to evaluate coronary artery disease. An impediment preventing its utilization as a routine clinical replacement for angiography is the presence of image “blooming” artifacts due to the presence vascular calcium. We develop MBAI for the purpose of ameliorating artifacts in cardiac images and thus increase the applicability of MDCT for the evaluation of at-risk patient population. We demonstrate a reduction of calcium blooming-effect both in software simulated data and phantom scanning data.

6913-69, Session 13**Monte-Carlo scatter correction for cone-beam computed tomography with limited scan field-of-view**

M. Bertram, T. Sattel, S. Hohmann, J. Wiegert, Philips Research Europe Aachen (Germany)

In flat detector cone-beam computed tomography (CBCT), scattered radiation is a major source of image degradation, making accurate a posteriori scatter correction inevitable. For simulation of scatter distributions in X-ray projections, Monte Carlo simulations are a widely used technique, and advances in computer power have recently also allowed to utilize Monte Carlo simulations for computerized scatter correction in CBCT based on voxelized patient models obtained from a coarse intermediate reconstruction of the imaged object. However, as a major drawback, for standard CBCT geometries and with standard size flat detectors such as mounted on interventional C-arms, the reconstructable field of view is too small to accommodate the human torso without lateral truncations, and thus this technique cannot be readily applied. In this work, we present two novel methods for constructing a model of the object in a laterally and axially extended field of view, which enable meaningful application of Monte-Carlo based scatter correction even in case of heavy truncations. Both methods are based on minimization of the difference between the acquired projections and virtual forward projections of the extended model. A ground truth for evaluation and comparison was created using simulations of a clinical CT data set of a human abdomen, which strongly exceeded the field of view of the C-arm based CBCT imaging geometry. The results demonstrate that the suggested methodology allows to reduce scatter artifacts in truncated CBCT scans by about 90%.

6913-70, Session 13**Influence of imaging geometry on noise texture in x-ray in-line phase-contrast imaging**

C. Chou, National Taiwan Univ. (Taiwan); M. A. Anastasio, Illinois Institute of Technology

X-ray in-line phase-contrast imaging is a technique that aims to

reconstruct the projected absorption and refraction properties of an object. To achieve this, phase retrieval algorithms are employed. The statistical properties of the reconstructed images in phase-contrast imaging remains unexplored. An understanding of the second-order statistical properties of the reconstructed images is vital for characterizing how the imaging geometry affects object detectability, which will facilitate task-based system design. In this work, the covariance structure of the absorption and refractive index images is derived analytically, to characterize the noise texture in quantitative in-line phase-contrast imaging.

The influence of the imaging geometry on noise texture is analyzed. This information is utilized to establish how the Hotelling observer performance is affected by specification of imaging geometry.

6913-71, Session 13**Temporal modulation transfer function of fluoroscopic systems: small-signal vs large-signal approaches**

S. N. Friedman, Robarts Research Institute (Canada) and Univ. of Western Ontario (Canada); I. A. Cunningham, Robarts Research Institute (Canada) and Univ. of Western Ontario (Canada) and London Health Sciences Ctr. (Canada)

Metrics of system performance are used to assess the abilities and safety of x-ray imaging systems. The detective quantum efficiency (DQE) is used as a measure of “dose efficiency” but, when applied to fluoroscopic systems, requires a measurement of the temporal modulation transfer function (MTF) to account for the effects of system lag. It is shown that the temporal MTF is exposure-rate dependent, and hence must be measured under the specific exposure conditions of interest. We develop a small-signal approach to temporal MTF measurements using a semi-transparent moving slanted edge. Using an x-ray image intensifier-based bench-top system, we show that there is a 50% overstatement of the DQE when not properly accounting for lag. The small-signal approach is used to calculate a lag-free fluoroscopic DQE that agrees with a radiographic DQE measurement under the same exposure-rate conditions. It was found that the temporal MTF did not change within measured precision over normal fluoroscopic conditions, and the radiopaque falling-edge results were consistent with the small-signal temporal MTF. This approach could be implemented in a clinical setting with access to raw (linear or linearized) fluoroscopic image data and could be generalized for use on pulsed-exposure systems.

6913-72, Session 14**Exact and approximate cone-beam reconstruction algorithms for C-arm based cone-beam CT using a two-concentric-arc source trajectory**

T. Zhuang, J. N. Zambelli, B. E. Nett, S. Leng, G. Chen, Univ. of Wisconsin/Madison

In this work, we develop shift-invariant filtered backprojection cone-beam image reconstruction algorithms for cone-beam CT implemented using a clinical C-arm system. The source trajectory consists of two concentric arcs which is complete in the sense that the Tuy data sufficiency condition is satisfied. A complete source trajectory enables mathematically exact reconstruction. Therefore cone-beam artifacts in the reconstructed images can be theoretically eliminated compared to those images reconstructed using the single circular scan with the FDK algorithm. In this new geometry, however, the image volume is not well populated by DM-lines (PI-lines, R-lines). Thus, DM-line based cone-beam image reconstruction schemes can not be used to reconstruct the image volume. The algorithms proposed in this work are based upon the image reconstruction scheme developed by Pack and Noo. When no truncation is present in the projection data, a mathematically exact algorithm was obtained. An approximate algorithm was also developed based upon the exact algorithm to handle longitudinal data truncation. Mathematical phantom data and experimental data have been utilized to validate the reconstruction algorithms.

6913-73, Session 14**Three-dimensional iterative full scan and half scan reconstruction in CT architectures with distributed sources**

M. Iatrou, B. De Man, D. Beque, T. Benson, K. B. Khare, Z. Yin, GE Global Research

In 3rd generation CT systems, projection data generated by X-rays emitted from a single source and passing through the imaged object are acquired by a single detector covering the entire field of view (FOV). Novel CT system architectures employing distributed sources [1,2] can extend the axial coverage, while removing cone-beam artifacts and improving spatial resolution and dose. The sources can be distributed in-plane and/or in the longitudinal direction. In this paper we investigate statistical iterative reconstruction of the corresponding multi-axial datasets. We explore the feasibility of 3D iterative full scan and half scan reconstruction methods for CT systems with two different architectures. In the first architecture the sources are distributed in the longitudinal direction, and in the second architecture the sources are distributed both longitudinally and trans-axially. We use Penalized Weighted Least Squares Transmission Reconstruction (PWLSTR) and incorporate a projector-backprojector model matching the simulated architectures. The results demonstrate that iterative reconstruction results in images without significant geometry-related artifacts. The reconstructed images also show that the investigated architectures can achieve good image quality for very large coverage without severe cone-beam artifacts.

6913-74, Session 14**A Fourier rebinning algorithm for cone-beam CT**

S. R. Mazin, N. J. Pelc, Stanford Univ.

It is known that x-ray projections collected from a circular orbit of an x-ray source is insufficient for accurate reconstruction of a 3D object. For each local region of the object (except in the plane containing the source trajectory) there is a conical volume in the object's spatial frequency space that is unmeasured due to the circular geometry. The Feldkamp, Davis and Kress (FDK) algorithm based on filtered backprojection (FBP) involves a 3D backprojection step so that these unmeasured spatial frequencies are set to zero, resulting in cone beam artifacts for certain objects. We present a new type of cone beam CT reconstruction algorithm based on the Fourier rebinning (FORE) framework of DeFrise et al. The cone beam x-ray projection data are rebinned into a set of in-plane sinograms using the FORE rebinning approximation, followed by 2D FBP to reconstruct each axial slice. The algorithm is able to extrapolate data into the missing region of the object's frequency space in a computationally efficient way, allowing for a reduction of cone beam artifacts for certain objects. Unlike FDK, the algorithm is exact for an impulse object located anywhere along the axis of rotation. Reconstruction errors are dependent on the radial distance, cone angle, and the second-derivative of the projection data in the longitudinal direction. Finally, an extension to the algorithm is presented that permits reconstruction in regions of the object that are not seen by the detector in every view.

6913-75, Session 14**Image reconstruction from undersampled radial acquisition using compressed sensing with various penalty functions**

J. V. Velikina, B. E. Nett, S. Leng, Y. Wu, O. Unal, G. Chen, Univ. of Wisconsin/Madison

Compressed sensing is a recent theory that provides new sampling criteria for exact image

reconstruction from a small number of uniformly distributed random samples via solution of a Compressed sensing is a recent theory that provides new sampling criteria for exact image reconstruction from a small number of uniformly distributed random samples via solution of a constrained minimization problem. We apply the compressed sensing ideas to undersampled magnetic resonance (MR) imaging with deterministic radial sampling. We develop a series of optimization algorithms with different penalty functions such as the L1 norm of the

image itself, its gradient, or its Laplacian. The choice of a suitable penalty function depends on a particular imaging application. We discuss the general considerations for selecting the right penalty function in each case. Our algorithms are validated through an extensive number of experiments using in-vivo MR data from different applications. The results demonstrate that in the case of radial acquisition it is possible to achieve undersampling factors on the order of 6-25 relative to the Nyquist criterion without loss of spatial resolution while reducing streaking artifacts and improving the signal-to-noise ratio. Such acceleration factors can be used to shorten the scan times and to increase coverage or spatial resolution for a fixed noise and artifact level in MR applications. In CT applications the new algorithms can result in x-ray dose reduction. constrained minimization problem. We apply the compressed sensing ideas to undersampled magnetic resonance (MR) imaging with deterministic radial sampling. We develop a series of optimization algorithms with different penalty functions such as the L1 norm of the image itself, its gradient, or its Laplacian. The choice of a suitable penalty function depends on a particular imaging application. We discuss the general considerations for selecting the right penalty function in each case. Our algorithms are validated through an extensive number of experiments using in-vivo MR data from different applications. The results demonstrate that in the case of radial acquisition it is possible to achieve undersampling factors on the order of 6-25 relative to the Nyquist criterion without loss of spatial resolution while reducing streaking artifacts and improving the signal-to-noise ratio. Such acceleration factors can be used to shorten the scan times and to increase coverage or spatial resolution for fixed noise and artifact level in MR applications. In CT applications the new algorithms can result in x-ray dose reduction.

6913-76, Session 14**Intensity-weighted region-of-interest imaging in cone-beam CT**

S. Cho, E. Pearson, D. Xia, X. Han, C. A. Pelizzari, X. M. Pan, The Univ. of Chicago

Purpose: We propose an innovative image reconstruction technique for the data acquired by intensity-weighting in order to reduce the dose delivered to the normal tissue surrounding the imaging target in image-guided radiation therapy applications.

Methods: Key features of the image reconstruction algorithm used in this work, which is the chord-based backprojection-filtration algorithm, are as following. Accurate region-of-interest image can be reconstructed from truncated data, and the noise from a local region in the projection data does not propagate significantly to the neighboring regions in the reconstructed image. Numerical study has been conducted to validate the proposed method.

Results: Noise transfer property of the image reconstruction algorithm has been confirmed, and the region-of-interest image was successfully reconstructed from truncated, intensity-weighted projection data.

Conclusion: Our proposed method can reconstruct the accurate, region-of-interest image with locally varying noise level from intensity-weighted, truncated data. The proposed method can contribute substantially to reducing the patient dose in routine cone-beam CT for image-guided radiation therapy.

6913-77, Session 15**An acquisition and image reconstruction scheme for reduced x-ray exposure dynamic 3D CTA**

M. P. Supanich, H. A. Rowley, A. S. Turk, M. A. Speidel, K. Pulfer, Univ. of Wisconsin/Madison; J. Hsieh, GE Healthcare; G. Chen, C. A. Mistretta, Univ. of Wisconsin/Madison

We present novel Computed Tomography (CT) acquisition and reconstruction schemes for low-dose neuro-angiography based on the method of Highly constrained back Projection (HYPR). Simulated and experimental low X-ray radiation dose scans were prepared using the techniques of interleaved view angle undersampling and tube current reduction. Dynamic CT Angiograms (CTAs) were produced for both standard and low dose images sets. The spatial correlation coefficient, r , between the two reconstruction approaches was determined for each

time frame and the SNR and CNR values in arterial ROIs were calculated. The undersampled HYPR reconstructions produced r values of > 0.95 at undersampling and dose reduction factors of 10 and SNR and CNR were more than doubled using HYPR techniques at a tube current of 25 mA. HYPR approaches to contrast enhanced neuro-imaging provide not only volumetric brain hemodynamics but also the ability to produce high quality maps of standard perfusion parameters. The synergy of volumetric hemodynamics and assessment of tissue function provides the medical imaging community with high quality diagnostic information at a fraction of the radiation dose in a single contrast-enhanced scan.

6913-78, Session 15

Region-of-interest image reconstruction in x-ray differential phase-contrast tomography

M. A. Anastasio, Illinois Institute of Technology; X. M. Pan, The Univ. of Chicago

X-ray differential phase-contrast tomography (DPCT) is a method for reconstructing the spatial distribution of the X-ray refractive index within an object from knowledge of differential projection data. Assuming geometrical optics wave propagation, these data describe the angles by which the probing optical beams are deflected by the object due to refraction.

Phase-sensitive X-ray imaging methods such as diffraction enhanced imaging can measure the required beam-deflection data, and are being actively developed for medical imaging applications. Existing reconstruction algorithms assume the projection data are untruncated, and will generally yield image artifacts if this condition is violated.

The need to acquire untruncated projections can result in long acquisition time and an increased radiation dose to the object. Furthermore, in many applications of DPCT one is interested only in structures within a region-of-interest (ROI) of the object and/or that the object is larger than the FOV of the imaging system, leading to a data-truncation problem.

In this work, we investigate and demonstrate the applicability of algorithms recently developed for conventional tomography for obtaining ROI images in DPCT from knowledge of truncated differential projection data. A preliminary numerical study is conducted to validate and demonstrate the proposed reconstruction algorithm.

6913-79, Session 15

Practical iterative image reconstruction in digital breast tomosynthesis by non-convex TpV optimization

E. Y. Sidky, I. S. Reiser, R. M. Nishikawa, X. M. Pan, The Univ. of Chicago; R. Chartrand, Los Alamos National Lab.; D. B. Kopans, R. H. Moore, Massachusetts General Hospital

Digital breast tomosynthesis (DBT) is a rapidly developing imaging modality that gives some tomographic information for breast cancer screening. The effectiveness of standard mammography can be limited by the presence of overlapping structures in the breast. A DBT scan, consisting of a limited number of views covering a limited arc projecting the breast onto a fixed flat-panel detector, involves only a small modification of digital mammography, yet DBT yields breast image slices with reduced interference from overlapping breast tissues.

One-shot algorithms such as filtered back-projection (FBP) have been developed for DBT image reconstruction. Though efficient, they tend to yield conspicuous artifacts. Iterative algorithms such as expectation-maximization (EM) have also been employed with DBT. Such algorithms sacrifice efficiency, but yield images with fewer artifacts. An additional drawback for EM, however, is that in general some form of regularization is needed which tends to reduce resolving power necessary for calcification detection. We have recently developed an iterative image reconstruction algorithm for DBT based on image total variation (TV) minimization that improves on EM in that the resulting images have fewer artifacts and there is no need for additional regularization. In this abstract, we present the total p -norm variation (TpV) image reconstruction algorithm. TpV has the advantages of our previous TV algorithm, while improving substantially on the efficiency. Results for the TpV algorithm on clinical data are shown and compared with EM.

6913-80, Session 15

Sinogram smoothing with bilateral filtering for low-dose CT

L. Yu, A. Manduca, J. D. Trzasko, N. Khaylova, J. M. Kofler, C. H. McCollough, J. G. Fletcher, Mayo Clinic College of Medicine

Optimal noise control is critical for dose reduction in CT. In this work, we investigated the use of a locally-adaptive method for noise reduction in low-dose CT. This method is based upon bilateral filtering, which smoothes the log-transformed sinogram using a weighted average in a local neighborhood, where the weights are determined according to both the spatial proximity and intensity similarity between the center pixel and the neighboring pixels. This filtering is locally adaptive and can preserve important edge information in the sinogram, thus without significantly sacrificing the spatial resolution. It is closely related to anisotropic diffusion, but is significantly faster. More importantly, a CT noise model can be readily incorporated in the filtering and denoising process. We have evaluated the noise-resolution properties of the bilateral filtering in a low-dose CT colonography study. The results demonstrated that it can achieve a better noise-resolution tradeoff than a series of commercial reconstruction kernels. This improvement on noise-resolution properties can be used for improving the image quality in low-dose CT and can also be translated to substantial dose reduction.

6913-81, Session 15

Tomosynthesis with source positions distributed over a surface

D. Xia, J. Bian, E. Y. Sidky, C. A. Pelizzari, X. M. Pan, The Univ. of Chicago

In the last several years, there have been renewed interests in the development of tomosynthesis for applications in breast imaging, image-guided radiation therapy, and security scans. In these studies, the X-ray source generally is moved along a curve within a plane, which often is a segment along a circular trajectory. For convenience, we refer to such a trajectory as a planar trajectory.

In various practical applications of tomosynthesis, however, the source position need not be restricted to a planar trajectory such as the circular curve in the conventional tomosynthesis. Instead, the source position can be moved freely over a surface such as a portion of the sphere, and the source trajectory does not stay in a single plane. In this case, we refer to the trajectory as a non-planar trajectory. We hypothesize that the tomosynthesis with a non-planar trajectory would yield images with quality higher than that only obtained with a planar trajectory.

In this work, we investigate and evaluate image quality in the conventional tomosynthesis that uses only a planar trajectory and tomosynthesis with a non-planar trajectory. Our preliminary numerical study indicates that with the same number of projection views (or, equivalently, the same dose level,) the new imaging configuration seems to lead to images with improved quality over that obtained with the conventional tomosynthesis. The proposed imaging strategy may find important applications in IGRT and security scan.

6913-82, Session 15**Iterative scatter correction based on artifact assessment**

J. Wiegert, S. Hohmann, M. Bertram, Philips Research Europe Aachen (Germany)

In this paper we propose a novel scatter correction methodology that allows to combine the advantages of both projection-based and volume-based correction approaches. The basic idea is to use a potentially non-optimal projection-based scatter correction method and to iteratively optimize its performance by repeatedly assessing remaining scatter-induced artifacts in intermediately reconstructed volumes. The novel approach exploits the fact that due to the flatness of the scatter-background, compensation itself is most easily performed in the projection-domain, while the scatter-induced artifacts can be better observed in the reconstructed volume. The presented method foresees to evaluate the scatter correction efficiency after each iteration by means of a quantitative measure characterizing the amount of residual cupping and to adjust the parameters of the projection-based scatter correction for the next iteration accordingly.

The potential of this iterative scatter correction approach is demonstrated using voxelized Monte Carlo scatter simulations as ground truth. Using the proposed iterative scatter correction method, remarkable scatter correction performance was achieved both using simple parametric heuristic techniques as well as by optimizing previously presented scatter estimation schemes. For the human head, scatter induced artifacts were reduced from initially 148HU to less than 8.1HU and 8.65HU, respectively, corresponding to an artifact reduction factor (ARF) exceeding 95%.

6914-01, Session 1

Area prior constrained level set evolution

I. Ben Ayed, S. Li, GE Healthcare (Canada); A. Islam, G. Garvin, St. Joseph's Hospital (Canada); R. Chhem, London Health Sciences Ctr. (Canada)

The level set framework has proven well suited to medical image segmentation due to its ability of balancing contributions of image data and prior knowledge in a principled, flexible, and transparent way. It consists of evolving a curve towards the target object boundaries. The curve evolution equation is sought following the minimization of a cost functional containing two types of terms: data terms, which measure the fidelity of segmentation to image intensities, and prior terms, which traduce learnt knowledge. Without priors, many algorithms are likely to fail due to high noise, low contrast, and data incompleteness. Different priors have been investigated such as shape and appearance priors. In this study, we investigate a new type of priors: the area prior. This prior embeds knowledge of an approximate object area, and has two positive effects. First, it speeds up significantly the evolution when the curve is far from the target object boundaries. Second, it slows down the evolution when the curve is close to the target. Consequently, it reinforces curve stability at the desired boundaries when dealing with low contrast intensity edges. The algorithm is validated with several experiments using Magnetic Resonance (MR) images and Computed Tomography (CT) images.

A comparison with another level set method illustrates the positive effects of the area prior.

6914-02, Session 1

A resistive-network model for image segmentation

P. J. Yim, Robert Wood Johnson Medical School

A novel physical analogy and associated algorithm is proposed for image segmentation. The physical analogy is that of an electrical network. The network is composed of discrete resistive elements that are interconnected, according to adjacency relations in the image. The resistances vary linearly with the image gradient and exponentially with the voltage across the elements. Segmentation is obtained by applying a voltage between a voltage source and ground that are located at points on the inside and outside of an object, respectively. Those points are identified in an interactive manner. Provided that a sufficiently high voltage is applied, a dichotomization of the voltages in the network occurs. In practice, the solution can be obtained in an iterative manner by gradually increasing the applied voltage. At each step as the source voltage is increased, the resistances are held constant and the Kirchoff's-law system of equations is solved algebraically. It is not clear yet whether image segmentation obtained by this algorithm is globally optimal with respect to a cost-function, as is the case for minimum s-t cut image segmentation. However, like minimum s-t cut algorithm, the resistive-network algorithm does tend to favor segmentation boundaries with shorter, and thus smoother, boundaries. A potential advantage of the resistive-network algorithm is that it is amenable to parallelization. The algorithm was found to provide reasonable results for segmentation of a synthetic image of step boundary degraded by blurring and Gaussian noise, low-contrast computed tomography (CT) of a ball, and CT of a liver lesion.

6914-03, Session 1

A new distribution metric for image segmentation

R. S. Sandhu, Georgia Institute of Technology; T. Georgiou, Univ. of Minnesota; A. Tannenbaum, Georgia Institute of Technology

In this paper, we present a new distribution metric for image segmentation that arises as a result in prediction theory. Motivated by the quadratic prediction problem, the metric is originally derived as a distance measure for spectral densities; however, it generalizes distances between probability distribution functions (pdf) as well. Resulting in a geodesic, this intrinsic metric quantifies "distance" for two density functions as the standard deviation of the difference between logarithms of those density

functions. It then is quite natural for us to cast this distribution metric in the Geometric Active Contour framework (GAC) for image segmentation. This is done by performing gradient descent on an energy functional describing our metric, resulting in a separation of the photometric variable of interest, intensity.

Thus, our method belongs to a new class of region based contours that discriminates on the entire distribution. While these metrics propose to measure dissimilarity between two "shapes," they have produced varying segmentation results. We demonstrate our segmentation method on several examples, including both medical and synthetic images. The success of our results are comparable and similar to those obtained with other distribution metrics; however, in particular cases we show where our proposed metric succeeds while one such metric, the Bhattacharyya distance, fails.

6914-04, Session 1

Segmenting images analytically in shape space

Y. Rathi, Harvard Medical School; S. Dambreville, Georgia Institute of Technology; M. Niethammer, Harvard Medical School; J. Malcolm, Georgia Institute of Technology; J. Levitt, M. Shenton, Harvard Medical School; A. Tannenbaum, Georgia Institute of Technology

This paper presents a novel analytic technique to perform shape-driven segmentation. In our approach, shapes are represented using binary maps, and linear PCA is utilized to provide shape priors for segmentation. Intensity based probability distributions are then employed to convert a given test volume into a binary map representation, and a novel energy functional is proposed whose minimum can be analytically computed to obtain the desired segmentation in the shape space. We compare the proposed method with the log-likelihood based energy to elucidate some key differences.

Our algorithm is applied to the segmentation of brain caudate nucleus and hippocampus from MRI data, which is of interest in the study of schizophrenia and Alzheimer's disease. Our validation (we compute the Hausdorff distance and the DICE coefficient between the automatic segmentation and ground-truth) shows that the proposed algorithm is very fast, requires no initialization and outperforms the log-likelihood based energy.

6914-05, Session 1

A unified framework for joint registration and segmentation

K. Ens, Univ. zu Lübeck (Germany) and Philips Research Europe Hamburg (Germany); J. von Berg, S. Kabus, C. Lorenz, Philips Research Europe Hamburg (Germany); B. Fischer, Univ. zu Lübeck (Germany)

Accurate image registration is a necessary prerequisite for many diagnostic and therapy planning procedures where complementary information from different images has to be combined. The design of robust and reliable non-parametric registration schemes is currently a very active research area. Modern approaches combine the pure registration scheme with other image processing routines such that both ingredients may benefit from each other. One of the new approaches is the combination of registration and segmentation. Here, the segmentation part guides the registration to its wanted configuration, whereas on the other hand the registration does lead to an automatic segmentation. By joining these image processing methods it is possible to overcome some of the pitfalls of the individual methods. Here, we focus on the benefits of the registration part.

We presented a framework for non-parametric registration improved through manual segmentation. We demonstrated that this technique considerably improves registration results. A next step is the investigation of automatic segmentation schemes. In the current work, we present a novel unified framework for non-parametric registration combined with segmentation through active contours. In the literature, one may find various ways to combine these image processing routines. Here, we present the most promising approaches within the general framework. It is based on a variational formulation of both the registration and the

segmentation part. The performance tests are carried out for MR brain images.

6914-06, Session 2

Adaptive local multiatlas segmentation: application to heart segmentation in chest CT scans

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Atlas-based segmentation is a popular generic technique for automated delineation of structures in volumetric data sets. Several studies have shown that multi-atlas based segmentation methods outperform schemes that use only a single atlas, but running multiple registrations on large volumetric data is too time-consuming for routine clinical use. We propose a generally applicable adaptive local multi-atlas segmentation method (ALMAS) that locally decides how many and which atlases are needed to segment a target image. Only the selected parts of atlases are registered. The method is iterative and automatically stops when no further improvement is expected. ALMAS was applied to segmentation of the heart on chest CT scans and compared to three existing atlas-based methods as well as an independent human observer. It performed significantly better than single-atlas methods (two-tailed t-test, $p < 0.01$) and as good as an independent human observer ($p = 0.62$) and multi-atlas methods ($p = 0.60$) at a much lower computational cost.

6914-07, Session 2

Robust registration between cardiac MRI images and atlas for segmentation propagation

X. Zhuang, D. J. Hawkes, W. R. Crum, Univ. College London (United Kingdom); R. Boubertakh, S. Uribe, King's College London (United Kingdom); D. Atkinson, Univ. College London (United Kingdom); P. G. Batchelor, T. Schaeffter, R. Razavi, King's College London (United Kingdom); D. L. G. Hill, Univ. College London (United Kingdom)

Current methods for segmenting cardiac images based on registrations either propagate a manual segmentation on one frame to other frames or propagate the labels in a statistical atlas/model to images. These methods have a limited impact on automating segmentations due to the poor robustness of the registration methods used to transfer segmentation across the population. In this paper, we propose a new robust registration method, initialisation-using-region-based-registration (IRBReg), and apply it to register a heart atlas to MRI images of different subjects providing automatic segmentations. The registration rigidly registers some regions of the atlas, for example the ventricles, to the MRI image. The rigid transformations are then combined using distance weighting to provide the starting estimate. Finally, a mask-based fluid registration is used to fine-tune the labelling in the atlas to the detail in the MRI image. The segmentation in our proposed framework is fully automatic, and without any code optimisation takes around 20 minutes for one cardiac MRI image. Two groups of experiments based on in-vivo data have been done to evaluate the segmentation results (all success) and its reproducibility (average 0.8746, 0.7571, 0.7485 overlap for left, right ventricles, and myocardium respectively). The IRBReg method also serves as a common framework for other applications in which the nonrigid registrations fail due to a poor starting estimate derived from a single global transformation.

6914-08, Session 2

The SRI24 multichannel brain atlas: construction and applications

T. Rohlfing, SRI International; N. M. Zahr, Stanford Univ. and SRI International; E. V. Sullivan, Stanford Univ.; A. Pfefferbaum, SRI International

We present a new standard atlas of the human brain based on magnetic resonance images. The atlas was generated using unbiased population registration from high-resolution images obtained by multiple-coil acquisition at 3T in a group of 24 normal subjects. The final atlas comprises three anatomical channels (T1-weighted, early and late spin echo), three diffusion tensor-derived channels (fractional anisotropy,

mean diffusivity, diffusion image), and three tissue probability maps (CSF, gray matter, white matter). The atlas is dynamic in that it is implicitly represented by nonrigid transformations between the 24 subject images, as well as distortion-correction alignments between the image channels in each subject. The atlas can, therefore, be generated at essentially arbitrary image resolutions and orientations (e.g., AC/PC aligned), without compounding interpolation artifacts. We demonstrate in this paper two different applications of the atlas: (a) for region definition by label propagation in a fiber tracking study, which is enabled by the increased sharpness of our atlas compared with other available atlases, and (b) for spatial normalization, which is enabled by its average shape property. In summary, our atlas has unique features and will be made available to the scientific community as a resource and reference system for future imaging-based studies of the human brain.

6914-09, Session 2

A generalization of voxel-wise procedures for high-dimensional statistical inference using ridge regression

K. Sjöstrand, EXINI Diagnostics AB (Sweden); V. A. Cardenas, Univ. of California/San Francisco; R. D. Larsen, Technical Univ. of Denmark (Denmark); C. Studholme, Univ. of California/San Francisco

Whole-brain morphometry denotes a group of methods with the aim of relating clinical and cognitive measurements to regions of the brain. Typically, such methods requires the statistical analysis of a data set with many variables (voxels and exogenous variables) paired with few observations (subjects). A common approach to this ill-posed problem is to analyze each spatial variable separately, dividing the analysis into manageable subproblems. A disadvantage of this method is that the correlation structure of the spatial variables is not taken into account. This paper investigates the use of ridge regression to address this issue, allowing for a gradual introduction of correlation information into the model. We make the connections between ridge regression and voxel-wise procedures explicit and discuss relations to other statistical methods. Results are given on an in-vivo data set of deformation based morphometry from a study of cognitive decline in an elderly population.

6914-10, Session 2

The evaluation of a population-based diffusion tensor image atlas using a ground truth method

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Voxel based morphometry (VBM) is increasingly being used to detect diffusion tensor (DT) image abnormalities in patients for different pathologies. An important requisite for these VBM studies is the use of a high-dimensional, non-rigid coregistration technique, which is able to align both the spatial and the orientational information. Recent studies furthermore indicate that high-dimensional DT information should be included during coregistration for an optimal alignment. In this context, a population based DTI atlas is created that preserves the orientational DT information robustly and contains a minimal bias towards any specific individual data set. A ground truth evaluation method is developed using a single subject DT image that is deformed with 20\$ deformation fields. Thereafter, an atlas is constructed based on these 20\$ resulting images. Thereby, the non-rigid coregistration algorithm is based on a viscous fluid model and on mutual information. The fractional anisotropy (FA) maps as well as the DT elements are used as DT image information during the coregistration algorithm, in order to minimize the orientational alignment inaccuracies. The population based DT atlas is compared with the ground truth image using accuracy and precision measures of spatial and orientational dependent metrics.

Results indicate that the population based atlas preserves the orientational information in a robust way. A subject independent population based DT atlas is constructed and evaluated with a ground truth method. This atlas contains all available orientational information and can be used in future VBM studies as a reference system.

6914-11, Session 2

Multivariate longitudinal statistics for neonatal-pediatric brain tissue development

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The topic of studying the growth of human brain development has become of increasing interests in the neuroimaging community. Cross-sectional studies may allow comparisons between means of different age groups, but they do not provide any growth model that integrates the continuum of time, nor do they present any information about how individuals/population change over time. Longitudinal data analysis method arises as a strong tool to address these questions. In this paper, we use the longitudinal analysis methods to study tissue development in early brain growth; a novel approach of multivariate longitudinal analysis is applied to study the associations between the growth of different brain tissues.

We present in this paper the methodologies to statistically study scalar (univariate) and vector (multivariate) longitudinal data, and our exploratory results in the studies of neonatal-pediatric brain tissue development. We obtained growth curves as a quadratic function of time for all three tissues. The quadratic terms were then tested to be statistically significant, showing that there was indeed a quadratic growth of tissues in early brain development. Moreover, our result shows that there is a positive correlation between repeated measurements of any single tissue, and among those of different tissue volumes.

Our approach is generic in natural and thus can be applied to any longitudinal data with multiple outcomes, even shape analysis. Also, our joint mixed model is flexible enough to allow unbalanced data, i.e. subjects need not to have the same number of measurements, or they measured at the exact time points.

6914-12, Session 3

Adaptive mask and mutual information-based method for rigid intra-operative 3D ultrasound and CT image registration

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We propose a two stages CT and ultrasound registration method. The method can automatically select the useful regions for registration process. In the first stage, the registration is done by the MI based method with whole images considered. After convergence to the global optimum, there is usually some errors with the correct transform parameters. In the second stage, to refine the result of the previous one, a new MI based registration is computed with the selected high statistical dependency region as mask and with transform of the first stage as initialization. In the intraoperative case, the mask will be obtained by dilation or a bounding box around the vessel trees. We developed an improved version of vessel tracing method with automatic branching dealing. It will automatically discard the unsuccessful tube objects usually occurred in tracing into artefacts regions, by measuring their likelihood to be vessel tubes. We use phantom and real patient datasets to validate our registration method and results show the improvements in accuracy and robustness.

6914-13, Session 3

Mosaicing of single-plane illumination microscopy images using population registration and fast content-based image fusion

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Single Plane Illumination Microscopy (SPIM; Huisken et al., Nature 305(5686):1007--1009, 2004) is an emerging microscopic technique that enables live imaging of large biological specimens in their entirety. By imaging the living biological sample from multiple angles SPIM has the potential to achieve isotropic resolution throughout even relatively

large biological specimens. For every angle, however, only a relatively shallow section of the specimen is imaged with high resolution, whereas deeper regions appear increasingly blurred. In order to produce a single, uniformly high resolution image, we propose here an image mosaicing algorithm that combines state of the art groupwise image registration for alignment with content-based image fusion to prevent degrading of the fused image due to regional blurring of the input images. We also propose a new fusion algorithm based on Gaussian filters, which is substantially faster than fusion based on local image entropy. We demonstrate the performance of our mosaicing method on data acquired from living embryos of the fruitfly, *Drosophila*, using four and eight angle acquisitions.

6914-14, Session 3

(ST) Ultrasound specific similarity measures for three-dimensional mosaicing

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The introduction of 2D array ultrasound transducers enables the instantaneous acquisition of ultrasound volumes in the clinical practice. The next step coming along is the combination of several scans to create compounded volumes that provide an extended field-of-view, so called mosaics. The correct alignment of multiple images, which is a complex task, forms the basis of mosaicing. Especially the simultaneous intensity-based registration has many properties making it a good choice for ultrasound mosaicing in comparison to the pairwise one.

Fundamental for each registration approach is a suitable similarity measure. So far, only standard measures like SSD, NNC, CR, and MI were used for mosaicing, which implicitly assume an additive Gaussian distributed noise. For ultrasound images, which are degraded by speckle patterns, alternative noise models based on multiplicative Rayleigh distributed noise were proposed in the field of motion estimation.

Setting these models into the maximum likelihood estimation framework, which enables the mathematical modeling of the registration process, led us to ultrasound specific bivariate similarity measures. Subsequently, we used an extension of the maximum likelihood estimation framework, which we developed in a previous work, to also derive multivariate measures. They allow us to perform ultrasound specific simultaneous registration for mosaicing. These measures have a higher potential than afore mentioned standard measures since they are specifically designed to cope with problems arising from the inherent contamination of ultrasound images by speckle patterns. The results of the experiments that we conducted on a typical mosaicing scenario with only partly overlapping images confirm this assumption.

6914-15, Session 3

(ST) Three-dimensional image registration of MR proximal femur images for the analysis of trabecular bone parameters

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This study investigated the feasibility of automatic image registration of MR high-spatial resolution trabecular bone images of the proximal femur as well as the effects of gray-level interpolation and VOI misalignment on MR-derived trabecular bone parameters. An automatic image registration technique, based on mutual information, utilized a baseline and a follow-up scan to compute registration parameters. These parameters were subsequently used to perform retrospective registration with three different gray-level interpolators. Nearest neighbor interpolator and b-spline approximator did not significantly change bone parameters, while linear interpolation significantly modified bone parameters ($p < 0.01$). Improvement in image alignment due to the automatic registration was determined by visually inspecting difference images and 3D renderings. This work demonstrates the first application of automatic registration, without prior segmentation, of MR images of the proximal femur. Additionally, effects due to imprecise analysis volume alignment are investigated. Inherent heterogeneity in bone trabecular structure along the slice direction and imprecise positioning of the VOI along the slice

direction resulted in significant changes in bone parameters ($p < 0.01$). Results suggest that automatic mutual information registration with nearest-neighbor gray-level interpolation ensures VOI alignment between baseline and follow-up images and does not compromise the integrity of MR-derived trabecular bone parameters.

6914-16, Session 3

Vertebral surface registration using ridgelines/crestlines

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The Iterative Closest Point (ICP) algorithm is an efficient and popular technique for surface registration. It however suffers from the well-known problem of local minima that make the algorithm stop before it reaches the desired global solution. ICP can be improved by the use of landmarks or features. We recently developed a level set capable of evolving on the surface of an object represented by a triangular mesh. This level set permits the segmentation of portions of a surface based on curvature features. The boundary of a segmented portion forms a ridgeline/crestline. We show the ridgelines/crestlines and corresponding enclosed surfaces extracted by the algorithm can substantially improve ICP registration. We compared the performance of an ICP algorithm in three setups: 1) ICP without landmarks. 2) ICP using ridgelines. 3) ICP using ridgelines and corresponding enclosed surfaces. Our material consists of vertebral body surfaces extracted for a study about the progression of Ankylosing Spondylitis. Same vertebrae scanned at intervals of one or two years were rigidly registered. Vertebral body rims and the end plate surfaces they enclose were used as landmarks. The performance measure was the mean error distance between the registered surfaces. From the one hundred registrations that we performed the average mean error was respectively 0.503mm, 0.335mm and 0.254mm for the three setups. Setup 3 almost halved the average error of setup 1. Moreover the error range is dramatically reduced from [0.0985, 2.19]mm to just [0.0865, 0.532]mm, making the algorithm very robust.

6914-17, Session 3

Bi-planar 2D-to-3D registration in Fourier domain for stereoscopic x-ray motion tracking

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In this paper we present a new method to track bone movements in stereoscopic X-ray image series of the knee joint. The method is based on two different X-ray image sets: a rotational series of acquisitions of the still subject knee that allows the tomographic reconstruction of the three-dimensional volume, and a stereoscopic image series of orthogonal projections as the subject performs movements. Tracking the movements of bones throughout the stereoscopic image series means to determine, for each frame, the best pose of every moving bone previously identified in the 3D reconstructed model. The quality of a pose is reflected in the similarity between its theoretical projections and the actual radiographs. We use direct Fourier reconstruction to approximate the three-dimensional volume of the knee joint. Then, to avoid the expensive computation of digitally rendered radiographs (DRR) for pose recovery, we develop a corollary to the 3-dimensional central-slice theorem and reformulate the tracking problem in the Fourier domain.

Under the hypothesis of parallel X-ray beams, the heavy 2D-to-3D registration of projections in the signal domain is replaced by efficient slice-to-volume registration in the Fourier domain. Focusing on rotational movements, the translation-relevant phase information can be discarded and we only consider scalar Fourier amplitudes. The core of our motion tracking algorithm can be implemented as a classical frame-wise slice-to-volume registration task. Results on both synthetic and real images confirm the validity of our approach.

6914-18, Session 4

Cortical thickness measurement from magnetic resonance images using partial volume estimation

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Measurement of the cortical thickness from 3D Magnetic Resonance Imaging (MRI) can aid diagnosis and longitudinal studies of a wide range of neurodegenerative diseases. We estimate the cortical thickness using a Laplacian approach whereby equipotentials analogous to layers of tissue are computed. The thickness is then obtained using an Eulerian approach where partial differential equations (PDE) are solved, avoiding the explicit tracing of trajectories along the streamlines gradient. This method has the advantage of being relatively fast and insure unique correspondence points between the inner and outer boundaries of the cortex. The original method is challenged when the thickness of the cortex is of the same order of magnitude as the image resolution since partial volume (PV) effect is not taken into account at the gray matter (GM) boundaries. We propose a novel way to take into account PV which improves substantially accuracy and robustness. We model PV by computing a mixture of pure Gaussian probability distributions and use this estimate to initialize the cortical thickness estimation. On synthetic phantoms experiments, the errors were divided by three while reproducibility was improved when the same patients were scanned three consecutive times.

6914-19, Session 4

Parallel optimization of tumor model parameters for fast registration of brain tumor images

E. I. Zacharaki, C. S. Hoge, D. Shen, G. Biros, C. A. Davatzikos, Univ. of Pennsylvania

The motivation of this work is to register MR brain tumor images with a brain atlas. Such a registration method can make possible the pooling of data from different brain tumor patients into a common stereotaxic space, thereby enabling the construction of statistical brain tumor atlases. Moreover, it allows the mapping of neuroanatomical brain atlases into the patient's space, for segmenting brains and thus facilitating surgical or radiotherapy treatment planning. However, the methods developed for registration of normal brain images are not directly applicable to the registration of a normal atlas with a tumor-bearing image, due to substantial dissimilarity and lack of equivalent image content between the two images, as well as severe deformation or shift of anatomical structures around the tumor. Accordingly, a model that can simulate brain tissue death and deformation induced by the tumor is considered to facilitate the registration. Such tumor growth simulation models are usually initialized by placing a small seed in the normal atlas. The shape, size and location of the initial seed are critical for achieving topological equivalence between the atlas and patient's images. In this study, we focus on the automatic estimation of these parameters, pertaining to tumor simulation. In particular, we propose an objective function reflecting feature-based similarity and elastic stretching energy and optimize it with APPSPACK (Asynchronous Parallel Pattern Search), for achieving significant reduction of the computational cost. The results indicate that the registration accuracy is high in areas around the tumor, as well as in the healthy portion of the brain.

6914-20, Session 4

Spatial normalization of diffusion tensor images based on anisotropic segmentation

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A comprehensive framework is proposed for the spatial normalization of diffusion tensor (DT) brain images using tensor-derived tissue attributes. In this framework, the brain tissues are first classified into three categories: the white matter (WM), the gray matter (GM), and the

cerebral-spinal fluid (CSF) using the anisotropy and diffusivity information derived from the full tensor. The tissue attributes obtained from this anisotropic segmentation are then incorporated into a very-high-dimensional elastic registration method to produce a spatial deformation field. Finally, the rotational component in the deformation field, together with the estimated underlying fiber direction, is used to determine an appropriate tensor reorientation. This framework has been assessed quantitatively and qualitatively based on a sequence of experiments. A simulated experiment has been performed to evaluate the accuracy of the spatial warping by examining the variation between deformation fields. To verify the tensor reorientation, especially, in the anisotropic microstructures of WM fiber tissues, an experiment has been designed to compare the fiber tracts generated from the DT template and the normalized DT subjects in some regions of interest (ROIs). Finally, this method has been applied to spatially normalize 31 subjects to a common space, the case in which there exist large deformations between subjects and the existing approaches are normally difficult to achieve satisfactory results. The average across the individual normalized DT images shows a significant improvement in signal-to-noise ratio (SNR).

6914-21, Session 4

Fusion of rat brain histology and MRI using weighted multi-image mutual information

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Introduction: Fusion of histology and MRI is frequently demanded in biomedical research to study in vitro tissue properties in an in vivo reference space. Distortions and artifacts caused by cutting and staining of histological slices as well as differences in spatial resolution make even the rigid fusion a difficult task. State-of-the-art methods start with a mono-modal restacking yielding a histological pseudo-3D volume. The 3D information of the MRI reference is considered subsequently.

However, consistency of the histology volume and consistency due to the corresponding MRI seem to be diametral goals. Therefore, we propose a novel fusion framework optimising histology/histology and histology/MRI consistency at the same time finding a balance between both goals.

Method: Direct slice-to-slice correspondence even in irregularly-spaced cutting sequences is achieved by registration-based interpolation of the MRI. Introducing a weighted multi-image mutual information metric (WI), adjacent histology and corresponding MRI are taken into account at the same time. Therefore, the reconstruction of the histological volume as well as the fusion with the MRI is done in a single step.

Results: Based on two data sets with more than 110 single registrations in all, the results are evaluated quantitatively based on Tanimoto overlap measures and qualitatively showing the fused volumes. In comparison to other multi-image metrics, the reconstruction based on WI is significantly improved. We evaluated different parameter settings with emphasis on the weighting term steering the balance between intra- and inter-modality consistency.

6914-22, Session 4

Comparison of EM-based and level set partial volume segmentations of MR brain images

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EM and level set algorithms are competing methods for segmenting MRI brain images. This paper presents a fair comparison of the two techniques using the Montreal Neurological Institute's 'software' phantom.

There are many flavors of level set algorithms. The specific algorithm evaluated by us is a variant of the multi-layer level set algorithm. It uses a single level set function for segmenting the image into multiple classes and can be run to completion without restarting. The EM-based algorithm is standard.

Both algorithms have the capacity to model a variable number of partial volume classes as well as image inhomogeneity. Our evaluation consists of systematically changing the number of partial volume classes, additive image noise, and regularization parameters. The results suggest that the performances of both algorithms are comparable across noise, number of partial volume classes, and regularization. The segmentation errors of both algorithms are around 5-10% for csf, gray and white matter. The level set algorithm appears to have a slight advantage for gray matter segmentation. This may be beneficial in studying certain brain diseases (M.S. or Alzheimer's disease) where small changes in gray matter volume are significant, provided errors from other sources are smaller or comparable.

6914-23, Session 4

(ST) 3D MRI brain-image segmentation based on region-restricted EM algorithm

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This paper presents a novel algorithm of 3D human brain tissue segmentation and classification in magnetic resonance image (MRI) based on region restricted EM algorithm (RREM). The RREM is a level set segmentation method while the evolution of the contours was driven by the force field composed by the probability density functions of the Gaussian models. Each tissue is modeled by one or more Gaussian models restricted by free shaped contour so that the Gaussian models are adaptive to the local intensities. Compact configuration analysis is applied for smoothing. The RREM is guaranteed to be convergency and achieving the local minimum. The segmentation avoids to be trapped in the local minimum by the split and merge operation. A fuzzy rule based classifier finally groups the regions belonging to the same tissue and forms the segmented 3D image of white matter (WM) and gray matter (GM) which are of major interest in numerous applications. The presented method can be extended to segment brain images with tumor or the images having part of the brain removed with the adjusted classifier.

6914-24, Session 4

(ST) Automatic segmentation of the facial nerve and chorda tympani using image registration and statistical priors

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In cochlear implant surgery, an electrode array is permanently implanted in the cochlea to stimulate the auditory nerve and allow deaf people to hear. Current surgical techniques for cochlear access require wide excavation of the mastoid region of the temporal bone and a period of one to three hours to avoid damage to vital structures. Recently a far less invasive approach has been proposed-percutaneous cochlear access, in which a single hole is drilled from the skull surface to the cochlea. The drill path is determined by choosing an entry and target point on a pre-operative CT. For the surgical method to be feasible, determination of a safe and effective drilling trajectory must be accomplished. Segmentation of the structures of the ear would improve trajectory planning safety and efficiency, and enable the possibility of automated planning. Two important structures of the ear, the facial nerve and chorda tympani, present difficulties in intensity based segmentation due to their diameter (as small as 1.0 and 0.4mm) and adjacent inter-patient variable structures of similar intensity in CT imagery. A multipart model-based segmentation algorithm is presented in this paper, which accomplishes automatic segmentation of the facial nerve and chorda tympani. Segmentation results are presented and compared to surfaces manually segmented by an experienced physician. These results show that the method we propose is robust and accurate.

6914-25, Session 5

Feature selection and classification of multiparametric medical images using bagging and SVM

Y. Fan, Univ. of Pennsylvania; S. M. Resnick, National Institute on Aging; C. A. Davatzikos, Univ. of Pennsylvania

This paper presents a classification framework for brain classification based on multi-parametric medical images. This method takes advantage of multi-parametric imaging to provide a set of discriminative features for classifier construction by using a regional feature extraction method which takes into account joint correlations among different image parameters; in the experiments herein, MRI and PET images of the brain are used. Support vector machine classifiers are then trained based on the most discriminative features selected from the feature set. To facilitate robust classification and optimal selection of parameters involved in classification, in view of the well-known “curse of dimensionality”, base classifiers are constructed for building an ensemble classifier in a bagging (bootstrap aggregating) framework and the classification parameters of these base classifiers are optimized by means of maximizing the area under the ROC (receiver operating characteristic) curve estimated from their prediction performance on left-out samples of bootstrap sampling. This classification system is tested on a sex classification problem, where it yielded a correct classification rate of over 90% for unseen subjects. The proposed classification method is also compared with other commonly used classification algorithms, with favorable results. These results illustrate that methods built upon information jointly extracted from multi-parametric images have the potential to perform classification with high sensitivity and specificity.

6914-26, Session 5

Bleeding detection in wireless capsule endoscopy using adaptive color histogram model and support vector classification

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Wireless Capsule Endoscopy (WCE) is a colour imaging technology that enables detailed examination of the interior of the gastrointestinal tract. A typical WCE examination takes ~8 hours and captures ~40,000 useful images. After the examination, the images are viewed as a video sequence, which generally takes a clinician over an hour to analyse. The manufacturers of the WCE provide certain automatic image analysis functions e.g. Given Imaging offers in their Rapid Reader software the Suspected Blood Indicator (SBI), which is designed to report the location in the video of areas of active bleeding. However, this tool has been reported to have insufficient specificity and sensitivity. Therefore it does not free the specialist from reviewing the entire footage and was suggested only to be used as a fast screening tool. In this paper we propose a method of bleeding detection that uses in its first stage Hue-Saturation-Intensity colour histograms to track a moving background and bleeding colour distributions over time. Such an approach addresses the problem caused by drastic changes in blood colour distribution that occur when it is altered by gastrointestinal fluids and allow detection of other red lesions, which although are usually “less red” than fresh bleeding, they can still be detected when the difference between their colour distributions and the background is large enough. In the second stage of our method, we analyse all candidate blood frames, by extracting colour (HSI) and texture (LBP) features from the suspicious image regions (obtained in the first stage) and their neighbourhoods and classifying them using Support Vector Classifier into Bleeding, Lesion and Normal classes. We show that our algorithm compares favourably with the SBI on the test set of 84 full length videos.

6914-27, Session 5

Statistical modeling and MAP estimation for body fat quantification with MRI ratio imaging

W. C. K. Wong, D. H. Johnson, D. L. Wilson, Case Western Reserve Univ.

We are developing small animal imaging techniques to characterize the kinetics of lipid accumulation/reduction of fat depots in response to genetic/dietary factors associated with obesity and metabolic syndromes. Recently, we developed an MR ratio imaging technique that approximately yields lipid/[lipid]+water. In this work, we develop a statistical model for the ratio distribution that explicitly includes a partial volume (PV) fraction of fat and a mixture of a Rician and multiple

Gaussians. Monte Carlo hypothesis testing showed that our model was valid over a wide range of coefficient of variation of the denominator distribution (c.v.: 0-0.20) and correlation coefficient among the numerator and denominator (0-0.95), which cover the typical values that we found in MRI data sets (c.v.: 0.027-0.063, rho: 0.50-0.75). Then a maximum a posteriori (MAP) estimate for the fat percentage per voxel is proposed. Using a digital phantom with many PV voxels, we found that ratio values were not linearly related to PV fat content and that our method accurately described the histogram. In addition, the new method estimated the ground truth within +1.6% vs. +43% for a naive approach where we simply threshold the ratio image. On the six genetically obese rat data sets, the MAP estimate gave total fat volumes of 279 +/- 45mL, values approx 21% smaller than those from the naive approach, principally due to the non-linear PV effect. We conclude that our algorithm can increase the accuracy of fat volume quantification even in regions having many PV voxels, e.g. ectopic fat depots.

6914-28, Session 5

A variational method for automatic localization of the most pathological ROI in the knee cartilage

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Osteoarthritis (OA) is a degenerative joint disease characterized by degradation of the articular cartilage, and is a major cause of disability. At present, there is no cure for OA and currently available treatments are directed towards relief of symptoms. Recently it was shown that cartilage homogeneity visualized by MRI and representing the biochemical changes undergoing in the cartilage is a potential marker for early detection of knee OA. In this paper based on homogeneity we present an automatic technique, embedded in a variational framework, for localization of a region of interest in the knee cartilage that best indicates where the pathology of the disease is dominant. The technique is evaluated on 283 knee MR scans. We show that OA affects certain areas of the cartilage more distinctly, and these are more towards the peripheral region of the cartilage. We propose that this region in the cartilage corresponds anatomically to the area covered by the meniscus in healthy subjects. This finding may provide valuable clues in the pathology and the etiology of OA and thereby may improve treatment efficacy. Moreover our method is generic and may be applied to other organs as well.

6914-29, Session 5

Motion blur detection in radiographs

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Image blur introduced by patient motion is one of the most frequently cited reasons for image rejection in radiographic diagnostic imaging. The goal of the present work is to provide an automated method for the detection of anatomical motion blur in digital radiographic images to help improve image quality and facilitate workflow in the imaging department. To achieve this goal, the method first reorients the image to a predetermined hanging protocol. Then it locates the primary anatomy in the radiograph and extracts the most indicative region for motion blur detection, i.e., the region of interest (ROI). The third step computes a set of motion-sensitive features from the extracted ROI. Finally, the extracted features are evaluated using a classifier that has been trained to detect motion blur. Preliminary experiments show promising results with 87% detection sensitivity, 72% specificity, and an overall accuracy of 81%.

6914-30, Session 6

Hybrid physics-based elastic image registration using approximating splines

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We introduce a new hybrid physics-based approach for elastic image registration using approximating splines. As underlying deformation model we employ Gaussian elastic body splines (GEBS), which are analytic solutions of the Navier equation under Gaussian forces and are

represented by matrix-valued basis functions. Our approach is formulated as an energy-minimizing functional that incorporates both landmark and intensity information as well as a regularization based on GEBS. We also include landmark localization uncertainties represented by weight matrices. Since the approach is based on a physical deformation model, cross-effects in elastic deformations can be handled. We demonstrate the applicability of our scheme based on MR images of the human brain. It turns out that the new scheme is superior to a pure landmark-based as well as a pure intensity-based scheme.

6914-31, Session 6

On the development of a new nonrigid image registration using deformation-based grid generation

C. Hsieh, H. Chen, T. Lin, H. Hsiao, M. Chu, G. Liao, The Univ. of Texas at Arlington; H. Zhong, Virginia Commonwealth Univ.

In this paper, we present the latest results of the development of a novel non-rigid image registration method using a well-established mathematic work known as deformation based grid generation. Deformation based grid generation is able to generate a grid with desired grid point distribution which is free of grid folding. This is achieved by devising a positive monitor function describing the anticipated grid point density in the computational domain. Based on it, we have successfully developed a new non-rigid image registration method with many advantages. First of all, the functional to be optimized consists of only one term, the similarity term. Thus, no regularization functional is required in this method, not to mention the weight to balance the regularization functional and the similarity functional as commonly required in many non-rigid image registration methods. Nevertheless, the regularity (no mesh folding) of the resultant deformation is theoretically guaranteed. Secondly, since no regularization term is introduced in the functional to be optimized, the resultant deformation field is highly flexible that large deformation frequently experienced in inter-patient or image-atlas registration tasks can be recovered. Detailed description of the deformation based grid generation, a least square finite element (lsfem) solver for the underlying div-curl system, a fast div-curl solver approximating the lsfem solution using inverse filtering, along with several 2D and 3D experimental results will be presented in the paper.

6914-32, Session 6

A novel framework for multimodal intensity-based similarity measures based on internal similarity

G. P. Penney, King's College London (United Kingdom); L. D. Griffin, Univ. College London (United Kingdom); A. P. King, King's College London (United Kingdom); D. J. Hawkes, Univ. College London (United Kingdom)

We present a novel framework for describing intensity-based multimodal similarity measures which is based around a concept of internal similarity. Firstly the locations of multiple regions or patches which are "similar" to each other are identified within an image. Then if we examine the second image in the same locations, and this image is registered to the first image, we should find that the patches in these locations are also 'similar', though the actual features in the patches when compared between the images could be very different. We propose that a measure based on this principle could be used as an inter-modality similarity measure because, as the two images become increasingly misregistered then the patches within the second image should become increasingly dissimilar. Our framework results in an inter-modal similarity measure by using two intra-modal similarity measures applied separately within each image.

In this paper we describe how popular multi-modal similarity measures such as mutual information can be described within this framework. The framework has the potential to form novel similarity measures which can register using regional information, rather than individual pixel/voxel intensities. An example similarity measure is produced which is able to register images where a boundary is represented by a step in one image, but as a line in the other image. Experiments are carried out on CT and ultrasound images of bone which show that the new similarity measure can achieve accurate registrations. Standard intensity-based measures such as mutual information do not perform well on such images.

6914-33, Session 6

Volume preserving image registration via a post-processing stage

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In this paper a method to remove the divergence from a vector field is presented. When applied to a displacement field, this will remove all local compression and expansion. The method can be used as a post-processing step for (unconstrained) registered images, when volume changes in the deformation field are undesired. The method involves solving Poisson's equation for a large system. Algorithms to solve such systems include Fourier analysis and Cyclic Reduction. These solvers are vastly applied in the field of fluid dynamics, to compensate for numerical errors in calculated velocity fields. The application to medical image registration as described in this paper, has to our knowledge not been done before. To show the effect of the method, it is applied to the registration of both synthetic data and dynamic MR series of the liver. The results show that the divergence in the displacement field can be reduced by a factor of 10-1000 and that the accuracy of the registration increases.

6914-34, Session 6

Improved CT and MR image registration with the introduction of a dual-modality contrast agent: performance assessment using quantitative and information theoretic methods

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The ability of computed tomography (CT) and magnetic resonance (MR) imaging to visualize and discriminate between normal and diseased tissues is improved with contrast agents, which are designed to differentially accumulate in tissues and modify their inherent imaging signal. Conventional contrast agents are limited to a single modality and require fast acquisitions due to rapid clearance following injection. Encapsulation of iohexol and gadoteridol within a nano-engineered liposome has been achieved and can increase their in vivo half-life to several days. We hypothesize that the persistence of this contrast agent in vivo, and the simultaneous co-localized contrast enhancement across modalities will improve longitudinal image registration. This work investigates the in vivo registration performance of the dual-modality contrast agent under realistic conditions. Previous characterizations of single-modality contrast agents were limited to qualitative inspections of signal intensity enhancement. We present quantitative, information theoretic methods for assessing image registration performance. The effect of increased localized contrast upon the mutual information of the MR and CT image sets was shown to increase post-injection. Images registered post-injection had a decreased registration error compared with pre-contrast images. Performance was maintained over extended time frames, contrast agent concentrations, and with decreased field-of-view. This characterization allows optimization of the contrast agent against desired performance for a given imaging task. The ability to perform robust longitudinal image registration is essential for pre-clinical investigations of tumor development, monitoring of therapy response, and therapy guidance over multiple fractions where registration of online cone-beam CT to planning CT and MR is necessary.

6914-35, Session 6

Conditional statistical model building

M. F. Hansen, M. S. Hansen, R. D. Larsen, Danmarks Tekniske Univ. (Denmark)

We present a new statistical deformation model suited for parameterized grids with different resolutions. Our method models the covariances between multiple grid levels explicitly, and allows for very efficient fitting of the model to data on multiple scales. The model is validated on a data set consisting of 585 annotated MR images of Corpus Callosum. One fifth of the data set was used as a training set, which was non-rigidly registered to each other without a shape prior. From the non-rigidly

registered training set a shape prior was constructed by performing PCA on each grid level and using the results to construct a conditional shape model, conditioning the finer parameters with the coarser grid levels. The remaining shapes were registered with the constructed shape prior. The dice measures for the registration without prior and the registration with a prior were 0.875 +- 0.042 and 0.8615 +- 0:051, respectively.

6914-36, Session 7

Nonrigid registration of carotid ultrasound and MR images using a 'twisting and bending' model

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Atherosclerosis at the carotid bifurcation resulting in cerebral emboli is a major cause of ischemic stroke. Most strokes associated with carotid atherosclerosis can be prevented by lifestyle/dietary changes and pharmacological treatments if identified early by monitoring carotid plaque changes. Plaque composition information from magnetic resonance (MR) carotid images and dynamic characteristics information from 3D ultrasound (US) are necessary for developing and validating US imaging tools to identify vulnerable carotid plaques. Combining these images requires nonrigid registration to correct the non-linear misalignments caused by relative twisting and bending in the neck due to different head positions during the two image acquisitions sessions.

The high degree of freedom and large number of parameters associated with existing nonrigid image registration methods causes several problems including unnatural plaque morphology alteration, computational complexity, and low reliability. Our approach was to model the normal movement of the neck using a "twisting and bending model" with only six parameters for nonrigid registration. We evaluated our registration technique using intra-subject in-vivo 3D US and 3D MR carotid images acquired on the same day. We calculated the Mean Registration Error (MRE) between the segmented vessel surfaces in the target image and the registered image using a distance-based error metric after applying our "twisting bending model" based nonrigid registration algorithm. We achieved an average registration error of 1.33+/-0.41mm using our nonrigid registration technique. Visual inspection of segmented vessel surfaces also showed a substantial improvement of alignment with our non-rigid registration technique.

6914-37, Session 7

Deformable registration of 3D vessel structures to a single projection image

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Alignment of angiographic preoperative 3D scans to intraoperative 2D projections is an important issue for 3D depth perception and navigation during interventions. Currently, in a setting where only one 2D projection is available, methods employing a rigid transformation model present the state of the art for this problem. In this work, we introduce a method capable of deformably registering 3D vessel structures to a respective single projection of the scene. Our approach addresses the inherent ill-posedness of the problem by incorporating a priori knowledge about the vessel structures into the formulation. We minimize the distance between the 2D points and corresponding projected 3D points together with regularization terms encoding the properties of length preservation of vessel structures and smoothness of deformation. Thus, our method enables meaningful 3D deformations of 3D vessel structures based on a single 2D projection of the same structure. To the best of our knowledge this is the first time that this problem is addressed in the field of medical image processing. We demonstrate the performance and accuracy of the proposed method by quantitative tests on synthetic examples as well as real angiographic scenes.

6914-38, Session 7

3D inter-subject cardiac registration using 4D information

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In this paper we present a new approach for the registration of cardiac 4D image sequences of different subjects, where we assume that a temporal association between the sequences is given. Moreover, we allow for a selected pair of associated points in time of both sequences, which we call the bridging points in time, the use of additional information such as the semi-automatic segmentation of the investigated structure. We establish the 3D inter-subject registration for all other pairs of points in time exploiting the inter-subject registration for the bridging pair of points in time, the intra-subject motion calculation in both sequences with respect to the bridging pair and the concatenation of the obtained transformations. We formulate a cost functional integrating the similarity measures comparing the images of the two bridging pairs of points in time and of the current pair of points in time, respectively. We evaluated our algorithm on 8 healthy volunteers leading to 28 inter-subject combinations and we study the influence of the components on the whole procedure. The approach based on the bridging pairs outperforms a direct 3D registration of corresponding points in time, in particular in the right ventricle we gain up to 33% in registration accuracy. Here, the results improve stepwise by integrating, firstly, information from the current pair of points in time and secondly, from a second bridging point in time. Our results also show a leverage effect of regularization during intra-sequence registration and direct registration in the bridging point on the gain in registration accuracy with respect to the comparable bridging point registration process. In mean, the latter amounts to 17% compared to a sum of less than 1% gain obtained for the former registration processes.

6914-39, Session 7

Level set segmentation of the heart from 4D phase contrast MRI

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Blood flow properties in the heart can be examined non invasively by means of Phase Contrast MRI (PC MRI), an imaging technique that provides not only morphology images but also velocity information. We present a novel feature combination for level set segmentation of the heart's cavities in PC MRI data. The challenge in performing the segmentation task successfully in this context is first of all the bad image quality, as compared to classical MRI. As generally in heart segmentation, the intra and inter subject variability of the heart has to be coped with as well. The central idea of our approach is to integrate a set of essentially differing sources of information into the segmentation process to make it capable of handling qualitatively bad and highly varying data. Our system is the first to concurrently incorporate a flow measure as well as a priori shape knowledge into a level set framework in addition to the commonly used edge and curvature information. The flow measure is derived from PC MRI velocity data. As shape knowledge we use a 3D shape of the respective cavity. We validated our system design by a series of qualitative performance tests. The combined use of shape knowledge and a flow measure increases segmentation quality compared to results obtained by using only one of those features. A first clinical study was performed on two 4D datasets, from which we segmented the left ventricle and atrium. The segmentation results were examined by an expert and judged suitable for use in clinical practice.

6914-40, Session 7

Segmentation of myocardial perfusion MR sequences with multiband active appearance models driven by spatial and temporal features

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This work describes a knowledge driven segmentation method for cardiac MR perfusion sequences. We build upon previous work on multi-band AAMs to integrate into the segmentation both spatial priors about myocardial shape as well as temporal priors about characteristic perfusion patterns. We also investigate which (combination of) spatial and temporal features yield the best segmentation performance. In a quantitative evaluation on 19 perfusion studies, we found that that:

1)the MIP+orientation map feature combination yields the best performance in terms of convergence rate (lowest number of failures), lowest point-to-curve errors and lowest area errors; this feature combination clearly outperforms the other tested feature combinations

2)the inclusion of multiple temporal features does not necessarily improve the segmentation results. This may be due to a certain redundancy between the MIP feature and other temporal features, but also due to the noisy nature of features such as time-to-peak, which may actually deteriorate the segmentation performance.

3)the multi-band AAM driven by MIP+orientation map features yields a point-to-curve error of less than one pixel, which is in the same order of magnitude as inter observer variation in manual cardiac MR contour drawing; therefore, the achieved results can be regarded as adequate for clinical application.

6914-41, Session 7

Four-chamber heart modeling and automatic segmentation for 3D cardiac CT volumes

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Multi-chamber heart segmentation is a prerequisite for quantification of the cardiac function. In this paper, we propose an automatic heart chamber segmentation system. There are two closely related tasks to develop such a system: heart modeling and automatic model fitting to an unseen volume. The heart is a complicated non-rigid organ with four chambers and several major vessel trunks attached. A flexible and accurate model is necessary to capture the heart chamber shape at an appropriate level of details. In our four-chamber surface mesh model, the following two factors are considered and traded-off: 1) accuracy in anatomy and 2) easiness for both annotation and automatic detection. Important landmarks such as valves and cusp points on the LV/RV septum are explicitly represented in our model. These landmarks can be detected reliably to guide the automatic model fitting process. Since the statistical shape model will be used to enforce priori shape constraints in the model fitting procedure, we propose two mechanisms, the rotation-axis based and parallel-slice based resampling methods, to establish the mesh point correspondence during mesh editing.

Using this model, we develop an efficient and robust approach for automatic heart chamber segmentation in 3D computed tomography (CT) volumes. Our approach is based on recent advances in learning discriminative object models and we exploit a large database of annotated CT volumes. We formulate the segmentation as a two-step learning problem: anatomical structure localization and boundary delineation. A novel algorithm, Marginal Space Learning (MSL), is introduced to solve the 9-dimensional similarity transformation search problem for localizing the heart chambers. MSL reduces the number of testing hypotheses by about six orders of magnitude. After determining the pose of the heart chambers, we estimate the 3D shape through learning-based boundary delineation. Extensive experiments demonstrate the efficiency and

robustness of the proposed approach, comparing favorably to the state-of-the-art. This is the first study reporting stable results on a large cardiac CT dataset with 323 volumes. In addition, we achieve a speed of less than eight seconds for automatic segmentation of all four chambers.

6914-42, Session 7

(ST) Segmentation of the heart and major vascular structures in cardiovascular CT images

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Segmentation of organs in medical images can be successfully performed with shape-constrained deformable models. A surface mesh is attracted to detected image boundaries by an external energy, while an internal energy keeps the mesh similar to expected shapes. Complex organs like the heart with its four chambers can be automatically segmented using a suitable shape variability model based on piecewise affine degrees of freedom.

In this paper, we extend the approach to also segment highly variable vascular structures. We introduce a dedicated framework to adapt an extended mesh model to freely bending vessels. This is achieved by subdividing each vessel into (short) tube-shaped segments ("tubelets"). These are assigned to individual similarity transformations for local orientation and scaling. Proper adaptation is achieved by a progressive scheme adapting distal vessel parts to the image only after proximal neighbor tubelets have already converged. In addition, each newly activated tubelet inherits the local orientation and scale of the preceding one.

To arrive at a joint segmentation of chambers and vasculature, we extended a previous model comprising endocardial surfaces of the four chambers, the left ventricular epicardium, and a pulmonary artery trunk. Newly added are the ascending and descending aorta, superior and inferior vena cava, coronary sinus, and four pulmonary veins. These vessels are organized as stacks of triangulated rings. This mesh configuration is most suitable to define tubelet segments. Validation experiments show that surface-to-surface errors below 1mm can be achieved.

6914-135, Session 7

(ST) AdaBoost classification for model-based segmentation of the outer wall of the common carotid artery in CTA

D. Vukadinovic, T. van Walsum, R. Manniesing, A. van der Lugt, T. T. de Weert, W. J. Niessen, Univ. Medisch Ctr. Rotterdam (Netherlands)

A novel 2D slice based automatic method for model based segmentation of the outer vessel wall of the common carotid artery in CTA data set is introduced. The method utilizes a lumen segmentation and AdaBoost, a fast and robust machine learning algorithm, to initially classify (mark) regions outside and inside the vessel wall using the distance from the lumen and intensity profiles sampled radially from the gravity center of the lumen. A similar method using the distance from the lumen and the image intensity as features is used to classify calcium regions. Subsequently, an ellipse shaped deformable model is fitted to the classification result. The method has achieved smaller detection error than the inter observer variability, and the method is robust against variation of the training data sets.

6914-65, Poster Session

A machine learning approach for body part recognition based on CT images

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Body part recognition based on CT slice images is very important for many applications in CAD systems and PACS. In this paper, we propose a novel approach that can recognize which body part a slice image belongs to robustly. We focus on how to effectively express and use the

unique statistical information of the correlation between CT value and position information of each body part. We apply a machine learning method AdaBoost to express and use the statistical information. Our approach consists of a training process and a recognition process. In the training process, we define the whole body by specific classes to ensure that slice images in the same class have high similarity. Then, we normalize sizes and rotations of training images in each class. Finally, we use AdaBoost to train classifiers to classify one specific class from the others. After the training process, each class has its own classifiers. In the recognition process, given a series of CT images, we calculate the scores of all classes for each slice image based on the classifiers obtained in the training process. Then, based on the scores of each slice and continuity character, we use DP (Dynamic Programming) to eliminate false recognition results. Experimental results on 440 unknown series including lesions show that our approach has a high recognition rate and high robustness.

6914-66, Poster Session

Personal identification based on blood vessels of retinal fundus images

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Biometric technique has been implemented instead of conventional identification methods such as password in computer, automatic teller machine (ATM), and entrance and exit management system. We propose a personal identification (PI) system using color retinal fundus images which are unique to each individual. The proposed procedure for identification is based on comparison of an input fundus image with reference fundus images in the database. In the first step, compensation of positional displacement is performed. The compensation includes translational and rotational movement. The PI is based on the measure of similarity between blood vessel images generated from the input and reference images. The similarity measure is defined as the cross-correlation coefficient calculated from the pixel values. When the similarity is greater than a predetermined threshold, the input image is identified. This means both the input and the reference images are associated to the same person. Four hundred sixty-two fundus images including forty-one same-person's image pairs were used for the estimation of the proposed technique. The false rejection rate and the false acceptance rate were $9.9 \cdot 10^{-5}\%$ and $4.3 \cdot 10^{-5}\%$, respectively. The results indicate that the proposed method has a higher performance than other biometrics except for DNA. To be used for practical application in the public, the device which can take retinal fundus images easily is needed. The proposed method is applied to not only the PI but also the system which warns about misfiling of fundus images in medical facilities.

6914-67, Poster Session

Efficient classifier generation and weighted voting for atlas-based segmentation: two small steps faster and closer to the Combination Oracle

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Atlas-based segmentation has proven effective in multiple applications. Usually, several reference images are combined to create a representative average atlas image. Alternatively, a number of independent atlas images can be used, from which multiple segmentations of the image of interest are derived and later combined. One of the major drawbacks of this approach is the required number of registrations and the consequent large computation times. To address this problem, we introduce "One Registration, Multiple Segmentations" (ORMS), a procedure to obtain multiple segmentations with a single online registration. This can be achieved by pre-computing intermediate transformations from the initial atlas images to an average image. We show that, compared to the usual approach, our method reduces time considerably with little or no loss in accuracy.

On the other hand, optimum combination of these segmentations remains an unresolved problem. Different approaches have been adopted, but they are all far from the upper bound for any combination strategy. This

is given by the Combination Oracle, which classifies a voxel correctly if any individual segmentation coincides with the ground truth. We present here a novel combination approach, based on weighting the different segmentations according to the mutual information between the test image and the atlas image after registration. We compare this method with other existing combination strategies using microscopic MR images of mouse brains, achieving statistically significant improvement in segmentation accuracy.

6914-68, Poster Session

Matching of structural prototypes for content-based medical image retrieval

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The relevant contents of medical images can often be described as a composition of objects with distinct relationships. Each object is represented as a graph node with regional features as node attributes e.g. centroid coordinates. The relations between objects are represented as graph edges with annotated relational features, e.g. relative size. For a given setting, e.g. a hand radiograph, a generalization of the relevant objects, e.g. hand bones, can be obtained by the statistical distributions of the attributes. These yield a structural prototype graph which consists of one node per relevant object. In contrast to the aforementioned graph, the mean and standard deviation of each regional or relational feature are used to annotate the prototype nodes or edges, respectively. The prototype graph can then be used to identify the generalized objects in new images. As new image content is represented by hierarchical attributed region adjacency graphs (HARAGs) which are obtained by region-growing, the task of object identification corresponds to the problem of inexact graph matching between the small prototypes and HARAGs. For this purpose, five approaches are evaluated in an example application of bone-identification in 96 hand-radiographs: Nested Earth Mover's Distance, Graph Edit Distance, a Hopfield neural net, Pott's Mean Field Annealing and Similarity Flooding. The discriminative power of 34 regional and 12 relational features for each object is judged by sequential forward selection. The structural prototypes improve recall by up to 17% in comparison to the approach without relational information.

6914-69, Poster Session

An ANOVA-based study for liver texture invariance using co-occurrence matrices

R. Susomboon, D. S. Raicu, J. D. Furst, DePaul Univ.; T. B. Johnson, Northwestern Univ. Medical School

Texture-based models are intensively used in medical image processing to quantify the homogeneity and consistency of soft tissues across different patients. Several research studies have shown that the co-occurrence texture model and its Haralick descriptors can be successfully applied to capture the statistical properties of the soft tissues' patterns. Given that the calculation of the co-occurrence texture model is a computationally-intensive task, in this paper we investigate the usefulness of using all possible angles and all displacements for capturing the texture properties of an organ of interest, specifically, the liver. Based on the Analysis of Variance (ANOVA) technique and multiple pair-wise comparisons, we found that using only the 'near' and 'far' displacements is enough to capture the spatial properties of the texture for the liver.

6914-70, Poster Session

Tissue classification using cluster features for lesion detection in digital cervigrams

X. Huang, W. Wang, Lehigh Univ.; Z. Xue, L. R. Long, S. K. Antani, National Library of Medicine; J. Jeronimo, National Cancer Institute

In this paper, we propose a new method for automated detection and segmentation of different tissue types in cervigrams by using mean-shift clustering and support vector machines (SVM) classification on cluster features. We specifically target digitized uterine cervix images in a NCI/NLM archive of 60,000 cervigrams. Due to large variations in image appearance in the archive, color and texture features of a

tissue type in one image often overlap with that of a different tissue type in another image. This makes reliable tissue segmentation in a large number of images a very challenging problem. In this paper, we propose the use of powerful machine learning techniques such as Support Vector Machines (SVM) to learn, from a database with ground truth annotations, critical visual signs that correlate with important tissue types and to use the learned classifier for tissue segmentation in unseen images. In our experiments, SVM performs significantly better than un-supervised methods such as Gaussian Mixture clustering, but it does not scale very well to large training sets and does not always guarantee improved performance given more training data. To address this problem, we combine SVM and clustering so that the features we extracted for classification are features of clusters returned by the mean-shift clustering algorithm. Compared to classification using pixel-wise features, classification by cluster features greatly reduces the dimensionality of the problem, thus it is much more efficient while producing results with comparable accuracy.

6914-71, Poster Session

An image reconstruction method based on machine learning for dual-energy subtraction radiography

Y. Kitamura, M. Yamada, W. Ito, FUJIFILM Corp. (Japan)

We propose a novel image reconstruction method for dual-energy subtraction radiography. When one of the dual-energy images is obtained at a low dose, a bone image generated with dual-energy subtraction technique is degraded due to noise especially at high frequency. Our method restores the degraded bone image using a regression filter trained by support vector regression. The regression filter is trained based on the input of degraded bone images against output of corresponding noiseless bone images. Due to strong correlation between high frequency signal and low frequency signal of bone, high frequency signal can be accurately generated based on the observed low frequency signal. However learning such correlation directly is generally difficult. Therefore our technique firstly generates a "2-class bone model" that explicitly expresses a bone structure that should be restored. Then while utilizing this model, regression filtering is applied. The accuracy of regression learning is largely improved with this approach. Verification test shows that our method works well: A soft-tissue image obtained by subtracting a restored bone image from a standard radiograph reveals that rib structure has been thoroughly removed and sharpness of soft-tissue signal is improved including fine vessels. In conclusion, the proposed method can provide superior dose reduction as well as better reflection of anatomical structures of an object in an image. With these advantages, the proposed method can offer high clinical value for the detection of lung lesions.

6914-72, Poster Session

Development of adaptive noise reduction filter algorithm for pediatric body images in a multidetector CT

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Recently, several kinds of post-processing image filters which reduce the noise of computed tomography (CT) images have been proposed. However, these image filters are mostly for adults. Because these are not very effective in small (< 20 cm) display fields of view (FOV), we cannot use them for pediatric body images (e.g., premature babies and infant children). We have developed a new adaptive noise reduction filter algorithm for pediatric body CT images. This algorithm is based on a 3D post-processing in which the output pixel values are calculated by nonlinear interpolation and adaptive weighting summation in z-directions on original volumetric-data-sets. This algorithm does not need the in-plane (axial plane) processing, so the spatial resolution does not change. From the phantom studies, our algorithm could reduce SD up to 40% without affecting the spatial resolution of in-plane and z-axis, and improved the CNR up to 30%. This newly developed filter algorithm will be useful for the diagnosis and radiation dose reduction of the pediatric body CT images.

6914-74, Poster Session

Retinal vessel enhancement based on directional field

J. Chen, J. Tian, Institute of Automation (China)

Motivated by the goal of improving detection of micro-vessels with low contrast, a new technique based on directional field is presented for enhancing vessels in retinal image. This technique consists of three steps: Estimation of directional field, enhancement and normalization, and Gabor filtering. We will make enhancement along the vascular direction and normalize the brightness of image in a single step. After estimating the DF, the mean and variance values in a local neighborhood were calculated pixel-by-pixel, accordingly normalize and enhance the local neighborhood. In order to eliminate the artificial boundary between two adjacent areas, an anisotropic Gaussian kernel was introduced to weight the enhancement. The proposed method can obviously increase the contrast of retinal vessels. 20 retinal images were tested in our experiments, and the results demonstrate a effective vessel enhancement algorithm.

6914-75, Poster Session

Fast multiscale vessel enhancement

D. H. Ye, D. Kwon, Seoul National Univ. (South Korea); I. D. Yun, Hankuk Univ. of Foreign Studies (South Korea); S. U. Lee, Seoul National Univ. (South Korea)

This paper describes a fast multi-scale vessel enhancement filter in 3D medical images. For efficient review of the vascular information, clinicians need rendering the 3D vascular information as a 2D image. Although the maximum intensity projection (MIP) is a useful and widely used technique for visualizing 2D images from the 3D vascular data, the MIP algorithm reduces the conspicuousness for small and faint vessels owing to the overlap of non-vascular structures. To overcome this invisibility, researchers have examined the multi-scale vessel enhancement filter which is based on a combination of the eigenvalues of the 3D Hessian matrix. This multi-scale vessel enhancement filter produces higher contrast. However, it is time-consuming due to large volume of data and complex 3D convolution. For fast vessel enhancement, we propose a novel multi-scale vessel enhancement filter. It approximates previously proposed multi-scale vessel enhancement filter with comparable performance, yet can be computed ten times faster. This is achieved by relying on integral images for 3D convolution; by approximating Gaussian to box kernel optimized layer by layer. Each layer of box kernel approximates 2D Gaussian second order derivative by dividing it into three rectangular regions whose sum is integer. Box kernel is a pile of these approximations which are normalized by Frobenius norm. Its size fits to vessel width in order to achieve better visualization of the small vessel. We provide experimental results on synthetic and clinical data.

6914-76, Poster Session

Adaptive kernel algorithm for FPGA-based speckle reduction

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Image quality from ultrasound and optical coherence tomography (OCT) is degraded by speckle patterns, which limit the detection of small features and cause a loss of image contrast. To reduce speckle patterns, a novel adaptive kernel algorithm suitable for log-compressed OCT and ultrasound images is presented. This algorithm combines region growing with a stick based approach. For each direction from the center of a square window to its border, a stick length is selected depending on a homogeneity criterion. Such a set of sticks forms an individual filter kernel for each image pixel. The current kernel size is observed to detect outliers in speckle. If the kernel size drops below a threshold, an outlier is assumed and the filter output is corrected by using a median filter in a second filtering stage. A new homogeneity model is presented that incorporates two existing models and can be fit to actual image statistics. Thresholds for stick selection are estimated considering two-dimensional speckle shape by directional image statistics. In addition, methods to compute filter parameters for different speckle correlation lengths and imaging systems are presented. An FPGA real-time implementation

is proposed and discussed. Measured and simulated speckle images are processed and results compared to existing FPGA based speckle reduction methods. The proposed algorithm provides good results for various kinds of medical speckle images. The flexible nature of the proposed kernel guarantees suitability for strongly correlated as well as for uncorrelated speckle patterns.

6914-77, Poster Session

Characterizing regional lymph nodes from endoscopic ultrasound images

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Esophageal ultrasound (EUS) is particularly useful for isolating lymph nodes in the N-staging of esophageal cancer, a disease with very poor overall prognosis. Although EUS is relatively low-cost and real time, and it provides valuable information to the clinician, its usefulness to less trained “users” including opportunities for computer-aided diagnosis is still limited due to the strong presence of spatially correlated interference noise called speckles. To this end, in this paper, we present a technique for enhancing lymph nodes in EUS images by first reducing the spatial correlation of the specular noise and then using a modified structured tensor-based anisotropic filter to complete the speckle reduction process. We report on the extent of automatic processing possible, after the speckle reduction process has taken place. Also, we show the limitations of the process by extracting relevant lymph node features from the despeckled images. When tested on five representative image types, we found the despeckling process to greatly reduce the specularity of the original EUS images, therefore proving very useful for visualization purposes. But it still requires additional work for the complete automation of the lymph node characterizing process.

6914-78, Poster Session

Clinical validation and performance evaluation of enhancement methods acquired from interventional c-arm x-ray

L. Wei, D. Kumar, A. Khemka, Eigen; R. Turlapati, Univ. of Wisconsin; J. S. Suri, Eigen

Digital Subtraction Angiography (DSA) is a well-established powerful modality for the visualization of stenosis and blood vessels in general. This paper presents two novel approaches which address image quality. In the first approach we combine anisotropic diffusion with nonlinear normalization. The second approach consists of an introduction of a regularization strategy followed by a classification procedure to improve the enhancement. The performances of two strategies are evaluated based on a database of 73 subjects using SNR, CNR and Tenengrad's metric. Compared with conventional DSA, Eigen's diffusion embedded nonlinear enhancement strategies can improve image quality 95.25% in terms of SNR. The regularization embedded linear enhancement strategy can also improve SNR 51.46% compared with conventional DSA. Similar results are obtained by CNR and Tenengrad's metric measurements. We validate two algorithms using GE's PMMA phantoms. Our system runs on a PC-based workstation using C++ in Windows environment.

6914-79, Poster Session

Dermoscopic hair disocclusion using inpainting

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Inpainting, a technique originally used to restore film and photographs, is used to disocclude hair from dermoscopic images of skin lesions. The technique is compared to the conventional software DullRazor, which uses linear interpolation to perform disocclusion. Inpainting is found to perform on average 32.7% better than DullRazor's linear interpolation, and is more stable under heavy occlusion. The results are also compared to published results from two other alternatives: AR model signal extrapolation and BL signal extrapolation.

6914-80, Poster Session

Denoising of brain MRI using modified PDE based on pixel similarity

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Although various image denoising methods such as PDE-based algorithms have made remarkable progress in the past years, the trade-off between noise reduction and edge preservation is still an interesting and difficult problem in the field of image processing and analysis. A new image denoising algorithm, using a modified PDE model based on pixel similarity, is proposed to deal with the problem. The pixel similarity measures the similarity between two pixels. Then the degree of consistency of the center pixel with its surrounding pixels can be calculated. Informally, if a pixel is not consistent enough with its surrounding pixels, it can be considered as a noise, but an extremely strong inconsistency suggests an edge. The pixel similarity is a probability measure; its values are between 0 and 1. According to the consistency of the pixel with its surrounding pixels, a diffusion control factor can be determined by a simple thresholding rule. The factor is combined into the primary partial differential equation as an adjusting factor for controlling the speed of diffusion for different type of pixels. An evaluation of the proposed algorithm on the simulated brain MRI is carried out. Experimental results showed that the new algorithm can smooth the MRI images better while keeping the edges better and achieve higher peak signal to noise ratio (PSNR) comparing with the existing denoising algorithms.

6914-81, Poster Session

Pyramidal flux in an anisotropic diffusion scheme for enhancing structures in 3D images

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Pyramid based methods in image processing provide a framework for accelerating the propagation of information over large spatial domains, increasing the efficiency for large data set applications. Combined with an anisotropic diffusion scheme tailored to preserve the boundaries at each level, an efficient way for enhancing large structures in 3D images is presented. In our approach, the partial differential equation defining the evolution of the intensity in the image is solved in an explicit scheme at multiple resolutions in an ascending-descending cycle. Intensity ‘flux’ between distant voxels is allowed, while preserving borders relative to the scale. Experiments were performed with phantoms and real data from 3D Transrectal Ultrasound Imaging. By using two scales, the computation time is reduced by 87% as compared to a single scale for enhancing large structures such as the prostate. The boundaries are preserved as compared with manually outlined edges.

6914-82, Poster Session

Informative frame detection from wireless capsule video endoscopic images

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Wireless capsule endoscopy is a new clinical technology permitting the visualization of the small bowel, the most difficult segment of the digestive tract. The major drawback of this technology is the high amount of time for video diagnosis. In this study, we propose a method for informative frame detection by isolating useless frames that are substantially covered by turbid fluids or their contamination with other materials, e.g., faecal, semi-processed or unabsorbed foods etc. Such materials and fluids present a wide range of colors, from brown to yellow, and/or bubble-like texture patterns. The detection scheme therefore consists of two stages: highly contaminated non-bubbled (HCN) frame detection and significantly bubbled (SB) frame detection. Local color moments in the Ohta color space are used to characterize HCN frames, which are isolated by the Support Vector Machine (SVM) classifier in stage-1. The rest of the frames go to the stage-2, where

Laguerre gauss Circular Harmonic Functions (LG-CHFs) extract the characteristics of the bubble-structures in a multi-resolution framework. An automatic segmentation method is designed to extract the bubbled regions based on local absolute energies of the CHF responses, derived from the grayscale version of the original color image. Final detection of the informative frames is obtained by using threshold operation on the extracted regions. An experiment with 20,558 frames from the three videos shows the excellent average detection accuracy (96.75%) by the proposed method, when compared with the Gabor based- (74.29%) and discrete wavelet based features (62.21%).

6914-83, Poster Session

Automated motion correction based on target tracking for dynamic nuclear medicine studies

X. Cao, T. Tetrault, F. Fahey, T. Treves, Children's Hospital Boston

Nuclear medicine dynamic studies of kidneys, bladder and stomach are important tools in clinical diagnosis. Accurate generation of time-activity curves from organs and regions of interest (ROI) depends on the patient not moving for the duration of the study. This is not always possible since some dynamic studies may last several minutes to one hour. Motion correction using external point source is inconvenient and not accurate when motion results from breathing, organ motion or feeding rather than from body motion. Centroid-based motion correction assumes that activity distribution is only inside the organ (without background) and uniform, but this approach is impractical in most clinical studies. In this paper, we present a novel technique of motion correction that first tracks the organ of interest in a dynamic series then aligns the organ. The implementation algorithm for target tracking-based motion correction consists of image preprocessing, target detection, target positioning, motion estimation and prediction, tracking (new search region generation) and target alignment. The targeted organ is tracked from the first frame to the last one in the dynamic series to generate a moving trajectory of the organ. Motion correction is implemented by aligning all organ's ROIs in the series of image to the organ seen the first image. The proposed method of motion correction has been applied to several dynamic nuclear medicine studies including radionuclide cystography, dynamic renal scintigraphy, diuretic renography and gastric emptying.

6914-84, Poster Session

Multiobject tracking of human spermatozoa

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We propose a system for tracking of human spermatozoa in phase-contrast image sequences. Using a computer for examination of sperm is commonly referred to as computer-aided sperm analysis (CASA), and one of the main aims of a CASA system is to automatically assess sperm quality based on spermatozoa motility variables. In our case, the problem of assessing sperm quality is cast as a multi-object tracking problem, where the objects being tracked are the spermatozoa.

The system combines a particle filter and Kalman filters for robust motion estimation of the spermatozoa tracks. Further, the combinatorial aspect of assigning observations to labels in the particle filter is formulated as a linear assignment problem solved using the Hungarian algorithm on a rectangular cost matrix, making the algorithm able to handle missing/excessive observations. The costs are calculated using hidden Markov models that express the plausibility of an observation being the next position in the track history of the particles. Observations are extracted using a scale-space blob detector utilizing the fact that the spermatozoa appear as bright blobs in a phase-contrast microscope. The output of the system is the complete motion track of each of the spermatozoa. Based on these tracks, different CASA motility variables can be computed, for example curvilinear velocity or straight-line velocity.

The performance of the system is tested on three different phase-contrast image sequences of varying complexity, both by visual inspection and by measuring the mean squared error (MSE) between the estimated spermatozoa tracks and manually annotated tracks, showing good agreement.

6914-85, Poster Session

Tracking the motion of the hyoid bone in videofluoroscopic swallowing studies

P. M. Kellen, J. M. Reinhardt, The Univ. of Iowa; D. van Daele, The Univ. of Iowa Hospitals and Clinics

The number of people having difficulty swallowing, or dysphagia, has increased dramatically in recent years, especially in middle-aged and elderly patients. A common diagnostic procedure uses X-ray videofluoroscopy to image a subject swallowing a radio-opaque liquid. The motion pattern of the hyoid bone can be a key indicator of muscular dysfunction. Currently, the video-fluoroscopy sequences are analyzed by experts, but the motion of the hyoid bone and other anatomy is assessed qualitatively instead of quantitatively. We describe a semi-automatic hyoid bone tracking algorithm that can be used to measure the position of the hyoid bone in the video sequence. In addition, we present a method to automatically define a patient-centric coordinate system, based on the position and orientation of the spine, which is more tolerant of patient head and neck movement during the swallowing maneuver. Hyoid bone tracking begins with a user-defined boundary on one key frame and the algorithm then locates the hyoid center of mass on the remaining frames. The algorithm uses kinematics to predict the hyoid position on each frame based on the position, velocity, and acceleration of the hyoid in neighboring frames, and then uses template matching to find the exact position. The difference in accuracy between the algorithm and human observers was found to be about one pixel in a validation study using video data from ten subjects manually analyzed by two observers.

6914-86, Poster Session

Towards user-independent DTI quantification

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Quantification of diffusion tensor imaging (DTI) parameters has become an important role in the neuroimaging, neurosurgical and neurological community as a method to identify major white matter tracts afflicted by pathology or tracts at risk for a given surgical approach. We introduce a novel framework for a reliable and robust quantification of DTI parameters, which overcomes problems of existing techniques introduced by necessary user inputs. The key idea of our approach is a hybrid clustering method which allows for extracting a specific fiber bundle independently of other existing, anatomically different fibers. This cannot always be achieved by previous algorithms whose automatic detection of the number of clusters is sensitive to the whole number of fibers. Our technique determines the overall number of clusters iteratively within two steps. In the first step, we propose a eigenvalue thresholding technique to detect disjoint clusters of independent fiber bundles. In a second step, possible finer substructures based on our eigenvalue regression are determined within each bundle. Our experimental tests confirm that major white matter fiber tracts may be determined very robustly and can be quantified automatically along their mean curvature. A great advantage of our framework is its easy integration into existing quantification applications so that uncertainties can be reduced and higher intrarater- as well as interrater reliabilities can be achieved.

6914-87, Poster Session

An exploration of spatial similarities in temporal noise spectra in fMRI measurements

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In this paper, we describe a method to evaluate similarities in estimated temporal noise spectra of functional Magnetic Resonance Imaging (fMRI) time series. Accurate noise spectra are needed for reliable activation detection in fMRI. Since these spectra are a-priori unknown, they have to be estimated from the fMRI data. A noise model can be estimated for each voxel separately, but when noise spectra of neighboring voxels are (almost) equal, the power of the activation detection test can be improved by estimating the noise model from a set of neighboring voxels.

In this paper, we describe a method to evaluate the similarity of noise spectra of neighboring voxels and show some results of applying this method to a real fMRI dataset. The parameters of the model describing the voxel time series are estimated using a Maximum Likelihood (ML) estimator. The similarity of the ML estimated noise processes is assessed by the Model Error (ME), which is based on the Kullback Leibler divergence. Spatial correlations in the fMRI data reduce the ME between the noise spectra of (neighboring) voxels. This undesired effect is quantified by simulation experiments where spatial correlation is introduced. By plotting the ME as a function of distance between voxels, it is observed that the ME increases as a function of this distance. Additionally, by using the theoretical distribution of the ME, it is observed that neighboring voxels indeed have similar noise spectra and these neighbors can be used to improve the noise model estimate.

6914-89, Poster Session

White matter tractographies registration using Gaussian mixture modeling

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This paper proposes a novel and robust approach to the registration (matching) of intra-subject white matter (WM) fiber sets extracted from DT-MRI scans by Tractography. For each fiber, a feature space representation is obtained by appending the sequence of its 3D coordinates. Clustering by non-parametric adaptive mean shift provides a representative fiber for each cluster hereafter termed the fiber-mode (FM). For each FM, the parameters of a multivariate Gaussian are computed from its fiber population, leading to a mixture of Gaussians (MoG) for the whole fiber set. The number of Gaussians used for each set equals the number of FM representing it. The alignment of two fiber sets is then treated as the alignment between two MoGs, and is solved by maximizing the correlation ratio between them. Initial results are presented for real intrasubject fiber sets and synthetic transformations. Additional quantitative and qualitative intra subject results will be presented and discussed in the full paper.

6914-90, Poster Session

Tensor distribution function

A. D. Leow, S. Zhu, Univ. of California/Los Angeles

Diffusion weighted MR imaging is a powerful tool that can be employed to study white matter microstructure by examining the 3D displacement profile of water molecules in brain tissue. By applying diffusion-sensitizing gradients along a minimum of 6 directions, second-order tensors (represented by 3-by-3 positive definite matrices) can be computed to model dominant diffusion processes. However, it has been shown that conventional DTI is not sufficient to resolve more complicated white matter configurations, e.g. crossing fiber tracts. More recently, High Angular Resolution Diffusion Imaging (HARDI) seeks to address this issue by employing more than 6 gradient directions. To account for fiber crossing when analyzing HARDI data, several methodologies have been introduced. For example, q-ball imaging was proposed to approximate Orientation Diffusion Function (ODF). Similarly, the PAS method seeks to resolve the angular structure of displacement probability functions by using maximum entropy. Alternatively, deconvolution methods extract multiple fiber tracts by computing the Fiber Orientation Function. In this study, we introduce the Tensor Distribution Function (TDF), a probability function defined on the space of symmetric and positive definite matrices. Using least square fitting, we solve for the TDF that optimally describes the observed data. Here, fiber crossing is modelled as an ensemble of Gaussian diffusion processes with weights specified by the TDF. Once this optimal TDF is determined, ODF can easily be computed by analytic integration of the resulting displacement probability function. Moreover, principal fiber directions can also be directly derived from the TDF.

6914-91, Poster Session

Susceptibility correction for improved tractography using high field DT-EPI

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Visionlab (Belgium); A. Van der Linden, Bio Imaging Lab. (Belgium); J. Sijbers, Visionlab (Belgium)

Diffusion Tensor Magnetic Resonance Imaging (DTI) is a well known technique that can provide information about the neuronal fiber structure of the brains. However, for this technique, a large amount of data has to be acquired, so a high speed MRI acquisition technique is needed to obtain all this data within a reasonable time. Echo Planar Imaging (EPI) is a technique that provides the desired speed, but unfortunately, this advantage of speed is overshadowed by image artefacts, especially at high fields. EPI artefacts originate from susceptibility differences in adjacent tissues and correction techniques are required to obtain reliable images.

In this work, we optimized the fieldmap method by using a non linear least squares estimator for calculating the pixelshifts. This method is tested on simulated data and proves to be more robust against noise.

This new way of estimating the fieldmap will be demonstrated on a hardware phantom, which consists of parallel made of woven strands of Micro Dyneema fibers, tightly held together with heat shrinking tubes. Using a modified EPI-sequence, reference data was measured for the calculation of fieldmaps. This allowed us to reposition the pixels in order to obtain images with fewer distortions. The correction is applied on non-diffusion weighted images as well as on the diffusion weighted images and fiber tracking is performed on this corrected data.

6914-92, Poster Session

A Bayesian method with reparameterization for diffusion tensor imaging

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Diffusion tensor imaging (DTI) is a non-invasive method for quantifying the water molecular motion in biological tissues with a 3x3 symmetric positive-definite matrix, diffusion tensor. We clarify the non-identifiability of the standard parametric multi-compartment model. A new multi-tensor model with identifiable parameters for capturing diffusion behavior in crossing fiber bundles with different orientations has been proposed. A new Bayesian method with reparameterization of diffusion tensor has been developed for parameters estimation. By setting reasonable prior distribution and updating our beliefs with the measured diffusion-weighted data, we obtain the posterior distribution of diffusion tensor and variance of model noise in Basser's single tensor model and our multi-tensor model. And the new parametrization can ensure the positive-definiteness of the diffusion tensor. For application, Monte Carlo simulated data from three distinct DTI direction schemes have been analyzed with the Bayesian method. As a result, Chris Tench's 32-direction scheme has been selected for its optimal performance. In line with best practice, the multi-tensor model with automatic model selection has been applied to a health human brain data. For the region of interest containing one dominant fiber orientation, applying Bayesian estimation with the single tensor model attains the tensor-derived maps. High anisotropy diffusion flows and main diffusion directions can be shown clearly in the FA map and diffusion ellipsoid map. For another region containing crossing fiber bundles, we draw the joint ellipsoid map of single tensor model and multi-tensor model (two tensors) with setting threshold of Bayes factor for model selection.

6914-93, Poster Session

Automatic regional analysis of DTI properties in the developmental Macaque brain

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Many neuroimaging studies are applied to monkeys as pathologies and environmental exposures can be studied in well-controlled settings and environment. In this work, we present a framework for the use of an atlas based, fully automatic segmentation of brain tissues, lobar parcellations, subcortical structures and the regional extraction of

Diffusion Tensor Imaging (DTI) properties. We first built a structural atlas from training images by iterative, joint deformable registration into an unbiased average image. On this atlas, probabilistic tissue maps, a lobar parcellation and subcortical structures were determined. This information is applied to each subject's structural image via affine, followed by deformable registration. The affinely transformed atlas is employed for a joint T1 and T2 based tissue classification. The deformed parcellation regions mask the tissue segmentations to define the parcellation for white and gray matter separately. Each subject's structural image is then non-rigidly matched with its DTI image by normalized mutual information, b-spline based registration. The DTI property histograms were then computed using the probabilistic white matter information for each lobar parcellation.

We successfully built an average atlas using a developmental training datasets of 18 cases aged 16-34 months. Our framework was successfully applied to over 50 additional subjects in the age range of 9 - 70 months. The probabilistically weighted FA average in the corpus callosum region showed the largest increase over time in the observed age range. Most cortical regions show modest FA increase, whereas the cerebellum's FA values remained stable.

The individual methods used in this segmentation framework have been applied before, but their combination is novel, as is their application to macaque MRI data. Furthermore, this is the first study to date looking at the DTI properties of the developing macaque brain.

6914-94, Poster Session

Short basis functions for constant-variance interpolation

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An interpolation model is a necessary ingredient of intensity-based registration methods. The properties of such a model depend entirely on its basis function, which has been traditionally characterized by features such as its order of approximation and its support. However, as has been recently shown, these features are blind to the amount of registration bias created by the interpolation process alone; an additional requirement that has been named constant-variance interpolation is needed to remove this bias.

In this paper, we present a theoretical investigation of the role of the interpolation basis in a registration context. Contrarily to published analyses, ours is deterministic; it nevertheless leads to the same conclusion, which is that constant-variance interpolation is beneficial to image registration.

In addition, we propose a novel family of interpolation bases that can have any desired order of approximation while maintaining the constant-variance property. Our family includes every constant-variance basis we know of. It is described by an explicit formula that contains two free functional terms: an arbitrary 1-periodic binary function that takes values from $\{-1, 1\}$, and another arbitrary function that must satisfy the partition of unity. These degrees of freedom can be harnessed to build many family members for a given order of approximation and a fixed support. We provide the example of a symmetric basis with two orders of approximation that is supported over $[-3/2, 3/2]$; this support is one unit shorter than a basis of identical order that had been previously published.

6914-95, Poster Session

Efficient random access high resolution region-of-interest (ROI) image retrieval using backward coding of wavelet trees (BCWT)

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Efficient retrieval of high quality Regions-Of-Interest (ROI) from high resolution medical images is essential for reliable interpretation and accurate diagnosis. Random access to high quality ROI from coded bitstreams is becoming an essential feature in many still image compression applications, particularly in viewing diseased areas from large medical images. This feature is easier to implement in block based

codecs because of the inherent spatial independency of the code blocks. This independency implies that the decoding order of the blocks is unimportant as long as the position for each is properly identified. In contrast, wavelet-tree based codecs naturally use some interdependency that exploits the "decaying spectrum" model of the wavelet coefficients. Thus one must keep track of the decoding order from level to level with such codecs. We have developed an innovative image multi-rate subband coding scheme using Backward Coding Of Wavelet Trees (BCWT) which is fast, memory efficient, and resolution scalable. It offers far less complexity than many other existent codecs including both, wavelet-tree, and block based varieties. The ROI feature in BCWT is implemented by means of a transcoder that is capable of generating a new BCWT bitstream containing only the information associated with the user-defined ROI. This paper presents an efficient technique that locates a particular ROI within the BCWT coded domain, and decodes it back to the spatial domain. This technique assists proper identification of pathologies in high resolution images since only a small fraction of the coded bitstream is required to be transmitted and analyzed.

6914-43, Poster Session

Semi automatic matching of OCT and IVUS images for image fusion

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Medical imaging is essential in the diagnosis of atherosclerosis. In this paper, we propose the semi automatic matching of two promising and complementary intravascular imaging techniques, Intravascular Ultrasound (IVUS) and Optical Coherence Tomography (OCT), with the ultimate goal of producing hybrid images with increased diagnostic value for assessing arterial health. If no ECG gating has been performed on the IVUS and OCT pullbacks, there is typically an anatomical shuffle (displacement in time and space) in the image sequences due to the catheter motion in the artery during the cardiac cycle, and thus, this is not possible to perform a 3D registration. Therefore, the goal of our work is to detect semi automatically the corresponding images in both modalities as a preprocessing step for the fusion. Our method is based on the characterization of the lumen shape by a set of Gabor Jets features. We also introduce different corrections term based on the approximate position of the slice in the artery. Then we train different support vector machines based on these features to recognize these correspondences. Experimental results demonstrate the usefulness of our approach, which achieves up to 95% matching accuracy for our data.

6914-96, Poster Session

Nonlinear elastic model for image registration and soft tissue simulation based on piecewise St. Venant-Kirchhoff material approximation

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Realistic modeling of soft tissue deformations is essential to many biomedical applications which require non-rigid image registration and biomechanical simulation. Different techniques to deformable modeling can be formally subdivided into two major groups: physical and non-physical approaches. Both physical and non-physical techniques are closely related to continuum mechanics. While physical methods are based on consistent numerical solution of partial differential equations of elasticity theory, non-physical methods rely on their special closed-form solutions. Due to complexity of mechanical properties of biological tissues certain simplifications concerning the underlying physical laws are usually made. One of such common simplifications is the linearization of originally nonlinear equations of continuum mechanics for the range of small deformations and rotations. Since deformation of soft tissue in biomedical applications often do not meet these limitations, linear elastic predictions imply a substantial error. In this paper, we present a framework for more accurate modeling of deformable structures based on the St. Venant-Kirchhoff law with the nonlinear Green-Lagrange strain tensor and variable material constants. The proposed model considers both material and geometrical nonlinearities. We derive the governing

partial differential equation of nonlinear elasticity, which can be seen as a consequent extension of the Lamé-Navier PDE, and describe two alternative numerical schemes for solving this nonlinear PDE via the Newton's and fixed point method, respectively. The results of our experimental studies demonstrate that the proposed nonlinear elastic model is capable of accurately computing large deformations and rotations compared to the linear elastic approximation.

6914-97, Poster Session

Validation and comparison of registration methods for free-breathing 4D lung CT

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We have compared and validated image registration methods with respect to the clinically relevant use-case of lung CT max-inhale to max-exhale registration. Four fundamentally different algorithms representing the main approaches for image registration were compared using clinical images. Each algorithm was assigned to a different person with extensive working knowledge of its usage. We performed quantitative comparison using landmarks and similarity measures and we performed different qualitative comparisons.

6914-98, Poster Session

Effective 2D-3D medical image registration using support vector machine

W. Qi, L. Gu, Shanghai Jiao Tong Univ. (China)

Registration of pre-operative 3D volume dataset and intra-operative 2D images gradually plays an important role to assist radiologists in diagnosing complicated diseases. As a key technology of intensity-based 2D-3D registration, generation of intra-operative digitally rendered radiographs (DRRs), however, becomes a bottleneck of the whole registration routine. In the process of optimization, great number of time consuming DRRs had to be computed from the 3D volume dataset in order to compare with intra-operative 2D image to obtain similarity metric instantly. In this paper, we proposed a novel 2D/3D registration framework based on Support Vector Machine (SVM) to compensate the drawback of generating considerable DRR images in the stage of intra-operation. Estimated similarity metric distribution could be built up from the relationship between parameters of transform and prior sparse target metric values by means of Support Vector Regression (SVR) method. Based on which, global optimal parameters of transform, without calculating intra-operative DRRs, are searched out by an optimizer in order to guide 3D volume dataset to match 2D image. As a result, indispensable information of pre-operation 3D data could be fused into intra-operative 2D image. This novel registration framework is divided into three stages: pre-operation, pre-registration and intra-registration. It had been applied for testing 3D MRI volume and intra-operative X-Ray image registration in the case of most suitable SVR method. Experimental results reveal that our proposed registration method boost up the performance of algorithm compared to conventional registration method and also provided a precise registration result efficiently.

6914-99, Poster Session

Nonrigid surface registration for open and closed 2D manifold in 3D Euclidian space

S. Darkner, M. Vester-Christensen, Danmarks Tekniske Univ. (Denmark); R. R. Paulsen, Oticon A/S (Denmark); R. D. Larsen, Danmarks Tekniske Univ. (Denmark)

This work describes a fast non-rigid registration method for 2D manifold embedded in 3D Euclidian space. The method is based on difference of distance maps and grid based warps interpolated by splines constrained in such a way that the deformations field is diffeomorphic. Dense surface to surface correspondence is created using angle weighted normal and ray tracing. The implementation using a derivation of the inverse compositional algorithm for optimization of computational speed

is described as well as some implementation issues for increasing performance. It is shown how the specific formulation enable the use of standard computer graphics algorithm for speed up and that the formulation in principle makes the algorithm independent of the sampling density. The results are evaluated by building a shape model showing the principal modes of variation and on synthetic data.

6914-100, Poster Session

Two-dimensional-3D registration of angiographic data with model-based methods

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We propose a novel registration method, which combines well-known vessel detection techniques with aspects of model adaptation. The proposed method is tailored to the requirements of 2D-3D registration of interventional angiographic X-ray data. As prerequisite, a vessel centerline is extracted out of rotational angiography (3DRA) data set to build a representative model of the vascular tree. Following the two steps of local vessel detection and model transformation the centerline model is matched to a DSA target image. Thereby the actual position of the centerline is related to the vessel candidates found in the target image minimizing the residual error in least squares manner. In contrast to purely point based methods like the iterative closest point (ICP) algorithm, no segmentation of the vessel tree in the 2D target image is required. First experiments with clinical data sets acquired during a TACE procedure show that matching with the proposed model-based registration approach is precise and efficient. Furthermore, it was found that the capture range of our method is extraordinarily large and is mainly limited by the pre-set seek range of the algorithm.

6914-101, Poster Session

Robust registration for change detection

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We address the problem of intra-subject registration for change detection. The goal is to separate stationary and changing subsets to be able to robustly perform rigid registration on the stationary subsets and thus improve the subsequent change detection. An iterative approach using a hybrid of parametric and non-parametric statistics is presented. The method uses non-parametric clustering and large scale hypothesis testing with estimation of the empirical null hypothesis. The method is successfully applied to 3D surface scans of human ear impressions containing true changes as well as data with synthesized changes. It is shown that the method improves registration and is capable of reducing the difference between registration using different norms.

6914-102, Poster Session

Reconstruction and registration of multispectral x-ray images for reliable alignment correction in radiation treatment devices

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To align patients in radiation treatment devices in six degrees of freedom, automated image-guided radiotherapy approaches perform the task of correction computation for the patient position. Therefore, digital radiography (DR) images acquired from within the treatment machine are compared to projections of a CT series to estimate respective misalignments. A major problem is that digital reconstructed radiographs (DRRs) have to be created from the CT to be registered with the X-ray images. Depending on the X-ray tube energy settings, the detector

sensitivity and the involved body part, DRRs and DRs may look very different and often cannot be registered properly. We present a method that reconstructs multi-spectral DRRs for different X-ray settings, which can be registered to real X-ray images. As short rendering times are crucial for fast correction calculation, multiple spectra of a DRR are generated in one single ray-tracing process. We then register the multi-spectral DRR with the respective DR. Normally a rigid 2D registration would be used. We add a further degree of freedom, to find a best match not only for the translations and in-plane rotation, but also the best fitting spectral planes. The registration results are used to identify a patient's misalignment. Results of the alignment correction show that higher reliability can be achieved compared to conventional approaches. Misalignments can correctly be identified even if ineligible X-ray settings have been used for acquisition. As our approach allows application of lower X-ray energies for DR creation, an additional benefit is the reduction of the dose delivered to the patient.

6914-103, Poster Session

Registration of standardized histological images in feature space

U. Bagci, L. Bai, The Univ. of Nottingham (United Kingdom)

In this paper, we propose three novel and important methods for the registration of histological images to 3D reconstruction. First, possible intensity variations and non-standardness in images are corrected by an intensity standardization process which maps the image scale into a standard scale where the similar intensities have similar tissue meaning. Second, 2D histological images are mapped into a feature space where continuous variables are used as high confidence image features for accurate registration. Third, we propose an automatic best reference slice selection algorithm that improves reconstruction quality based on both image entropy and mean square error of the registration process. We demonstrate that the choice of reference slice has a significant impact on registration error, standardization, feature space and entropy information. After 2D histological slices are registered through an affine transformation with respect to an automatically chosen reference, the 3D volume is reconstructed by co-registering 2D slices elastically.

6914-104, Poster Session

A new parametric nonrigid image registration work based on Helmholtz's theorem

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Helmholtz's theorem states that, with suitable boundary condition, a vector field is completely determined if both of its divergence and curl are specified everywhere [1]. Based on this, we developed a new parametric non-rigid image registration algorithm. Instead of the displacements of regular control grid points, the curl and divergence at each grid point are employed as the parameters. The most closely related work was done by Kybic [2] where the parameters are the B-spline coefficients of the displacement field at each control grid point. However, in Kybic's work, it is very likely to result in grid folding in the final deformation field if the distance between adjacent control grid points is less than 8. This implies that the high frequency components in the deformation field can not be accurately estimated. Another relevant work is due to Chen [3] where by solving a div-curl system, an intermediate vector field is generated and, in turn, a well regularized deformation field can be obtained. Though the present work does not guarantee the regularity of the resulting deformation field, which is also suffered by [2], it allows for a more efficient implementation over [3]. Our experimental results showed that the proposed method is less prone to grid folding than Kybic's work and that in many cases, in a multi-resolution fashion, the distance between adjacent control grid points can be reduced down to 1 and thus high registration accuracy can be achieved. Detailed comparison among the three algorithms is described in the paper.

6914-105, Poster Session

Three-dimensional statistical cancer atlas-based targeting of prostate biopsy using ultrasound image guidance

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The spatial inhomogeneity of cancer occurrences in the prostate has now been widely reported in several medical journals. This has also been followed up via the optimization of targeted biopsy where needle placements are made in regions more likely to have developed cancer. To this end, a statistical cancer atlas of the prostate was recently discussed where a nearly 94-96% detection accuracy was reported using only 6-7 needles. In this paper we discuss the warping of this atlas to the segmented side-fire ultrasound image of the patient in real time with an accuracy of over 0.87 volume overlap intersection to union ratio. Speed advantage is achieved using a shape model trained from over 38 expert segmented subjects off-line. This training yielded as few as 15-20 degrees of freedom that were optimized to warp the atlas surface to the patient's ultrasound image followed by elastic interpolation of the 3-D atlas.

As a result the atlas is completely mapped to the patient's prostate anatomy along with optimal predetermined needle locations for biopsy. These do not preclude the use of additional biopsies if desired. A color overlay of the atlas is also displayed on the ultrasound image showing high cancer zones within the prostate. Finally current biopsy locations are saved in the atlas space and may be used to update the atlas based on the pathology report. In addition to the optimal atlas plan, previous biopsy locations and alternate plans can also be stored in the atlas space and warped to the patient with no additional time overhead.

6914-107, Poster Session

Optimized GPU implementation of learning-based nonrigid multimodal registration

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Non-rigid multi-modal volume registration is computationally intensive due to its high-dimensional parameter space, i.e. common computation times range between 1.5 and 10 minutes. Medical imaging applications using registration, however, demand ever faster implementations for several purposes: matching the data acquisition speed, providing smooth user interaction and steering for quality control, and performing population registration involving multiple datasets. Current GPUs offer an opportunity to boost the registration speed through high computational power at low cost. In our previous work, we have presented a GPU implementation of a non-rigid multi-modal volume registration that was 6 - 8x times faster than a software implementation. In this paper, we extend this work by describing how new features of the latest DX10-compatible GPUs and additional optimization strategies can be employed to further improve the algorithm's performance. We have compared our optimized version with the previous version on the same GPU, and have observed a speedup factor of 3.6. Compared with the software implementation, we achieve a speedup factor of up to 44.

6914-108, Poster Session

Efficient 3D rigid body registration of micro-MR and micro-CT trabecular bone images

C. S. Rajapakse, The Univ. of Pennsylvania; J. F. Magland, The Univ. of Pennsylvania Health System; S. L. Wehrli, The Children's Hospital of Philadelphia; H. Zhang, S. Liu, E. Guo, Columbia Univ.; F. W. Wehrli, The Univ. of Pennsylvania

Registration of 3D images acquired from different imaging modalities such as MRI and CT are of interest in a number of medical imaging applications. General-purpose multimodality registration algorithms often tend to be computationally intensive and do not take into account the

directional misalignments present in the imaging volume. Multimodality trabecular bone images of cylindrical cores, for example, tend to be misaligned along and around the axial directions more than that around other directions. Additionally, trabecular bone images acquired by micro-magnetic resonance imaging (μ MRI) can differ substantially from those acquired by μ CT due to apparent trabecular thickening from magnetic susceptibility boundary effects and non-linear intensity correspondence. However, they share very similar contrast characteristics since the images essentially represent a binary tomographic system. The directional misalignment and the fundamental similarities of the two types of images can be exploited to achieve a fast 3D registration. Here we present an intensity cross-correlation based 3D registration algorithm for registering 3D specimen images from cylindrical cores of trabecular bone acquired by μ MRI and μ CT in the context of finite-element modeling to assess the bone's mechanical constants. The algorithm achieves the desired registration by first coarsely approximating the three translational and three rotational parameters required to align the μ MR images to μ CT scan coordinate frame and fine-tuning the parameters in the neighborhood of the approximate solution. The algorithm described here is suitable for 3D rigid-body image registration where through-plane rotations are known to be relatively small. The accuracy of the technique is constrained by the image resolution and in-plane angular increments used.

6914-109, Poster Session

Histopathology and MR fusion of the prostate using semi-automatic stitching and nonrigid registration

H. H. Jo, J. Jung, Y. Jang, H. Hong, Seoul Women's Univ. (South Korea); H. J. Lee, Bundang Hospital (South Korea)

We propose a method for combining histopathology image with MR image of the prostate using semi-automatic stitching and nonrigid registration. Our method consists of four steps. First, two or four tissue sections of the prostate in histopathology image are combined to produce a single prostate image by semi-automatic stitching. The process of our semi-automatic stitching is divided into correlation-based registration, image merging and blending. Second, the intensity of prostate bleeding area on T2-weighted MR image is substituted for that on T1-weighted MR image. Our intensity correction prevents a mistake which a prostate bleeding is considered as a tumor on T2-weighted MR image. Third, automatic correlation search is performed to find the best match for pixel overlap between histopathology and MR images. Then the initial alignment is deformed by the TPS warping. Finally, aligned images are displayed by the intensity intermixing. Experimental results show that the prostate tumor lesions can be properly located and clearly visualized within MR images for tissue characterization comparison.

6914-110, Poster Session

Three-dimensional-3D alignment using particle swarm optimization

S. Schafer, K. R. Hoffmann, Univ. at Buffalo; P. Noël, C. L. Bloebaum, State Univ. of New York at Buffalo

Three-dimensional datasets of unique, complex objects are readily available from the tomographic modalities, and fusion of these data sets leads to new understanding of the data and their relationships. In many cases, automatic alignment of the objects is difficult or time consuming, when substantial misalignments are present or point correspondences cannot be established or the solution space is non-convex. These issues effectively exclude most optimization algorithms used in conventional data alignment. Here, we present the particle swarm optimization (PSO) approach which is not sensitive to initial conditions, local minima or non-convex solution space.

Intercommunicating particle swarms are randomly placed in the parameter space (representing the parameters of the rigid transformations). Each member of each swarm traverses the parameter space, constantly evaluating the objective function at its own position and communicating with other members of the swarm about theirs. In addition, the swarms communicate between themselves. Through this information sharing between swarm members and the swarms, the space is searched completely and efficiently as a result all swarms converge to the globally optimal rigid transformation. To evaluate the technique, high-resolution

micro-CT data sets of single mouse jaws were acquired with large initial misalignments.

Using two particle swarms, the global minimum (intersecting volume 86%) was found in about 100 seconds on a standard PC independent of initial conditions. Faster speeds (better accuracy) can be obtained by relaxing (restricting) the convergence criteria. These results indicate that the particle swarm approach may be a valuable tool for stand-alone or hybrid alignments.

6914-111, Poster Session

Automatic alignment of renal DCE-MRI image series for improvement of quantitative tracer kinetic studies

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Tracer kinetic modeling with dynamic contrast enhanced MRI (DCE-MRI) and the quantification of the kinetic parameters are active fields of research which have the potential to improve the measurement of renal function. However, the strong coronal motion of the kidney in the time series inhibits an accurate assessment of the kinetic parameters. Automatic motion correction is challenging due to the large movement of the kidney and the strong intensity changes caused by the injected bolus. In this work, we improve the quantification results by a template matching motion correction method using a gradient-based similarity measure. Thus, a tedious manual motion correction is replaced by an automatic procedure. The only remaining user interaction is reduced to a selection of a reference slice and a coarse manual segmentation of the kidney in this slice. These steps do not present an overhead to the interaction needed for the assessment of the kinetic parameters. In order to achieve reliable and fast results, we constrain the degrees of freedom for the correction method as far as possible. Furthermore, we compare our method to deformable registration using the same similarity measure. In all our tests, the presented template matching correction was superior to the deformable approach in terms of reliability, leading to more accurate parameter quantification. The evaluation on 10 patient data series with 180-230 images each demonstrate that the quantitative analysis by a two-compartment model can be improved by our method.

6914-112, Poster Session

Consistent detection of mid-sagittal planes for follow-up MR brain studies

Y. Wang, Univ. of Florida; L. Zhang, Siemens Corporate Research

The mid-sagittal plane (MSP) is a commonly used anatomic landmark for standardized MR brain acquisition. In addition to the requirement of accurate detection of the MSP geometry, it is also imperative from clinical point of view to consistently prescribe scan planning for evaluation of pathology process in follow-up studies. In this work, an adaptive technique of scan planning has been developed to enforce the consistency among scans acquired at different time points from the same patient by maximizing image similarity in the proximity of MSP. The geometry parameters of the sagittal plane of current study are adapted by simplex algorithm to achieve better similarity to the reference study, where different similarity measures are studied and evaluated within the object of the interest of each sagittal image. The method is successfully tested on self-reference consistency study by manually setting the reference sagittal image. It is also tested with clinical follow-up studies of MR images acquired from 30 patients. By visual inspection, the adaptive consistency method improves the similarity to the reference images in 22 follow-up studies evidently, while the similarity to the reference images in 7 studies improves slightly. This result demonstrates the efficacy of our method on consistent detection of mid-sagittal planes for follow-up MR brain study

6914-113, Poster Session**A rapid and robust iterative closest point algorithm for image-guided radiotherapy**

J. C. Barbiere, J. Hanley, Hackensack Univ. Medical Ctr.

Our work presents a rapid and robust process that can analytically evaluate and correct patient setup error for head and neck radiotherapy by comparing orthogonal megavoltage portal images with digitally reconstructed radiographs. For robust data Photoshop is used to interactively segment images and registering reference contours to the transformed PI. MatLab is used for matrix computations and image analysis. The closest point distance for each PI point to a DRR point forms a set of homologous points. The translation that aligns the PI to the DRR is equal to the difference in centers of mass. The original PI points are transformed and the process repeated with an Iterative Closest Point algorithm until the transformation change becomes negligible. Using a 3.00 GHz processor the calculation of the 2500x1750 CPD matrix takes about 150 sec per iteration. Standard down sampling to about 1000 DRR and 250 PI points significantly reduces that time. We introduce a local neighborhood matrix consisting of a small subset of the DRR points in the vicinity of each PI point to further reduce the CPD matrix size. Our results demonstrate the effects of down sampling on accuracy. For validation, analytical detailed results are displayed as a histogram.

6914-114, Poster Session**Retinal image mosaicing using the radial distortion correction (RADIC) model**

S. Lee, The Univ. of Iowa; M. D. Abramoff, The Univ. of Iowa Hospitals and Clinics; J. M. Reinhardt, The Univ. of Iowa

Fundus camera imaging can be used to examine the retina to detect disorders such as diabetic retinopathy, age-related macular degeneration, glaucoma, etc. Similar to looking through a small keyhole into a large room, imaging the fundus with an ophthalmologic camera allows only a limited view at a time. Thus, the generation of a retinal montage using multiple images has the potential to increase diagnostic accuracy by providing larger field of view. A method of mosaicing multiple retinal images using the RADIC model is proposed in this paper. Our method determines the inter-image connectivity by detecting feature correspondences. The connectivity information is converted to a tree structure that describes the relationships between the reference and target images for pairwise registration. The montage is generated by cascaded pairwise registrations starting from the anchor image downward through the connectivity tree hierarchy. The RADIC model corrects the radial distortion that is due to the spherical-to-planar projection during retinal imaging. Therefore, after applying the RADIC transformation, individual images can be properly mapped onto a montage space by a linear geometric transformation, e.g. affine transform. Compared to the most existing montaging methods, our method is unique in that only a single registration per image is required because of the distortion correction property of RADIC model. As a final step, pyramidal intensity blending is employed to correct non-uniform illumination encountered when forming the montage. Visual inspection of the experimental results using two mosaicing cases with 6 and 9 individual fundus camera images shows our method can produce satisfactory montages.

6914-115, Poster Session**Deformation estimation and analysis for adaptive radiation therapy**

B. Wang, J. Xuan, Virginia Polytechnic Institute and State Univ.; J. Q. Wu, Duke Univ.; S. Zhang, Y. Wang, Virginia Polytechnic Institute and State Univ.

To accommodate the inter- and intra-fractional motion of the internal organs in prostate cancer treatment, a large margin (5mm-25mm) has to be considered during the radiation therapy planning. Normally, the inter-fractional motion is more substantial than the intra-fractional counterpart. Therefore, the study of the patterns of the inter-fractional motion is of special interest for adaptive radiation therapy. Existing methods on organ's motion analysis mainly focus on the deviation of

the organ's shape from the mean shape. The deviation information is helpful in choosing the statistically proper margin, but is of limited use for adapting the plan. In this paper, we propose a new deformation analysis method that can be directly used for plan adaption. First, deformation estimation is accomplished by a fast deformable registration method, which utilizes a contour based multigrid strategy to register the treatment cone-beam CT (CBCT) images with the planning CT images. Second, the dominant deformation modes are extracted by a novel deformation analysis approach. Specifically, a cooperative principal component analysis (PCA) method is developed to analyze the deformation field from coarse to fine. The deformation modes are initialized by applying the PCA on the organs as a whole and refined by analyzing the individual organs subsequently. The experimental results show that the motion of the organs can be well characterized by a few dominant deformation modes. Based on the modes, a corresponding set of dominant modal plans can be generated for further optimization. Ultimately, an adaptive plan for each treatment can be obtained on-line while the margin can be effectively reduced to minimize the unnecessary radiation dosage.

6914-116, Poster Session**Simultaneous segmentation and motion estimation in 4D-CT data using a variational approach**

J. Ehrhardt, A. Schmidt-Richberg, H. Handels, Univ. Medical Ctr. Hamburg-Eppendorf (Germany)

In this paper a variational approach for the combined segmentation and registration of temporal image sequences is presented. The purpose of the proposed method is to estimate respiratory--induced organ motion in 4D CT image sequences and to segment a structure of interest simultaneously. In this model the segmentation of all images in the sequences is obtained by finding a non--linear registration to an initial segmentation in a reference image. A dense non-linear displacement field is estimated using image intensities and segmentation information in the images. Both problems (registration and segmentation) are formulated in a joint variational approach and solved simultaneously.

A validation of the combined registration and segmentation approach is presented using low dose 4D CT data sets of the liver. The results demonstrate that the simultaneous solution of both problems improves the segmentation performance over a sequential application of the registration and segmentation steps.

6914-117, Poster Session**Recent advances in 3D-CSC based MR brain image segmentation**

F. Schmitt, L. Priebe, Univ. Koblenz-Landau (Germany)

Today most automated approaches to brain segmentation rely on anatomical atlases providing a priori information about the spatial distribution of tissue types. However those methods require a registration of the analysed image with the atlas which is time consuming and may fail in the case of severe anatomical anomalies.

Recently an atlas free method for fully automatic segmentation of MR brain images has been proposed which builds upon the 3D-CSC, a general segmentation method for voxel images. It was shown that the method is able to deliver results of similar quality to those produced by the established atlas based SPM method even in the case of images without anatomical anomalies. In this paper we introduce improvements of the 3D-CSC based segmentation method which further enhance both reliability and quality while pertaining the low computational complexity of the method.

The 3D-CSC partitions the image into gray value similar, spatially connected regions. Applied to the image of the whole head, normally some of those regions include both brain and non-brain tissue. Further on, gray and white matter are not represented each by only one region, instead we have several large and many small regions which we classify by mean gray value.

Instead of separating brain from non-brain tissue using morphological operations, we here use a modification of the skull-stripping method proposed by Hahn. Further on we incorporate new methods for histogram analysis where we trim the histogram to voxels supposed to consist of

pure brain tissue and analyse the modified histogram by a combination of k-harmonic means clustering and expectation maximization. We present plausibility checks for the found gray value thresholds as well as for the segmentation resulting from classifying the 3D-CSC regions according to those thresholds and show validation results on both simulated and real MRI images.

6914-118, Poster Session

Fuzzy pulmonary vessel segmentation in contrast enhanced CT data

J. N. Kaftan, RWTH Aachen (Germany) and Siemens Medical Solutions (Germany); A. P. Kiraly, Siemens Corporate Research; A. Bakai, Siemens Medical Solutions (Germany); M. Das, RWTH Aachen Univ. Hospital (Germany); C. L. Novak, Siemens Corporate Research; T. Aach, RWTH Aachen (Germany)

Pulmonary vascular tree segmentation has numerous applications in medical imaging and computer-aided diagnosis (CAD), including detection and visualization of pulmonary emboli (PE), improved lung nodule detection, and quantitative vessel analysis. We present a novel approach to pulmonary vessel segmentation based on a fuzzy segmentation concept, combining the strengths of both threshold and seed point based methods. The lungs of the original image are first segmented and a threshold-based approach identifies core vessel components with a high specificity. These components are then used to automatically identify reliable seed points for a fuzzy seed point based segmentation method, namely fuzzy connectedness. The output of the method consists of the probability of each voxel belonging to the vascular tree. Hence, our method provides the possibility to adjust the sensitivity/specificity of the segmentation result a posteriori according to application specific requirements, through definition of a minimum vessel-probability required to classify a voxel as belonging to the vascular tree.

The method has been evaluated on contrast-enhanced thoracic CT scans from clinical PE cases and demonstrates overall promising results. For quantitative validation we compare the segmentation results to randomly selected, semi-automatically segmented sub-volumes and present the resulting receiver operating characteristic (ROC) curves. Although we focus on contrast enhanced chest CT data, the method can be generalized to other regions of the body as well as to different imaging modalities

6914-120, Poster Session

Automatic knee cartilage delineation using inheritable segmentation

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We present a fully automatic method for segmentation of knee joint cartilage from fat suppressed MRI. The method first applies 3-D model-based segmentation technology, which allows to reliably segment the bones of the knee. Thin plate spline interpolation is used in the next step to position the deformable cartilage model with reference to the segmented bone models. After initialization, the cartilage model is fine adjusted by automatic adaptation to image data. The method has been validated on a collection of 8 (3 left, 5 right) fat suppressed datasets and demonstrated the sensitivity of 83±6% compared to manual segmentation.

6914-121, Poster Session

Computerized image analysis for acetic acid induced intraepithelial lesions

W. Li, STI Medical Systems; D. G. Ferris, Medical College of Georgia; R. W. Lieberman, Univ. of Michigan Medical School

Cervical precursor lesions and invasive cancer exhibit certain morphologic features that can be identified during a visual inspection exam. Immature and dysplastic cervical squamous epithelium turns white after application

of acetic acid during the exam. The whitening process occurs visually over several minutes and subjectively discriminates between dysplastic and normal tissue. Digital imaging technologies allow us to assist the physician analyzing the acetic acid induced lesions (acetowhite region) in a fully automatic way. In this paper we study and compare two different approaches to detect and characterize acetowhite regions. One approach is based on extracting the spatial change of aceto-whitening using color and texture information in the image. The other is based on extracting temporal changes of the lesions by registering images before and after acetic acid application. For the first approach, we use an iterative histogram analysis and different unsupervised clustering approaches such as Expectation Maximization (EM) and Mean Shift to segment color and texture lesions respectively. For the second approach, we applied an elastic registration algorithm first to align the pre and post acetic acid images, representing the problem as an optimization over a set of continuous deformation vector fields. Multiple levels of acetowhite opacity regions are extracted by further clustering the difference of the two images. Opacity parameters are also extracted based on the difference of color changes. A combination of the above approaches demonstrated a substantial correlation with pathology confirmed disease spectrum of 99 human subjects.

6914-122, Poster Session

Improving 3D active appearance model segmentation of the left ventricle with Jacobian tuning

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Automated image processing techniques may prove invaluable in facilitating the examination of real-time three-dimensional (3D) echocardiograms, and in removing observer subjectivity in the analysis. In this study, we investigate the use of active appearance models (AAMs) for automatic detection of left ventricular (LV) endocardial contours in 3D ultrasound images, to assess functional parameters such as LV volume and ejection fraction. AAMs are especially useful in segmenting ultrasound images, due to their ability to model the typical LV appearance, including characteristic artifacts. However, current AAM matching procedures may fail due to the large variability in ultrasound image appearance, whereas only a limited number of images is available for training. Recently, a Jacobian-tuning method for AAM matching was proposed, which allowed the model's training matrix to adapt to the new, unseen image, therefore potentially resulting in a more robust matching. To compare both matching methods, AAMs were built with end-diastolic images from 13 patients, acquired with Philips Sonos 7500 equipment, and images from 27 patients, acquired with the Fast Rotating Ultrasound transducer, developed at our lab. Better converged results were obtained when using the new method (90.4% convergence with the traditional AAM versus 94.8% with Jacobian-tuning). Better results were also found when matching the end-diastolic model to full-cycle sequences. In conclusion, this method has great potential for segmentation in echocardiograms and will improve the assessment of LV functional parameters.

6914-123, Poster Session

Novel method for digital subtraction of tagged stool in virtual colonoscopy

L. Guendel, M. Suehling, H. Eckert, Siemens Medical Solutions (Germany)

Colon Cancer is one of the most frequent causes of death. CT colonography is a novel method for the detection of polyps and early cancer. The general principle of CT colonography includes a cathartic bowel preparation. The resulting discomfort for the patients leads to limited patient acceptance and therefore to limited cancer detection rates.

Reduced bowel preparation, techniques for stool tagging, and electronic cleansing, however, improve the acceptance rates. Hereby, the high density of oral contrast material highlights residual stool and can be digitally removed.

Known subtraction methods cause artifacts: additional 3D objects are introduced and small bowel folds are perforated.

We propose a new algorithm that is based on the 2nd derivative of the data using the Hessian matrix and the following principal axis transform to detect tiny folds which shall not be subtracted together with the stool found by a thresholding method. Since the stool is usually not homogeneously tagged with contrast media a detection algorithm for island-like structures is incorporated. The interfaces of air-stool level and colon wall are detected by a 3-dimensional difference of Gaussian module. A 3-dimensional filter smoothes the transitions between removed stool and colon tissue.

We evaluated the efficacy of the new algorithm with 10 patient data sets. The results showed no introduced artificial objects and no perforated folds. The artifacts at the interfaces of air-stool level and colon tissue are considerably reduced compared to those known from the literature.

6914-124, Poster Session

Airway segmentation by topology-driven local thresholding

J. Vanderhyde, Georgia Institute of Technology; A. Szymczak, Colorado School of Mines

When viewing 3D medical images such as CT and MRI scans, specialists often step through one slice at a time in order to see all the information provided by the scans. Usually, organs would appear as regularly shaped regions of almost uniform intensity in these slices. Motivated by this observation, we have implemented a technique for segmentation of airways in the lungs that searches for topologically simple components in the sets obtained by applying a threshold to thick slices, i.e. sections of the input volume consisting of a fixed and small number of slices (10 in the experiments described here). In order to avoid inclusion of very large components, we put a user-specified bound on the thresholds that are considered by our algorithm. The segmented airway is obtained by selecting a connected component from the union of the topologically simple thresholded sets. Our approach is flexible enough to incorporate a variety of topological simplicity measures. In the experiments described in this abstract, we decide if a component C is topologically simple if and only if the following conditions are true: (i) The intersection of C and any of the two bounding slices of the thick slice has no more than 3 connected components. (ii) The boundary of C has no more than two connected components. (iii) C has no handles. The above conditions allow us to successfully reject many components that do not belong to airways.

6914-125, Poster Session

Improving cervical region of interest by eliminating vaginal walls and cotton swabs for automated image analysis

S. Venkataraman, W. Li, STI Medical Systems

Image analysis for automated diagnosis of cervical cancer has attained high prominence in the last decade. Automated image analysis at all levels requires a basic segmentation of the region of interest (ROI) within a given image. The precision of the diagnosis is often reflected by the precision in detecting the initial region of interest, especially when some features outside the ROI mimic the ones within the same. Work described here discusses algorithms that are used to improve the cervical region of interest as a part of automated cervical image diagnosis.

A vital visual aid in diagnosing cervical cancer is the aceto-whitening of the cervix after the application of acetic acid. Color and texture are used to segment acetowhite regions within the cervical ROI. Vaginal walls along with cotton-swabs sometimes mimic these essential features leading to several false positives. Work presented here is channeled towards detecting in-focus vaginal wall boundaries and then extrapolating them to exclude vaginal walls from the cervical ROI. Also discussed here is a marker-controlled watershed segmentation that is

used to detect cotton-swabs from the cervical ROI.

A dataset comprising 50 high resolution images of the cervix acquired after 60 seconds of acetic acid application were used to test the algorithm. Out of the 50 images, 27 benefited from a new cervical ROI. Significant improvement in overall diagnosis was observed in these images as false positives caused by features outside the actual ROI mimicking acetowhite region were eliminated.

6914-126, Poster Session

CALM: cascading system with leaking detection mechanism for medical image segmentation

J. Liu, J. H. Lim, H. Li, Institute for Infocomm Research (Singapore)

Medical image segmentation is a challenging process due to possible image over-segmentation and under-segmentation (leaking). The CALM medical image segmentation system is constructed with an innovative scheme that cascades threshold level-set and region-growing segmentation algorithms using Union and Intersection set operators. These set operators help to balance the over-segmentation rate and under-segmentation rate of the system respectively. While adjusting the curvature scalar parameter in the threshold level-set algorithm, we observe that the abrupt change in the size of the segmented areas coincides with the occurrences of possible leaking. Instead of randomly choose a value or use the system default curvature scalar values, this observation prompts us to use the following formula in CALM to automatically decide the optimal curvature values r to prevent the occurrence of leaking: $\partial^2 S / \partial r^2 \geq M$, where S is the size of the segmented area and M is a large positive number.

Motivated for potential applications in organ transplant and analysis, the CALM system is tested on the segmentation of the kidney regions from the Magnetic Resonance images taken from the National University Hospital of Singapore. Due to the nature of MR imaging, low-contrast, weak edges and overlapping regions of adjacent organs at kidney boundaries are frequently seen in the datasets and hence kidney segmentation is prone to leaking. The kidney segmentation accuracy rate achieved by CALM is 22% better compared with those achieved by the component algorithms or the system without leaking detection mechanism. CALM is easy-to-implement and can be applied to many applications besides kidney segmentation.

6914-127, Poster Session

Validation of automatic landmark identification for atlas-based segmentation for radiation treatment planning of the head-and-neck region

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Manual contouring of target volumes and organs at risk in radiation therapy is extremely time-consuming, in particular for treating the head-and-neck area, where a single patient treatment plan can take several hours to contour. As radiation treatment delivery moves towards adaptive treatment, the need for more efficient segmentation techniques will increase. We are developing a method for automatic model-based segmentation of the head and neck. This process can be broken down into three main steps: i) automatic landmark detection in the image dataset of interest, ii) automated landmark-based initialization of deformable surface models to the patient image dataset, and iii) adaptation of the deformable models to the patient-specific anatomical boundaries of interest. In this paper, we focus on the validation of the first step of this method, quantifying the results of our automatic landmark detection method.

We used an image atlas formed by applying thin-plate spline interpolation using 27 manually identified landmarks in 10 training clinical datasets. The principal variation modes returned by principal component analysis of the landmark positions were used by an automatic registration algorithm, which sought the corresponding landmarks in the clinical dataset of interest using a controlled random search algorithm. The performance was assessed by running the algorithm on 10 further

datasets. Applying a run time of 60 seconds, a root mean square (rms) distance to the ground-truth landmark position of 9.5 ± 0.5 mm was calculated for the identified landmarks. Automatic segmentation of the brain, mandible and brain stem, using the detected landmarks, is demonstrated.

6914-128, Poster Session

Robust image segmentation based on integrated squared estimation

J. Liu, S. Xie, Ohio Univ.

Image segmentation is one of the most fundamental problems in a variety of applications. Many histogram-based technologies are not robust to poor intensity contrast and heavy acquisition noise, and perform poorly with the images that have blurred object boundaries. This paper proposes a new Finite Gaussian Mixture (FGM) segmentation model that is based on minimizing the integrated square error or L2 estimation (L2E). Our model, which we named as FGML2E, has a very strong discriminative ability in capturing the major parts of intensity distribution, without being affected by outlier structures or heavy noise. With a group of experiments on synthetic data sets, the inherent robustness properties of L2E in FGM fitting are clearly shown in this paper, which justifies the usage of L2E as a segmentation model.

Our solution works particularly well for the input cases where the image contains structures whose intensity profiles are vastly overlapped. To demonstrate the improvement made by our FGML2E algorithm, segmentation experiments on MicroCT mouse images are carried out. Comparisons are made with the Expectation-Maximization (EM) and the Fuzzy C-Means (FCM) algorithms. Experimental results show that our model is clearly a better choice than the EM and FCM in terms of rejecting outlier structures and capturing the target structures with great accuracy.

6914-129, Poster Session

Segmentation in noisy medical images using PCA model based particle filtering

W. Qu, Siemens Medical Solutions USA, Inc.; X. Huang, Lehigh Univ.; Y. Jia, Univ. of Illinois at Chicago

In this paper, we propose a robust segmentation approach for noisy medical image analysis using PCA-based particle filtering. It exploits the prior clinical knowledge of desired object's shape through a PCA model. By carefully modeling the segmentation process, we design a novel particle filter. The preliminary results have shown the effectiveness and efficiency of the proposed approach on both synthetic and real clinical data.

6914-130, Poster Session

Automatic subcortical structure segmentation using probabilistic atlas

J. Liu, Ohio Univ.; C. D. Smith, H. Cherolu, Univ. of Kentucky

In this paper, we propose a probabilistic atlas-based active contour model for subcortical structure segmentation. As a generalization of the Chan-Vese piecewise-constant model, our solution uses Bayesian a posteriori probabilities as the driving forces for curve evolution. Probabilistic atlas for the structure of interest, e.g. caudate nucleus, can be seamlessly integrated into the level set evolution procedure, and no thresholding step is needed for capturing the target. Unlike other region-based active contour models, our solution relaxes the global piecewise-constant assumption, and uses locally varying Gaussians to better account for intensity inhomogeneity and local variations existing in many MR images. More accurate and robust segmentations are therefore achieved.

6914-131, Poster Session

Semi-automatic detection of Gd-DTPA-saline filled capsules for colonic transit time assessment in MRI

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wig-Maximilians-Univ. München (Germany); A. Keil, Technische Univ. München (Germany) and Klinikum der Univ. München (Germany); C. Kirchoff, T. Mussack, Klinikum der Univ. München (Germany); A. Lienemann, M. Reiser, Ludwig-Maximilians-Univ. München (Germany); N. Navab, Technische Univ. München (Germany)

Functional gastrointestinal disorders result in a significant number of consultations in primary care facilities. Chronic constipation and diarrhea are regarded as two of the most common diseases affecting between 2% and 27% of the population in western countries [1-3]. Defecatory disorders are most commonly due to dysfunction of the pelvic floor or the anal sphincter. Although an exact differentiation of these pathologies is essential for adequate therapy, diagnosis is still only based on a clinical evaluation [1].

Regarding quantification of constipation only the ingestion of radio-opaque markers or radioactive isotopes and the consecutive assessment of colonic transit time using X-ray or scintigraphy, respectively, has been feasible in clinical settings [4-8]. However, these approaches have several drawbacks such as involving rather inconvenient, time consuming examinations and exposing the patient to ionizing radiation. Therefore, conventional assessment of colonic transit time has not been widely used.

Most recently a new technique for the assessment of colonic transit time using MRI and MR-contrast media filled capsules has been introduced [9]. However, due to numerous examination dates per patient and corresponding datasets with many images, the evaluation of the image data is relatively time-consuming.

The aim of our study was to develop a computer tool to facilitate the detection of the capsules in MRI datasets and thus to shorten the evaluation time. We present a semi-automatic tool which provides an intensity, size, and shape-based detection of ingested Gd-DTPA-saline filled capsules. After an automatic pre-classification, radiologists may easily correct the results using the application-specific user interface, therefore decreasing the evaluation time significantly.

6914-132, Poster Session

A learning-based automatic spinal MRI segmentation

X. Liu, J. Samarabandu, The Univ. of Western Ontario (Canada); G. Garvin, St. Joseph's Hospital (Canada); R. Chhem, London Health Sciences Ctr. (Canada); S. Li, GE Healthcare (Canada)

Image segmentation plays an important role in medical image analysis and visualization since it greatly enhances the clinical diagnosis. Although many algorithms have been proposed, it is still challenging to achieve an automatic clinical segmentation which requires speed and robustness. Automatically segmenting the vertebral column in Magnetic Resonance Imaging (MRI) image is extremely challenging as variations in soft tissue contrast and radio-frequency (RF) in-homogeneities cause image intensity variations. Moreover, little work has been done in this area. We proposed a generic slice-independent, learning-based method to automatically segment the vertebrae in spinal MRI images. A main feature of our contributions is that the proposed algorithm is able to simultaneously segment multiple images of different slices efficiently. By using multiple images, on the one hand, image pairs can be used as the guidance for each other, which provides an accurate segmentation. On the other hand, previously segmented images can also be used as a prior or initial solution, which can also increase the segmentation efficiency. The proposed method consists of two stages: candidate generation and verification. The candidate generation stage is aimed at obtaining the segmentation through the energy minimization. In this stage, images are first partitioned into a number of image regions. Then, Support Vector Machines (SVM) is applied on the pre-partitioned image regions to obtain the class conditional distributions, which are then fed into an energy function and optimized with the graph-cut algorithm. The verification stage applies domain knowledge to verify the segmented candidates and reject unsuitable ones. Experimental results show that the proposed method is very efficient and robust with respect to image slices. The proposed algorithm also has the potential to be imaging modality independent as it is not specific to a particular imaging modality. In conclusion, the proposed method is able to achieve a fully automatic, efficient and robust clinical spinal MRI image segmentation, which provides the baseline for further diagnosis.

6914-133, Poster Session

Reclassification of segmentation boundary base on neighboring function

J. Chen, J. Tian, Institute of Automation (China)

Motivated by the goal of improving the performance of segmentation, a new technique based on Neighboring Function is presented to reclassify the rough segmentation boundary pixels. The NF is a novel measurement of neighboring relationship, it takes into consideration of both spatial and intensity information and their distribution pattern. With the rough boundary provided by other segmentation algorithms, the value of the NF at each boundary pixel is calculated in a specific neighborhood, and then the reclassification will be implemented by comparing these values. In order to obtain the expected boundary, this step is iterated for several times until convergence. In our study, the proposed method is applied to real medical images; a great improvement of segmentation boundary has been achieved. The accuracy and reproducibility of this reclassification method has been proven by experimental results. Experiments also show that this method is insensitive to noise.

6914-134, Poster Session

Effect of various binning methods and ROI sizes on the accuracy of the automatic classification system for differentiation between diffuse infiltrative lung diseases on the basis of texture features at HRCT

N. Kim, J. Seo, Asan Medical Ctr. (South Korea); Y. Sung, B. Park, Y. Lee, Seoul National Univ. (South Korea); Y. K. Lee, Asan Medical Ctr. (South Korea); S. Kang, Seoul National Univ. (South Korea)

To find optimal binning method and ROI size of the automatic classification system for differentiation between diffuse infiltrative lung diseases on the basis of textural analysis at HRCT Six-hundred circular regions of interest (ROI) with 10, 20, and 30 pixel diameter, comprising of each 100 ROIs representing six regional disease patterns (normal, NL; ground-glass opacity, GGO; reticular opacity, RO; honeycombing, HC; emphysema, EMPH; and consolidation, CONS) were marked by an experienced radiologist from HRCT images. Histogram (mean) and co-occurrence matrix (mean and SD of angular second moment, contrast, correlation, entropy, and inverse difference momentum) features were employed to test binning and ROI effects. To find optimal binning, variable binning size linear binning (bin size Q: 4~30, 32, 64, 128, 144, 196, 256, 384) (LB) and non-linear binning (Q: 4~30) (NLB) methods (K-means, and Fuzzy C-means clustering) were tested. For automated classification, a SVM classifier was implemented. To assess cross-validation of the system, a five-folding method was used. Each test was repeatedly performed twenty times. Overall accuracies with every combination of variable ROIs, and binning sizes were statistically compared.

In case of small binning size (Q = 10), NLB shows significant better accuracy than the LB. K-means NLB (Q = 26) is statistically significant better than every LB. In case of 30x30 ROI size and most of binning size, the K-means method showed better than other NLB and LB methods. When optimal binning and other parameters were set, overall sensitivity of the classifier was 92.85%. The sensitivity and specificity of the system for each class were as follows: NL, 95%, 97.9%; GGO, 80%, 98.9%; RO 85%, 96.9%; HC, 94.7%, 97%; EMPH, 100%, 100%; and CONS, 100%, 100%, respectively.

We determined the optimal binning method and ROI size of the automatic classification system for differentiation between diffuse infiltrative lung diseases on the basis of texture features at HRCT.

6914-136, Poster Session

Interactive surface correction for 3D shape-based segmentation

T. Schwarz, T. Heimann, R. Tetzlaff, A. Rau, I. Wolf, H. Meinzer, Deutsches Krebsforschungszentrum (Germany)

Statistical shape models have become a fast and robust method for segmentation of anatomical structures in medical image volumes. In clinical practice, however, pathological cases and image artifacts

often lead to local deviations of the detected contour from the true object boundary that have to be corrected manually. We present an intuitively applicable solution for surface interaction based on Gaussian deformation kernels. The method is evaluated by two radiological experts on segmentations of the liver in contrast-enhanced CT images and of the left heart ventricle (LV) in MRI data. For both applications, five datasets are segmented automatically using deformable models, and the resulting surfaces are corrected manually. The interactive correction step improves the average surface distance against ground truth from 2.43mm to 2.17mm for the liver, and from 2.71mm to 1.34mm for the LV. We expect this method to raise the acceptance of automatic segmentation methods in clinical application.

6914-137, Poster Session

An approach to segment lung pleura from CT data with high precision

E. Angelats Company, K. Chaisawong, A. Knepper, RWTH Aachen (Germany); T. Kraus, Univ. Hospital Aachen (Germany); T. Aach, RWTH Aachen (Germany)

A new approach to segment lung pleura from CT data with high precision is introduced. This approach is developed in the segmentation's framework of an image analysis system to automatically detect pleural thickenings. The new technique to carry out the 3D segmentation of lung pleura is based on supervised range-constrained thresholding and Gibbs-Markov random field model. First, an initial segmentation is done using 3D histogram with the technique of supervised range-constrained thresholding in two steps. Step one, after an initial thresholding, 3D connected component labelling is applied to detect the thorax. The region of the detected thorax is used as initial mask for the next step.

Step two, lung pleura, trachea and bronchi therein are detected using 3D histogram with supervised-range constrained thresholding. In order to detect and remove trachea and bronchi, the 3D histogram of lung, trachea and bronchi is modelled as a finite mixture of Gaussians distributions.

Parameters are estimated using Expectation-Maximization algorithm, which led to the classification of that pulmonary region. As consequence lungs are separated, left and right. Finally we apply a Gibbs-Markov random field model to our initial segmentation in order to achieve a high accuracy segmentation of lung pleura. Gibbs-Markov random field is combined with maximum a posteriori to estimate optimal pleural contours.

With these methods, a new segmentation strategy is developed in order to improve the reliability and accuracy of the detection of pleural contours and to achieve a better assessment performance of pleural thickenings.

6914-138, Poster Session

Boundary-precise segmentation of nucleus and plasma of leukocytes

T. Zerfass, Fraunhofer Institute for Integrated Circuits IIS (Germany); T. Rehn, Otto-von-Guericke-Univ. Magdeburg (Germany)

A robust detection and exact segmentation of white blood cells (leukocytes) in stained blood smears of the peripheral blood provides the base for a fully automatic, image based preparation of the so called differential blood cell count in the context of medical laboratory diagnostics (so called Computer-Assisted-Microscopy CAM). Especially for the classification and in particular for the feature extraction it is necessary to have a precise segmentation result to get good classification results. In this contribution we present an approach for the according segmentation of leukocytes. After a preprocessing by a Kuwahara filter a fast-marching-method for the localization of a rough cell boundary is defined. To retrieve the cell area a shortest-path-algorithm is applied afterwards. The localization of the cell nucleus is done by a threshold operation. An evaluation of the presented method was done on a prestigious sample set of 80 images and is based on the Dice-coefficient and the Hausdorff-distance compared with a manual segmentation. The results of the presented approach show the capability of the presented algorithm, especially concerning the precise boundary detection and the adaptability for the different types of leukocyte cells.

6914-139, Poster Session

Fully automated segmentation of carotid and vertebral arteries from contrast-enhanced CTA

O. Cuisenaire, Philips Medical Systems (France); S. Virmani, M. E. Olaszewski, Philips Medical Systems; R. Ardon, Philips Medical Systems (France)

We propose a method for segmenting and labeling the main head and neck vessels (common, internal, external carotid, vertebral) from a contrast enhanced CTA volume. First, a rough centerline of each vessel is extracted. Next, the vessels are segmented using 3D active objects initialized using the first step. Finally, the true centerline is identified by smoothly deforming it away from the segmented mask edges using a spline-snake.

We focus particularly on the novel rough centerline extraction technique. It uses a locally adaptive fast marching algorithm that attempts to find the optimal path connecting the ends of the vessel, typically from the lowest image of the scan to the Circle of Willis in the brain. It uses a patient adapted anatomical model of the different vessels both to initialize and constrain this fast marching, thus eliminating the need for manual selection of seed points.

The method is evaluated using data from multiple regions (USA, India, China, Israel) including a variety of scanners (10, 16, 40, 64 slice), contrast agent dose, and image resolution. It is fully successful in over 90% of patients and only misses a single vessel in most remaining cases. We also demonstrate its robustness to metal and dental artifacts and anatomical variability.

Total processing time is approximately two minutes with no user interaction, which dramatically improves the workflow over existing clinical software. It also reduces patient dose exposure by obviating the need to acquire an unenhanced scan for bone suppression as this can be done by applying the segmentation masks.

6914-140, Poster Session

Simultaneous detection of multiple elastic surfaces with application to tumor segmentation in CT images

K. Li, Carnegie Mellon Univ.; M. Jolly, Siemens Corporate Research

We present a new semi-supervised method for segmenting multiple interrelated object boundaries with spherical topology in volumetric images. The core of our method is a novel graph-theoretic algorithm that simultaneously detects multiple surfaces under smoothness, distance, and elasticity constraints. The algorithm computes the global optimum of an objective function that incorporates boundary, regional and surface elasticity information. A single straight line drawn by the user in a cross-sectional slice is the sole user input, which roughly indicates the extent of the object. We employ a multi-seeded Dijkstra-based "range competition" algorithm to pre-segment the object on two orthogonal multiplanar reformatted (MPR) planes that pass through the input line. Based on the 2D pre-segmentation results, we estimate the object and background intensity histograms, and employ an adaptive mean-shift mode-seeking process on the object histogram to automatically determine the number of surface layers to be segmented. The final multiple-surface segmentation is performed in an ellipsoidal coordinate frame constructed by an automated ellipsoid fitting procedure. We apply our method to the segmentation of liver lesions with necrosis or calcification, and various other tumors in CT images. For liver tumor segmentation, our method can simultaneously delineate both tumor and necrosis boundaries. This capability is unprecedented and is valuable for cancer diagnosis, treatment planning, and evaluation.

6914-141, Poster Session

An efficient topology adaptation system for parametric active contour segmentation of 3D images

J. Abhau, O. Scherzer, Leopold-Franzens-Univ. Innsbruck (Austria)

Active contour models have already been used successfully for segmentation of organs from medical images in 3D. In implicit models, the contour is given as the isosurface of a scalar function, and therefore topology adaptations are handled naturally during a contour evolution.

Nevertheless, explicit or parametric models are often preferred since user interaction and special geometric constraints are usually easier to incorporate. Although many researchers have studied topology adaptation algorithms in explicit mesh evolutions, no stable algorithm is known for interactive applications. In this paper, we present a topology adaptation system, which consists of two novel ingredients:

A spatial hashing technique is used to detect self-colliding triangles of the mesh whose expected running time is linear with respect to the number of mesh vertices.

For the topology change procedure, we have developed formulas by homology theory. During a contour evolution, we just have to choose between a few possible mesh retriangulations by local triangle-triangle intersection tests.

Our algorithm has several advantages compared to existing ones: Since the new algorithm does not require any global mesh reparametrizations, it is very efficient. Since the topology adaptation system does not require constant sampling density of the mesh vertices nor especially smooth meshes, mesh evolution steps can be performed in a stable way with a rather coarse mesh.

We apply our algorithm to 3D ultrasonic data, showing that accurate segmentation is obtained in some seconds.

6914-142, Poster Session

Time-dependent joint probability speed function for level-set segmentation of rat brain slices

C. Palm, Univ. College London (United Kingdom) and Forschungszentrum Jülich GmbH (Germany); U. Pietrzyk, Forschungszentrum Jülich GmbH (Germany) and Bergische Univ. Wuppertal (Germany)

Introduction: The segmentation of rat brain slices suffers from illumination inhomogeneities and staining effects. State-of-the-art level-set methods model slice and background with intensity mixture densities defining the speed function as difference between the respective probabilities. Nevertheless, the overlap of these distributions causes an inaccurate stopping at the slice border. In this work, we propose the characterisation of the border area with intensity pairs for inside and outside estimating joint intensity probabilities.

Method: In contrast to whole object and background models, we focus on the object border characterised by a joint mixture density. This specifies the probability of the occurrence of an inside and an outside value in direct adjacency. These values are not known beforehand, because inside and outside depend on the level-set evolution and change during time. Therefore, the speed function is computed time-dependently at the position of the current zero level-set. Given the zero level-set, the inside and outside values are derived as mean along the curvature normal directing inside and outside the object. Advantage of the joint probability distribution is to resolve the distribution overlaps, because these are assumed to be not located at the same border position.

Results: The novel time-dependent joint probability based speed function is compared experimentally with single probability based speed functions. Two rat brains with about 40 slices are segmented and the results analysed using manual segmentations and the Tanimoto overlap measure. Improved results are recognised for both data sets.

6914-143, Poster Session

Multiphase image segmentation using level sets

P. Zhilkin, M. Alexander, National Research Council Canada (Canada)

A hierarchical multi-phase image segmentation using the original and modified Chan-Vese 2-phase method is considered. A method of capturing features inside a pre-selected region of interest (ROI) is proposed that effectively restricts the segmentation operation to the ROI. At the first step, a modified image is created by setting the portion of the image outside the ROI to a uniform intensity equal to the mean image intensity inside the ROI. Effectively, this procedure partitions the initial image into two phases, in such a way that the ROI becomes a 'segmented' feature. At the second step the segmentation procedure is applied to the modified image, partitioning the image in two phases - object and background - inside the ROI. By confining segmentation

to the ROI, it is shown, using an artificial image, that objects can be discriminated that could not have been found if segmentation had been performed on the entire image. If necessary, this second step can be repeated to further segment features of interest within the ROI, thereby providing a multi-phase segmentation procedure. ROI placement around features of interest requires prior knowledge, and may be derived from an atlas or manually prescribed by the operator. In this way, segmentation is possible on low-contrast features of interest, while ignoring features irrelevant for a particular application. Examples are provided for segmentation of several 2D/3D images performed on entire images and inside a ROI.

6914-144, Poster Session

Bidirectional segmentation of prostate capsule from ultrasound volumes: an improved strategy

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Prostate volume is an indirect indicator for several prostate diseases. Volume estimation is a desired requirement during prostate biopsy, therapy and clinical follow up. Image segmentation is thus necessary.

Previously, discrete dynamic contour (DDC) was implemented in orthogonal unidirectional on the slice-by-slice basis for prostate boundary estimation. This suffered from the glitch that it needed stopping criteria during the propagation of segmentation procedure from slice-to-slice. To overcome this glitch, axial DDC was implemented and this suffered from the fact that central axis never remains fixed and wobbles during propagation of segmentation from slice-to-slice. The effect of this was a multi-fold reconstructed surface. This paper presents a bidirectional DDC approach, thereby removing the two glitches.

Our bidirectional DDC protocol was tested on a clinical dataset on 28 3-D ultrasound image volumes acquired using side fire Philips transrectal ultrasound. We demonstrate the orthogonal bidirectional DDC strategy achieved the most accurate volume estimation compared with previously published orthogonal unidirectional DDC and axial DDC methods. Compared to the ground truth, we show that the mean volume estimation errors were: 18.48%, 9.21% and 7.82% for unidirectional, axial and bidirectional DDC methods, respectively. The segmentation architecture is implemented in Visual C++ in Windows environment.

6914-145, Poster Session

Kernel and spatial-based fuzzy segmentation on breast x-ray images

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Robust methods for precise segmentation of breast region or volume from breast X-ray images, including mammogram and tomosynthetic image, is crucial for applications of these medical images. However, this task is challenging because the acquired images not only are inherent noisy and inhomogeneous, but there are also connected or overlapped artifacts, or noises on the images as well, due to local volume effect of tissues, parametric resolutions and other physical limitations of the imaging device.

This paper proposes and develops robust fuzzy c-means (FCM) segmentation methods for segmentation of breast region on breast x-ray images, including mammography and tomosynthesis, respectively. We develop spatial information- and kernel function- based FCM methods to differentiate breast area or breast volume. Spatial information based FCM method incorporates neighborhood pixels' intensities into segmentation because neighbored pixels on an image are highly correlated. Kernel based FCM algorithm is developed by transforming pixel intensity using kernel functions to better improve segmentation performance. The proposed segmentation methods are implemented on mammograms and tomosynthetic images and compared with conventional FCM results. Experiment results demonstrate the proposed segmentation methods are much better compared with traditional FCM method, and are more robust to noises. The developed kernel and spatial based FCM method will be applied for differentiation of breast density and abnormal regions

within the breast region to examine its performance in reducing false positive segmentations.

6914-147, Poster Session

Hierarchical segmentation of malignant gliomas via integrated contextual filter response

S. Dube, J. J. Corso, A. L. Yuille, T. F. Cloughesy, S. El-Saden, U. Sinha, Univ. of California/Los Angeles

We present a novel methodology for the automated segmentation of Glioblastoma Multiforme tumors given only a high-resolution T1 post-contrast enhanced channel, which is routinely done in clinical MR acquisitions. The main contribution of the paper is the integration of contextual filter responses, to obtain a better class separation of abnormal and normal brain tissues, into the multilevel segmentation by weighted aggregation (SWA) algorithm. The SWA algorithm uses neighboring voxel intensities to form an affinity between the respective voxels. The affinities are then recursively computed for all the voxel pairs in the given image and a series of cuts are made to produce segments that contain voxels with similar intensity properties. SWA provides a fast method of partitioning the image, but does not produce segments with meaning. Thus, a contextual filter response component was integrated to label the aggregates as tumor or non-tumor. The contextual filter responses were computed via texture filter responses based on the gray level co-occurrence matrix (GLCM) method. The GLCM results in texture features that are used to quantify the visual appearance of the tumor versus normal tissue. Our results indicate the benefit of incorporating contextual features and applying non-linear classification methods to segment and classify the complex case of grade 4 tumors.

6914-148, Poster Session

Local control of speed function in level set segmentation using interactive interface for CT images

S. Tate, N. Tsumura, T. Nakaguchi, Y. Miyake, Chiba Univ. (Japan)

In this research, parameters of a speed function in level set segmentation are locally changed in the regions specified by a human using an interactive interface for CT images. The parameters are usually set homogeneously in the CT images to certain values which are obtained iteratively and empirically. The empirically set values for the parameters can be used as appropriate parameter values for full-automated segmentation for medical images, and the results of the segmentation can be applied in various areas such as surgery planning and quantitative diagnosis. However, the appropriate parameter values are changed depending on the organs, and also the homogeneous values for each organ in the CT images can not give the best result for entire region in the organ. In this paper, therefore, the interactive interface is used to specify the three dimensional region in the CT images for local control of speed function. To achieve the interactive interface, we combined the narrow band method and approximated re-initialization to reduce the costs of computation for boundary propagation in the level set segmentation. The proposed method is applied to pancreas segmentation to evaluate the effectiveness of the local control of speed function.

6914-149, Poster Session

Automated retinal layer segmentation in optical coherence tomography images

A. M. Bagci, R. Ansari, M. Shahidi, Univ. of Illinois at Chicago

We have developed a new method to segment and analyze retinal layers in optical coherence tomography (OCT) images with the intent of monitoring changes in thickness of retinal layers due to disease. OCT is an imaging modality that obtains cross-section images of the retina, which makes it possible to measure thickness of individual layers. In this paper we present a method that identifies six key layers in OCT image. OCT images present challenges to conventional edge detection algorithms, including that due to the presence of speckle noise which affects the sharpness of inter-layer boundaries significantly. We use a directional filter bank, which has a wedge shaped passband that helps reduce noise while maintaining edge sharpness, in contrast to previous

methods that use Gaussian filter or median filter variants that reduce the edge sharpness resulting in poor edge-detection performance. The extracted edge cues are rated according to the amount of gray-level transition across the edge, strength, curvature, continuity, relative location and polarity. These cues are processed according to the retinal model that we have developed and the processing yields edge contours. The gaps along these edge contours are filled in according to the retinal model to form continuous boundaries. Retinal thickness measurements obtained by the algorithm are compared with manual expert segmentation results on thirty normal eye images, and the results show an average difference of less than 2.1 pixels. On high resolution images, measurements obtained with our algorithm were compared with measurements generated by the OCT system. The OCT system generates measurements only for some layers, and for these layers the results differed by 1.74 pixels on average. The comparison of thickness measurements obtained on low and high resolution instruments of the same subject, and retinal thickness values in diseased eyes will be reported in the final paper along with details of the algorithm.

6914-150, Poster Session

Neuronal nuclei localization in 3D using level set and watershed segmentation from laser scanning microscopy images

Y. Zhu, Syracuse Univ.; E. Olson, Upstate Medical Univ./SUNY; A. Subramanian, Syracuse Univ.; D. Feiglin, A. Krol, Upstate Medical Univ./SUNY

Abnormalities of cell number or location are hallmarks of both developmental and degenerative neurological diseases. However, standard stereological methods are impractical for assigning each cell's nucleus position within a large volume of brain tissue. We propose an automated approach to this problem that starts with an exceptionally high contrast stain (Hoechst 33342). Volumes of Hoechst-stained brain tissue are acquired using laser scanning microscopy (LSM). The nuclei in these images are segmented using the level set (LS) method. Because LS tends to merge clustered cells resulting in under-segmentation, it is followed by the watershed segmentation that in turn might produce over-segmentation. Therefore, the segmentation results need to be further refined by application of decision rules that are based on topological properties of the nuclei of interest. The centroid of a nucleus (CN) is defined as a central point of its skeleton in 3D. An algorithm has been developed to locate all CNs in the volume. Each volume of tissue is thus represented by a collection of centroids leading to an approximate 10,000-fold reduction in the data set size, as compared to the original image series. Our method has been tested on LSCM images obtained for an embryonic mouse brain, and compared to CNs segmentation performed by an expert. The average Euclidian distance between locations of CNs obtained using these methods is $1.58 \pm 1.24 \mu\text{m}$, a value well within the $\sim 5 \mu\text{m}$ average radius of each nucleus. We conclude that our approach accurately locates the CNs within cell dense embryonic tissue.

6914-151, Poster Session

Prostate segmentation on pelvic CT images using a genetic algorithm

P. Ghosh, M. Mitchell, Portland State Univ.

This paper describes a genetic algorithm (GA) for segmenting of the prostate on pelvic computed tomography (CT) images. The images consist of slices from three-dimensional CT scans. Segmentation is typically performed manually on these images by an expert physician who uses his "learned" knowledge of organ shapes, textures and locations to delineate the prostate on these images. Using a GA brings the flexibility to incorporate new "learned" information into the segmentation process without modifying the fitness function that is used to train the GA. Currently the GA uses prior knowledge in the form of texture and shape of the prostate for segmentation. We compare and contrast our algorithm with a level-set based segmentation algorithm, thereby providing justification for using a genetic algorithm.

Each individual of the GA population represents a segmenting contour. Shape variability of the prostate derived from manually segmented

images is used to form a shape representation from which, an individual of the GA population is randomly generated. The fitness of each individual is evaluated based on the texture of the region it encloses. The segmenting contour that encloses the prostate region is considered more fit than others and is more likely to be selected to produce an offspring over successive generations of the GA run. This process of selection, crossover and mutation is iterated until the desired region is segmented. Results of 2D and 3D segmentation are presented and possible future work is also discussed here.

6914-152, Poster Session

Robust segmentation of tubular structures in medical images

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Segmentation of blood vessels is a challenging problem due to poor contrast, noise, as well as to their branching and changing geometry. Even harder the problem is when the vessel surface along a particular path through branching vasculature is of interest. This paper describes a robust semi-automatic approach to extract the surface between two or more user-supplied end points for tubular- or vessel-like structures. We first use a minimal path technique to extract the shortest path between the user-supplied points. This path is the global minimizer of an active contour model's energy along all possible paths joining the end-points. Subsequently, the surface of interest is extracted using an edge-based level set segmentation approach. To prevent leakage into adjacent tissues, the algorithm uses a diameter constraint that does not allow the moving front to grow wider than the predefined diameter. Some or all of the points constituting the extracted path(s) are automatically used as initialization seeds for the evolving level set function. To cope with any further leaks that may occur in the case of large variations of the vessel width between the user-supplied end-points, a freezing mechanism is designed to prevent the moving front to leak into undesired areas. The regions to be frozen are determined from few clicks by the user. The potential of the proposed approach is demonstrated on several synthetic and medical images.

6914-153, Poster Session

Segmentation of large periapical lesions toward dental computer-aided diagnosis in cone-beam CT scans

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Historically the field of Endodontics has been unable to determine if a periapical granuloma will heal with non-surgical methods. A recently proposed technique non-invasively classifies target lesions using cone-beam computed tomography (CBCT). Manual segmentation of these CBCT images for classification, however, is too time consuming and unreliable for real world adoption. State-of-the-art algorithms have been developed to address both biomedical and non-biomedical segmentation problems, but have not yet been applied to dentistry. Presented in this paper is the application of three such segmentation algorithms: a normalized cut algorithm based on a generalized eigenvalue problem, a graph cut algorithm implementing energy minimization techniques, and a random walks algorithm derived from discrete electrical potential theory. All three algorithms will be modified to globally segment three-dimensional images either using random or user provided seed points, and will be applied to dental CBCT images. Preliminary segmentation results of two-dimensional cross sections of a three-dimensional image are provided and the benefits and pitfalls of each algorithm will be highlighted.

6914-154, Poster Session

Segmentation of sonographic breast lesions: fuzzy cell-competition algorithm and bias field reduction

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Bias field is a common phenomenon in a breast sonogram. Although artifacts caused by bias field may carry important information, e.g., shadowing behind a lesion, they are generally disturbing in the process of automatic boundary delineation for sonographic breast lesions. This paper presents a new segmentation algorithm aiming to decompose the region of interest (ROI) into prominent components while estimating the bias field in the ROI. A prominent component is a contiguous region with a visually perceivable boundary, which might be a noise, an artifact, a substructure of a tissue or a part of breast lesion. The prominent components may be used as the basic constructs for a higher level segmentation algorithm to identify the lesion boundary.

The bias field in an ROI is modeled as a spatially-variant Gaussian distribution with a constant variance and spatially-variant means, which is a polynomial surface of order n . The true gray levels of the pixels in a prominent component are assumed to be Gaussian-distributed. The proposed algorithm is formulated as an EM-algorithm composed of two major steps. In the E-step, the ROI is decomposed into prominent components using a new fuzzy cell-competition algorithm based on the bias field and model parameters estimated in the previous M-step. In the M-step, the bias field and model parameters are estimated based on the prominent components derived in the E-step under a maximum a posteriori framework. The results show that the effect of bias field on segmentation has been reduced and better segmentation results have been attained.

6914-155, Poster Session

A novel geometric active contour model using segmented external force field

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In this paper, we propose a novel active contour model using an external force field to drive the motion of the contour toward the object boundaries. In the proposed method, the contours can be automatically initialized within the capture ranges of the objects in the image so that each of them can be attracted by the external force to an object boundary inside the corresponding capture range. The capture ranges is obtained from the segmented external force field. The proposed active contour model can be converted to a level set formulation. In the proposed level set formulation, we introduce a level set regularization term to maintain the stable evolution and therefore eliminate the need for reinitialization. Moreover, the proposed level set formulation allows for the use of binary step functions as the initial level set function. The binary step function is not only efficient to generate, but also necessary for the automatic initialization of the level set function using the segmented external force field. The proposed model is superior to the traditional active contour models for its fully automated applications and its desirable performance in the presence of weak object boundaries.

6914-156, Poster Session

Three-dimensional segmentation of bones from CT and MRI using fast level sets

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The main application is to segment bones from 3D CT and MRI images. Our main application is creation of 3D mesh models for finite element modeling. These surface and volume vector models can be used for further biomechanical processing and analysis. We selected a novel fast level set method because of its high computational efficiency, while preserving all advantages of traditional level set methods. Unlike in traditional level set methods, we are not solving partial differential equations (PDEs). Instead, the contours are represented by two sets of points, corresponding to the inner and outer edge of the object boundary. We have extended the original implementation to 3D, where the speed advantage over classical level set segmentation is even more pronounced. We could segment a CT image of 512x512x125 pixels in less than 20 s by this methods. It is approximately two orders of magnitude faster than standard narrow band algorithms. Our experiments with real 3D CT and MRI images presented in this paper showed high ability of the fast level set algorithm to solve complex segmentation problems.

6914-157, Poster Session

Segmentation of articular cartilages from knee MR images using graph cuts with propagation of hard constraints

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Knee osteoarthritis is the most common debilitating health condition affecting elderly population. MR imaging of the knee is highly sensitive for diagnosis and evaluation of the extent of knee osteoarthritis. Quantitative analysis of the progression of osteoarthritis is commonly based on segmentation and measurement of articular cartilage from knee MR images. Segmentation of the knee articular cartilage, however, is highly laborious and technically demanding, because the cartilage is of complex geometry and thin and small in size. To improve precision and efficiency of the segmentation of the cartilage, we have developed and tested a semi-automated segmentation method that is based on an s/t graph cut algorithm, which optimized a cost function on a slice level. The cost function was defined on a slice level integrating regional and boundary cues. While regional cues can encode any intensity distributions of two regions, "object" (cartilage) and "background" (the rest), boundary cues are based on the intensity differences between neighboring pixels. For 3D segmentation, segmentation determined at the initial slice was propagated to an adjacent slice to setup the hard constraints. The propagation is based on the likelihood of each pixel to be either "object" or "background". When our proposed semi-automated method was tested on patients' MR images (160 slices, 0.7 mm slice thickness), a considerable amount of segmentation time was saved with improved efficiency, compared to a manual segmentation approach.

6914-158, Poster Session

Segmentation and volumetric measurement of renal cysts and parenchyma from MR images of polycystic kidneys using multispectral analysis method

K. T. Bae, Univ. of Pittsburgh; P. Commean, Washington Univ.

Purpose: To develop and test a semi-automated, multispectral analysis (MSA) method for segmentation and volume measurement of renal cysts and parenchyma from MR images of the kidneys in subjects with autosomal dominant polycystic kidney disease (ADPKD)

Methods and Materials: MSA method was developed and applied to T1- and T2-weighted MR images of the kidneys. In this method, renal cysts and parenchyma were characterized and segmented for their characteristic T1 and T2 signal intensity differences. The performance of the MSA segmentation method was tested on ADPKD phantoms and patients. Segmented renal cysts and parenchyma volumes were measured and compared with reference standard measurements (fluid displacement method in the phantoms and stereology and region-based thresholding methods in patients).

Results: Renal cysts and parenchyma were segmented successfully with the MSA method. The volume measurements obtained with MSA were in good agreement with the measurements by other segmentation methods for both phantoms and subjects. The MSA method, however, was more time-consuming than the other segmentation methods because it required pre-segmentation image registration and tissue classification-determination steps.

Conclusion: With MSA, renal cysts and parenchyma can be segmented and measured volumetrically from MR images of ADPKD phantoms and subjects. Although the MSA method has the advantage of using multiple MR signal characteristics to facilitate the segmentation of different tissue types, it was more time-consuming than other segmentation methods that mainly rely on the operator's perception.

6914-159, Poster Session

Semi-automated segmentation of the prostate gland boundary in ultrasound images using a machine learning approach

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This paper presents a semi-automated algorithm for prostate boundary segmentation from three-dimensional (3D) ultrasound (US) images. The US volume is sampled into 36 slices which go through the center of the prostate and are separated at a uniform angular spacing of 5 degrees. The approach requires the user to select four points from the central slice (0 degrees) which are used to initialize a discrete dynamic contour (DDC) algorithm. A Support Vector Machine (SVM) is trained over the output of the DDC. The trained SVM classifies the next slice (at 5 degrees). The output of the SVM is refined using DDC. This process is repeated until all the slices have been segmented. The algorithm was tested on ten ex-vivo 3D US images of prostate glands embedded in a gelatin mold. Initial results show that the algorithm-based segmentation is comparable to manual segmentation.

6914-160, Poster Session

Multiscale hierarchical support vector clustering

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Clustering is the preferred choice of method in many applications, and support vector clustering (SVC) has proven efficient for clustering noisy and high-dimensional data sets. A method for multiscale hierarchical support vector clustering is demonstrated, using the recently emerged method for fast calculation of the entire regularization path of the support vector domain description. The method is illustrated on artificially generated data, but by changing only one parameter it can be tuned for detecting clusters in very high dimensional data, when a reasonable covariance kernel can be defined.

We applied the method for assessing angiogenesis from high resolution time series of magnetic resonance imaging data. The obtained results are robust in the presence of a high level of noise, while the need for parameter estimation is vastly reduced, compared to support vector clustering.

6914-161, Poster Session

Fast approximate level set evolution in arbitrary dimension

J. Malcolm, Georgia Institute of Technology; Y. Rathi, Harvard Medical School; A. Yezzi, A. Tannenbaum, Georgia Institute of Technology

The level set method is a popular technique used in medical image segmentation. However, the numerics involved make its use cumbersome. This paper proposes an approximate level set scheme that removes much of the computational burden while maintaining accuracy.

Abandoning a floating point representation for the signed distance function, we use the integral values $\{-1, 0, 1\}$ to represent the interior, zero level set, and exterior, respectively. For both cases of 2D and 3D imagery, we detail rules governing the evolution and maintenance of these three regions. Arbitrary energies can be implemented with the definition of three operations: initialize iteration, move points in, move points out.

This scheme has several nice properties. First, going from an energy to the implementation of its first variation is simple. Second, computations are only performed along the zero level set. Third, this approximate distance function representation requires only a few simple integer comparisons for maintenance. Fourth, smoothness regularization involves only a few integer calculations and may be handled apart from the energy itself. Fifth, the zero level set is represented exactly removing

the need for interpolation off the interface. Lastly, evolutions proceed on the order of microseconds per iteration on conventional uniprocessor workstations.

To highlight its accuracy, flexibility and speed, we demonstrate the technique on intensity-based segmentations under various statistical metrics as well as more complicated shape-based segmentations. Results for 3D imagery show the technique is fast even on image volumes.

6914-162, Poster Session

An accurate segmentation method for volumetry of brain tumor in 3D MRI

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Accurate volumetry of brain tumors in magnetic resonance imaging (MRI) is important for evaluating the interval changes in tumor volumes during and after treatment, and also for planning of radiation therapy. In this study, an automated volumetry method for brain tumors in MRI was developed by use of a new three-dimensional (3-D) image segmentation technique. First, the central location of a tumor was identified by a radiologist, and then a volume of interest (VOI) was determined automatically. To substantially simplify tumor segmentation, we transformed the 3-D image of the tumor into a two-dimensional (2-D) image by use of a "spiral-scanning" technique, in which a radial line originating from the center of the tumor scanned the 3-D image spirally from the "north pole" to the "south pole". The voxels scanned by the radial line provided a transformed 2-D image. We employed dynamic programming to delineate an "optimal" outline of the tumor in the transformed 2-D image. We then transformed the optimal outline back into 3-D image space to determine the volume of the tumor. The volumetry method was trained and evaluated by use of 16 cases with 35 brain tumors. The agreement between tumor volumes provided by computer and a radiologist was employed as a performance metric. Our method provided relatively accurate results with a mean agreement value of 88%.

6914-163, Poster Session

Automated segmentation of middle hepatic vein in non-contrast x-ray CT images based on an atlas-driven approach

T. Kitagawa, X. Zhou, T. Hara, H. Fujita, Gifu Univ. School of Medicine (Japan); R. Yokoyama, H. Kondo, Gifu Univ. Hospital (Japan); G. N. Lee, Gifu Univ. School of Medicine (Japan); M. Kanematsu, H. Hoshi, Gifu Univ. Hospital (Japan)

For the diagnosis of hepatic diseases, information of anatomical structures such as liver lobes, vessel tree is important. Although the media-enhanced CT images are widely used in clinical practice, the non-contrast X-ray CT images are more practical for the screening purpose. We are developing a computer-aided diagnosis (CAD) system to support the liver diagnosis based on non-contrast X-ray CT images. This paper proposes a new approach to segment the middle hepatic vein (MHV), a key structure (landmark) in separating the liver region into left and right lobes. Extraction and classification of hepatic vessels are difficult in non-contrast X-ray CT images because the contrast between hepatic vessels and other liver tissues is low. Our proposed approach includes the following three stages. (1) Construction of liver atlases of left and right liver lobes using manually extracted liver regions. (2) Fully-automated extraction of hepatic vessels using extracted liver regions and algorithm enhanced hepatic vessels. (3) Extraction of MHV using results of (1) and (2). This proposed approach was applied to 22 normal liver cases of non-contrast X-ray CT images. The preliminary results show that the proposed approach achieves a success rate of 50% (11 out 22 cases) for MHV extraction. The moderate success rate is due to the poor accuracy of the liver atlases which were constructed based on a small number of CT cases. The success rate can be improved by using a larger database in constructing the liver atlases.

6914-164, Poster Session**A deformable model-based minimal path segmentation method for kidney MR images**

K. Li, B. Fei, Case Western Reserve Univ.

We developed a new minimal path segmentation method for mouse kidney MR images. We used dynamic programming and minimal path segmentation approach to detect the optimal path within a weighted graph between two end points. We used an energy function to combine distance and gradient information to guide the marching curve and thus evaluate the best path and span a broken edge. We developed an algorithm to automate the placement of initial end points. Dynamic programming was used to automatically optimize and update end points in the procedure of searching curve. A deformable model was generated using principle component analysis (PCA) and it was used as the prior knowledge for the selection of initial end points and for the evaluation of the best path. The method has been tested for kidney MR images of 44 mice. To quantitatively assess the automatic segmentation method, we compared the results with manual segmentation. The average and standard deviation of the overlap ratios is $95.19 \pm 0.03\%$. The distance error between the automatic and manual segmentation is 0.82 ± 0.41 pixel. The automatic minimal path segmentation method is fast, accurate, and robust. It provides a useful tool for quantification and characterization of polycystic kidney disease in transgenic mice.

6914-165, Poster Session**Automated lung tumor detection and quantification for respiratory gated PET/CT images**

J. Wang, Florida International Univ.; J. Franquiz, Radiological Physics of South Florida, Inc.; A. J. McGoron, Florida International Univ.

Purpose: Develop and validate an automatic algorithm for the detection and functional assessment of lung tumors on three-dimensional slices derived from respiratory gated PET/CT images. Method and Materials: First the algorithm will automatically segment lung regions in CT images, identifies and localizes focal increases of activity in lung regions of PET images at each gated bin. Once the tumor voxels have been determined, an integration algorithm will include all the tumor counts collected at different bins within the respiratory cycle into one reference bin. Then the total activity (Bq), concentration (Bq/ml), functional volume (ml) and standard uptake values (SUV) were calculated for each tumor on PET images. Validation of the automatic algorithm was demonstrated by conducting experiments with the computerized 4D NCAT phantom and with a lung-chest phantom using GE PET/CT System at Baptist Hospital of Miami. Tumor variables to be controlled were: volume, total number of counts (activity), maximum and average number of counts, these values were the gold standard to which the results of the algorithm was compared. Tumors were also controlled with different respiratory periods and amplitudes. Results: Validation, feasibility and robustness of the algorithm were demonstrated. With the algorithm, the best compromise between short PET scan time and reduced image noise can be achieved, makes quantification and clinical analysis more precise and faster.

6914-166, Poster Session**Efficient curvature estimations for real-time (25 Hz) segmentation of volumetric ultrasound data**

C. R. Wagner, Cybernet Systems Corp.; D. P. Perrin, Harvard Univ.

This paper discusses implementation of active deformable models for real-time volumetric segmentation. We demonstrate that using an efficient approximation of local curvature in the implementation of dynamic contours leads to real-time volumetric segmentation on mid-range off-the-shelf hardware without the use of specialized graphics hardware.

While Moore's law has eliminated the need for algorithm optimization when computing 2D dynamic contours, real-time 3D image analysis remains limited by computational bottlenecks. We have investigated segmenting 3D volumetric ultrasound streams from echocardiograph machines (Phillips Medical Systems, Andover, MA) for analysis of cardiac function. The system uses a 3000 element array that produces 20-25

volumes per second at a resolution of $128 \times 48 \times 204$ voxels requiring efficient algorithms and implementations to track moving cardiac tissue in real-time. We present a 3D image segmentation algorithm based on an efficient implementation of 2D dynamic contours, and timing validation using both water tank phantoms and in-vivo images.

Our dynamic contour implementation relies on an optimal estimation of local curvature. We discuss the role of curvature approximations with respect to optimal contour point motions and step size in real-time implementations. Active dynamic contours rely on internal and external "forces" that influence the motion of contour points. External force components relate the underlying image data, model priors, and user input to local contour shape.

Internal force components act to regularize (smooth) the contour or surface. This smoothness provides reasonable shape estimates in the absence of appropriate or conflicting external component input. We investigate performance of active contours using different approximations of smoothness.

6914-167, Poster Session**Semi-automatic segmentation and modeling of the cervical spinal cord for volume quantification in multiple sclerosis patients from magnetic resonance images**

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Spinal cord (SC) tissue loss is known to occur in some patients with multiple sclerosis (MS), resulting in SC atrophy. Currently, no measurement tools exist to determine the magnitude of SC atrophy from Magnetic Resonance Images (MRI). We have developed and implemented a novel semi-automatic method for quantifying the cervical SC volume (CSCV) from Magnetic Resonance Images (MRI) based on level sets. The image dataset consisted of SC MRI exams obtained at 1.5 Tesla from 12 MS patients (10 relapsing-remitting and 2 secondary progressive) and 12 age- and gender-matched healthy volunteers (HVs). 3D high resolution image data were acquired using an IR-FSPGR sequence acquired in the sagittal plane. The mid-sagittal slice (MSS) was automatically located based on the entropy calculation for each of the consecutive sagittal slices. The image data were then pre-processed by 3D anisotropic diffusion filtering for noise reduction and edge enhancement before segmentation with a level set formulation which did not require re-initialization. The developed method was tested against manual segmentation (considered as a gold standard) and intra-observer and inter-observer variability were evaluated.

6914-168, Poster Session**Integrating local voxel classification and global shape models for medical image segmentation**

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Segmentation of anatomical structures is a prerequisite for many medical image analysis tasks. We propose a method that integrates local voxel classification and global shape models. The method starts by computing a local feature vector for every voxel and mapping this, via a classifier trained from example segmentations, to a probability that the voxel that it belongs to the structure to be segmented. Next, this probabilistic output entered into a global shape model.

This shape model is constructed by mapping aligned blurred versions of reference segmentations of the training data into a vector space and applying principal component analysis (PCA). The mapping onto a vector space that is applied guarantees valid results from the PCA. An advantage of using such a shape model is that there is no need to define corresponding landmarks on all training scans, which is a hard task on 3D data.

Segmentation of unseen test data is performed by a least squares fit of the results of the voxel classification, after alignment and blurring, into the PCA space. The result of this procedure is for each voxel a probability

that it belongs to the structure to be segmented conditioned on both local and global information. We demonstrate the effectiveness of the method on segmentation of lungs containing pathologic abnormalities in 3D CT data.

6914-169, Poster Session

Lung lobe and segmental lobe extraction from 3D chest CT datasets based on figure decomposition process

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In this paper, we present a method for segmenting lung lobe regions and segmental lobe regions from 3D CT datasets. In a CAD system for the chest, it is very important to understand structures of the chest by a computer. It is required to develop algorithms that automatically segment organ regions of the chest area from input 3-D chest CT datasets. This paper tries to divide lung regions into lung lobe regions and segmental lobe regions by the figure decomposition process and the Voronoi division process. In this method, we enhance sheet structures on CT images by using eigenvalues of a Hessian matrix. Also, the lung regions are segmented by simple thresholding and morphological filtering. Then, we subtract sheet structures from the lung regions. By applying the figure decomposition process, we obtain each lung lobe region. Segmental lobe regions are obtained by the Voronoi figure decomposition process using bronchial branch information. The proposed method was applied to thirteen cases of 3-D chest CT images. Experimental results showed that the proposed method can extract lung lobe regions and segmental lobe regions even for cases of incomplete fissure or over-extraction of interlobar pleura.

6914-170, Poster Session

A novel method for automatic detection of glaucoma from color fundus images

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The main cause of glaucoma is the increasing intraocular pressure, which can be measured by the cup-to-disc ratio. As the glaucoma progresses, the area of cup, or the depression, increases. Therefore, a patient with a high ratio has more damage. The purpose of this paper is to propose a new method for automatic evaluation of glaucoma that provides dependable cup-to-disc ratio for assisting physicians or eye doctors in diagnosing the presence, severity and progression of glaucoma. We first detect the optic disc by using the image color histogram and the center of convergence of major vessels, and estimate the contour and area of the disc by adaptive region growing and morphology operations. Samples of color domains within the disc are then selected to represent the three objects: the disc, the cup and the vessels. The spatial-color compactness degree (SCD), which measures the connectedness and the homogeneity of a color subset, is used to segment the regions of the disc, the cup and the vessels based on the selected color samples. The cup-to-disc ratio is measured by AC/AD, where AC is the area of the cup, and AD is the area of the disc. A glaucoma candidate is identified when $AC/AD > 0.05$. 100 images with 22 having glaucoma are used to test the proposed method. The result achieves 86.4% true positive rate and 97.4% true negative rate. Larger samples of images will be used to test the proposed method, and the result will be provided with the manuscript.

6914-171, Poster Session

A novel approach to fracture risk assessment in osteoporosis by ROI-oriented application of the Minkowski functionals to dual x-ray absorptiometry scans of the hip

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Fractures of the proximal femur represent the worst complication in

osteoporosis with a mortality rate of up to 50% during the first post-traumatic year.

Bone mineral density (BMD) as obtained from dual energy x-ray absorptiometry (DXA) is a good predictor of fracture risk. However, there is a considerable overlap in the BMD-results between individuals who have fractured and those who have not. As DXA uses highly standardized radiographic projection images to obtain the densitometric information, it can be postulated that these images contain much more information than just mineral density. Lately, geometric dimensions, e.g. hip axis length (HAL) or femoral neck axis length (FNAL), are considered in conjunction with BMD, which may allow to enhance the predictive potential of bone mass measurements.

In recent studies we successfully introduced a novel methodology for topological analysis of multi-dimensional graylevel datasets, that, for instance, allows to predict the ultimate mechanical strength of femoral bone specimens. The new topological parameters are based on the so called Minkowski Functionals (MF), which represent a set of topographical descriptors that can be used universally. Since the DXA-images are multi-graylevel datasets in 2D obtained in a standardized way, they are ideally suited to be processed by the new method.

In this study we introduce a novel algorithm to evaluate DXA-scans of the proximal femur using quantitative image analysis procedures based on the MF in 2D. The analysis is conducted in four defined regions of interest in analogy to the standard densitometric evaluation. The objective is to provide a tool to identify individuals with critically reduced mechanical competence of the hip. The result of the new method is compared with the evaluation bone mineral density obtained by DXA, which - at present - is the clinical standard of reference.

6914-172, Poster Session

Reconstructing liver shape and position from MR image slices using an active shape model

M. Fenchel, Siemens Medical Solutions (Germany) and Eberhard Karls Univ. Tübingen (Germany); S. Thesen, Siemens Medical Solutions (Germany); A. Schilling, Eberhard Karls Univ. Tübingen (Germany)

We present an algorithm for fully automatic reconstruction of 3D position, orientation and shape of the human liver from a sparsely covering set of n 2D MR slice images. Reconstructing the shape of an organ from slice images can be used for scan planning, for surgical planning or other purposes where 3D anatomical knowledge has to be inferred from sparse slices. The algorithm works by adapting an active shape model of the liver surface to a given set of slice images. The active shape model was created using a training set of semi-manual segmentations of the liver from a group of 23 volunteers. The segmentations were done on T1-weighted morphological MR image data. Searching for the optimal shape model that best fits to the image data is done by maximizing a similarity measure based on a local appearance model at the surface. Two different algorithms for the active shape model search are proposed and compared: both algorithms seek to maximize the a-posteriori probability of the grey value appearance at the surface while constraining the surface to the space of valid shapes. The first algorithm works by using grey value profile statistics in normal direction. The second algorithm uses average and variance images to calculate the local surface appearance for the given search direction on the fly. Both algorithms are validated by fitting the active shape model to abdominal 2D slice images in leave-all-in and leave-one-out scenarios and comparing the results to the manual segmentations, as the ground truth, and to surfaces obtained from active shape model searches from 3D image data. Those latter surfaces can be considered to be the best achievable results given the active shape and its local appearance model. The results of the comparison turn out to be competitive and promising.

6914-173, Poster Session

Tracheal stent prediction using statistical deformable models of tubular shapes

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Tracheal stenosis is a narrowing of the trachea that impedes normal

breathing. Tracheotomy is one solution, but subjects patients to intubation. An alternative technique employs tracheal stents, which are tubular structures that push the walls of the stenotic areas to their original location. They are implanted with endoscopes, therefore reducing the surgical risk to the patient. Stents can also be used in tracheal reconstruction to aid the recovery of reconstructed areas.

Correct preoperative stent length and diameter specification is crucial to successful treatment, otherwise stents might not cover the stenotic area nor push the walls as required. The level of stenosis is usually measured from inside the trachea, either with endoscopes or with image processing techniques that, eg compute the distance from the centre line to the walls of the trachea. These methods are not suited for the prediction of stent sizes because they can not trivially estimate the healthy calibre of the trachea at the stenotic region. We propose an automatic method that enables the estimation of stent dimensions with statistical shape models of the trachea. An average trachea obtained from a training set of CT scans of healthy tracheas is placed in a CT image of a diseased person. The shape deforms according to the statistical model to match the walls of the trachea, except at stenotic areas. Since the deformed shape gives an estimation of the healthy trachea, it is possible to predict the size and diameter of the stent to be implanted in that specific subject.

6914-174, Poster Session

Vertebral classification using localized pathology-related shape model

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Radiographs of the spine are frequently examined for assessment of vertebral abnormalities. Features like osteophytes (bony growth of vertebra's corners), and disc space narrowing are often used as visual evidence of osteoarthritis or degenerative joint disease. These symptoms result in remarkable changes in the shapes of the vertebral body. Statistical analysis of anatomical structure has recently gained increased popularity within the medical imaging community, since they have the potential to enhance the automated diagnosis process. In this paper, we present a novel method for computer-assisted vertebral classification using a localized, pathology-related shape model. The new classification scheme is able to assess the condition of multiple vertebrae simultaneously, hence is possible to directly classify the whole spine anatomy according to the condition of interest (anterior osteophytes). At the core of this method is a new localized shape model that uses concepts of sparsity, dimension reduction, and statistical independence to extract sets of localized modes of deformations specific to each of the vertebrae under investigation. By projection of the shapes onto any specific set of deformation modes (or basis), we obtain low-dimensional features that are most directly related to the pathology of the vertebra of interest. These features are then used as input to a support vector machine classifier to classify the vertebra under investigation as normal or upnormal. Experiments are conducted using contours from digital x-ray images of five vertebrae of lumbar spine. The accuracy of the classification scheme is assessed using the ROC curves. An average specificity of 96.8 % is achieved with a sensitivity of 80 %.

6914-175, Poster Session

Local curvature scale: a new concept of shape description

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Shape description plays a fundamental role in computer vision and pattern recognition, especially in the fields of shape analysis, image segmentation, and registration. Shape representations must be unique, complete and should be able to reflect the differences between similar objects while abstracting from detail and keeping the basic features. Although many methods for shape description exist, they are usually application dependent. Our method of boundary shape description is based on the notion of curvature-scale, which is a new local scale concept, defined at each boundary element. From this representation, we can extract special points of interest such as convex and concave corners, straight lines, circular segments, and inflection points. This

method is different from existing methods of curvature estimation and can be directly applied to digital boundaries without requiring prior approximation of the boundary. The results show that it produces a complete boundary shape description capable of handling different levels of shape detail. It also has numerous potential applications such as automatic landmark tagging which becomes necessary to build model-based approaches toward the goal of organ modelling and segmentation. The method is applicable to spaces of any dimensionality, although we have focused in this paper on 2D shapes.

6914-176, Poster Session

Conditional-mean initialization using neighboring objects in deformable model segmentation

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Most model-based segmentation methods find a target object in a new image by constructing an objective function and optimizing it using a standard minimization algorithm. In general, the objective function has two penalty terms: 1) for deforming a template model and 2) for mismatch between the trained image intensities relative to the template model and the observed image intensities relative to the deformed template model in the target image. Establishing an objective function with a global minimum at the desired segmentation result is challenging. However, even such an objective function is typically non-convex due to the complexity of the intensity patterns and the many structures surrounding the target object. Therefore, unless the optimization starts at a point close to the global minimum of the objective function, it can be difficult to find that minimum.

When good segmentations of objects adjacent to the target object are available, we can exploit their relation to the target object to produce an initialization of position, orientation, and even deformation of the target object. The initialization we propose is the mean of the conditional probability distribution of the target object model given neighboring object models when target objects are aligned by their neighboring objects. We describe a new method for learning this conditional probability on m-rep deformable models and its application to prostate initialization in CT. Our results indicate improvement of the prostate initialization using bladder as a neighboring object.

6914-177, Poster Session

An integrated multimodal prostate segmentation scheme by combining magnetic resonance spectroscopy and active shape models

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Segmentation of the prostate boundary on clinical images is useful in a large number of applications including calculating prostate volume during biopsy, tumor estimation and treatment planning. Manual segmentation of the prostate boundary is, however, time consuming and subject to inter and intra reader variability. Multi-modal Magnetic Resonance (MR) imaging (MRI) including structural MRI and MR Spectroscopy (MRS) has recently emerged as promising modalities for detection of prostate cancer (CaP). In this paper we present a novel scheme for accurate and automated segmentation of the prostate on in vivo 1.5 Tesla multimodal MRI. The segmentation algorithm consists of two steps: (i) using a hierarchical scheme on MRS to obtain a bounding box, and (ii) using this bounding box as an initialization for an Active Shape Model (ASM) search. The hierarchical MRS segmentation scheme first identifies spectra corresponding to locations within the prostate, and the algorithm prunes non-informative MR spectra (those lying outside the prostate) by projecting the spectral data non-linearly into a lower dimensional space. The spatial extent of the prostate spectra so identified are used as the initial starting location for the ASM. The ASM is trained by identifying user-selected landmarks on the prostate boundary on T2 MRI images. Mutual information (MI) is used to drive the ASM as opposed to the traditional Mahalanobis distance. By using affine transformations (shear, rotation, scaling, translation) the model shape is deformed. Finer adjustments are made by changing the shape within +/- 2.5 standard deviations from the

mean shape, using the trained ASM. We demonstrate that without the accurate initialization for the ASM provided by the MRS pruning scheme, it is almost impossible to segment out the exact prostate boundaries in an automated fashion. Cross validation on 150 prostate slices yields an average segmentation sensitivity, specificity, overlap, and positive predictive value of 89%, 86%, 83%, and 93% respectively. The method is fully automated, robust to system parameters, and computationally efficient.

6914-178, Poster Session

Comparison of statistical shape models built on correspondence probabilities and one-to-one correspondences

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A fundamental problem when computing statistical shape models is the determination of correspondences between the observations of the associated data set. Often, homologies between points that represent the surfaces are assumed which might lead to imprecise mean shape and variability results. We propose an approach where exact correspondences are replaced by evolving correspondence probabilities. These are the basis for a novel algorithm that computes a generative statistical shape model. We developed a unified Maximum A Posteriori (MAP) framework to compute the model parameters ('mean shape' and 'modes of variation') and the nuisance parameters which leads to an optimal adaptation of the model to the set of observations. The registration of the model on the observations is solved using the Expectation Maximization - Iterative Closest Point algorithm which is based on probabilistic correspondences and proved to be robust and fast. The alternated optimization of the MAP explanation with respect to the observation and the generative model parameters leads to very efficient and closed-form solutions for (almost) all parameters. A comparison with a statistical shape model which is built using the ICP registration algorithm and a PCA shows the superior performance measures of our method.

6914-179, Poster Session

Studying the effect of noise on the performance of 2D and 3D texture measures for quantifying the trabecular bone structure as obtained with high resolution MR imaging at 3 Tesla

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The visualization and quantification of the trabecular bone structure plays an important role for better understanding the disease- or drug-induced changes of the bone in the context of osteoporosis. The recent development of clinical 3.0 Tesla MRI has been stimulated by promise of increased signal-to-noise ratio (SNR). It is not yet known whether higher SNR improves the quantitative image analysis or if other 3.0T-specific effects (e.g. increased susceptibility, higher resolution) can be beneficial for the quantitative image analysis.

In this in vitro study we performed a detailed analysis of the effect of noise on the performance of 2D histomorphometric measures (BV/TV, Tb.N, Tb.Th and Tb.Sp) and a 3D nonlinear measure, namely scaling indices, with respect to their correlation with biomechanical properties of the bone, e.g. the maximum compressive strength (MCS). 3.0T MR images of a sample of 31 trabecular bone specimen of human calcanei were acquired. Maximum compressive strength (MCS) was determined in a biomechanical test. Seven artificial data sets with superimposed noise of different levels were generated. For all data the 2D and 3D texture measures were calculated.

We found for the undisturbed case (SNR=7.3) comparable good correlation with MCS for BV/TV ($r=0.82$), Tb.Sp ($r=-0.81$), Tb.Th ($r=0.82$) and scaling indices ($r=0.08$), whereas Tb.N performed worse ($r=0.63$). Interestingly enough, the correlations for all texture parameters stayed nearly constant up to SNR=2.3. Only at higher noise levels a significant decrease in the correlation was observed.

In conclusion, the performance of both the 2D and 3D texture measures was relatively insensitive to superimposed artificial noise. Thus, our findings suggest that MR sequences for visualizing bone structures at 3T should rather be optimised to spatial resolution (or scanning time) than to SNR.

6914-180, Poster Session

Comparison and combination of scaling index method and Minkowski functionals in the analysis of high resolution magnetic resonance images of the distal radius in vitro

I. N. Sidorenko, Max-Planck-Institut für extraterrestrische Physik (Germany); J. Bauer, D. Mueller, E. J. Rummeny, Technische Univ. München (Germany); R. A. Monetti, Max-Planck-Institut für extraterrestrische Physik (Germany); F. Eckstein, Paracelsus Medizinische Privatuniv. (Austria); C. W. Raeth, Max-Planck-Institut für extraterrestrische Physik (Germany)

High resolution magnetic resonance imaging can reveal the major characteristics of trabecular bone. The quantification of this trabecular micro architecture can be useful for better understanding the progression of osteoporosis and improve its diagnosis. In the present work we applied the scaling index method and Minkowski Functionals for analysing 3D images of 48 distal radius specimens in vitro. For both methods, the correlation with the maximum compressive strength as determined in a biomechanical test and the diagnostic performance with regard to the spine fracture status were calculated. Both local SIM and global MF methods showed significantly better results compared to bone mineral density measured by quantitative computed tomography, which is a standard clinical parameter for the diagnosis of osteoporosis. The receiver operating characteristic analysis for differentiating fractured and non-fractured subjects revealed area under the curve (AUC) values of 0.716 for BMD, 0.897 for SIM and 0.911 for MF. The correlation coefficients with MCS were 0.6771 for BMD, 0.843 for SIM and 0.772 for MF. We simulated the effect of perturbations, namely noise effects and intensity variations. Overall, the MF method was more sensitive to noise than SIM. A combination of SIM and MF methods could, however, increase AUC values from 0.85 to 0.89 and correlation coefficients from 0.71 to 0.82.

In conclusion, local SIM and global MF techniques can successfully be applied in analysing of HRMR image data. Since these methods are complementary, their combination offers a new possibility of describing MR images of the trabecular bone, especially noisy ones.

6914-181, Poster Session

Semi-synthetic digital phantoms incorporating natural structured noise and boundary inhomogeneities

S. Tan, M. M. Ward, National Institutes of Health

Validating segmentation algorithms remains a difficult problem. Manual segmentation taken as gold standard is time-consuming and can still be contentious especially in the case of complex 3D objects and in the presence of important partial volume effect (PVE). In contrast digital phantoms have well-defined built-in boundaries even when PVE is simulated. However their degree of realism is questionable. In particular the rich natural structures inside an object that constitute one of the most difficult obstacles to segmentation are to this day too complex to model. A new method for constructing semi-synthetic digital phantoms was recently proposed that incorporates natural structured noise and boundary inhomogeneities. However only one phantom was presented and validation was lacking. In the present work we constructed 5 phantoms of vertebral bodies. Validation of phantoms should test their ability to predict how an algorithm will perform when confronted to real data. Our phantoms were used to compare the performance of two

level set based segmentation algorithms and find the parameters that optimize their performances. We validated the phantoms by correlating the results obtained on them with those obtained on 50 real vertebrae. We show that: 1) the phantoms accurately predict which segmentation algorithm will perform better with real clinical data. 2) by combining the results obtained by the 5 different phantoms we can extract useful predictions about the performance of different sets of parameters on real data. Because the phantoms possess the high variability of real data, predictions based on only one phantom would fail.

6914-182, Poster Session

Evaluation of accuracy in partial volume analysis of small objects

J. Rexilius, H. Peitgen, MeVis Research GmbH (Germany)

Accurate and robust assessment of quantitative parameters is a key issue in many fields of medical image analysis, and can have a direct impact on diagnosis and treatment monitoring. Especially for the analysis of small structures such as focal lesions in patients with Multiple Sclerosis (MS), the finite spatial resolution of imaging devices is often a limiting factor that results in a mixture of different tissues, known as partial volume effect (PVE).

We propose a new method that allows for an accurate quantification of medical image data, focusing on a dedicated model for PVE. Today, a widely accepted model assumption is that of a uniformly distributed linear mixture of pure tissues. However, several works have clearly shown that this is not an appropriate choice in many cases. To this end, we introduce a generalization of current approaches to medical image analysis based on the Beta distribution. Furthermore, we present a new classification scheme based on intensity features, providing a robust initial estimate of the proper model parameters, even in cases of objects with predominant PVE. A maximum likelihood based clustering algorithm is employed, which results in a robust and fast volume estimate. Several experiments are carried out on more than 100 synthetic images as well as data sets of a healthy volunteer with incorporated realistic digital lesion phantoms. Furthermore, a detailed comparison of current mixture models with our new approach is performed.

6914-183, Poster Session

A software assistant for the design of realistic software phantoms

J. Rexilius, O. Konrad-Verse, H. Peitgen, MeVis Research GmbH (Germany)

Segmentation and quantification of medical image data are difficult problems in image analysis. Especially an accurate and robust assessment of quantitative parameters is a key issue in many fields, and can have a direct impact on diagnosis and treatment planning. To this end, physical and software phantom data sets have become an integral tool during the design, implementation, and optimization of new algorithms. Unfortunately, a common research resource has not been established until now for many applications.

In this work we propose a software assistant for the development of realistic software phantoms. Our aim is an easy to use tool with an intuitive user interface. Furthermore, we provide a software for other researchers including a common basis of reference data, which facilitates a standardized and objective validation of performance and limitations of own developments as well as the comparison of different methods. The fundamental phantom design focuses on objects that can be incorporated into a given background. This can either be a homogeneous artificial background, or an actual volunteer or patient data set. For each phantom the exact ground truth of the investigated object is available, which provides us with an excellent tool for the generation of realistic data sets. Several experiments are carried out for a number of different applications including software phantoms of small, hyperintense brain lesions, focusing on MS lesions, as well as software phantoms of liver metastases.

6914-44, Session 8

Image intensity standardization in 3D rotational angiography and its application to vascular segmentation

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Knowledge-based vascular segmentation methods typically rely on a pre-built training set of segmented images, which is used to estimate the probability of each voxel to belong to a particular tissue. In 3D Rotational Angiography (3DRA) the same tissue can correspond to different intensity ranges depending on the imaging device, settings and contrast injection protocol. As a result, pre-built training sets do not apply to all images and the best segmentation results are often obtained when the training set is built specifically for each individual image. We present an Image Intensity Standardization (IIS) method designed to ensure a correspondence between specific tissues and intensity ranges common to every image that undergoes the standardization process. The method applies a piecewise linear transformation to the image that aligns specific landmarks automatically identified on the intensity histogram to the ones identified on a histogram taken as reference. The reference histogram is obtained by averaging histograms and landmark locations extracted from a number of high quality images. This is a pre-processing step that allows employing a training set built on a limited number of standardized images for the segmentation of standardized images which were not part of the training set. The effectiveness of the presented IIS technique in combination with a well validated knowledge-based vasculature segmentation method is quantified on a variety of 3DRA images depicting cerebral arteries and intracranial aneurysms. The proposed IIS method offers a solution to the standardization of tissue classes in routine medical images and effectively improves automation and usability of knowledge-based vascular segmentation algorithms.

6914-45, Session 8

Fast bias field estimation by localized Lloyd-Max quantization

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Bias field reduction is a common problem in medical imaging. A bias field usually manifests itself as a smooth intensity variation across the image. The resulting image inhomogeneity is a severe problem for posterior image processing and analysis techniques such as registration or segmentation. In this paper, we present a novel debiasing technique based on localized Lloyd-Max quantization. Thereby, the local bias is modelled as a multiplicative field and is assumed to be slowly varying. The method is based on the assumption that the local, undegraded histogram is characterized by a limited number of gray values. The goal is then to find the discrete intensity values such that spreading those values according to the local bias field reproduces the global histogram as good as possible. We show that our method is capable of efficiently reducing (even strong) bias fields in a fast way.

6914-46, Session 8

Feature-preserving artifacts removal from dermoscopy images

H. Zhou, Georgia Institute of Technology; M. Chen, R. Gass, Intel Research Lab. Pittsburgh; J. M. Rehg, Georgia Institute of Technology; L. Ferris, J. Ho, L. M. Drogowski, Univ. of Pittsburgh Medical Ctr.

Dermoscopy, also called surface microscopy, is a non-invasive imaging procedure developed for early screening of skin cancers.

With recent advances in skin imaging technologies and development of new image processing techniques, there has been a significant increase of interest in computer-aided diagnosis of pigmented skin lesions from dermoscopy images. Such diagnosis requires the identification of over one hundred cutaneous morphological features. However, computer procedures designed for extracting and classifying these intricate features can be distracted by the presence of artifacts like hair, ruler markings, and air bubbles.

Therefore, reliable artifact removal is an important pre-processing step for improving the performance of computer-aided dermoscopy diagnosis. In this paper, we present a new scheme that automatically detects and removes hairs and ruler markings from dermoscopy images. Moreover, our method also addresses the issue of preserving morphological features during the artifact removal process. The key component of our methods include explicit curvilinear structure detection and modeling, as well as feature guided exemplar-based inpainting. We experiment on a number of dermoscopy datasets and demonstrate that our method produces superior results compared to existing artifact removal procedures.

6914-47, Session 8

A quantitative performance measure for the clinical evaluation of comb structure removal algorithms for flexible endoscopy

S. Rupp, Fraunhofer Institute for Integrated Circuits IIS (Germany)

Modern techniques for technical inspection as well as medical diagnostics and therapy in keyhole-surgery scenarios make use of flexible endoscopes. Common to both application fields are very small natural or man-made entry points to the observed scene, as well as the complexity of the hollow itself. These make the use of rigid lens-based endoscopes or tip chip videoscopes impossible. Due to the fact that the fiber-optic image guide of a flexible endoscope introduces a comb structure to the acquired images, many research has been devoted to algorithms for an effective removal of these artefacts. Oftentimes, this research has been motivated by the fact, that the comb structure prevents an application of some well-established methods offered by the computer vision and image processing community. Unfortunately, the performance of the presented approaches are commonly visually evaluated or with respect to proprietary, non-standardized metrics and thus, the performances of individual algorithms are hard to compare with each other. For this reasons, we propose a performance measure for fiber-optic imaging devices that has been motivated by the physics of optics. In this field, an optical system is frequently described by linear systems theory and the system's quality can be expressed by its transfer function. The determination of this transfer function has been standardized by the ISO for lens based imaging systems and represents a widely accepted measure for the quality of such systems. In this contribution, we present adapted methods that account for the artefacts introduced by the image conductor of fiber-optic imaging systems and thus enable a standardized performance evaluation. Finally, we demonstrate its use by comparing two recent state of the art comb structure removal algorithms, each of them being a representative of a spatial and a frequency domain method, respectively.

6914-48, Session 8

Adaptive algorithms for digital mammogram enhancement

R. Peng, P. K. Varshney, H. Chen, Syracuse Univ.; J. H. Michels, JHM Technologies, LLC

As a fundamental step in computer-aided diagnosis, image enhancement can be very helpful in detecting and diagnosing breast cancers. This paper presents several adaptive mammogram enhancement algorithms that attempt to improve contrast and at the same time maintain similarity. The basic enhancement strategy automatically sets a threshold, dividing a mammogram into regions of interest (ROI) and background. Adaptive gray level stretching techniques are used in the ROI and background respectively to enhance contrast and reduce distortion the enhancement may produce. Weighted mean gray value and fuzzy cross-point of the mammogram are calculated and employed as thresholds. Contrasts of the two resulting mammograms are significantly improved. Next, we develop a number of strategies to further enhance digital mammograms. These strategies include algorithm fusion, iterative enhancement and threshold determination based on statistical decision theory. A novel quality metric combining five sub-metrics is also developed that yields evaluation results more consistent with visual evaluation than some existing criteria. Using various abnormal mammograms from the MIAS database, our adaptive algorithms prove to be more robust and yield superior performance when compared with six representative enhancement approaches.

6914-49, Session 9

Model-based biomedical image analysis (Keynote)

J. S. Duncan, Yale Univ.

The development of methods to accurately and reproducibly recover useful quantitative information from medical images is often hampered by uncertainties in handling the data related to: image acquisition parameters, the variability of normal human anatomy and physiology, the presence of disease or other abnormal conditions, and a variety of other factors. This talk will review image analysis strategies that make use of models based on geometrical and physical/biomechanical information to help constrain the range of possible solutions in the presence of such uncertainty. The discussion will be focused by looking primarily at several problem areas in the realms of neuroanatomical structure analysis and cardiac function analysis, with an emphasis on image segmentation and motion/deformation tracking. The presentation will include a description of the problem areas and visual examples of the image datasets being used, an overview of the mathematical techniques involved and a presentation of results obtained when analyzing actual patient image data using these methods. Emphasis will be placed on how image-derived information and appropriate modeling can be used together to address the image analysis and processing problems noted above.

6914-50, Session 9

Adaptive directional region growing segmentation of the hepatic vasculature

Q. Shang, B. M. Dawant, Vanderbilt Univ.

Accurate analysis of the hepatic vasculature is of great importance for many medical applications, such as liver surgical planning and diagnosis of tumors and/or vascular diseases. Vessel segmentation is a pivotal step for morphology and topology analysis of the vascular systems. Physical imaging limitations together with the inherent geometrical complexity of the vessels make the problem challenging. In this paper, we propose a series of methods and techniques that separate and segment the portal vein and the hepatic vein from CT images, and extract the centerlines of both vessel trees. We compare the results obtained with our iterative segmentation-and-reconnection approach with those obtained with a traditional region growing method, and we show that our results are substantially better.

6914-51, Session 9

Quantitative growth measurement of lesions in hepatic interval CT exams

S. Sarkar, R. Narayanan, H. Park, B. Ma, P. H. Bland, C. R. Meyer, Univ. of Michigan Health System

Standard clinical radiological techniques for determining lesion volume changes in interval exams are, as far as we know, quantitatively non-descriptive or approximate at best. We investigate two new registration based methods that help sketch an improved quantitative picture of lesion volume changes in hepatic interval CT exams. The first method, Jacobian Integration, employs a constrained Thin Plate Spline warp to compute the deformation of the lesion of interest over the intervals. The resulting jacobian map of the deformation is integrated to yield the net lesion volume change. The technique is fast, accurate and requires no segmentation, but is sensitive to misregistration. The second scheme uses a Weighted Gray Value Difference image of two registered interval exams to estimate the change in lesion volume. A linear weighting and trimming curve is used to accurately account for the contribution of partial voxels. This technique is insensitive to slight misregistration and useful in analyzing simple lesions with uniform contrast or lesions with insufficient mutual information to allow the computation of an accurate warp. The methods are tested on both synthetic and in vivo liver lesions and results are evaluated against estimates obtained through careful manual segmentation of the lesions. Our findings so far have given us reason to believe that the estimators are reliable. Further experiments on numerous in vivo lesions will probably establish the improved efficacy of these methods in supporting earlier detection of new disease or conversion from stable to progressive disease in comparison to existing clinical estimation techniques.

6914-52, Session 9**Liver segmentation combining Gabor filtering and traditional vector field snake**

A. M. Mintz, Carnegie Mellon Univ.; D. S. Raicu, J. D. Furst, DePaul Univ.

This paper presents a study of a more accurately propagating deformable contour for outlining the liver in a Computed Tomography image of the abdomen, relying on the idea that a deformable parametric snake will propagate more accurately to the correct edges of an image when applied to textural information of the image as opposed to simple gray level information. The texture information is quantified using a set of Gabor filters and various methods of curve deformation are investigated, including a traditional vector field, gradient vector flow, and an expanding level-set method. Given the relative similarity in gray values of adjacent soft tissues, we found that a deformation algorithm that provides too large a capture range would be easily distracted by nearby values and therefore unsuitable for the particular task of segmenting the liver. Our results demonstrate both a general increase in performance of snake segmentation across the dataset as well as a significant regional improvement in accuracy, particularly in images corresponding with the top of the liver.

6914-53, Session 10**Lung lobe modeling and segmentation with individualized surface meshes**

T. Blaffert, H. Barschdorf, J. von Berg, S. P. M. Dries, A. Franz, T. Klinder, C. Lorenz, S. Renisch, R. Wiemker, Philips Research Europe Hamburg (Germany)

An automated segmentation of lung lobes in thoracic CT images is of interest for various diagnostic purposes like the quantification of emphysema or the localization of tumors within the lung. Although the separating lung fissures are visible in modern multi-slice CT-scanners, their contrast in the CT-image often does not separate the lobes completely. This makes it impossible to build a reliable segmentation algorithm without additional information. Our approach uses general anatomical knowledge represented in a geometrical mesh model to construct a robust lobe segmentation, which even gives reasonable estimates of lobe volumes if fissures are not visible at all. The paper describes the generation of the lung model mesh including lobes by an average volume model, its adaptation to individual patient data using a special fissure feature image, and a performance evaluation over a test data set showing an average segmentation accuracy of 1 to 2 mm.

6914-54, Session 10**Robust system for human airway-tree segmentation**

W. E. Higgins, M. W. Graham, J. D. Gibbs, The Pennsylvania State Univ.

Robust and accurate segmentation of the human airway tree from multi-detector computed-tomography (MDCT) chest scans is vital for many pulmonary-imaging applications. As modern MDCT scanners can detect hundreds of airway tree branches, manual segmentation and semi-automatic segmentation requiring significant user intervention are impractical for producing a full global segmentation. Fully-automated methods, however, may fail to extract small peripheral airways. We propose an automatic algorithm that searches the entire lung volume for airway branches and poses segmentation as a global graph-theoretic optimization problem. The algorithm has shown strong performance on 23 human MDCT chest scans acquired by a variety of scanners and reconstruction kernels. Visual comparisons with adaptive region-growing results and quantitative comparisons with manually-defined trees indicate a high sensitivity to peripheral airways and a low false-positive rate. In addition, we propose a suite of interactive segmentation tools for cleaning and extending critical areas of the automatically segmented result. These interactive tools have potential application for image-based guidance of bronchoscopy to the periphery, where small, terminal branches are sometimes required as visual landmarks. Together, the global automatic segmentation algorithm and interactive tool suite comprise a robust system for human airway-tree segmentation.

6914-55, Session 10**Voxel classification-based airway tree segmentation**

P. Lo, Copenhagen Univ. (Denmark); M. de Bruijne, Copenhagen Univ. (Denmark) and Univ. Medisch Ctr. Rotterdam (Netherlands)

This paper presents a voxel classification based method for segmenting the human airway tree in volumetric computed tomography (CT) images. In contrast to standard methods that use only voxel intensities, our method uses a more complex appearance model based on a set of local image appearance features and Kth nearest neighbor (KNN) classification. The optimal set of features for classification is selected automatically from a large set of features describing the local image structure at several scales.

The use of multiple features enables the appearance model to differentiate between airway tree voxels and other voxels of similar intensities in the lung, thus making the segmentation robust to pathologies such as emphysema. The classifier is trained on imperfect segmentations that can easily be obtained using region growing with a manual threshold selection. Experiments show that the proposed method results in a more robust segmentation that can grow into the smaller airway branches without leaking into emphysematous areas, and is able to segment many branches that are not present in the training set.

6914-56, Session 10**4D CT image-based lung motion field extraction and analysis**

T. Klinder, Univ. Hannover (Germany) and Philips Research Europe Hamburg (Germany); C. Lorenz, J. von Berg, S. Renisch, T. Blaffert, Philips Research Europe Hamburg (Germany); J. Ostermann, Univ. Hannover (Germany)

Respiratory motion is a complicating factor in radiation therapy, tumor ablation, and other treatments of the thorax and upper abdomen. In most cases, the treatment requires a demanding knowledge of the location of the organ under investigation. One approach to reduce the uncertainty of organ motion caused by breathing is to use prior knowledge of the breathing motion. In this work, we extract lung motion fields of seven patients in 4DCT inhale-exhale images using an iterative shape-constrained deformable model approach. Since data was acquired for radiotherapy planning, images of the same patient over different weeks of treatment were available. Although, respiratory motion shows a repetitive character, it is well-known that patient's variability in breathing pattern impedes motion estimation. A detailed motion field analysis is performed in order to investigate the reproducibility of breathing motion over the weeks of treatment. For that purpose, parameters being significant for breathing motion are derived. The analysis of the extracted motion fields provides a basis for a further breathing motion prediction. Patient-specific motion models are derived by averaging the extracted motion fields of each individual patient. The obtained motion models are adapted to each patient in a leave-one-out test in order to simulate motion estimation to unseen data. By using patient-specific mean motion models 60% of the breathing motion can be captured on average.

6914-57, Session 10**The evaluation of a highly automated mixture model based technique for PET tumor volume segmentation**

M. Aristophanous, C. A. Pelizzari, The Univ. of Chicago

PET-based tumor volume segmentation techniques are under investigation in recent years due to the increased utilization of FDG-PET imaging in radiation therapy. Several researchers have tried to develop segmentation methods that will help radiation oncologists obtain a PET-based tumor volume, but none of them has proven reliable enough to be regarded as the standard. We have taken the approach of using a Gaussian mixture model (GMM) to model the image intensity distribution of a selected 3D region that completely covers the tumor, called the "analysis region". The modeling is performed with a predetermined number of Gaussian classes and results in a classification of every voxel into one of these classes. The classes are then grouped together to obtain the tumor volume. The only user interaction required is the selection of the "analysis region" and

then the algorithm proceeds automatically to initialize the parameters of the different classes and finds the maximum likelihood estimate with expectation maximization. We used 13 clinical and 19 phantom cases to evaluate the precision and accuracy of the segmentation. Reproducibility was within 10% of the average tumor volume estimate and accuracy was $\pm 35\%$ of the true tumor volume and better when compared to two other proposed techniques. The GMM segmentation is extremely user friendly with good precision and accuracy. It has shown great potential to be used in the clinical environment.

6914-58, Session 11

Shape priors for segmentation of the cervix region within uterine cervix images

S. Lotenberg, Tel-Aviv Univ. (Israel); S. Gordon, H. Greenspan, Tel Aviv Univ. (Israel)

The work focuses on a unique medical repository of digital Uterine Cervix images ("Cervigrams") collected by the National Cancer Institute (NCI), National Institute of Health (NIH), in longitudinal multi-year studies. NCI together with the National Library of Medicine (NLM) is developing a unique web-based database of the digitized cervix images to study the evolution of lesions related to cervical cancer. Tools are needed for the automated analysis of the cervigram content to support the cancer research. In recent works, a multi-stage automated system for segmenting and labeling regions of medical and anatomical interest within the cervigrams was developed. The current paper concentrates on incorporating prior-shape information in the cervix region segmentation task. In accordance with the fact that human experts mark the cervix region as circular or elliptical, two shape models (and corresponding methods) are suggested. The shape models are embedded within an active contour framework that relies on image features. Experiments indicate that incorporation of the prior shape information augments previous results.

6914-59, Session 11

Use of a CT statistical deformation model for multimodal pelvic bone segmentation

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We present a segmentation algorithm using a statistical deformation model constructed from CT data of adult male pelvis coupled to MRI appearance data. The algorithm allows the semi-automatic segmentation of bone for a limited population of MRI data sets. Our application is pelvic bone delineation from pre-operative MRI for image guided pelvic surgery. Specifically, we are developing image guidance for prostatectomies using the daVinci telemanipulator. Hence the use of male pelvis only. The algorithm takes advantage of the high contrast of bone in CT data, allowing a robust shape model to be constructed relatively easily. This shape model can then be applied to a population of MRI data sets using a single data set that contains both CT and MRI data. The model is constructed automatically using fluid based non-rigid registration between a set of CT training images, followed by principal component analysis. MRI appearance data is imported using CT and MRI data from the same patient. Registration optimisation is performed using differential evolution. Based on our limited validation to date, the algorithm may outperform segmentation using non-rigid registration between MRI images without the use of shape data. The mean surface registration error achieved was 1.74 mm. The algorithm shows promise for use in segmentation of pelvic bone from MRI, though further refinement and validation is required. We envisage that the algorithm presented could be extended to allow the rapid creation of application specific models in various imaging modalities using a shape model based on CT data.

6914-60, Session 11

(ST) Prostate segmentation from 3D transrectal ultrasound using statistical shape models and local histogram matching

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Due to the high noise and artifacts typically encountered in ultrasound images, segmenting objects from this modality is one of the most challenging tasks in medical image analysis. Model-based approaches like statistical shape models (SSMs) incorporate prior knowledge that supports object detection in case of incomplete evidence from the image data. How well the model adapts to an unseen image is primarily determined by the suitability of the used appearance model, which evaluates the goodness of fit during model evolution. The commonly employed profile models only capture a small amount of the available image data, which makes them more susceptible to noise.

In this paper, we employ an appearance model based on histogram matching of local regions to detect the prostate in 3D transrectal ultrasound (TRUS) images. Around each landmark of the SSM, a number of gray-values from the inside and the outside of the model are sampled to generate two intensity distributions. Using the L1-distance, these distributions are compared to the collection of histograms learned during training. The minimum obtained distance is a measure for the goodness of fit at the current location. For a preliminary test, we trained the SSM on 30 TRUS images and evaluated the method on five other datasets. Comparing the resulting segmentations to contours outlined by a human expert yielded an average surface distance of 1.2mm.

6914-61, Session 11

(ST) ARGALI: an automatic cup-to-disc ratio measurement system for glaucoma analysis using level-set image processing

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The retinal optic cup-to-disc ratio (CDR) is widely regarded as an important indicator for the diagnosis of glaucoma, one of the major causes of blindness worldwide. In current clinical practice, the CDR is measured manually by an eye physician and is subjective, which restricts the assessment of the CDR for deployment to mass screening. The proposed ARGALI system automatically calculates the CDR from retinal photographs, and provides a fast, objective and consistent measurement with potential for screening. It is tested using images collected from patients at the Singapore Eye Research Institute; and achieves an average 98.6% consistency with the clinical ground truth (clinician assessment of the CDR). It has great potential to be developed into a low cost, efficient glaucoma mass screening system.

In order to calculate the CDR, the cup and disc boundaries need to be segmented. Variational level-set algorithm is used to segment the disc boundary. A multi-modal approach is proposed for cup boundary segmentation which is a challenging problem due to the cup's interweaving with blood vessel and surrounding tissues. Wavelets and pixel classification algorithm is used to identify and remove the blood vessels; color histogram analysis helps to separate the cup from the surrounding rim area; threshold level-set algorithm is then applied to segment the cup boundary. The segmented cup is later smoothed using ellipse fitting and maximum inscribed circle fitting separately. A neural network is trained to fuse the cup-to-disc calculation results from level-set algorithms as well as the results after different smoothing processes. This neural network learning mechanism integrates the knowledge embedded in the clinical practice and provides an optimal CDR for the glaucoma screening, diagnosis and analysis.

6914-62, Session 11**Vessel segmentation in 3D spectral OCT scans of the retina**

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The latest generation of spectral optical coherence tomography (OCT) scanners is able to image 3D cross-sectional volumes of the retina at a high resolution and high speed. These scans offer a detailed view of the structure of the retina. Automated segmentation of the vessels in these volumes may lead to more objective diagnosis of retinal vascular disease including hypertensive retinopathy, retinopathy of prematurity, as well as allow color fundus images to be registered to these 3D volumes, leading to a better understanding of the structure and localization of retinal structures and lesions. In this paper we present a method for automatically segmenting the vessels in a 3D OCT volume. First, the retina is automatically segmented into two layers, using simultaneous segmentation of their boundary surfaces in 3D. Next, a 2D projection of the vessels is produced by only using information from the segmented layers. Finally, a supervised, pixel classification based vessel segmentation approach is applied to the projection image. We compared the influence of two methods for the projection on the performance of the vessel segmentation on 10 optic disc centered 3D OCT scans. The method was trained on 5 independent scans. Using ROC analysis, our proposed vessel segmentation system obtains an area under the curve of 0.970 when compared with the segmentation of a human expert.

6914-63, Session 11**Lymph node segmentation on CT images by a shape model guided deformable surface method**

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With many tumor entities, quantitative assessment of lymph node growth over time is important to make therapy choices or to evaluate new therapies. The clinical standard is to document diameters on transversal slices, which is obviously not the best measure for a volume.

We present a new algorithm to segment lymph nodes (metastases) and evaluate the algorithm with 29 lymph nodes in clinical CT images. The algorithm is based on a recently developed deformable surface search, which uses statistical shape models to restrict free deformation. To model lymph nodes, we construct an ellipsoid shape model, which strives for a surface with strong gradients and user-defined gray values.

The evaluation shows that the algorithm gives good results in the majority of cases and is comparable to manual segmentation, which is too time-consuming for clinical routine. Integrated into an application, it is possible to perform lymph node volumetry for a whole patient within the 10 to 15 minutes time limit imposed by clinical routine.

6914-64, Session 11**A novel shape prior based segmentation of touching or overlapping ellipse-like nuclei**

X. He, Q. Liao, Tsinghua Univ. (China)

Cell nuclei segmentation is a key issue in automatic cell image analysis for nuclear malignancy. However, due to the complexity of microscopic images, it is usually not easy to obtain satisfied segmentation results, especially on the separation of overlapping or touching nuclei. This work aims at proposing a method to separate overlapping and touching nuclei whose shapes are given as ellipses in images, even if they are tightly clustered and no edge is present where they touch. Therefore, a statistical shape model has been introduced as the constraint to construct energy functional, by minimizing which the desired contours of each nucleus can be obtained. The overall algorithm consists of three steps. Firstly, a set of training ellipse templates are used to build the shape model for the elliptic nuclei. Secondly, the gray intensity is also taken into consideration to form the energy functional, which measures the homogeneity of both the nucleus region and background in the given images. As a final step, the segmentation problem is converted into an optimization problem searching for the appropriate shape and pose parameters. The propose algorithm has been tested on human cervical nuclei images. Experiment results show that our method can separate touching or overlapping ellipse-like nuclei from each other accurately, and the tests on noisy and textured nuclei images also demonstrate its robustness. Moreover, the resulting segmentation contours are ellipses in different sizes and directions, therefore the shapes of the nuclei have been preserved to a certain extent.

6915-12, Session 1

Clinical relevance of model based computer-assisted diagnosis and therapy (Keynote)

H. Peitgen, MeVis Research GmbH (Germany) and Florida Atlantic Univ.

Four characteristics assure clinical relevance of models for computer-assisted diagnosis and therapy: ability of patient individual adaption, treatment of errors and uncertainty, dynamic behavior and user interaction during application, and in-depth evaluation. Due to the morphologic and functional variability, the patient individual adaption of models is necessary to achieve maximum diagnostic accuracy. The limited information provided by patient image data can be improved significantly when combined with adaptive models. The reliable use of models requires the understanding and treatment of sources and impact of errors and uncertainty in image data as well as in the model itself. To incorporate intra-diagnostic and intra-therapeutic findings, models must not be static. In particular, pathologic abnormalities as well as the detection of new lesions during intervention require dynamic models that are able to adapt. This includes the ability to recognize when models leave their envelope of reliability, and to allow intelligent manual corrections by the operator. Finally, the in-depth evaluation of model based methods requires new strategies, which go far beyond traditional medical studies. The lecture will reflect these four characteristics of model based computer-assisted diagnosis and therapy along three exemplary areas: volumetric assessment of tumor growth, fibertracking in diffusion tensor imaging, and image based preoperative planning and risk assessment.

6915-13, Session 1

Feature selection for computer-aided detection: comparing different selection criteria

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In this study we investigated different feature selection methods for use in computer-aided mass detection. The data set we used (1357 malignant mass regions and 58444 normal regions) was much larger than used in previous research where feature selection did not directly improve the performance compared to using the entire feature set. We introduced a new performance measure to be used during feature selection, defined as the mean sensitivity in an interval of the free response operating characteristic (FROC) curve computed on a logarithmic scale. This measure, denoted by SL, is similar to the final validation performance measure we were optimizing. Therefore it was expected to give better results than more general feature selection criteria. We compared the performance of feature sets selected using SL to sets selected using the Wilks' lambda statistic. In both cases features were selected using a sequential floating algorithm. For comparing feature set performances during the selection procedure, we used a linear discriminant classifier. This classifier is only optimal when the feature values for the two classes have a multivariate Gaussian distribution with equal covariance matrices. Therefore we investigated the effect of reducing the skewness in the distribution of the feature values before performing feature selection. In the case of Wilks' lambda, we found that reducing skewness had a clear positive effect, yielding performances similar or exceeding performances obtained when the entire feature set was used. Our results indicate that a general measure like Wilks' lambda selects better performing feature sets than SL.

6915-14, Session 1

Hybrid linear classifier for jointly normal data: theory

W. Chen, U.S. Food and Drug Administration; C. E. Metz, M. L. Giger, The Univ. of Chicago

Classifier design for a given classification task needs to take into consideration both the structure of the classifier and the size of the data set that is available for training the classifier. With limited training data, as often is the situation in computer-aided diagnosis of medical

images, a classifier with simple structure (e.g., a linear classifier) is more robust and therefore preferred. We consider the two-class classification problem in which the feature data arise from two multivariate normal distributions. A linear function is used to combine the multi-dimensional feature vector onto a scalar variable. This scalar variable, however, is generally not an ideal decision variable unless the covariance matrices of the two classes are the same. We propose using the likelihood ratio of this scalar variable as a decision variable and, thus, generalizing the traditional classification paradigm to a hybrid two-stage procedure: a linear combination of the feature vector to form a scalar variable followed by a nonlinear transformation that maps the scalar variable onto its likelihood ratio (i.e., the ideal decision variable, given the scalar variable). We show that the traditional Fisher's linear discriminant function is generally not the optimal linear function for the first stage in this two-stage paradigm. We further show that the optimal linear function can be obtained with a numerical optimization procedure using the area under the "proper" ROC curve as the objective function.

6915-06, Session 2

Computer-aided detection of breast masses in tomosynthesis reconstructed volumes using information-theoretic principles

S. Singh, G. D. Tourassi, A. S. Chawla, R. S. Saunders, E. Samei, J. Y. Lo, Duke Univ.

The purpose of this project is to study two Computer Aided Detection (CADE) systems for breast masses for digital tomosynthesis using reconstructed slices. This study used eighty human subject cases collected as part of on-going clinical trials at Duke University. Raw projections images were used to identify suspicious regions in the algorithm's high sensitivity, low specificity stage using a Difference of Gaussian filter. The filtered images were thresholded to yield initial CADE hits that were then shifted and added to yield a 3D distribution of suspicious regions. The initial system performance was 94.7% sensitivity at 10.11 false positives per breast volume. Two CADE systems were developed. In system A, the central slice located at the centroid depth was used to extract a 256x 256 Regions of Interest (ROI) centered at the lesion coordinates. For system B, 5 slices centered at the lesion coordinates were summed before the extraction of 256x 256 ROIs. To avoid problems associated with feature extraction, selection, and merging, information theory principles were used to reduce false positives for both the systems resulting in a classifier performance of 0.81 and 0.865 Area Under Curve with leave-one-case-out sampling. This resulted in an overall system performance of 87.25% with 6.06 FPs/volume and 84.69% sensitivity with 3.8 FPs/volume for systems A and B respectively. This system therefore has the potential to detect breast masses in tomosynthesis data sets.

6915-07, Session 2

Digital tomosynthesis mammography: comparison of mass classification using 3D slices and 2D projection views

H. Chan, Y. Wu, B. Sahiner, Y. Zhang, J. Wei, Univ. of Michigan; R. H. Moore, D. B. Kopans, Massachusetts General Hospital; M. A. Helvie, L. M. Hadjiiski, T. W. Way, Univ. of Michigan

We are developing computer-aided diagnosis (CAD) methods for classification of masses on digital breast tomosynthesis mammograms (DBTs). A DBT data set containing 107 masses (56 malignant and 51 benign) collected at the Massachusetts General Hospital was used. The DBTs were obtained with a GE prototype system which acquired 11 PVs over a 50-degree arc. We reconstructed the DBTs at 1-mm slice interval using a simultaneous algebraic reconstruction technique. The regions of interest (ROIs) containing the masses in the DBT volume and the corresponding ROIs on the PVs were identified. The mass on each slice or each PV was segmented by an active contour model. Spiculation measures, texture features, and morphological features were extracted from the segmented mass. Four feature spaces were formed: (1) features from the central DBT slice, (2) average features from

5 DBT slices centered at the central slice, (3) features from the central PV, and (4) average features from all 11 PVs. In each feature space, a linear discriminant analysis classifier with stepwise feature selection was trained and tested using a two loop leave-one-case-out procedure. The test Az of 0.91 ± 0.03 from the 5-DBT-slice feature space was significantly ($p=0.003$) higher than that of 0.84 ± 0.04 from the 1-DBT-slice feature space. The test Az of 0.83 ± 0.04 from the 11-PV feature space was not significantly different ($p=0.18$) from that of 0.79 ± 0.04 from the 1-PV feature space. The classification accuracy in the 5-DBT-slice feature space was significantly better ($p=0.006$) than that in the 11-PV feature space. The results demonstrate that the features of breast lesions extracted from the DBT slices may provide higher classification accuracy than those from the PV images.

6915-08, Session 2

Reduction of CAD-cued false-positive microcalcification clusters on digital breast tomosynthesis images

S. C. Park, B. Zheng, X. Wang, D. Gur, Univ. of Pittsburgh

Because digital breast tomosynthesis (DBT) projection images usually have much higher level of image noise than screen-film based mammograms, applying computer-aided detection (CAD) schemes to detect micro-calcification clusters depicted on DBT images is likely to generate much higher false-positive detection rate. In this study, we proposed and tested a grouping method to substantially reduce false-positive detections cued by CAD on DBT images. We selected a dataset involving 68 views of DBT examinations. Each view includes 11 projection images. Thirteen true-positive micro-calcification clusters were verified. In the experiment, we first applied a CAD scheme that was previously developed in our laboratory for the digitized mammograms directly to the DBT projection images to detect suspicious micro-calcification clusters. We then tested a grouping method to reduce false-positive detections based on a hypothesis that true-positive micro-calcification clusters are more likely to be detected by CAD on more DBT projection images than the false-positive clusters. A computer program was designed to match the clusters detected by CAD on DBT images and count the detection times (from 1 to 11) for each individually suspicious cluster. We finally compared CAD performance before and after applying the grouping method using ROC analytic method. Two view-based ROC curves were generated. One uses CAD-generated detection scores and the other uses counted detection times as the performance summary index. As a result, the area under ROC curve increases from 0.65 to 0.85 after using the grouping method. This study demonstrates that the proposed grouping method is effective to compensate the negative impact of DBT image noise in CAD results of micro-calcification cluster detection.

6915-09, Session 2

Classification of breast masses and normal tissues in digital tomosynthesis mammography

J. Wei, H. Chan, Y. Zhang, B. Sahiner, C. Zhou, J. Ge, Y. Wu, L. M. Hadjiiski, Univ. of Michigan

Our purpose is to design an effective classifier to distinguish breast masses from normal tissues in digital tomosynthesis mammography (DTM). A data set of 100 DTM cases collected with a GE prototype DTM system at the Massachusetts General Hospital was used. We reconstructed the DTMs using a simultaneous algebraic reconstruction technique (SART). Mass candidates were identified by 3D gradient field analysis. Three approaches to distinguish breast masses from normal tissues were evaluated. In the 3D approach, we extracted morphological and run-length statistics texture features from DTM slices as input to a linear discriminant analysis (LDA) classifier. In the 2D approach, the raw input PVs were first preprocessed with a Laplacian pyramid multiresolution enhancement scheme. A mass candidate was then forward-projected to the preprocessed PVs in order to determine the corresponding regions of interest (ROIs). Spatial gray-level dependence (SGLD) texture features were extracted from each ROI and averaged over 11 PVs. An LDA classifier was designed to distinguish the masses from normal tissues. In the combined approach, the LDA scores from the 3D and 2D approaches were averaged to generate a mass likelihood

score for each candidate. The Az values were 0.87 ± 0.02 , 0.86 ± 0.02 , and 0.91 ± 0.02 for the 3D, 2D, and combined approaches, respectively. The difference between the Az values of the 3D and 2D approaches did not achieve statistical significance. The performance of the combined approach was significantly ($p < 0.05$) better than either the 3D or 2D approach. The combined classifier will be useful for false-positive reduction in computerized mass detection in DTM.

6915-10, Session 2

Masses classification using fuzzy active contours and fuzzy decision trees

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In this paper we propose a method to classify masses in digital breast tomosynthesis (DBT) datasets. First, markers of potential lesions are extracted and matched over the different projections. Then two level-set models are applied on each finding corresponding to spiculated and circumscribed mass assumptions respectively. The

formulation of the active contours within this framework leads to several candidate contours for each finding. In addition, a membership value to the class contour is derived from the energy of the segmentation model, and allows associating several fuzzy contours from different projections to each set of markers corresponding to a lesion. Fuzzy attributes are computed for each fuzzy contour. Then the attributes corresponding to fuzzy contours associated to each set of markers are aggregated. Finally, these cumulated fuzzy attributes are processed by two distinct fuzzy decision trees in order to validate/invalidate the spiculated or circumscribed mass assumptions. The classification has been validated on a database of 23 real lesions using the leave-one-out method. An error classification rate of 9% was obtained with these data, which confirms the interest of the proposed approach.

6915-11, Session 2

Texture in digital breast tomosynthesis: a comparison between mammographic and tomographic characterization of parenchymal properties

D. Kontos, P. R. Bakic, A. D. A. Maidment, The Univ. of Pennsylvania Health System

A number of studies have demonstrated a relationship between mammographic parenchymal texture and breast cancer risk. Mammography, however, is limited by tissue superimposition. Digital Breast Tomosynthesis (DBT) is a novel 3D x-ray imaging modality in which breast images are reconstructed from a limited number of source projection images. Tomosynthesis avoids tissue superimposition and offers the ability to perform volumetric texture analysis. In this study, we analyzed texture in DBT; we computed texture features that have been previously correlated to cancer risk. Our goal was to compare tomographic and mammographic texture characterization and evaluate the robustness of the texture descriptors in characterizing parenchymal properties. We computed the correlation between mammographic and tomographic features and investigated the effects of gray-level quantization on co-occurrence texture statistics. Texture correlation was also computed between contralateral and ipsilateral breasts. We analyzed bilateral DBT and DM images from 40 women; our population included women with recently detected abnormalities and previous cancer patients. Filtered-backprojection was used for DBT reconstruction. Retroareolar ROIs were manually segmented from the DBT images; corresponding ROIs were segmented from the DM images. Our analysis showed low correlation between DBT and DM features. The correlation between contralateral and ipsilateral breasts was significant for both modalities; it was overall stronger for DBT. We observed that the selection of the gray-level quantization algorithm affects the detected correlations. The strong correlation between contralateral and ipsilateral breasts shows that parenchymal properties of the unaffected breast can potentially be used as a surrogate for breast cancer risk.

6915-01, Session 3**Automated matching of supine and prone colonic polyps based on PCA and SVMs**

S. Wang, R. L. Van Uitert, R. M. Summers, National Institutes of Health

Computed tomographic colonography (CTC) is a feasible and minimally invasive method for the detection of colorectal polyps and cancer screening. In current practice, a patient will be scanned twice during the CTC examination - once supine and once prone. In order to assist the radiologists in evaluating colon polyp candidates in both scans, we expect the computer aided detection (CAD) system can provide not only the locations of suspicious polyps, but also the possible matched pairs of polyps in two scans. In this paper, we propose a new automated matching method based on the extracted features of polyps by using principal component analysis (PCA) and Support Vector Machines (SVMs). Our dataset comes from the 104 CT scans of 52 patients with supine and prone positions collected from three medical centers. From it we constructed two groups of matched polyp candidates according to the size of true polyps: group A contains 12 true polyp pairs (> 9 mm) and 454 false pairs; group B contains 24 true polyp pairs (6-9 mm) and 514 false pairs. By using PCA, we reduced the dimensions of original data (with 157 attributes) to 30 dimensions. We did leave-one-patient-out test on the two groups of data. ROC analysis shows that it is easier to match bigger polyps than that of smaller polyps. On group A data, when false alarm probability is 0.18, the sensitivity of SVM achieves 0.83 which shows that automated matching of polyp candidates is practicable for clinical applications.

6915-02, Session 3**DMLLE: a large-scale dimensionality reduction method for detection of polyps in CT colonography**

S. Wang, J. Yao, R. M. Summers, National Institutes of Health

Computer-aided diagnosis systems have been shown to be feasible for polyp detection on computed tomography (CT) scans. After 3-D image segmentation and feature extraction, the dataset of colonic polyp candidates has large-scale and high dimension characteristics. In this paper, we propose a large-scale dimensionality reduction method based on Diffusion Map and Locally Linear Embedding for detection of polyps in CT colonography. By selecting partial data as landmarks, we first map the landmarks into a low dimensional embedding space using Diffusion Map. Then by using Locally Linear Embedding algorithm, non-landmark samples are embedded into the same low dimensional space according to their nearest landmark samples. The local geometry of samples is preserved in both the original space and the embedding space. We applied the proposed method called DMLLE to a colonic polyp dataset which contains 58336 candidates (including 85 6-9mm true polyps) with 155 features. Visual inspection shows that true polyps with similar shapes are mapped to close vicinity in the low dimensional space. FROC analysis shows that SVM with DMLLE achieves higher sensitivity with lower false positives per patient than that of SVM using all features. At the false positives of 8 per patient, SVM with DMLLE improves the average sensitivity from 64% to 75% for polyps whose sizes are in the range from 6 mm to 9 mm ($p < 0.05$).

6915-03, Session 3**Mosaic decomposition method for detection and removal of inhomogeneously tagged regions in electronic cleansing for CT colonography**

W. Cai, M. Zalis, H. Yoshida, Massachusetts General Hospital

Electronic cleansing (EC) is a method that segments fecal materials tagged by an X-ray-opaque oral contrast agent in CT colonography (CTC) images, and effectively removes them for digitally cleansing the colon. In this study, we developed a novel EC method, called mosaic decomposition, for reduction of the artifacts due to incomplete cleansing of heterogeneously tagged fecal materials in reduced- or non-cathartic fecal-tagging CTC examinations. In our approach, a segmented colonic lumen including the tagged regions was first separated into a set of

local homogeneous regions by application of a watershed transform to the gradient of the CTC images. Then, each of the local homogeneous regions was classified into five different material classes, including air, soft tissue, tagged feces, air bubble, and foodstuff, based on texture features at each homogeneous region. A single index, called a heterogeneity index, is formulated for differentiation of these materials from the submerged solid soft-tissue structures such as polyps and folds. Here, a larger value of the index indicates a higher likelihood of heterogeneity. Then, EC is performed by first initializing the level-set front with the classified tagged regions, and the front is evolved by use of a speed function that was designed, based on the heterogeneity index, to reserve the submerged soft-tissue structures while suppressing the air bubbles and foodstuffs. Visual assessment and application of our CAD scheme showed that the use of our new EC method substantially improved the detection performance of CAD, indicating the effectiveness of our EC method in reducing incomplete cleansing artifacts.

6915-04, Session 3**Simultaneous feature selection and classification based on genetic algorithms: an application to colonic polyp detection**

Y. Zheng, X. Yang, M. M. Siddique, G. R. Beddoe, Medicsight PLC (United Kingdom)

Selecting a set of relevant features is a crucial step in the process of building robust classifiers. Searching all possible subsets of features is computationally impractical for large number of features. Generally, classifiers are used for the evaluation of the separability of a certain feature subset. The performance of these classifiers depends on some predefined parameters. However, the choice of these parameters for a given classifier is influenced by the given feature subset and vice versa. The computational cost for feature selection would be largely increased by including the selection of optimal parameters for the classifier (for each subset). This paper attempts to tackle the problem by introducing genetic algorithms (GAs) to combine the processes. The proposed approach can choose the most relevant features from a feature set whilst simultaneously optimising the parameters of the classifier. Its performance was tested on a colon polyp database from a cohort study using a weighted support vector machine (SVM) classifier. As a general approach, other classifiers such as artificial neural networks (ANN) and decision trees could be used. This approach could also be applied to other classification problems such as other computer aided detection/diagnosis applications.

6915-05, Session 3**A CAD scheme incorporating massive-training ANNs for detection of polyps in false-negative CT colonography cases in a large multicenter clinical trial: preliminary results**

K. Suzuki, I. Sheu, The Univ. of Chicago; M. L. Epstein, Univ. of Chicago; R. Kohlbrenner, The Univ. of Chicago; A. Lostumbo, Univ. of Illinois at Chicago; D. C. Rockey, The Univ. of Texas Southwestern Medical Ctr. at Dallas; A. H. Dachman, The Univ. of Chicago

A major challenge in computer-aided detection (CAD) of polyps in CT colonography (CTC) is the detection of "difficult" polyps which radiologists are likely to miss. Our purpose was to develop a CAD scheme incorporating massive-training artificial neural networks (MTANNs) and to evaluate its performance on false-negative (FN) cases in a large multicenter clinical trial. We developed an initial polyp-detection scheme consisting of colon segmentation based on CT value-based analysis, detection of polyp candidates based on morphologic analysis, and quadratic discriminant analysis based on 3D pattern features for classification. For reduction of false-positive (FP) detections, we developed multiple expert 3D MTANNs designed to differentiate between polyps and seven types of non-polyps. Our independent database was obtained from CTC scans of 155 patients with polyps from a multicenter trial in which 15 medical institutions participated nationwide. Among them, about 45% patients received FN interpretations in CTC. For testing our CAD, 14 cases with 14 polyps/masses were randomly selected from

the FN cases. Lesion sizes ranged from 6-35 mm, with an average of 10 mm. The initial CAD scheme detected 71.4% (10/14) of "missed" polyps, including sessile polyps and polyps on folds, with 18.9 (264/14) FPs per case. The MTANNs removed 75% (197/264) of the FPs without loss of any true positives; thus, the performance of our CAD scheme was improved to 4.8 (67/14) FPs per case. With our CAD scheme incorporating MTANNs, 71.4% of polyps "missed" by radiologists in the trial were detected correctly, with a reasonable number of FPs.

6915-15, Session 4

Computerized self-assessment of automated lesion segmentation in breast ultrasound: implication for CADx applied to findings in the axilla

K. Drukker, M. L. Giger, The Univ. of Chicago

The aim of this research is to demonstrate the feasibility of a computerized auto-assessment method in which the computer-aided diagnosis (CADx) system itself provides a confidence rating for the quality of the automated lesion segmentation.

We developed a self-assessment method in which the CADx system provided a confidence level for its lesion segmentations. The self-assessment was performed by a fuzzy-inference system based on 4 computer-extracted features of the computer-segmented lesions in a leave-one-case-out evaluation protocol. In instances where the initial segmentation received a low confidence rating, lesions were re-segmented using the same segmentation method but based on a user-defined region-of-interest. A total of 542 cases with 1133 lesions were collected in this study, and we focused here on the 97 normal lymph nodes in this dataset since these pose challenges for automated segmentation due to their inhomogeneous appearance.

The percentage of all lesions with satisfactory segmentation (i.e., normalized overlap with the radiologist-delineated lesion >0.3) was 85%. For normal lymph nodes, however, this percentage was only 36%. Of the 53 lymph nodes receiving a low confidence rating (<0.3) for their initial segmentation, 50 were poorly segmented, while for 3 the segmentation was slightly better. In 12 instances, the confidence rating overestimated the quality of the segmentation. When the lesions with a confidence rating smaller than 0.3 were re-segmented, the percentage of normal lymph nodes with a satisfactory segmentation improved to 80.0%

Computer-assessed confidence levels demonstrated potential to 1) help radiologists decide whether to use or disregard CADx output, and 2) provide a guide for improvement of lesion segmentation.

6915-16, Session 4

Design and evaluation of a new automated method for the segmentation and characterization of masses on ultrasound images

J. Cui, B. Sahiner, H. Chan, A. Nees, C. Paramagullu, L. Hadjiyski, C. Zhou, J. Shi, Univ. of Michigan

Segmentation of masses is the first step in most computer-aided diagnosis (CAD) systems for characterization of breast masses as malignant or benign. In this study, we designed an automated method for segmentation of masses on ultrasound images. Our method automatically estimated an initial contour for the active contour (AC) segmentation algorithm and performed self-examination and correction on the segmentation result, which increased its robustness to initialization. To evaluate our method, we quantitatively compared it with manual segmentation by two radiologists on a data set of 337 images from 171 cases (50 malignant and 121 benign). Four quantitative performance measures were used for accuracy evaluation. Area overlap measure I was defined as the ratio of the intersection of the computer-segmented and manually-segmented areas relative to the manually-segmented area, and area overlap measure II was defined as the ratio of the intersection to the union of the areas. Our third and fourth measures were the percentage of area error and absolute area error for the computer-segmented area, respectively. For our data set, area overlap I was 0.88 ± 0.12 (mean \pm s.d.), area overlap II was 0.77 ± 0.11 , area error was 0.03 ± 0.25 , and absolute area error was 0.18 ± 0.18 . Two feature spaces, consisting of texture, width-to-height and posterior shadowing features, were extracted from the computer

and manual segmented mass. A classifier based on stepwise feature selection and linear discriminant analysis was designed to classify the masses as malignant or benign. The leave-one-case-out method was used to train and test the CAD system. For case-based classification, the area under the test receiver operating characteristic (ROC) curve was 0.87 ± 0.03 and 0.85 ± 0.03 for the feature sets based on manual segmentation and computer segmentation, respectively.

6915-17, Session 4

Computer-aided diagnosis of breast color elastography

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Breast cancer is the most frequently diagnosed cancer in women, and it is the second leading cause of cancer death. In recent years, ultrasound has been an important imaging technique for detecting breast tumors. As opposed to the conventional B-mode image, the ultrasound elastography is a new technique for imaging the elasticity and applied to detect the stiffness of tissues. The red region of color elastography indicates the soft tissue and the blue one indicates the hard tissue, and the harder tissue usually is classified to malignancy. The computer-aided diagnosis (CAD) is able to objectively classify the tumor to benign or malignant, and is an effective tool for aiding the physician's diagnosis. In this paper, we proposed a CAD system on elastography to measure whether this system is effective and accurate to classify the tumor into benign and malignant. According to the features of elasticity, the color elastography was transferred to HSV color space and extracted meaningful features from hue images. Then the neural network was utilized in multiple features to distinguish tumors. In this experiment, there are 180 pathology-proven cases including 113 benign and 67 malignant cases used to examine the classification. The results of the proposed system showed an accuracy of 83.89%, a sensitivity of 85.07% and a specificity of 83.19%. Compared with the physician's diagnosis, an accuracy of 78.33%, a sensitivity of 53.73% and a specificity of 92.92%, the proposed CAD system had better performance. Moreover, the agreement of the proposed CAD system and the physician's diagnosis was calculated by kappa statistics 0.54 indicated there is a fair agreement of observers.

6915-18, Session 4

Computer-aided classification of lesions by means of their kinetic signatures in dynamic contrast-enhanced MR images

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The kinetic characteristics of tissue in dynamic contrast-enhanced MRI data are an important source of information. Kinetic curves measured for each lesion voxel allow to infer information about the state of the local tissue. As a whole, they reflect the heterogeneity of the vascular structure within a lesion, an important criterium for the preoperative staging of lesions.

We propose a new method which exploits the full range of kinetic information for the classification of lesions. Instead of breaking down the large amount of kinetic information to a single curve, each lesion is considered as a probability distribution, efficiently represented by its kinetic signature. Dissimilarity of signatures can be objectively measured using the Mallows distance. The embedding of this metric in a kernel function enables us to employ modern supervised machine-learning techniques, yielding in our study an Az value of 0.89 for the classification of benign and malignant breast masses.

6915-19, Session 4

Expanded pharmacokinetic model for population studies in breast MRI

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We propose a new model for pharmacokinetic analysis based on the one proposed by Tofts. Our model both eliminates the need for estimating the Arterial Input Function (AIF) and normalizes analysis so that comparisons across patients can be performed. Previous methods have attempted to circumvent the AIF estimation by using the pharmacokinetic parameters of multiple reference regions (RR). Viewing anatomical structures as filters, pharmacokinetic analysis tells us that 'similar' structures will be similar filters. By cascading the inverse filter at a RR with the filter at the voxel being analyzed, we obtain a transfer function relating the concentration of a voxel to that of the RR. We show that this transfer function simplifies into a five-parameter nonlinear model with no reference to the AIF. These five parameters are combinations of the three parameters of the original model at the RR and the region of interest. Contrary to existing methods, ours does not require explicit estimation of the pharmacokinetic parameters of the RR. Also, cascading filters in the frequency domain allows us to manipulate more complex models, like accounting for the vascular tracer component. We believe that our model can improve analysis across MR parameters because the analyzed and reference enhancement series are from the same image. Initial results are promising with the proposed model parameters exhibiting values that are more consistent across lesions in multiple patients. Additionally, our model can be applied to multiple voxels to estimate the original pharmacokinetic parameters as well as the AIF.

6915-20, Session 4

A knowledge-based approach to the computer-aided diagnosis of mammographic masses

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While screening mammography is accepted as the best tool for the early detection of breast cancer, its low positive predictive value leads to many breast biopsies performed on benign lesions. As a breast biopsy causes both mental and physical discomfort for the patient, we propose a knowledge-based system for the computer-aided diagnosis (CADx) of mammographic masses. The proposed system is a novel approach that combines standard texture analysis features with features that are specific to mammographic masses and have been adapted from computer assisted detection (CADe) approaches. In addition, the system also integrates clinical data like the patient's age. The knowledge-based reasoning is based on image retrieval techniques and works on feature vectors extracted from regions of interest cropped from mammograms. As a broad range of features is extracted, the high dimension of the feature space is reduced using feature selection and weighting techniques. The performance of the proposed CADx system is evaluated on a subset of the digital database for screening mammography (DDSM) using leaving-one-out sampling and receiver operating characteristic (ROC) curve analysis. ROCKIT is used to determine the area under the ROC curve $A(z)$. With an $A(z)$ of 0.86 ± 0.03 , the CADx system performs very well on the DDSM mammograms. Besides the high ROC performance, the proposed system features an intelligible reasoning process based on image retrieval that is easy to comprehend for the physician. Furthermore, it can easily be extended using relevance feedback techniques to increase the possible level of interaction of the physician with the CADx system.

6915-21, Session 5

Computerized assessment of coronary calcified plaques in CT images of a dynamic cardiac phantom

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Motion artifacts in cardiac CT are an obstacle to obtaining diagnostically usable images. Although phase-specific reconstruction can produce images with improved assessability (image quality), this requires that the radiologist spend time and effort evaluating multiple image sets from reconstructions at different phases. In this study, ordinal logistic regression (OLR) and artificial neural network (ANN) models were used to automatically assign assessability to images of coronary plaques obtained using a physical dynamic cardiac phantom. 350 plaque images

of 7 plaques from 5 data sets (heart rates 60, 60, 70, 80, 90) and ten phases of reconstruction were obtained using standard cardiac CT scanning parameters on a Phillips Brilliance 64-channel clinical CT scanner. Six features of the plaques (velocity, acceleration, edge-based volume, threshold-based volume, sphericity, and standard deviation of intensity) as well as mean feature values and heart rate were used for training the OLR and ANN in a round-robin re-sampling scheme based on training and testing groups with independent plaques. For each image, an assessability index (AI) rating on a 1-5 scale was assigned by a cardiac radiologist (D.B.) for use as a "truth" in training the OLR and ANN. The mean difference between the AI truth and model-predicted AI values was $+0.111$ with $SD=0.942$ for the OLR and $+0.143$ with $SD=0.916$ for the ANN. Comparing images from the repeat 60 bpm scans gave concordance correlation coefficients (CCC) of 0.794 [0.743, 0.837] (value, 95% CI) for the radiologist assigned values, 0.894 [0.856, 0.922] for the OLR, and 0.861 [0.818, 0.895] for the ANN. Thus, the variability of the OLR and ANN AI values appear to lie within the variability of the radiologist assigned values.

6915-22, Session 5

Hotspot quantification of myocardial focal tracer uptake from molecular targeted SPECT/CT images: canine validation

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We have developed a new single photon emission computerized tomography (SPECT) hotspot quantification method incorporating extra cardiac scatter correction and hotspot normal limits. The method was validated for estimation accuracy of myocardial tracer focal uptake in a canine model of myocardial infarction (MI). Dogs ($n=4$) at 2 weeks post MI were injected with Tl-201 and a Tc-99m-labeled hotspot tracer targeted at matrix metalloproteinases (MMPs). An external point source filled with Tc-99m was used for a reference of absolute radioactivity. Dual isotope (Tc-99m/Tl-201) images were acquired simultaneously followed by an X-ray CT acquisition. Dogs were sacrificed after imaging for myocardial gamma well counting. Images were reconstructed with CT-based attenuation correction (AC) and without AC (NAC) and were quantified using our quantification method. Normal limits for myocardial hotspot uptake were estimated based on 3 different schemes: maximum entropy, mean-squared-error minimization (MSEM) and global minimization. Absolute myocardial hotspot uptake was quantified from SPECT images using the normal limits and compared with well-counted uptake on a segment-by-segment basis ($n=12$ segments/dog). Radioactivity was expressed as % injected dose (%ID). Correlations between SPECT quantified and well-counted %IDs were excellent ($r=0.78-0.92$), regardless of AC or NAC. Quantification from SPECT/NAC resulted in significant underestimation in %ID. Quantification from SPECT/AC with the MSEM normal limit yielded the most consistent %ID with well-counted %ID. In conclusion, it is feasible to accurately quantify myocardial hotspot uptake in vivo using our method. SPECT/AC with a suitable normal hotspot limit is critical for a precise assessment of myocardial hotspot uptake.

6915-23, Session 5

Automated segmentation and tracking of coronary arteries in ECG-gated cardiac CT scans

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Cardiac CT has been reported to be an effective means for clinical diagnosis of coronary artery plaque disease. We are investigating the feasibility of developing a computer-aided detection (CAD) system to assist radiologist in detection of coronary artery plaque disease in ECG-gated cardiac CT scans.

The heart region was first extracted using morphological operations and an adaptive EM thresholding method. Vascular structures in the heart volume were enhanced by 3D multi-scale filtering and analysis of the eigenvalues of Hessian matrices using a vessel enhancement response function specially designed for coronary arteries. The enhanced vascular structures were then segmented by a hierarchical EM estimation

method. Finally, our newly developed 3D rolling balloon vessel tracking method (RBVT) was used to track the segmented coronary arteries. Starting at two manually identified points located at the origins of left and right coronary artery (LCA and RCA), the RBVT method moved a sphere of adaptive diameter along the vessels, tracking the vessels and identifying its branches automatically to generate the left and right coronary arterial trees.

Ten cardiac CT scans that contained various degrees of coronary artery diseases were used as test data set for our vessel segmentation and tracking method. Two experienced thoracic radiologists visually examined the computer tracked coronary arteries on a graphical interface to count untracked false-negative (FN) branches (segments). A total of 27 artery segments were identified to be FNs in the 10 cases, ranging from 0 to 6 FN segments in each case. No FN artery segment was found in 2 cases.

6915-24, Session 5

Computer-aided prognosis of neuroblastoma: classification of stromal development on whole-slide images

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Neuroblastoma is a cancer of the nervous system and one of the most frequent tumors in children. In clinical practice, pathologists examine the haematoxylin and eosin (H&E) stained tissue slides under the microscope for the diagnosis. According to the International Neuroblastoma Classification System, neuroblastoma tumors are categorized into favorable and unfavorable histologies. The subsequent treatment planning is based on this classification. However, this qualitative evaluation is time consuming, prone to error and subject to inter- and intra-reader variations and sampling bias. To overcome these shortcomings, we are developing a computerized system for the quantitative analysis of neuroblastoma slides. In this study, present a novel image analysis system to determine the degree of stromal development from digitized whole-slide neuroblastoma samples. The developed method uses a multi-resolution approach that works similar to how pathologists examine slides. Due to their very large resolutions, the whole-slide images are divided into non-overlapping image tiles and the proposed image analysis steps are applied to each image tile using a parallel computation infrastructure developed earlier by our group. The computerized system classifies image tiles as stroma-poor or stroma-rich subtypes using texture characteristics. The developed method has been independently tested on 20 whole-slide neuroblastoma slides and it has achieved 95% classification accuracy.

6915-25, Session 5

Automatic classification and detection of clinically relevant images for diabetic retinopathy

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We proposed a novel approach to automatic classification of Diabetic Retinopathy (DR) images and retrieval of clinically-relevant DR images from a database. Given a query image, our approach first classifies the image into one of the three categories: microaneurysm (MA), neovascularization (NV) and normal, and then it retrieves DR images that are clinically-relevant to the query image from an archival image database. In the classification stage, the query DR images are classified by Multi-class Multiple-Instance Learning (McMIL) approach, where images are viewed as bags, each of which contains a number of instances corresponding to non-overlapping blocks, and each block is characterized by low-level features including color, texture, histogram of edge directions and shape. McMIL first learns a collection of instance prototypes for each class that maximizes the Diverse Density function using EM algorithm. A nonlinear mapping is then defined using the instance prototypes and maps every bag to a point in a new multi-class bag feature space; finally a multi-class Support Vector Machine is trained in the multi-class bag feature space. In the retrieval stage, we retrieve images from the archival database who bear the same label with the query image, and who are the top K nearest neighbors of the

query image in terms of similarity in the multi-class bag feature space. The classification approach achieves high classification accuracy, and the retrieval of clinically-relevant images not only facilitates utilization of the vast amount of hidden diagnostic knowledge in the database, but also improves the efficiency and accuracy of DR lesion diagnosis and assessment.

6915-26, Session 6

Learning from imbalanced data: a comparative study for colon CAD

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Classification plays an important role in the reduction of false positives in many computer aided detection and diagnosis methods. The difficulty of classifying polyp lies on the variety of possible polyp shapes and sizes and the imbalance between the number of polyp and non-polyp regions available in the training data. CAD schemes for medical applications demand high levels of sensitivity even at the expense of keeping certain number of false positives. In this paper, we investigate the state-of-art solutions to the imbalanced data problem:

Synthetic Minority Over-sampling Technique (SMOTE) and weighted Support Vector Machines (SVM). We tested these methods using a large database of CT cases, which included a wide spectrum of difficult-to-classify polyps. In our experiments, SMOTE improved a traditional tree classifier (C4.5) performance. The weighted SVM yielded the best performance. We performed several experiments with different combinations of over-sampling techniques on training data. The results obtained show that weighted SVM can achieve comparable performance in terms of sensitivity and specificity to conventional SVM combined with the over-sampling approach.

6915-27, Session 6

Reduction of false positives by extracting fuzzy rules from data for polyp detection in CTC scans

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This paper presents a neural network based Fuzzy Inference System (FIS) which has been developed using ANFIS to reduce the false positive (FP) rate and detect colonic polyps in Computed Tomography Colonography (CTC) scans. Extracted fuzzy rules establish linguistically interpretable relationships in the data that are easy to understand, validate, and extend. The system takes several features identified from regions extracted by a segmentation algorithm and assigns them to one of two possible classes. In the training phase, subtractive clustering is used to down-sample the negative regions in order to get balanced data. The rule extraction method is based on estimating clusters in the data using the subtractive clustering algorithm; each cluster obtained corresponds to a fuzzy rule that maps a region in the input space to an output class. After the number of rules and initial rule parameters are obtained by cluster estimation, the rule parameters are optimized using a hybrid learning algorithm which is a combination of least-squares estimation with back propagation. The evolved Sugeno-type FIS has been tested on a total of 129 scans with 99 polyps of sizes 5-15 mm by human experts. The results indicate that for 88% detection sensitivity (on polyps), the evolved FIS method is able to remove 93% of FPs generated by the segmentation algorithm leaving 7.5 FPs per scan. The high sensitivity rate of our results show the promise of neuro-fuzzy classifiers as an aid for interpreting CTC examinations.

6915-28, Session 6

Computer aided detection of polyps in virtual colonoscopy with sameday fecal tagging

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One of the key factors which may lead to a greater patient compliance in virtual colonoscopy is a more tolerable preparation for the exam, possible with fecal tagging techniques. So-called "sameday fecal tagging" procedures are currently being tested in many clinical settings. The administration of oral contrast on the same day of the procedure, however, often results in a less homogenous marking of the fecal residue, so computer aided-detection systems must be able to treat these kinds of preparations. In this work, we present a CAD scheme capable of achieving good performances on these datasets, both in terms of sensitivity and specificity. The datasets are first processed in order to correctly identify and remap the tagged stool, distinguishing between tagged fecal residue and tissue voxels affected by partial volume effect. The electronically cleansed datasets are then processed by a scheme, which is essentially composed of four steps: colon surface extraction, polyp candidate segmentation through curvature-based features, pre-filtering of candidates composed of residual thin tagged stool and linear classifier-based discrimination between true polyps and false alarms. The system was evaluated on a set of TCs acquired on a total of 102 patients from three different medical centers. Patients were asked to observe a low residue diet and an iodinated oral contrast agent was administered two hours before the TC exam. A specificity of 10.04 false positives per scan was obtained at a sensitivity of 94.4 for polyps of size larger than 6 mm.

6915-29, Session 6**A consensus embedding approach for segmentation of high resolution in vivo prostate magnetic resonance imagery**

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Current techniques for localization of prostatic adenocarcinoma (CaP) via blinded trans-rectal ultrasound biopsy are associated with a high false negative rate. While high resolution endorectal in vivo Magnetic Resonance (MR) prostate imaging has been shown to have improved contrast and resolution for CaP detection over ultrasound, similarity in intensity characteristics between benign and cancerous regions on MR contribute to its low specificity. In this paper, we present a novel unsupervised segmentation scheme that employs manifold learning via a consensus scheme for prostate segmentation from high resolution 1.5 Tesla (T) and 3 T endorectal in vivo prostate MRI. After correcting for MR image intensity artifacts, our algorithm extracts over 350 3D texture features from the MR scene at multiple scales and orientations. In this paper we present a novel machine learning scheme to combine multiple weak low-dimensional representations of high-dimensional feature data to create a strong, stable embedding. The idea is analogous to feature ensemble schemes which combine weak classifiers to create a strong classifier. Non-linear dimensionality reduction schemes including Locally Linear Embedding and Graph Embedding are employed to create these low dimensional representations and then unsupervised consensus clustering is used to partition the objects in the "stable" embedding space. Quantitative evaluation on 1.5 T prostate MR data show our method has a sensitivity of 92.56% and a specificity of 82.11%, which suggests that our method is successfully able to detect suspicious regions in the prostate.

6915-30, Session 6**Improving supervised classification accuracy using non-rigid multimodal image registration: detecting prostate cancer**

J. C. Chappelow, S. E. Viswanath, J. Monaco, Rutgers Univ.; M. A. Rosen, J. Tomaszewski, M. Feldman, Univ. of Pennsylvania; A. Madabhushi, Rutgers Univ.

It has been shown that significant improvements in classification accuracy of supervised computer-aided diagnosis (CAD) systems can only happen by removal of mislabeled training instances. For most CAD applications expert segmentations are used as the reference or ground truth for evaluation or training of a supervised classification system.

We present a new method for improving the accuracy of supervised classification by improving the quality of training using a new multimodal registration method. While this paradigm is applicable to most supervised classification tasks where multi-modal data is present, we present an application for detection of prostate cancer on MRI. For instance, when ground truth may be more precisely defined on histology than MRI, a ground truth estimate from registration of MRI with histology may provide a better surrogate of ground truth on MRI. To demonstrate, we compare the validity of cancer labels determined by expert radiologists and four registration methods in the task of training a supervised classifier to detect cancer on MRI of the prostate. Two affine registration methods compared include maximization of mutual information (MI) and the method known as combined feature ensemble mutual information (COFEMI), which incorporates high-order statistical features for robust multimodal registration. Both affine registration methods are followed by elastic deformation using thin-plate splines. The registration and expert methods of mapping cancer are compared in terms of classifier accuracy by area under the receiver operating characteristic curve. For 26 multimodal image pairs with cancer present, elastic registration provides superior classifier accuracy compared with expert-derived training data.

6915-31, Session 6**Combining T2-weighted with dynamic MR images for computerized classification of prostate lesions**

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In this study, we investigate the diagnostic performance of our CAD system when discriminating prostate cancer from benign lesions and normal peripheral zone using registered multi-modal images. We have developed a method that automatically extracts quantitative T2 values out of acquired T2-w images and evaluated its additional value to the discriminating performance of our CAD system. This study addresses 2 issues when using both T2-w and dynamic MR images for the characterization of prostate lesions. Firstly, T2-w images do not provide quantitative values, and secondly, images can be misaligned due to patient movements. To compensate, a mutual information registration strategy is performed after which T2 values are estimated using the acquired proton density images. Relevant features are extracted from the registered and quantitative T2 volumes as well as the dynamic images to train a support vector machine as classifier. The output of the classifier was used as a measure of likelihood of malignancy. General performance of the scheme was evaluated using the area under the ROC curve.

We conclude that it is feasible to automatically extract quantitative T2 values out of acquired T2-w images. Furthermore, a discriminating performance of 0.75 (0.66-0.85) was obtained when only using T2-values as feature. Combining the T2 values with pharmacokinetic parameters did not increase diagnostic performance in a pilot study.

6915-32, Session 7**Automated detection of nodules attached to the pleural and mediastinal surface in low-dose CT scans**

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This paper presents a new computer-aided detection scheme for lung nodules attached to the pleural or mediastinal surface in low dose CT scans. First the lungs are automatically segmented and smoothed. Any connected set of voxels attached to the wall - with each voxel above minus 500 HU and the total object within a specified volume range - was considered as a candidate finding. For each candidate a refined segmentation was computed using morphological operators to remove attached structures. For each candidate, 35 features were defined, based on their position in the lung and relative to other structures, and the shape and density within and around each candidate using both segmentations. In a training procedure an optimal set of 15 features was determined with a k-nearest-neighbor classifier and sequential floating forward feature selection.

The algorithm was trained with a data set of 700 scans from a lung cancer

screening research study containing 224 pleural nodules and tested on an independent test set of 73 scans from the same program with 229 pleural nodules. The algorithm achieved a sensitivity of 79.5% with an average of 3.5 false positives per scan.

6915-33, Session 7

Performance levels for computerized detection of nodules in different size and pattern groups on thin-slice CT

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We developed a computer-aided diagnostic (CAD) scheme for detection of lung nodules in CT, and investigated its performance levels for nodules in different size and pattern groups. Our database consisted of 117 thin-slice CT scans with 153 nodules. There were 68 (44.4%) small, 52 (34.0%) medium-sized, and 33 (21.6%) large nodules; 101 (66.0%) solid and 52 (34.0%) nodules with ground glass opacity (GGO) in the database. Our CAD scheme consisted of lung segmentation, selective nodule enhancement, initial nodule detection, accurate nodule segmentation, and feature extraction and analysis techniques. The selective nodule enhancement filter was a key technique for achieving a high sensitivity and low false positive rate. We employed a case-based four-fold cross-validation method to evaluate the performance levels of our CAD scheme. The cross-validation testing method was repeated 10 times, and the average performance levels were reported. We detected 87% of nodules (small: 74%, medium-sized: 98%, large: 94%; solid: 85%, GGO: 90%) with 6.5 false positives per scan; 82% of nodules (small: 68%, medium-sized: 94%, large: 91%; solid: 78%, GGO: 89%) with 2.8 false positives per scan; and 77% of nodules (small: 63%, medium-sized: 90%, large: 89%; solid: 71%, GGO: 89%) with 1.5 false positives per scan. Our CAD scheme achieved a higher sensitivity for GGO nodules than for solid nodules, because most (82.4%) of small nodules were solid. In conclusion, our CAD scheme achieved a low false positive rate and a relatively high detection rate for nodules with a large variation in size and pattern.

6915-34, Session 7

A novel method of partitioning regions in lungs and their usage in feature extraction for reducing false positives

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Detection of nodules with a large number of false positives (FP) in chest X-ray images adds more work for the radiologists. In this paper we focus on reducing the FPs in an existing CAD system. Our CAD system relies on a two-step approach. In the first stage initial candidates for the nodules are detected. The second stage eliminates as many FP candidates as possible, without sacrificing much of true positives (TP). In the present work we propose two enhancements through this second stage.

Firstly different lung regions have different image characteristics. Taking advantage of this we propose an automatic lung partitioning into vessel, apical, basal and exterior pulmonary regions. Anatomical landmarks like aortic arch and end of cardiac-notch along-with inter intra-rib width and their shape characteristics are used for this partitioning.

Secondly likelihood of FPs is more in vessel, apical and exterior pulmonary regions due to (a) rib-crossing, (b) overlap of vessel with rib and (c) vessel branching. For each of these three cases, special features were designed based on histogram of rib slope and the structural properties of rib segments information. These features were assigned different weights based on the partitioning.

An experiment was carried out using a prototype CAD system 150 routine CXR studies were acquired from three institutions (24 negatives, rest with one or more nodules). Our algorithm provided a sensitivity of 70.4% with 5 FP/image for cross-validation without partition. Inclusion of the proposed techniques increases the sensitivity to 78.1% (76.03, 81.24) with 4.1 FP/image.

6915-35, Session 7

Comparison of computer versus manual determination of pulmonary nodule volumes in CT scans

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Accurate nodule volume estimation is necessary in order to estimate the clinically relevant growth rate or change in size over time. An automated nodule volume-measuring algorithm was applied to a set of pulmonary nodules that were documented by the Lung Image Database Consortium (LIDC). The LIDC process model specifies that each scan is assessed by four experienced thoracic radiologists and that boundaries are to be marked around the visible extent of the nodules for nodules 3 mm and larger. Nodules were selected from the LIDC database with the following inclusion criteria: (a) they must have a solid component on a minimum of three CT image slices and (b) they must be marked by all four LIDC radiologists. A total of 113 nodules met the selection criterion with diameters ranging from 3.59 mm to 32.68 mm (mean 9.37 mm, median 7.67 mm). The centroid of each marked nodule was used as the seed point for the automated algorithm. 107 nodules were correctly segmented; the remaining 6 (5.31%) were structurally too complex or extensively attached. Since the LIDC specifications, as aforementioned, instruct radiologists to include both solid and sub-solid parts, the automated method core capability of segmenting solid tissues was augmented to take into account the nodule sub-solid parts, too. We ranked the distances of the automated method volume and the radiologist-based volumes from the radiologist-based volume median. The automated method was in 70% of the cases closer to the median than at least one of the manual markings, which is a sign of a good agreement with the radiologists' markings.

6915-36, Session 7

Repeatability and noise robustness of spicularity features for computer-aided characterization of pulmonary nodules in CT

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Reduction of biopsies and unnecessary surgery while still allowing early detection and therapy of lung cancer is an important clinical aim. The computer aided characterization of pulmonary nodules is a step towards a comprehensive computer aided differential diagnosis. A number of published studies have correlated automatically computed features from image processing with clinical diagnoses of malignancy vs. benignity. Often, however, a very high number of features was trained on a small number of diagnosed nodules, raising a certain skepticism as to how salient and numerically robust the various features really are. On the way towards computer aided diagnosis which is trusted in clinical practice, the credibility of the individual numerical features has to be carefully established.

Nodule volume is the most crucial parameter in for nodule characterization, and a number of studies are testing their repeatability. Apart from functional parameters (such as dynamic CT enhancement and PET uptake values), the next most widely used parameter is the surface characteristic (vascularization, spicularity, lobulation, smoothness). In this study, we test the repeatability of two simple surface smoothness features which can discriminate between smoothly delineated nodules and those with a high degree of surface irregularity.

Robustness of the completely automatically computed features was tested with respect to the following aspects: (a) repeated CT scan of the same patient with equal dose, (b) repeated CT scan with much lower dose and much higher noise, (c) repeated automatic segmentation of the nodules using varying segmentation parameters, resulting in differing nodule surfaces. The tested nodules (81) were all solid or partially solid and included a high number of sub- and juxta-pleural nodules. We found that both tested surface characterization features correlated reasonably well with each other (80%), and that in particular the mean-surface-shape-index showed an excellent repeatability: 98% correlation between equal dose CT scans, 93% between standard-dose and low-dose scan (without systematic shift), and 97% between varying HU-threshold of the automatic segmentation, which makes it a reliable feature to be used in computer aided diagnosis.

6915-37, Session 8**Volume analysis of treatment response of head and neck lesions using 3D level set segmentation**

L. M. Hadjiiski, E. Street, B. Sahiner, S. Gujar, M. Ibrahim, H. Chan, S. K. Mukherji, Univ. of Michigan

A computerized system for segmenting lesions in head and neck CT scans was developed to assist radiologists in estimation of the response to treatment of malignant lesions. The system performs 3D segmentations based on a level set model and uses as input an approximate bounding box for the lesion of interest. In this preliminary study, CT scans from a pre-treatment exam and a post one-cycle chemotherapy exam of 13 patients containing head and neck neoplasms were used. A radiologist marked 35 temporal pairs of lesions. 13 pairs were primary site cancers and 22 pairs were metastatic lymph nodes. For all lesions, a radiologist outlined a contour on the best slice on both the pre- and post treatment scans. For the 13 primary lesion pairs, full 3D contours were also extracted by a radiologist. The average pre- and post-treatment areas for all lesions were 4.5 and 2.1 cm², respectively. For the 13 primary site pairs the average pre- and post-treatment primary lesions volumes were 15.4 and 6.7 cm³ respectively. The correlation between the automatic and manual estimates for the pre-to-post-treatment change in area for all 35 pairs was $r=0.97$, while the correlation for the percent change in area was $r=0.80$. The correlation for the change in volume for the 13 primary site pairs was $r=0.89$, while the correlation for the percent change in volume was $r=0.79$. The average signed percent error between the automatic and manual areas for all 70 lesions was $11.0 \pm 20.6\%$. The average signed percent error between the automatic and manual volumes for all 26 primary lesions was $37.8 \pm 42.1\%$. The preliminary results indicate that the automated segmentation system can reliably estimate tumor size change in response to treatment relative to radiologist's hand segmentation.

6915-38, Session 8**Automatic lesion tracking for a PET/CT based computer aided cancer therapy monitoring system**

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Response assessment of cancer therapy is a crucial component towards a more effective and patient individualized cancer therapy. Integrated PET/CT systems provide the opportunity to combine morphologic with functional information. However, dealing simultaneously with several PET/CT scans poses a serious workflow problem. It can be a difficult and tedious task to extract response criteria based upon an integrated analysis of PET and CT images and to track these criteria over time. In order to improve the workflow for serial analysis of PET/CT scans we introduce in this paper a fast lesion tracking algorithm.

We combine a global multi-resolution rigid registration algorithm with a local block matching algorithm. Whenever the user clicks on a lesion in the base-line PET scan the course of SUVs is automatically identified and shown to the user as a graph plot. We have validated our method by a data collection from 7 patients. Each patient underwent two or three PET/CT scans during the course of a cancer therapy. An experienced nuclear medicine physician manually measured the courses of the maximum SUVs for altogether 18 lesions. As a result we obtained that the automatic detection of the corresponding lesions resulted in SUV measurements which are nearly identical to the manually measured SUVs. Between 25 measured maximum SUVs derived from manual and automatic detected lesions we observed a correlation of 0.998 and a median error of 0.2 SUV units.

6915-39, Session 8**Unsupervised classification of cirrhotic livers using MRI data**

G. N. Lee, Gifu Univ. (Japan); M. Kanematsu, H. Kato, Gifu Univ. School of Medicine (Japan); X. Zhou, T. Hara, Gifu Univ. (Japan); H.

Kondo, Gifu Univ. School of Medicine (Japan); H. Fujita, Gifu Univ. (Japan); H. Hoshi, Gifu Univ. School of Medicine (Japan)

Cirrhosis of the liver is characterized by the presence of widespread nodules and fibrosis in the liver, resulting in characteristic texture patterns. Computerized analysis of hepatic texture patterns is usually based on regions-of-interest (ROIs), however, not all ROIs are typical representatives of the disease stage of the liver from which the ROIs originated. This leads to uncertainties in the labels of ROI feature vectors. On the other hand, supervised classifiers are commonly used in determining the assignment rule. This presents a problem as the training of a supervised classifier requires the correct labels of the feature vectors. In view of that, this paper investigates the use of an unsupervised classifier, the k-means clustering, in classifying ROI based data. In addition, a procedure for generating a receiver operating characteristic (ROC) curve depicting the classification performance of k-means clustering is also reported. A database consists of 44 patients' MRI data (16 cirrhotic; 28 non-cirrhotic) is used in this study. The MRI data are derived from gadolinium-enhanced equilibrium phase images and extracted from Kato et al [1]. For each patient, 10 ROIs selected by an experienced radiologist and 7 texture features measured on each ROI are included in the MRI data. Each texture feature is later averaged over the 10 ROIs. Using the k-means clustering and the proposed ROC curve generating procedure, the area under the curve (AUC) is found equal to 0.74. This is comparable to a resubstitution and leave-one-out AUC of 0.78 and 0.80 using a LDA classifier and an AUC of 0.80 using an ANN classifier as claimed in Kato et al [1].

6915-40, Session 8**An information-theoretic view of the scheduling problem in whole-body CAD**

Y. Zhan, X. S. Zhou, A. Krishnan, Siemens Medical Solutions USA, Inc.

With the advance of whole-body imaging technologies, computer aided detection/diagnosis (CAD) needs to scale up to deal with multiple organs or anatomical structure simultaneously, e.g., assessment of cancer metastasis in lymph, organs or bones. To be exploited in this paper is the fact that the various tasks in whole-body CAD are often highly dependent (e.g., the localization of the femur heads strongly predicts the position of the iliac bifurcation of the aorta). One way to exploit task dependency is to schedule the tasks such that outputs of some tasks are used to guide the others. In this sense, optimal task scheduling is key to improve overall performance of a whole-body CAD system.

In this paper, we propose a method for task scheduling that is optimal in an information-theoretic sense. The central idea is to schedule tasks in such an order that each operation achieves maximum expected information gain over all the tasks. The formulation embeds two intuitive principles: (1) a task with higher confidence tends to be scheduled earlier; (2) a task with higher predictive power for other tasks tends to be scheduled earlier. More specifically, task dependency is modeled by conditional probability; the outcome of each task is assumed to be probabilistic as well; and the objective function is based on the reduction of the summed conditional entropy over all tasks.

The validation is carried out on a multi-organ localization problem, where each task is the localization of an individual organ and the dependency between different tasks is represented by the spatial correlation between different organs. Compared to independent task executions, the scheduled execution achieves higher localization accuracy with much less computation time (>70% savings).

6915-41, Session 8**Multiparametric tissue abnormality characterization using manifold regularization**

K. Batmanghelich, X. Wu, C. E. Markowitz, R. Verma, Univ. of Pennsylvania

Tissue abnormality characterization is a generalized segmentation problem which aims at determining a continuous score that can be assigned to the tissue which characterizes the extent of tissue deterioration, with completely healthy tissue being one end of the spectrum and fully abnormal tissue such as lesions, being on the other

end. Our method is based on the assumptions that there is some tissue that is neither fully healthy or nor completely abnormal but lies in between the two in terms of abnormality; and that the voxel-wise score of tissue abnormality lies on a spatially and temporally smooth manifold of abnormality. Unlike in a pure classification problem which associates an independent label with each voxel without considering correlation with neighbors, or an absolute clustering problem which does not consider a priori knowledge of tissue type, we assume that diseased and healthy tissue lie on a manifold that encompasses the healthy tissue and diseased tissue, stretching from one to the other. We propose a semi-supervised method for determining such a abnormality manifold, using multi-parametric features incorporated into a support vector machine framework in combination with manifold regularization. We apply the framework towards the characterization of tissue abnormality to brains of multiple sclerosis patients.

6915-42, Session 8

Automated detection of breast vascular calcifications on full-field digital mammograms

J. Ge, H. Chan, B. Sahiner, C. Zhou, M. A. Helvie, L. M. Hadjiiski, J. Wei, Y. Zhang, Y. Wu, J. Shi, Univ. of Michigan

Breast vascular calcifications (BVCs) are parallel tracks or linear tubular calcifications that are clearly associated with breast blood vessels. BVC is one of the major causes of the false positive (FP) marks from computer-aided detection (CAD) systems for screening mammography. With the detection of BVCs and the calcified vessels identified, these FP clusters can be excluded. Moreover, recent studies reported the increasing interests in the correlation between mammographically detectable BVCs and the risk of coronary artery diseases. In this study, we developed an automated BVC detection method based on microcalcification prescreening and a new k-segment clustering algorithm. The mammogram is first processed with a difference-image filtering technique designed to enhance calcifications. The calcification candidates are selected by an iterative process that combines global thresholding and local thresholding. A modified k-segments algorithm is then used to find the k line segments that may be caused by the presence of calcified vessels. Three rule-based classifiers based on the principle component analysis of BVCs were designed to reduce false segments (not associated with BVCs) due to other structures. A data set of six FFDM cases (12 images) with vascular calcifications was collected for this preliminary study. On average, 79.5% of the calcified vessels were identified and the length of FP segments was about 5.5 mm/image. Our preliminary result demonstrated that breast vascular calcifications can be accurately detected and the calcified vessels identified. Further work is underway to improve this method and to validate its performance with a larger data set.

6915-60, Poster Session

Automated method for classification of Alzheimer's disease with atrophic image features on MR images

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The purpose of this study was to develop an automated method for classification of patients with Alzheimer's disease (AD) based on segmentation of cerebral cortical regions on three-dimensional (3-D) T1-weighted magnetic resonance (MR) images. Volumes and cortical thickness of specific regions (white matter and gray matter regions) related to the cerebral atrophy of AD were determined based on a level set method as image features, which were inputs to a novel classifier, support vector machine (SVM). The CSF volumes within cerebral sulci and lateral ventricles (LVs) were extracted by wrapping the brain tightly in a propagating surface determined with a level set method. Average cortical thickness was calculated in 32 subregions, which were obtained by dividing each brain region. To select mean cortical thicknesses in the most effective subregions, we employed a Golub statistic. Identification of AD patients was performed by using the SVM classifier, which was trained by the atrophic image features of AD and non-AD cases. We applied our proposed method to MR images of the whole brains obtained from 54 patients, including 29 clinically diagnosed AD cases and 25

non-AD cases. The area under a receiver operating characteristic curve obtained by our computerized method was 0.909 based on a leave-one-out test in identification of AD cases among 54 cases. This result showed that our method may be promising for detecting AD patients.

6915-61, Poster Session

Computerized detection of unruptured aneurysms in MRA images: reduction of false positives using anatomical location features

Y. Uchiyama, X. Gao, T. Hara, H. Fujita, Gifu Univ. (Japan); H. Ando, Gifu Municipal Hospital (Japan); H. Yamakawa, Chuno-Kosei Hospital (Japan); T. Asano, H. Kato, T. Iwama, M. Kanematsu, H. Hoshi, Gifu Univ. (Japan)

Cerebrovascular disease is the 3rd leading cause of death in Japan. Therefore, a screening system for early detection of asymptomatic brain diseases, which is named Brain Dock, is widely performed. In this screening system, unruptured aneurysms are often detected in magnetic resonance angiography (MRA). However, accurate detection of aneurysms is difficult because of the overlap between adjacent vessels on maximum-intensity projection (MIP) image. The purpose of this study was to develop a computerized method for the detection of aneurysms in order to assist radiologists' diagnosis as a "second opinion." The vessel regions were first segmented using gray-level thresholding and region growing technique. The gradient concentration (GC) filter was applied for the enhancement of aneurysms. The initial candidates were identified in the GC image with a gray-level threshold. For removal of false positives (FPs), we determined shape features and anatomical location features. Anatomical location features are important for the distinction between aneurysms and FPs, because aneurysms were often detected at the anterior communication artery, branch points of middle cerebral artery, and branch points between internal carotid artery and posterior communicating artery. In order to obtain anatomical location features, we used the image registration technique. Rule-based schemes and a quadratic discriminant analysis with these features were employed for distinguishing between aneurysms and FPs. The sensitivity for detection of aneurysms was 90.0% with 1.52 FPs per patient. Our computerized scheme would be useful in assisting radiologists for identifying correct aneurysms in MRA images.

6915-62, Poster Session

Coil compaction and aneurysm re-opening: image-based quantification using non-rigid registration

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Endovascular treatment of intracranial aneurysms can be associated to aneurysm recurrence due to coil compaction, aneurysm re-opening. Potential predictors of coil compaction are the percentage of aneurysm volume occupied by the coil after treatment (referred as packing, or hemodynamic features). The quantification of coil compaction is usually performed by manual measurements on consecutive images. Such manual measurements permit to detect large deformation but might have insufficient accuracy for detecting subtle changes between images. In this paper, we propose to quantify coil compaction using non-rigid image registration. Local changes of volume between images at successive time points are identified using the jacobian of the non-rigid transformation. This measure has been reported to be more accurate than comparing segmentation masks in the two images for measuring cerebral atrophy in potential Alzheimer's disease subjects. Three different non-rigid registration strategies (mutual information and BSplines, Demons, and Level Set motion) are applied in order to explore the sensitivity of the method. This volume-variation measure has been applied to 3 coiled aneurysms of which a series of 3DRA images ob-tained at different controls separated from 3 months to 2 year were available. The evolution of coil and aneurysm volumes along the period has been obtained separately, which allows distinguishing between coil compaction and aneurysm re-opening.

6915-63, Poster Session**Automatic segmentation of different-sized leukoaraiosis regions in brain MR images**

Y. Uchiyama, T. Kunieda, T. Hara, H. Fujita, Gifu Univ. (Japan); H. Ando, Gifu Municipal Hospital (Japan); H. Yamakawa, Chuno-Kosei Hospital (Japan); T. Asano, H. Kato, T. Iwama, M. Kanematsu, H. Hoshi, Gifu Univ. (Japan)

Cerebrovascular disease is the 3rd leading cause of death in Japan. Therefore, a screening system for early detection of asymptomatic brain diseases, which is named Brain Dock, is widely performed. In this screening system, leukoaraiosis is often detected on magnetic resonance (MR) images. The quantitative analysis of leukoaraiosis is important because their presence and extension are associated with an increased risk of severe stroke. However, subjective judgments by radiologists have been generally used. Therefore, the purpose of this study was to develop a computerized method for the segmentation of leukoaraiosis, and provide an objective measurement of lesion volume. Our database consisted of T1- and T2-weighted images obtained from 73 patients. The locations of leukoaraiosis were determined by an experienced neuroradiologist. We first segment cerebral regions in T1-weighted images by using thresholding and region growing techniques. For determining the initial candidate regions for leukoaraiosis, the k-means clustering with pixel values in T1- and T2-weighted images was applied to the segmented cerebral region. For the elimination of false positives (FPs), we determined features, such as location, size, and circularity, from each of the initial candidates. Finally, rule-based scheme and a quadratic discriminant analysis with these features were employed for distinguishing between leukoaraiosis and FPs. The results indicated that the sensitivity for detection of leukoaraiosis was 93.2% with 4.3 FPs per image. Tanimoto coefficient was 0.928. Our computerized scheme would be useful in assisting radiologists for quantitative analysis of leukoaraiosis in MR images.

6915-64, Poster Session**A multi-resolution image analysis system for computer-assisted grading of neuroblastoma differentiation**

J. H. Kong, O. H. Sertel, The Ohio State Univ.; H. Shimada, Univ. of Southern California; K. L. Boyer, The Ohio State Univ.; J. H. Saltz, M. N. Gurcan, The Ohio State Univ. Medical Ctr.

Neuroblastic Tumor (NT) is one of the most commonly occurring tumors in children. Of all types of NTs, neuroblastoma is the most malignant tumor that can be further categorized into undifferentiated (UD), poorly-differentiated (PD) and differentiating (D) types, in terms of the grade of pathological differentiation. Currently, pathologists determine the grade of differentiation by visual examinations of tissue samples under the microscope. However, this process is subjective and, hence, may lead to intra- and inter-reader variability. In this paper, we propose a multi-resolution image analysis system that helps pathologists classify tissue samples according to their grades of differentiation. The inputs to this system are color images of haematoxylin and eosin (H&E) stained tissue samples. The complete image analysis system has five stages: segmentation, feature construction, feature extraction, classification and confidence evaluation. Each input image is first partitioned into nuclei, cytoplasm, neuropil and background regions using our newly developed segmentation method that embeds the Fisher-Rao criterion within the Expectation Maximization framework. Twenty-four feature components of texture are derived from the segmented images. Next, the dimensionality of the feature space is reduced to two in the feature extraction stage using the Linear Discriminant Analysis. A multi-class Bayesian classifier decides the class output either as UD, PD, or D. The resulting classification decision is then evaluated by a Mahalanobis distance based confidence measure. Due to the large sizes of the input images (typically 50k by 50k), both parallel processing and multi-resolution analysis were carried out to reduce the execution time of the algorithm. Our training dataset consists of 387 images tiles of size 512x512 in pixels from three whole-slide images. We tested the developed system with an independent set of 24 whole-slide images, eight from each grade. The developed system has an accuracy of 83.33% in correctly identifying the grade of differentiation, and it takes about 2 hours, on average, to run for each whole slide image.

6915-65, Poster Session**Quantitative assessment of multiple sclerosis lesion load using CAD and expert input**

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Multiple sclerosis (MS) is a frequently encountered neurological disease with a progressive but variable course affecting the central nervous system. Outline based lesions quantification in the assessment of lesion load (LL) performed on MR images is clinically useful and provides information about the development and change reflecting overall disease burden.

Methods of LL assessment that rely on human input are tedious, have higher intra- and inter-observer variability and are more time-consuming than computerized automatic (CAD) techniques. At present it seems that methods based on human lesion identification preceded by non-interactive outlining by a CAD are best LL quantification strategies.

We have developed a CAD that automatically quantifies MS lesions, displays 3-D lesion map and appends radiological findings to original images according to current DICOM standard. The CAD is also capable to display and track changes and make comparison between patient's separate MRI studies to determine disease progression. The findings are exported to a separate imaging tool for review and final approval by expert. Capturing and standardized archiving of manual contours is also implemented. Similarity and reproducibility coefficients calculated from quantities of LL in collected exams show good correlation of CAD-derived results vs. those incorporated as expert's reading.

Combined CAD approach with expert interaction may have an impact to the diagnostic work-up of MS patients because it improves reproducibility in LL assessment and time of MR single or comparative exams reading. Inclusion of CAD generated outlines as DICOM compliant overlays into the image data can serve as better reference in MS progression tracking.

6915-66, Poster Session**Neurodegenerative changes in Alzheimer's disease: a comparative study of manual, semi-automated and fully automated assessment using MRI**

K. H. Fritzsche, F. L. Giesel, German Cancer Research Ctr. (Germany); P. A. Thomann, Ruprecht-Karls-Univ. Heidelberg (Germany); H. K. Hahn, MeVis Research GmbH (Germany); J. Pantel, Johann Wolfgang Goethe-Univ. Frankfurt am Main (Germany); J. Schröder, Ruprecht-Karls-Univ. Heidelberg (Germany); M. Essig, H. Meinzer, German Cancer Research Ctr. (Germany)

Objective quantification of disease specific neurodegenerative changes can aid diagnosis and therapeutic monitoring in several neuropsychiatric disorders. Reproducibility and easy-to-perform assessment are essential to ensure applicability in clinical environments. Aim of this comparative study is the evaluation of a fully automated approach that assesses atrophic changes in Alzheimer's disease (AD) and Mild Cognitive Impairment (MCI).

21 healthy volunteers (mean age 66.2), 21 patients with MCI (66.6), and 10 patients with AD (65.1) were enrolled. The subjects underwent extensive neuropsychological testing and MRI was conducted on a 1.5 Tesla clinical scanner. Atrophic changes were measured automatically by a series of image processing steps including state of the art brain mapping techniques. The results were compared with two reference approaches: a manual segmentation of the hippocampal formation and a semi-automated estimation of the temporal horn volume, which based upon interactive selection of two to six landmarks in the ventricular system.

All approaches separated controls and AD patients significantly ($p < 10^{-4}$) and showed a slight but not significant increase of neurodegeneration for subjects with MCI compared to volunteers. The automated approach correlated significantly with the manual ($p < 10^{-4}$) and semi automated ($p < 10^{-8}$) measurements. The fully automated approach proved high accuracy and at the same time maximized observer independency, time reduction and thus usefulness for clinical routine.

6915-67, Poster Session

Computer-aided detection of tumor and edema in brain FLAIR magnetic resonance image using ANN

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This work presents an efficient region based segmentation technique for pathological tissues (Tumor & Edema) detection for brain using fluid attenuated inversion recovery (FLAIR) magnetic resonance (MR) images. First of all this work segments FLAIR brain images for normal & pathological tissues based on statistical features and wavelet transform coefficients using k-mean algorithm. Whole image is divided into small blocks of 4_4 pixels. The k-mean algorithm is used to cluster the feature vectors of blocks of image into several classes with every class corresponding to one region in the segmented region. Knowing the feature vectors of different segmented regions, supervised technique is used to train Artificial Neural Network using fuzzy back propagation algorithm (BPA). Till now segmentation is mainly done for healthy tissues and tumors only using conventional MRI sequences like T1, T2 and PD weighted sequences. This work presents segmentation of healthy and pathological tissues (both Tumors & Edema) using FLAIR images. In the last pseudo coloring of segmented and classified regions are done for better human visualization.

6915-68, Poster Session

The effect of image quality on computer-aided detection (CADe) of microcalcifications in digitized screen-film mammography (dSFm) and full-field digital mammography (FFDM)

L. M. Yarusso, R. M. Nishikawa, The Univ. of Chicago

Many CADe schemes that were developed for dSFm are being transitioned to operate on FFDM detectors using patient images from new detectors. In this research, phantoms were used to relate image quality differences to the performance of the multiple components of a microcalcification CADe scheme (developed and optimized for dSFm), and to identify to what extent, if any, each CADe component is likely to require modification for FFDM. Multiple image quality metrics were compared for a dSFm imaging chain (GE DMR, MinR-2000 and Lumisys digitizer) and an FFDM system (GE Senographe 200D). Image quality was related to CADe performance on images of 1) contrast-detail (CD) disks and 2) microcalcification phantoms comprised of bone fragments and cadaver breasts. All CADe components were robust to image quality differences presented by FFDM. Higher object signal-to noise ratio (SNR) in FFDM compared with dSFm ($p < 0.05$ for 65% of CD phantom disks) led to superior CADe signal and cluster detection FROC performance. Signal segmentation was comparable ($p > 0.05$ for 79% of disks) in dSFm and FFDM, partly due to similar system resolutions. Superior FFDM temporal stability led to more stable CADe performance. For microcalcification phantoms, seven of eight computer-calculated features performed better ($p < 0.05$) or comparably at classifying true- and false-positive detections in the two modalities using ROC analysis. Our methods to identify CADe components requiring modification for FFDM without using patient data are expected to be generalizable to other detectors and CAD tasks are likely to facilitate the reoptimization of CADe for new imaging systems.

6915-69, Poster Session

Towards a standard reference database for computer-aided mammography

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The lack of mammography databases with a large amount of codified images and identified characteristics like pathology, type of breast tissue, and abnormality, is a problem for the development of robust systems for computer-aided diagnosis. Integrated to Image Retrieval Medical Applications (IRMA) project, we present an available mammography database developed from the union of: The Mammographic Image

Analysis Society Digital Mammogram Database (MIAS), the Digital Database for Screening Mammography (DDSM) and routine images from the Rheinisch-Westfälische Technische Hochschule (RWTH) Aachen. Using the IRMA code, standardized coding of tissue type, tumor staging, and lesion description was developed according to the American College of Radiology (ACR) tissue codes and the ACR breast imaging reporting and data system (BI-RADS). The import was done automatically using scripts for image download, file format conversion, file name, web page and information file browsing. In particular, 9,833 of 9,852 DDSM images and 54 of 170 RWTH images provided sufficient information for inclusion, while all 322 MIAS images were used, but the ACR tissue type classification was added manually. Disregarding the resolution, this results in a total of 10,209 reference images of 185 code classes. 6,767 images are associated with an IRMA contour information feature file. In accordance to the respective license agreements, the database will be made freely available for research purposes, and may be used for image based evaluation campaigns such as the Cross Language Evaluation Forum (CLEF). It can easily be extended with further cases imported from a picture archiving and communication system (PACS).

6915-70, Poster Session

A graph matching based automatic regional registration method for sequential mammogram analysis

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This paper presents a method for associating regions of sequential mammograms automatically using graph matching. The graph matching utilises relative spatial relationships between the regions of a mammogram to establish regional correspondences between two mammograms.

As a first step of the method, the mammogram is segmented into separate regions using an adaptive pyramid segmentation algorithm. This process produces both segmented regions of the mammogram and a graph. The nodes of the graph represent the segmented regions, and the lines represent the neighbourhood relationships between the regions. The regions are then filtered to remove undesired regions. To express the spatial relations between the regions, we use a fuzzy logic expression, which takes into account the characteristics of each region including the shape, size and orientation. The spatial relations between regions are utilised as weights of the graph. The backtrack algorithm is then used to find the common subgraph between two graphs.

The proposed method is applied to 44 temporal pairs of mammograms. For each temporal mammogram pair, an average of 13 regions is matched. All region matches are classified as "good", "average", "poor" and "unknown" by one of the authors (FM) based on visual perception. 72% of region matches are identified as "good", and 12% as "average". The percentages of "poor" and "unknown" are 11% and 5% respectively. These results indicate that our registration method may be useful for establishing regional correspondence between sequential mammograms.

6915-71, Poster Session

Comparison of mammographic parenchymal patterns of normal subjects and breast cancer patients

Y. Wu, B. Sahiner, H. Chan, J. Wei, L. M. Hadjiiski, M. A. Helvie, Y. Zhang, J. Shi, C. Zhou, J. Ge, J. Cui, Univ. of Michigan

In this study, we compared the mammographic parenchymal pattern (MPP) of normal subjects and breast cancer patients. Our data set contained 549 normal and 128 cancer cases with mammographic masses. Texture analysis was performed in regions of interest (ROIs) of 512x512 pixels in the retroareolar region on the cranio-caudal (CC) view mammograms. For the normal cases, a normal set (NS) of ROIs was extracted from only one breast. For the cancer cases, each case had a biopsy-proven mass in one breast. A mass set (MS) of ROIs was extracted from the mammograms with cancer, but ROIs overlapping with the mass were excluded. A contralateral set (CS) of ROIs was extracted from the contralateral mammograms. Each data set was randomly separated into two independent subsets for 2-fold cross-validation

training and testing. Texture features from the run-length statistics and the newly developed region-size statistics were then extracted from the ROIs to describe the MPP of the breast. Linear discriminant analysis (LDA) was performed to compare the MPP difference in each of the three pairs: CS-vs-NS, MS-vs-NS, and MS-vs-CS. For each pair comparison, an LDA with stepwise feature selection was trained with a leave-one-case-out resampling scheme within the training subset and tested on the independent subset. The average Az from the two test subsets for the CS-vs-NS, MS-vs-NS, and MS-vs-CS pair comparisons were 0.74 ± 0.025 , 0.79 ± 0.021 , and 0.58 ± 0.035 , respectively. The difference in Az between CS-vs-NS and MS-vs-NS was not significant ($p=0.082$), whereas the differences between CS-vs-NS and MS-vs-CS and between MS-vs-NS and MS-vs-CS were statistically significant ($p<0.001$). The MPP in both breasts of breast cancer patients may be different from that of normal subjects.

6915-72, Poster Session

Characterization of posterior acoustic features of breast masses on ultrasound images using artificial neural network

J. Cui, B. Sahiner, H. Chan, C. Paramagul, A. Nees, L. M. Hadjiiski, Y. Wu, Univ. of Michigan

Posterior acoustic enhancement and shadowing on ultrasound (US) images are important features used by radiologists for characterization of breast masses as cystic or solid. Furthermore, posterior shadowing is suggestive of malignancy for solid masses. In this study, we developed feature extraction and classification methods for characterization of the posterior acoustic patterns of masses into shadowing, no pattern, or enhancement categories. An automated method was used to segment the mass. Three adjacent rectangular regions of interest (ROIs) of identical sizes were automatically defined at the same depth immediately behind the mass. Three features related to enhancement, shadowing, and no posterior pattern were designed by comparing the image intensities within these ROIs. Two artificial neural network (ANN) classifiers were trained using a leave-one-case-out resampling method. The first ANN had three output nodes, which correspond to shadowing, no pattern, and enhancement categories. The estimated category for an unknown input mass was defined as that of the node with the highest output score. The second ANN had a single output node. Two thresholds on the output score were used to define the estimated category for an unknown mass. The test results of these two classifiers were compared based on two measures: the overall accuracy (percentage of correct decisions) and the adjusted accuracy (the average percentage of the diagonal entries of the confusion matrix). A data set consisting of 321 US images from 168 cases was used for performance evaluation. According to two radiologists' posterior acoustic pattern descriptors, 52 masses had posterior shadowing, 158 had enhancement, and 111 showed no posterior pattern. The overall and adjusted accuracies for the ANN with three output nodes were 0.79 and 0.79, respectively, while the corresponding accuracies for the ANN with a single output node were 0.81 and 0.78, respectively.

6915-73, Poster Session

Application of the Minkowski-Functionals for automated pattern classification of breast parenchyma depicted by digital mammography

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With an estimated life-time-risk of about 10% in western societies, breast cancer is the most common cancer among women. Extensive mammography-screening programs have been implemented for diagnosis of the disease at an early stage. Several algorithms for computer-aided detection (CAD) have been proposed to help radiologists manage the increasing number of mammographic image-data and identify new cases of cancer.

However, a major issue with most CAD-algorithms is the fact that performance strongly depends on the structure and density of the breast tissue. Prior information about the global tissue quality in a patient would

be helpful for selecting the most effective CAD-approach in order to increase the sensitivity of lesion-detection.

In our study, we propose an automated method for textural evaluation of digital mammograms using the Minkowski Functionals in 2D. 100 mammograms are consensus-classified by two experienced readers as fibrosis, involution/atrophy, or normal. For each case, the topology of graylevel distribution is evaluated within a retromamillary image-section of 512×512 pixels. In addition, we obtain parameters from the graylevel-histogram (20th percentile, median and mean graylevel intensity).

As a result, correct classification of the mammograms based on the densitometric parameters is achieved in between 37 and 47%, whereas topological analysis increases the rate to 83%.

The experimental findings demonstrate the effectiveness of the proposed algorithm. Compared to features obtained from graylevel histograms and published work, we draw the conclusion that the developed method performs equally good or better. Our future work will be focused on the characterization of the mammographic tissue according to the Breast Imaging Reporting and Data System (BI-RADS). Moreover, other databases will be tested for an in-depth evaluation of the efficiency of our proposal.

6915-74, Poster Session

Improving mass detection performance by use of 3D difference filter in a whole breast ultrasonography screening system

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Ultrasonography is one of most important methods for breast cancer screening in Japan. Several mechanical whole breast ultrasound (US) scanners for large-volume screening have been developed. However, the screening will generate a large volume of US images and radiologists might tire while interpreting them. Therefore, it is possible that masses may remain undetected. The screening accuracy and efficiency might be improved if a computer-aided detection (CAD) system could assist radiologists. We have reported a computerized method for the detection of masses in whole breast ultrasound images. The proposed method was applied to larger database than in the past. The false positives were remarkably increased. The false positives (FPs) were 16.8 per breast (4379/260) with a sensitivity of 80% (56/70). In this study, the detection method of mass candidates and reduction method of FPs were improved to advance the performance. A 3D difference (3DD) filter was developed to extract lower density regions, and five features, roundness, standard deviation of pixel value, posterior shadowing feature, maximum value and mean value of the 3DD filter, in addition to the other five features proposed by our previous study were extracted to reduce FPs. As a result, the FPs were reduced by 44%, and the FPs were 9.5 per breast (2470/260) with 80% sensitivity (56/70). This study indicates that 3DD filter is useful for detection of masses in whole breast ultrasound images and five features are effective for the reduction of false positives.

6915-75, Poster Session

Semiautomatic segmentation for the computer-aided diagnosis of clustered microcalcifications

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Screening mammography is recognized as the most effective tool for early breast cancer detection. However, its application in clinical practice shows some of its weaknesses. While clustered microcalcifications are often an early sign of breast cancer, the discrimination of benign from malignant clusters based on their appearance in mammograms is a very difficult task. Hence it is not surprising that typically only 15% to 30% of breast biopsies performed on calcifications will be positive for malignancy. As this low positive predictive value of mammography regarding the diagnosis of calcification clusters results in many unnecessary biopsies performed on benign calcifications, we propose a novel computer aided diagnosis (CADx) approach with the goal to improve the reliability of microcalcification classification. As effective

automatic classification of microcalcification clusters relies on good segmentations of the individual calcification particles, many approaches to the automatic segmentation of individual particles have been proposed in the past. Because none of the fully automatic approaches seem to result in optimal segmentations, we propose a novel semiautomatic approach that has automatic components but also requires some interaction of the physician. Based on the resulting segmentations we extract a broad range of features that characterize the morphology and distribution of calcification particles. Using regions of interest containing either benign or malignant clusters extracted from the digital database for screening mammography we evaluate the performance of our approach using a support vector machine and ROC analysis. The resulting ROC performance is very promising and we show that the performance of our semiautomatic segmentation is significantly higher than that of a comparable fully automatic approach.

6915-76, Poster Session

Rib detection for whole breast ultrasound image

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Recently, the whole breast ultrasound (US) is a new advanced screening technique for detecting breast abnormalities. Because a lot of images are acquired for a case, the computer-aided diagnosis (CAD) system is needed to help the physicians to reduce the diagnosis time. In the automatic whole breast US, the ribs are the pivotal landmark just like the pectoral muscle in the mammography. In this paper, we develop an automatic rib detection method for the whole breast ultrasound. The ribs could be helpful to define the screening area of a CAD system to reduce the tumor detection time and could be used to register different passes for a case. Due to the shadowing is occurred under the rib in the whole breast ultrasound images and is the sheet-like structure, the Hessian analysis and sheetness function are adopted to enhance the sheet-like structure. Then, the orientation thresholding is proposed to segment the sheet-like structures. In order to remove the non-rib components in the segmented sheet-like structures, some features of ribs in whole breast ultrasound are used. Thus, the connected component labeling is applied and then some characteristics such as orientation, length and radius are calculated. Finally, some criteria are applied to remove non-rib components. In our experiments, there are 65 ribs in 15 test cases and the 62 ribs have been detected by the proposed system with the detection ratio 95.38%. The ratio of position difference under 5 mm is 87.10 % and the ratio of length difference under 10 mm is 85.48 %. The results show that the proposed system almost could detect the ribs in the breast US images and has a good accuracy.

6915-77, Poster Session

Semantic-based mammographic masses classification and retrieval using BI-RADS as guidance

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In this study, we present a clinically guided technical method for content-based mammographic masses classification and retrieval. Our work is motivated by the continuing effort in content-based image retrieval to extract and to model the semantic content of images. Specifically, we classified the shape and margin of mammographic mass into different categories, which are designated by radiologists according to BI-RADS descriptors. Mass lesions are represented by the scores/likelihoods of each categories produced by the corresponding classifiers, and similarities between the query mass and masses in the database are derived from this representation. Through these experiments, we demonstrated that this representation is suited to extract the characteristics of mass appearances, and thus have potential use for categorization and retrieval in the clinical applications.

6915-78, Poster Session

Effect of ROI size on the performance of an information-theoretic CAD system in mammography: multisize analysis fusion

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Featureless, knowledge-based CAD systems are an attractive alternative to feature-based CAD because they require no to minimal image preprocessing. Such systems compare images directly using the raw image pixel values rather than relying on low-level image features. Specifically, information-theoretic (IT) measures such as mutual information (MI) have been shown to be an effective, featureless, similarity measure for image comparisons. MI captures the statistical relationship between the gray level values of corresponding image pixels. In a CAD system developed at our laboratory, the above concept has been applied for location-specific detection of mammographic masses. The system is designed to operate on a fixed size region of interest (ROI) extracted around a suspicious mammographic location. Since mass sizes vary substantially, there is a potential drawback. When two ROIs are compared, it is unclear how much the parenchymal background contributes in the calculated MI. This uncertainty could deteriorate CAD performance in the extreme cases, namely when a small mass is present in the ROI or when a large mass extends beyond the fixed size ROI. The present study evaluates the effect of ROI size on the overall CAD performance and proposes multisize analysis for possible improvement. Based on two datasets of ROIs extracted from DDSM mammograms, there was a statistically significant decline of the CAD performance as the ROI size increased. The best size ranged between 512x512 and 256x256 pixels. Multisize fusion analysis using a linear model achieved further improvement in CAD performance for both datasets.

6915-79, Poster Session

Optimized acquisition scheme for multiprojection correlation imaging of breast cancer

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We are reporting the optimized acquisition scheme of multi-projection breast Correlation Imaging (CI) technique, which was pioneered in our lab at Duke University. CI is similar to tomosynthesis in its image acquisition scheme. However, instead of analyzing the reconstructed images, the projection images are directly analyzed for pathology thereby avoiding reconstruction artifacts that can limit tomosynthesis. Images from 182 subjects recruited for an ongoing clinical trial for tomosynthesis were employed in this study. For each patient, 25 angular projections of each breast were acquired. Projection images were supplemented with a simulated 3 mm 3D lesion. Each projection was first processed by a traditional Computer Aided Detection (CADE) processor at high sensitivity, followed by reduction of false positives by combining geometrical correlation information available from the multiple images. Performance was measured in terms of free-response receiver operating characteristics (FROC) curves. For optimization, the number of projections, their angular span, and the acquisition dose level were systematically changed to maximize the obtainable sensitivity and specificity. Results indicated that the performance of the CI system depended on the geometry of acquisition and the dose level. Furthermore, the FROC curves revealed that while the CI scheme improved diagnostic performance, there was no appreciable gain in performance beyond 15 projections. Specifically, the number of false positives per patient at fixed sensitivity of 67 % approached an asymptote of 3.3 with an increase in the number of projections used. Thus an optimized CI system might potentially be an important diagnostic tool for improved breast cancer detection.

6915-80, Poster Session

Detection of architectural distortion in mammograms acquired prior to the detection of breast cancer using texture and fractal analysis

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Mammography is a widely used screening tool for the early detection of breast cancer. One of the commonly missed signs of breast cancer is architectural distortion. The purpose of this study is to explore the application of fractal analysis and texture measures for the detection of architectural distortion in screening mammograms taken prior to the detection of breast cancer. A method based on Gabor filters and phase portrait analysis was used to detect initial candidates for sites of architectural distortion. A total of 386 regions of interest (ROIs) were automatically obtained from 14 "prior mammograms", including 21 ROIs related to architectural distortion. The fractal dimension of the ROIs was calculated using the circular average power spectrum technique. The average fractal dimension of the normal (false-positive) ROIs were higher than that of the ROIs with architectural distortion. For the "prior mammograms", the best receiver operating characteristics (ROC) performance achieved was 0.74 with the fractal dimension and 0.70 with fourteen texture features, in terms of the area under the ROC curve.

6915-81, Poster Session

Breast mass segmentation on dynamic contrast-enhanced magnetic resonance imaging scans using the level set method

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The goal of this study was to develop an automated method to segment breast masses on dynamic contrast-enhanced (DCE) magnetic resonance imaging (MRI) scans that were performed to monitor the breast cancer response to neoadjuvant chemotherapy. A radiologist experienced in interpreting breast MRI defined the mass using a cuboid volume of interest (VOI). Our method then used the K-means clustering algorithm followed by a morphological opening operation for initial mass segmentation on the VOI. The initial segmentation was then refined by a three-dimensional level set (LS) method. The velocity field of the LS method was formulated in terms of the mean curvature which guaranteed the smoothness of the surface and the Sobel edge information which attracted the zero LS to the desired mass margin. We also designed a method to reduce segmentation leak by adapting a region growing technique. Our method was evaluated on 10 DCE-MRI scans of 5 patients who underwent neoadjuvant chemotherapy. Each patient had pre- and post- chemotherapy DCE-MRI scans on a 1.5 Tesla magnet. We selected coronal T1-weighted images. The in-plane pixel size ranged from 0.546 to 0.703 mm and the slice thickness ranged from 2.8 to 4.0 mm. The flip angle was 15 degrees, repetition time ranged from 5.98 to 6.601 ms, and echo time ranged from 1.2 to 1.3 ms. The computer segmentation results were compared to the radiologist's manual segmentation in terms of the overlap measure defined as the ratio of the intersection of the computer and the radiologist's segmentations to the radiologist's segmentation. Pre- and post-chemotherapy masses had overlap measures of 0.80 ± 0.08 (mean \pm s.d.) and 0.51 ± 0.21 , respectively.

6915-82, Poster Session

A study of mammographic mass retrieval based on shape and texture descriptors

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Content-based mass image retrieval technology utilizing both shape and texture features is investigated in this paper. In order to retrieve similar mass pattern that helps improving clinical diagnosis, the performances of mass retrieval using the curvature scale space descriptors (CSSDs) and R-transform descriptors were mainly studied. The mass contours in the DDSM database (Univ. of South Florida) were preprocessed to eliminate those curl cases, which is very important for the extraction of features. The peak extraction method from CSS contour map by circular shift and CSSDs matching method were introduced. Preliminary experiments show that the performance of CSSDs and R-transform descriptors outperforms other features such as moment invariants,

normalized Fourier descriptors (NFDs) and combined texture feature. By combining the CSSDs with R-transform descriptors and texture features based on Gray-level Co-occurrence Matrices (GLCMs), the experiments show that the hybrid method gives better performance of mass image retrieval than that of either CSSDs or R-transform descriptors.

6915-83, Poster Session

A comprehensive multiattribute, manifold learning scheme-based computer-aided diagnostic system for breast MRI

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Breast MRI has been shown to be a useful complement to X-ray mammography in breast cancer screening. Because of its higher sensitivity compared to ultrasound and x-ray, MRI can provide additional information in identifying lesions in instances where conventional x-ray mammography or ultrasound may be suboptimal. Currently, radiologists evaluate breast lesions based on qualitative description of lesion morphology and contrast uptake profiles. However, the subjective nature with which radiologists evaluate breast lesions introduces high rates of interobserver variability. In addition, the high sensitivity of MRI results in poor specificity and thus a high rate of biopsies on benign lesions. Previous work in the area of breast computer-aided diagnosis (CAD) has focused on either quantitating morphological attributes used by radiologists or characterizing kinetic curves obtained from dynamic contrast-enhanced (DCE) images; these two focuses are rarely studied in combination. In addition, little work has evaluated how one set of features compares with others in their importance in lesion classification. In this paper, we introduce a CAD system for breast lesions that uses a multi-feature analysis scheme, extracting over six hundred morphological, textural, and kinetic features three dimensionally for classification of manually segmented breast lesions as detected by expert radiologists. The large feature set for each lesion is transformed into a reduced feature space using manifold learning methods. The reduced feature space is then run on a support vector machine (SVM) classifier to classify each lesion as either benign or malignant. To our knowledge, this is the first work that integrates morphological, textural, and kinetic features in a quantitative analysis of breast lesions on MRI and that uses manifold learning and SVM to determine the importance of each individual feature class in distinguishing between benign and malignant breast lesions on MRI.

6915-84, Poster Session

Tumor classification using perfusion volume fractions in breast DCE-MRI

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This study was designed to classify kinetic patterns using both three-time-points (3TP) method and clustering approach at full-time points, and to introduce a new evaluation method using perfusion volume fractions for differentiation of benign and malignant lesions. DCE-MRI was applied to 24 lesions (12 malignant, 12 benign). After region growing segmentation for each lesion, hole-filling and 3D morphological erosion and dilation were performed for extracting final lesion volume. 3TP method and k-means clustering at full-time points were applied for classifying kinetic patterns into 6 classes. Intratumoral volume fraction for each class was calculated. ROC and linear discriminant analysis were performed with distributions of the volume fractions for each class, pairwise and whole classes, respectively. Best performance to each class showed AUC=0.847 (SE=100%, SP=66.7% to a single cSPIss) to 3TP method, whereas AUC=0.736 (SE=41.7%, SP=100% to a single class) to k-means clustering. Best performance to pairwise classes showed AUC=0.75 (SE=83.3%, SP=66.7% to four class pairs; SE=58.3%, SP=91.7% to a single class) to 3TP method and AUC=0.75 (SE=75%, SP=75% to a single class pair; SE=66.7%, SP=83.3% in three class pairs) to k-means clustering. Performance to whole classes showed AUC=0.75

(SE=83.3%, SP=66.7%) to 3TP method and AUC=0.75 (SE=91.7%, SP=58.3%) to k-means clustering. The results indicate that tumor classification using perfusion volume fractions is helpful in selecting meaningful kinetic patterns for differentiation of benign and malignant lesions, and that performances of the two classification methods are complementary to each other.

6915-85, Poster Session

Cell-based image partition and edge grouping: a nearly automatic ultrasound image segmentation algorithm for breast cancer computer-aided diagnosis

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Morphological features of breast lesion in sonography are valuable for computer aided diagnosis (CAD) study. To support effective feature extraction from the irregular boundary of breast lesion, this study proposes a two-phase data-driven approach for boundary demarcation. The first phase aims to partition the image or Region of Interest (ROI) into several prominent regions while the second phase tries to group the edge information, preserved in the prominent region partition, into boundary candidates. The two phases are implemented on the cell tessellation, which is generated by two-pass watershed transformation. With this unique integration of the three ingredients, i.e., the partition and grouping phases and cell tessellation, it will be shown that the breast lesion boundaries can be effectively and efficiently detected- even the lesion shape is very uneven. The proposed algorithm can be served as the kernel of CAD system on breast ultrasound to improve the automation and performance. Also the performance of CAD system supported by the proposed algorithm is reported.

6915-86, Poster Session

Scale-based scatter correction for computer-aided polyp detection in CT colonography

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CT colonography (CTC) is a feasible and minimally invasive method for the detection of colorectal polyps and cancer screening [1]. Computer-aided detection (CAD) of polyps has improved consistency and sensitivity of virtual colonoscopy interpretation and reduced interpretation burden. However, high-density orally administered contrast agents have scatter effects on neighboring tissues. The scattering manifests itself as an artificial elevation in the observed CT attenuation values of the neighboring tissues. This pseudo-enhancement phenomenon presents a problem for the application of computer-aided polyp detection, especially when polyps are submerged in the contrast agents [2]. We developed a scale-based correction method that minimizes scatter effects in CTC data by subtraction of the estimated scatter components from observed CT attenuations. By bringing a locally adaptive structure, object scale [3], into the correction framework, the region of neighboring tissues affected by contrast agents is automatically specified and adaptively changed in different parts of the image. The method was developed as one preprocessing step in our CAD system and was tested by using leave-one-patient-out evaluation on 33 clinical CTC cases. There were 58 colonoscopy-confirmed polyps within 6-9 mm. Visual evaluation indicated that the method reduced CT attenuation of pseudo-enhanced polyps to the usual polyp Hounsfield unit (HU) range without affecting luminal air regions. For all polyps within 6-9 mm, the sensitivity of our CAD with scatter correction is increased about 10% at a rate of 8 false-positive detections per patient. For polyps submerged in contrast agents, the sensitivity of CAD with correction is increased about 20% at a rate of 7 false-positive detections per patient. Our results indicated that CAD with this correction method as a preprocessing step can yield a high sensitivity and a relatively low FP rate in CTC.

6915-87, Poster Session

Spatio-temporal registration in multiplane MRI acquisitions

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In this paper we present a novel method for analyzing and visualizing dynamic peristaltic motion of the colon in 3D from two series of differently oriented 2D MRI images. To this end, we have defined an MRI examination protocol, and introduced methods for spatio-temporal alignment of the two MRI image series into a common reference. This represents the main contribution of this paper, which enables the 3D analysis of peristaltic motion. The objective is to provide a detailed insight into this complex motion, aiding in the diagnosis and characterization of colon motion disorders. We have applied the proposed spatio-temporal method on Cine MRI data sets of healthy volunteers. The results have been inspected and validated by an expert radiologist. Segmentation and cylindrical approximation of the colon results in a 4D visualization of the peristaltic motion.

6915-89, Poster Session

Digital bowel cleansing free detection method of colonic polyp from fecal tagging CT images

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The purpose of this paper is to present a digital bowel cleansing (DBC) free detection method of colonic polyp from fecal tagging CT images. Virtual colonoscopy (VC) or CT colonography is a new colon diagnostic method to examine the inside of the colon. However, since the colon has many haustra and its shape is long and convoluted, there is a risk of overlooking of lesions existing in blinded areas caused by haustra. Automated polyp detection from colonic CT images will reduce the risk of overlooking. Although many methods for polyp detection have been proposed, these methods needed DBC to detect polyps surrounded by tagged fecal material (TFM). However, DBC may change shapes of polyps or haustra while removing TFM and it adversely affect polyp detection. This paper presents a colonic polyp detection method enabling us to detect polyps surrounded by the air and polyps surrounded by the TFM simultaneously without any DBC processes. CT values inside polyps surrounded by the air and polyps surrounded by the TFM regions tend to gradually increase (blob structure) and decrease (inverse-blob structure) from outward to inward, respectively. We employ blob and inv-blob structure enhancement filters based on the eigenvalues of the Hessian matrix to detect polyps using intensity characteristic of polyps. False positive elimination is performed using three feature values: volume, maximum value of the filter outputs, and standard deviation of CT values inside polyp candidate regions. We applied the proposed method to 104 cases of abdominal CT images. Sensitivity for polyps >6mm was 89.5% with 9.0FPs/case.

6915-90, Poster Session

Variation of quantitative emphysema measurements from CT scans

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Emphysema is a lung disease characterized by destruction of the alveolar air sacs and is associated with long-term respiratory dysfunction. CT scans allow for imaging of the anatomical basis of emphysema, and several measures have been introduced for the quantification of the extent of disease. In this paper we compare these measures for repeatability

over time. The measures of interest in this study are emphysema index, mean lung density, histogram percentile, and the fractal dimension. To allow for direct comparisons, the measures were normalized to a 0-100 scale. These measures have been computed for a set of 2,027 scan pairs from a screening study in which the mean interval between scans was 1.15 years (lf : 93 days). These independent pairs were considered with respect to three different scanning conditions (a) 223 pairs where both were scanned with a 5 mm slice thickness protocol, (b) 695 with the first scanned with the 5 mm protocol and the second with a 1.25 mm protocol, and (c) 1109 pairs scanned both times using a 1.25 mm protocol. We found that average normalized emphysema index and histogram percentiles scores increased by 5.9 and 11 points respectively, while the fractal dimension showed stability with a mean difference of 1.2. We also found, a 4.5 point bias introduced for emphysema index under condition (b), and that the fractal dimension measure is least affected by scanner parameter changes.

6915-91, Poster Session

Computer-aided interpretation of portable chest x-ray images: automated detection of endotracheal (ET) tube positioning

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Purpose: In intensive care units (ICUs), endotracheal (ET) tubes are inserted to assist patients who may have difficulty breathing. A mal-positioned ET tube could lead to a collapsed lung, which is life threatening. The purpose of this study is to automatically detect the positioning of ET tubes on portable chest x-ray images.

Method: A computer-aided detection method has been developed to detect ET tubes in portable chest x-ray images. The method determines a region of interest (ROI) in the image and processes the raw image to provide edge enhancement forming an edge-enhanced image. The combination of a Canny filter and a Hough transform is applied to detect edges and lines on the edge-enhanced image. The detected edge segments are then analyzed to form a set of connected lines. From the set of connected lines, a tube structure is identified by pairing one or more pairs of edges separated by a width dimension in a predetermined range. The tip of a detected tube is ascertained by the convergence or divergence of paired connected lines. The detected tube and/or its tip are highlighted on the radiographic image as output.

Results: The method correctly detected 91% of 33 ET tubes previously identified by an experienced radiologist in initial training data with no false-positive detection. To test the robustness of the method, we independently collected 121 images, each with an identified ET tube. The method achieved a detection rate of 87% on the independent database.

Conclusion: Preliminary results show that computer-aided detection of tubes in portable chest x-ray images is promising. It is expected that automated detection of ET tubes could lead to timely detection of mal-positioned tubes, thus improve overall patient management in ICUs.

6915-92, Poster Session

Automatic segmentation of lung parenchyma based on curvature of ribs using HRCT images in scleroderma studies

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Segmentation of lungs in the setting of scleroderma is a major challenge in medical image analysis. Threshold based techniques tend to leave out lung regions that have increased attenuation, for example in the presence of interstitial lung disease or in noisy low dose CT scans. The purpose of this work is to perform segmentation of the lungs using a technique that selects an optimal threshold for a given scleroderma patient by comparing the curvature of the lung boundary to that of the ribs. Our approach is based on adaptive thresholding and it tries to exploit the fact that the curvature of the ribs and the curvature of the lung boundary are closely matched. At first, the ribs are segmented and

a polynomial is used to represent the ribs' curvature. A threshold value to segment the lungs is selected iteratively such that the deviation of the lung boundary from the polynomial is minimized. A Naive Bayes classifier is used to build the model for selection of the best fitting lung boundary. The performance of the new technique was compared against a standard approach using a simple fixed threshold of -400HU followed by region-growing. The two techniques were evaluated against manual reference segmentations using a volumetric overlap fraction (VOF) and the adaptive threshold technique was found to be significantly better than the fixed threshold technique.

6915-93, Poster Session

Algorithm of pulmonary emphysema extraction

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Emphysema patients have the tendency to increase due to aging and smoking. Emphysematous disease destroys alveolus and to repair is impossible, thus early detection is essential. CT value of lung tissue decreases due to the destruction of lung structure. This CT value becomes lower than the normal lung- low density absorption region or referred to as Low Attenuation Area (LAA). So far, the conventional way of extracting LAA by simple thresholding has been proposed. However, the CT value of CT image fluctuates due to the measurement conditions, with various bias components such as inspiration, expiration and congestion. It is therefore necessary to consider these bias components in the extraction of LAA. We removed these bias components and we proposed LAA extraction algorithm. This algorithm has been applied to the phantom image. Then, by using the low dose CT(normal: 30 cases, obstructive lung disease: 26 cases), we extracted early stage LAA and quantitatively analyzed lung lobes using lung structure.

6915-94, Poster Session

An evaluation of automated broncho-arterial ratios for reliable assessment of bronchiectasis

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Bronchiectasis, the permanent dilatation of the airways, is frequently evaluated by computed tomography (CT) in order to determine disease progression and response to treatment. Normal airways should have a diameter approximately the same size as the accompanying artery, and most scoring systems for quantifying bronchiectasis severity ask physicians to determine the broncho-arterial ratio. However, the lack of standardization coupled with inter-observer variability limits diagnostic sensitivity and the ability to use follow-up CT studies. We have developed a Computer Aided Diagnosis method to detect airway disease from abnormal broncho-arterial ratios. Our approach is based on the segmentation and skeletonization of the airways followed by automated measurements of broncho-arterial ratios at peripheral airway locations. The accompanying artery is automatically determined by correlation of its orientation and proximity to the airway, while the diameter measurements are based on the full-width half maximum method. This method was previously evaluated subjectively; in this work we quantitatively evaluate the airway and vessel measurements on 9 CT studies and compare the results with three independent readers. The automatically selected artery location was in agreement with the readers in 75.3% of the cases compared with 65.6% agreement of the readers with each other. The reader-computer variability in lumen diameters (7%) was slightly lower than that of the readers with respect to each other (9%), whereas the reader-computer variability in artery diameter (18%) was twice that of the readers (8%), but still acceptable for useful ratios. We conclude that the automatic system has comparable accuracy to that of readers, while providing greater speed and consistency.

6915-95, Poster Session**CT-guided, automated detection of lung tumors on PET images**

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Automated tumor detection and subsequent calculation of tumor's Standard Uptake Value (SUV) from serial PET images can be helpful to assessment of therapy response. In this paper, we present a computer method that automatically detects lung tumors on PET images using both anatomic CT and metabolic PET information. The method starts with automated identification and segmentation of relevant organs, including lung, bone, liver and spleen, on CT images based upon their locations and intensity distributions. Hot spots (SUV ≥ 1.5) on PET images are then labeled using the connected component analysis. The resultant "hot" objects (i.e., geometrically connected hot spots in three dimensions) that fall into the lungs, reside at the edges or are in the vicinity of the lungs are considered as tumor candidates. Further analyses, including reduction of false positives by masking out "hot" objects with the CT-determined organs and scrutiny of candidate's location, intensity distribution and shape on both CT and PET, are then performed to determine true lesions. The method was applied to 9 FDG PET-CT cases with 31 target lesions identified by a nuclear medicine radiologist during a lung cancer clinical trial. Out of 31 target lesions, 30 (97%) were detected by the computer method. However, sensitivity and specificity were not estimated since not all lesions had been marked up in the clinical trial. The preliminary result also showed the method's ability to effectively exclude the hot spots caused by mediastinum, liver, spleen, skeletal muscle, and bone metastasis.

6915-96, Poster Session**Characterization of pulmonary nodules on computed tomography (CT) scans: sample size effects on feature selection and classification performance**

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Using CT images from the National Lung Screening Trial (NLST) of the National Cancer Institute (NCI) our goal is to provide a robust representation of lung nodule signals for an automatic diagnosis system. For this purpose discrete wavelets transforms (DWT) and conventional methods for the lung nodule characterization and classification, and features robustness with regard to changes in the database size have been investigated. The lung nodules have been extracted in squared window frames. The performance of the DWT-based features is evaluated for lung nodule analysis and compared with a set of features based on conventional methods. The analysis was conducted in the "whole-profile" features mode; that is, for nodule characterization we used set of features calculated separately each time for databases of different size. A linear discriminant analysis with Fisher criterion (FLDA) approach was used for feature selection and classification, and decision matrix for matched sample to compare the classification accuracy. A linear trendline was used to analyze the sample size effect on classification performance and features selection. The preliminary results show that the robust representation of the lung nodule signal imposes the necessity for the bigger dataset as case diversity can explain up to 73% of the changes in the classification accuracy. The wavelet based features provide more promising results with regard to classification accuracy than conventional methods. The results show better classification accuracy with the DWT based features, as compared to the best results after conventional methods, shown here with co-occurrence matrix based features (p-value 0.02).

6915-97, Poster Session**Classifying pulmonary nodules using dynamic enhanced CT images based on CT number histogram**

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Thin-section CT images obtained by helical CT scanner have drawn interest in observing small pulmonary nodules for differential diagnosis. Recent intravenous contrast material administered during thin-section CT scanning is promising, and the results have been demonstrated for classifying the indeterminate nodules. The malignant lesions have been shown to enhance CT density more than the benign lesions because of the increased vascularity of malignant nodules. To quantify the rate of enhancement, a thin-section CT scan is acquired prior to the injection of contrast material, and followed by a dynamic sequence of thin-section CT scans. The rate enhancement can be estimated from the difference between pre- and post-contrast images.

Pulmonary nodules are classified into three types such as solid, mixed GGO, and pure GGO types on the basis of the visual assessment of CT appearance. In our current study a quantitative classification algorithm has been developed by using volumetric data sets obtained from thin-section CT images. The algorithm can classify the pulmonary nodules into five types on the basis of internal features extracted from CT number histograms inside nodules.

We applied dynamic enhanced CT images to this classification algorithm and we analyzed it in each type and size.

6915-98, Poster Session**Volume error analysis for lung nodules attached to pulmonary vessels in an anthropomorphic thoracic phantom**

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With the advent of high-resolution CT, three-dimensional (3D) methods for nodule volumetry have been introduced, with the hope that such methods will be more accurate and consistent than currently used planar measures of size. However, the error associated with volume estimation methods still needs to be quantified. Volume estimation error is multifaceted in the sense that there is variability associated with the patient, the software tool and the CT system. The overall goal of this research is to quantify the various sources of measurement error and, when possible, minimize their effects. In the current study, we estimated nodule volume from 10 repeat scans of an anthropomorphic phantom containing three synthetic lung nodules (diameters: 5, 8, and 10 mm; two densities: -630 and -800 HU), using a 16-slice Philips CT with 50 and 200 mAs exposures and 0.8, 1.5, and 3.0 mm slice thicknesses. We acquired two sets of truth, where the first was estimated from diameter measurements, and the second was determined using a micro CT scanner. The 200 mAs exposure yielded average bias ranging from -35.7-16%. For a particular volume measurement tool the variance associated with the CT scanner (200 mAs exposure) ranged from 56-250 (mm³)² for the 5 mm nodule, 209-1379 (mm³)² for the 8 mm nodule, and 73-2152 (mm³)² for the 10 mm nodule. We will report volume error results for other imaging acquisition and reconstruction parameters as well as for additional nodule sizes and densities.

6915-99, Poster Session**A novel software assistant for the clinical analysis of MR spectroscopy with MeVisLab**

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We present a novel software assistant for the analysis of Magnetic Resonance Spectroscopy (MRS) signals based on the rapid-prototyping platform MeVisLab. MRS is a valuable in-vivo metabolic window into tissue regions of interest, such as the brain, breast, or prostate. With this method, the metabolic state can be investigated non-invasively.

Different pathologies evoke characteristically different MRS signals, e.g. in prostate cancer, choline levels increase while citrate levels decrease compared to benign tissue. Concerning the majority of processing

steps, available MRS tools lack performance in terms of speed. Our purpose is consequently to support clinicians in a fast and robust interpretation of MRS signals and to enable them to interactively work with large volumetric data sets. These data sets consist of 3-dimensional spatially resolved measurements of metabolite signals. The software assistant provides standard analysis methods for MRS data including data import and filtering, spatio-temporal Fourier transformation, and basic calculation of peak areas and spectroscopic metabolic maps. Visualization relies on the facilities of MeVisLab, a platform for clinically applicable software assistants. It is augmented by special-purpose viewing extensions and offers synchronized 1D, 2D, and 3D views of spectra and metabolic maps. A novelty in MRS processing tools is the side-by-side viewing ability of standard FT processed spectra with the results of time-domain frequency analysis algorithms like Linear Prediction (LP-SVD) and Matrix Pencil Method. This enables research into the optimal toolset and workflow required to avoid the pitfalls of misinterpretation and misapplication.

6915-100, Poster Session

Bruise chromophore concentrations over time

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During investigations of potential child and elder abuse, clinicians and forensic practitioners are often asked to offer opinions about the age of a bruise. A commonality between existing methods of bruise aging is analysis of bruise color or estimation of chromophore concentration. Relative chromophore concentration is an underlying factor that determines bruise color. We investigate a method of chromophore concentration estimation that can be employed in a handheld imaging spectrometer with a small number of wavelengths. The method, based on absorbance properties defined by Beer-Lambert's law, allows estimation of differential chromophore concentration between bruised and normal skin. Absorption coefficient data for each chromophore are required to make the estimation. Two different sources of this data are used in the analysis; it is generated using Independent Component Analysis and it is taken from published values in related literature. Differential concentration values over time, generated using both sources, show high correlation to published models of bruise color change over time and total chromophore concentration over time.

6915-101, Poster Session

Efficient SVMs classifier based on color and texture region features for wound tissue images

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This work is part of the ESCALE project dedicated to the design of a complete 3D and color wound assessment tool using a simple hand held digital camera. The first part was concerned with the computation of a 3D model for wound measurements using uncalibrated vision techniques. This article presents the second part, which deals with color classification of wound tissues, a prior step before combining shape and color analysis in a single tool for real tissue surface measurements. We have adopted an original approach based on unsupervised segmentation prior to classification, to improve the robustness of the labelling stage. A database of different tissue types is first built; a simple but efficient color correction method is applied to reduce color shifts due to uncontrolled lighting conditions. A ground truth is provided by manual labelling of clinicians. Then, color and texture tissue descriptors are extracted from tissue regions of the images database, in order to learn an SVM region classifier with the aid of a ground truth resulting from the fusion of several clinicians manual labelling. The output of this classifier provides a prediction model, later used to label the segmented regions of database. Finally, we apply unsupervised color region segmentation on wound images and classify the tissue regions. Compared to the ground truth, segmentation based classification provides an overlap score, (66 % to 88%) higher than that between clinicians' and the ground truth.

6915-102, Poster Session

Automated detection of ureteral wall thickening on multidetector row CT urography

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We are developing a CAD system for automated detection of ureteral wall thickening on multi-detector row CT urography, which potentially can assist radiologists in detecting ureter cancer. In the first stage of our CAD system, given a starting point, the ureter is tracked based on the CT values of the contrast-filled lumen. In the second stage, the ureter wall is segmented and the ureter wall thickness is estimated based on polar transformation, separation of the ureter wall from the background and measuring the wall thickness. In this pilot study, a limited data set of 20 patients with 22 abnormal ureters was used. Fourteen patients had a total of 16 ureters with malignant ureteral wall thickening. Two of the patients had malignant wall thickening in both the left and right ureters. The other six patients had 6 ureters with benign ureteral wall thickening. All malignant wall thickenings were biopsy-proven. The benign thickenings were determined by biopsy or by 2-year follow-up. In addition 3 normal ureters were used to determine the false positive (FP) detection rate of the CAD system. The tracking program successfully tracked the 25 ureters (22 abnormal and 3 normal) and detected 90% (20/22) of the ureters having wall thickening with 2.3 (7/3) FPs per ureter. 93% (15/16) of the ureters with malignant wall thickening and 83% (5/6) of the ureters with benign wall thickening were detected. The missed ureteral wall thickenings were developed asymmetrically around the part of the ureter filled with contrast and the detection criteria in our current CAD system was not able to identify them reliably. The preliminary results show that our detection system can track the ureter and can detect ureteral wall thickening.

6915-103, Poster Session

True-false lumen segmentation of aortic dissections using multiscale wavelet analysis and generative/discriminative model matching

N. Lee, Columbia Univ.; H. Tek, Siemens Corporate Research; A. F. Laine, Columbia Univ.

Life threatening aortic dissection occurs in two types (A and B), where a tear of the inner artery wall leads to the separation of the whole lumen into two channels. One where blood continues to travel (true lumen) and another where blood remains still (false lumen). Treatment of aortic dissection requires automated quantification for assisted medical diagnosis of the aortic lumen disease structure. Manual quantification is time consuming and prone to inter- and intra-observer variability. In this paper we present a computer-aided diagnosis method for extracting the true and false lumen in CT medical datasets. First, we employ dyadic multi-scale wavelet analysis coupled with local maxima detection to extract edges within the aortic lumen. Then, we learn a probabilistic edge model of the true and false lumen by employing a discriminative learning approach. Prediction of the true and false lumen is then made in a Bayesian shape/appearance analysis framework through matching. The accuracy of the segmentation was quantitatively evaluated via comparisons with manual tracings on 3 randomly selected cross-sectional planes. The algorithm can reliably estimate the true and false lumen boundary. Sample experimental results are shown with a root-mean squared error was less than 5 pixels.

6915-104, Poster Session

A tool for computer-aided diagnosis of retinopathy of prematurity

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Retinopathy of Prematurity (ROP) is a leading cause of blindness for prematurely born infants. Since effective treatment is available, the accurate and timely diagnosis of ROP is crucial. A software tool, named ROPTool, is introduced in this paper to aid in diagnosing treatable ROP. Such an objective tool is highly desirable because the current diagnosis

of treatable ROP is based on subjective judgment of blood vessel dilation and tortuosity. ROPTool extracts retinal blood vessels and quantifies the tortuosity of these vessels. The degree of abnormality is then determined by comparing the average tortuosity of a given infant's retinal vessels with that of a standard photograph for severely increased tortuosity ('plus disease'). Furthermore, a novel metric of tortuosity is proposed. From the ophthalmologist's point of view, the new metric is an improvement from our previously published algorithm, since it uses smooth curves instead of straight lines to simulate normal vessels. Another advantage of ROPTool is that minimal user interactions are required. ROPTool utilizes a ridge traversal algorithm to extract retinal vessels. The algorithm reconstructs connectivity along a vessel automatically. A whole vessel can therefore be extracted and measured by a user's single mouse click. A pilot study using 20 retinal images has demonstrated promising performance. The areas under the ROC curves generated by two operators using the new metric to diagnose tortuosity sufficient for plus disease are from 0.86 to 0.91.

6915-105, Poster Session

Cancer treatment outcome prediction by assessing temporal change: application to cervical cancer

J. W. Prescott, D. Zhang, J. Wang, N. A. Mayr, W. Yuh, J. H. Saltz, M. N. Gurcan, The Ohio State Univ.

In this paper a novel framework is proposed for the classification of cervical tumors as susceptible or resistant to radiation therapy. The classification is based on both small- and large-scale temporal changes in the tumors' magnetic resonance imaging (MRI) response. The dataset consists of 11 patients who underwent radiation therapy for advanced cervical cancer. Each patient had dynamic contrast-enhanced (DCE)-MRI studies before treatment and early into treatment (approximately 2 weeks). For each study, a T1-weighted scan was performed before injection of contrast agent and again 75 seconds after injection. Using the 2 studies and the 2 series from each study, a set of tumor ROI features were calculated. These features were then exhaustively searched for the most separable set of three features based on a treatment outcome of local control or local recurrence. The dimensionality of the 3-feature set was then reduced to 2 dimensions using principal components analysis (PCA). Finally, the classification performance was tested using three different classification procedures: support vector machines (SVM), linear discriminant analysis (LDA), and k-nearest neighbor (KNN). The most discriminatory features were those of volume, standard deviation, skewness, kurtosis, and fractal dimension. Combinations of these features resulted in 100% classification accuracy using each of the three classifiers.

6915-106, Poster Session

A new method to efficiently reduce histogram dimensionality

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A challenge in Computer-Aided Diagnosis based on image exams is to provide a timely answer that complies to the specialist's expectation. In many situations when a specialist gets a new image to analyze, to have the information and knowledge from similar cases would be very helpful. For example, when a radiologist receives a new image to evaluate, it is common to recall similar cases that he/she has seen in the past. However, when processing similarity queries, to recall similar cases, the approach employs to extract meaningful features from the images and to search the image database considering such features. One of the most popular image features is the gray-level histogram, because it is simple and fast to obtain, and provides the global gray-level distribution of the image. Moreover, normalized histograms are also invariant to affine transformations on the image. Although the gray-level histograms are vastly used, it generates a large number of features, resulting in an increase on the complexity on indexing and searching. That is, the high dimensionality of histograms degrades the processing of similarity queries. In this paper we propose a new and efficient method associating the Shannon entropy and the gray-level histogram to considerably reduce the dimensionality of feature vectors generated by histograms. The

proposed method was applied to a real dataset and the results showed impressive reductions of up to 99% in the feature vector generated, and at the same time a considerable gain in precision (up to 125%) in comparison with the traditional gray-level histogram.

6915-107, Poster Session

A simple and robust method to screen cataracts using specular reflection appearance

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The high prevalence of cataracts is still a serious public health problem as a leading cause of blindness, especially in developing countries with limited health facilities. In this paper we propose a new screening system for cataract diagnosis by easy-to-use and low cost imaging equipment such as commercially available digital cameras. The difficulties in using this sort of digital camera equipment are seen in the observed images, the quality of which is not sufficiently controlled; there is no control of illumination, for example. A sign of cataracts is a whitish color in the pupil that usually is black, but it is difficult to analyze automatically color information under uncontrolled illumination conditions. To cope with this problem, we analyze specular reflection in the pupil region. When an illumination light hits the pupil, it makes a specular reflection on the frontal surface of pupil. Then the light goes through the lens and might be reflected again on the rear side of the lens. This characteristic enables us to screen out serious cataract by analyzing reflections observed the eye image. In this paper, we demonstrate the validity of our method through theoretical discussion and experimental results. By following a simple guideline shown in this paper, everyone would be able to screen cataracts.

6915-108, Poster Session

Assessment of the relationship between lesion segmentation accuracy and computer-aided diagnosis scheme performance

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In this study we randomly select 250 malignant and 250 benign mass regions as a training dataset. The boundary contours of these regions were manually identified and marked. Twelve image features were computed for each region. An artificial neural network (ANN) was trained as a region classifier. To select a specific testing dataset, we applied a topographic multi-layer region growth algorithm to detect boundary contours of 1,903 mass regions in an initial pool of testing regions. All processed regions are sorted based on a size difference ratio between manual and automated segmentation. We selected a testing dataset involving 250 malignant and 250 benign mass regions with larger size difference ratios. Using the area under ROC curve (value) as performance index we investigated the relationship between the accuracy of mass segmentation and the performance of a computer-aided diagnosis (CAD) scheme. CAD performance degrades as the size difference ratio increases. Then, we developed and tested a hybrid region growth algorithm that combined the topographic region growth with an active contour approach. In this hybrid algorithm, the boundary contour detected by the topographic region growth is used as the initial contour of the active contour algorithm. The algorithm iteratively searches for the optimal region boundaries. A CAD likelihood score of the growth region being a true-positive mass is computed in each iteration. The region growth is automatically terminated once the first maximum CAD score is reached. This hybrid region growth algorithm reduces the size difference ratios between two areas segmented automatically and manually to less than $\pm 15\%$ for all testing regions and the testing value increases to from 0.63 to 0.90. The results indicate that CAD performance heavily depends on the accuracy of mass segmentation. In order to achieve robust CAD performance, reducing lesion segmentation error is important.

6915-109, Poster Session**Automated discovery of meniscal tears on MR imaging: a novel, high-performance, computer-aided detection application for radiologists**

B. Ramakrishna, Univ. of Maryland/Baltimore County; N. Safdar, Univ. of Maryland Medical System; K. M. Siddiqui, VA Maryland Health Care System; W. Kim, Univ. of Pennsylvania; W. Liu, G. Saiprasad, C. Chang, Univ. of Maryland/Baltimore County; E. L. Siegel, Univ. of Maryland Medical Ctr.

Knee-related injuries including meniscal tears are common in both young athletes and the aging population, requiring accurate diagnosis and, if appropriate, surgical intervention. With proper techniques and experienced skills, the confidence in detection of meniscal tears can be very high. However, for many radiologists without musculoskeletal training, diagnosis of meniscal tears can be challenging. In this paper we present a computer-aided detection (CAD) application for automatic detection of meniscal tears of knees. Automated segmentation of sagittal T1-weighted MR imaging sequences of the knee and detection of meniscal tears was performed in two stages. The first stage consists of region of Interest (ROI) selection, slice selection (automatic), binarization, and enforcing shape constraints. The second stage is a 2 step process consisting of scoring of the slices for potential tears using two newly introduced metrics 'breakability' and 'degeneracy' and generation of the final recommendation regarding whether the meniscus is torn or normal. The results of this process were validated by comparison with the interpretations of 2 board-certified musculoskeletal radiologists. Evaluation of this CAD system using a database of 40 IRB approved cases obtained retrospectively demonstrated sensitivity and specificity of our CAD system was 83% and 75% respectively, compared to the mean sensitivity and specificity of 87% and 81% respectively by our experienced radiologists' diagnosis. This initial investigation has demonstrated that our CAD system has great potential and promise in automatic detection of both simple and complex meniscal tears of knees. This observation poses interesting possibilities for increasing radiologist productivity and confidence, improving patient outcomes, and applying more sophisticated CAD algorithms to orthopedic imaging tasks.

6915-110, Poster Session**Computer-aided diagnosis for classification of focal liver lesions on contrast-enhanced ultrasonography: image feature extraction and characterization of vascularity patterns**

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We have developed a computer-aided diagnostic (CAD) scheme for classifying focal liver lesions (FLLs) into liver metastasis, hemangioma, and three histological differentiation types of hepatocellular carcinoma (HCC), by use of B-mode and micro flow imaging (MFI) of contrast-enhanced ultrasonography. We used 98 cases in this study, of which 104 FLLs consisted of 21 metastases, 15 hemangiomas and 68 HCCs. MFI was obtained with the contrast-enhanced low mechanical index (MI) pulse subtraction imaging at the fixed plane which included a distinctive cross section of the FLL. In the MFI, the inflow high signals in the plane, which were due to the vascular patterns and the contrast agent, were accumulated following a flash scanning with a high MI ultrasound exposure. In this study, in addition to the existing 49 image features such as replenishment times, the average and the standard deviation of pixel values in a FLL, and the average vessel thickness, five specific image features were extracted based on the physician's diagnostic findings in FLLs such as (1) echogenicity of a FLL (hyperechoic, isoechoic, and hypoechoic), (2) uniformity of replenishment (homogeneous and heterogeneous), and (3) progression of replenishment (centripetal, simultaneous, and centrifugal). The 5 image features were determined by use of a histogram of the average pixel values obtained from a number of small square regions of interest within a FFL at three phases (early, middle, and delayed). Our preliminary results indicated that the average sensitivity (90.4%) for classification of the 104 liver lesions was improved from that (87.4%) of our previous result.

6915-111, Poster Session**The edge-driven dual-bootstrap iterative closest point algorithm for multimodal retinal image registration**

C. Tsai, National Chung Cheng Univ. (Taiwan); C. Li, National Chung-Cheng Univ. (Taiwan); G. Yang, DualAlign LLC

Color fundus retinal images and fluorescein angiogram (FA) sequence are often captured from an eye for diagnosis and treatment of abnormalities of the retina. With the aid of multimodal image registration, physicians can combine information to make accurate surgical planning and quantitative judgment of the progression of a disease. The goal of our work is to jointly align the color images and images of a FA sequence of the same eye in a common reference space. Our work is inspired by Generalized Dual-Bootstrap Iterative Closest Point (GDBICP), which is a fully-automatic, feature-based method using structural similarity. GDBICP rank-orders Lowe keypoint matches and refines the transformation computed from each keypoint match in succession. Albeit GDBICP has been shown robust to image pairs with illumination difference, the performance is not satisfactory for multimodal and some FA pairs which exhibit substantial non-linear illumination changes. Our algorithm, named Edge-Driven DBICP, modifies generation of keypoint matches for initialization by extracting the Lowe keypoints from the gradient magnitude image, and enriching the keypoint descriptor with global-shape context using the edge points. Our dataset consists of 61 randomly selected pathological sequences, each on average having two color and 13 FA images. There are total of 4985 image pairs, out of which 1323 are multimodal pairs. Edge-Driven DBICP successfully registered 93% of all pairs, and 82% multimodal pair, whereas GDBICP registered 80% and 40%, respectively. Regarding registration of the whole image sequence in a common reference space, Edge-Driven DBICP succeeded in 60 sequences, which is 26% improvement over GDBICP.

6915-112, Poster Session**Automated scoring system of standard uptake value for torso FDG-PET images**

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We have been developing the CAD scheme for whole body FDG-PET scans. The scoring approaches in PET scans were well employed in functional MRI and PET for brain imaging. In this work, we have developed an automated method to calculate the score of SUV (standard uptake value) for torso region on FDG-PET scans. As an initial work, we employed small number of normal cases in cancer screening program to assemble the metabolism distribution for SUV of FDG inside of normal body such as brain analysis using fMRI and PET/SPECT. The score was calculated after the mean and the standard deviation for normal organs and area were determined. Manually extracted regions from those normal scans were used to estimate the interval for the SUVs for normal organs and regions. The normal scans were registered using thin-plate-spline technique after the setting of the landmarks on the body surface. The three dimensional distributions for the mean and the standard deviation values were stored in each volume to score the SUV in corresponding pixel position within unknown scans. We employed 17 normal cases to assemble the normal metabolism distribution of FDG and 71 abnormal spots of cancer in lung, liver, colon, and metastasis spots in abdominal area. As a result of this work, the t-test of SUV showed the statistical significant difference between normal area and abnormal spots in corresponding regions. The score images correctly represented that the scores for normal cases were between zeros to plus/minus 2 SD. Most of the scores of abnormal spots associated with cancer and cancer metastasis were larger than the upper of the interval of 2SD calculated from normal organs. In conclusions, the scoring method for FDG-PET scans may be useful as a diagnostic indication for whole body cancer screening.

6915-113, Poster Session

Computerized microscopic image analysis of follicular lymphoma

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Follicular Lymphoma (FL) is a cancer arising from the lymphatic system.

Originating from follicle center B cells, FL is mainly comprised of centrocytes (usually middle-to-small sized cells) and centroblasts (relatively large malignant cells). According to the World Health Organization's recommendations, there are three grades of FL characterized by the number of centroblasts per high-power field (hpf) of area 0.159 mm². In current practice, these cells are manually counted from ten representative fields of follicles after visual examination of hematoxylin and eosin (H&E) stained slides by pathologists. Several studies clearly demonstrate the poor reproducibility of this grading system with very low inter-reader agreement. In this study, we are developing a computerized system to assist pathologists with this process. A hybrid approach that combines information from several slides with different stains has been developed. Thus, follicles are first detected from digitized microscopy images with immunohistochemistry (IHC) stains, (i.e., CD10 and CD20). The average sensitivity and specificity of the follicle detection tested on 30 images at 2x, 4x and 8x magnifications are 85.5±9.8% and 92.5±4.0%, respectively. Since the centroblasts detection is carried out in the H&E-stained slides, the follicles in the IHC-stained images are mapped to H&E-stained counterparts. To evaluate the centroblast differentiation capabilities of the system, 11 hpf images have been marked by an experienced pathologist who identified 41 centroblast cells and 53 non-centroblast cells. A non-supervised clustering process differentiates the centroblast cells from non-centroblast cells, resulting in 92.68% sensitivity and 90.57% specificity.

6915-114, Poster Session

Image-based grading of nuclear cataract by semi-supervised learning

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Cataract is one of the leading causes of blindness worldwide. Currently, ophthalmologists or graders diagnose cataracts by comparing the picture they view with standard photographs, which is subjective. An approach to assess nuclear cataract automatically and objectively is proposed in this paper. There are two main contributions in this paper: a model-based method is investigated to extract useful features from slit-lamp images; semi-supervised learning is proposed to grade nuclear cataract by learning from samples. The contour of lens is extracted by a modified ASM model which deforms the model to fit a new image data only in the ways that are consistent with the shapes in the training set. The mean intensity in the nuclear area, the colour information on the central posterior subcapsular reflex, and the profile on the visual axis are selected as the features for grading. A semi-supervised learning scheme is proposed to tackle the problem of limited availability of labelled samples. The automated grading score can be estimated by applying the scheme on the features extracted.

The proposed approach is tested by the lens images from Singapore National Eye Centre. Statistical analysis is performed to compare our regression grades with the clinical and grader's grading scores. Experimental results show that the grading error is acceptable and the proposed automatic grading approach is promising in facilitating nuclear cataract diagnosis. The proposed semi-supervised learning algorithm can be treated as a framework for medical image grading that can be applied to other medical images as well.

6915-115, Poster Session

Design of a benchmark dataset, similarity metrics and tools for liver segmentation

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Children's Hospital of Buffalo; V. Chaudhary, Univ. at Buffalo

Reliable segmentation of the liver has been acknowledged as a significant step in several computational and diagnostic processes. While several methods have been designed for liver segmentation, comparative analysis of reported methods is limited by the unavailability of annotated datasets of the abdominal area. Currently available generic data-sets constitute a small sample set, and most academic work utilizes closed datasets. We have collected a dataset containing abdominal CT scans of 50 patients, with coordinates for the liver boundary. The dataset will be publicly distributed with software to provide similarity metrics, and a liver segmentation technique that is based on GVF snakes. In this paper we discuss our data collection methodology, and implementation of the similarity metrics.

6915-116, Poster Session

Joint detection and localization of multiple anatomical landmarks through learning

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Reliable landmark detection in medical images provides the essential groundwork for successful automation of various open problems such as localization, segmentation, and registration of anatomical structures. In this paper, we present a learning-based system to jointly detect (is it there?) and localize (where?) multiple anatomical landmarks in medical images. The proposed method consists of three steps. First, a multi-landmark detector is applied to roughly detect candidate locations for multiple landmarks simultaneously. The multi-landmark detector still enjoys the cascaded framework from which the traditional boosted classifiers are known to gain significant run-time efficiency. Second, after the initial generation of landmark candidate locations through the multi-class classifier, the candidate points are verified via a landmark-specific classifier and some false detections are removed. Finally, the statistics of spatial correlations between different landmarks are used to further verify and correct the detected landmark locations. This method is extensively validated on CT scans of different body sections, e.g., whole body scans, chest scans and abdominal scans. Aside from improved robustness (due to the exploitation of spatial correlations), it gains a run time efficiency in landmark detection. It also shows good scalability performance under increasing number of landmarks. In addition, with a complete learning-based framework, the algorithm is applicable directly for other imaging modalities such as MRI.

6915-117, Poster Session

Robust vessel segmentation

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In the context of cardiac applications, the primary goal of coronary vessel analysis often consists in supporting the diagnosis of vessel wall anomalies, such as coronary plaque and stenosis. Therefore, a fast and robust segmentation of the coronary tree is a very important but challenging task.

We propose a new approach for coronary artery segmentation. Our method is based on an earlier proposed progressive region growing. A new growth front monitoring locally controls the segmentation and corrects local leakage by retrospective detection and removal of leakage artifacts. While progressively reducing the region growing threshold for the whole image, the growing process is locally analyzed using criteria based on the assumption of tubular, gradually narrowing vessels. If a voxel volume limit or a certain shape constraint is exceeded, the growing process is interrupted. Voxels affected by failed segmentation are detected and deleted from the result. To avoid further processing at these positions, a large neighborhood is frozen for growing.

Compared to a global region growing without local correction, our new local growth control and the adapted correction can deal with contrast decrease even in very small coronary arteries. Furthermore, our algorithm can efficiently handle noise artifacts and partial volume effects near the myocardium border. The enhanced segmentation of more distal vessel parts was tested on 120 CT datasets. Furthermore, a comparison between the pure progressive region growing and our new approach was conducted.

6915-118, Poster Session

Border-preserving skin lesion segmentation

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Melanoma is a fatal cancer with a growing incident rate. However it could be cured if diagnosed in early stages.

The first step in detecting melanoma is the separation of skin lesion from healthy skin. There are particular features associated with a malignant lesion whose successful detection relies upon accurately extracted borders. We propose a two step approach.

First, we apply K-means clustering method (to 3D RGB space) that extracts relatively accurate borders. However, since sometimes the lesion's color fades gradually, it is challenging to find an exact boundary separating the skin lesion from the skin. To overcome this problem, we perform an extra refining step for detecting the fading area as accurately as possible.

Our method has a number of novelties. Firstly as the clustering method is directly applied to the 3D color space, we do not overlook the dependencies between different color channels. It is in contrast with most available techniques where clustering is separately applied to different color channels and then the results are fused (or alternately the clustering is applied to a grayscale image). In addition, it is capable of extracting fine lesion borders up to pixel level in spite of the difficulties associated with fading areas around the lesion.

Performing clustering in different color spaces reveals that 3D RGB color space is preferred. Finally the results are cross validated according to a manual segmentation of a dermatologist. The application of the proposed algorithm to an extensive data-base of skin lesions shows that its performance is superior to that of existing methods both in terms of accuracy and computational complexity.

6915-119, Poster Session

AutoEDES: a model-based Bayesian framework for automatic end-diastolic and end-systolic frame selection in angiographic image sequence

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X-ray left ventricular analysis is widely used in catheterization lab. As the first step, end-diastolic (ED) and end-systolic (ES) frames are usually manually selected for the left ventricular analysis in current clinical practice. This process is very time consuming and sensitive to different persons at different time. In order to save clinician's time, release their burden, and enhance the selection accuracy, it's desirable to exploit a computer aided system. This paper presents a model-based Bayesian framework for ED and ES frame selection in angiographic image sequence. Preliminary experimental results have demonstrated the effectiveness and efficiency of the proposed algorithm on clinical data.

6915-120, Poster Session

Multifractal modeling, segmentation, prediction and statistical validation of posterior fossa tumors

A. U. Islam, K. M. Iftekharruddin, The Univ. of Memphis; R. J. Ogg, F. H. Laningham, St. Jude Children's Research Hospital; B. Sivakumar, The Univ. of Memphis

In this paper, we characterize the tumor texture in pediatric brain magnetic resonance images (MRIs) and exploit these features for automatic segmentation of posterior fossa tumors. We focus on posterior fossa (PF) tumor because of the prevalence of such tumor in pediatric patients. Due to varying appearance in MRI, we propose to model the tumor texture with a multi-fractal process, such as a multi-fractional Brownian motion (mBm). In mBm, the time-varying Holder exponent provides flexibility in modeling irregular tumor texture. We develop a detailed mathematical framework for mBm in two-dimension and propose a novel algorithm to estimate the multi-fractal structure of tissue texture in brain MRI based on wavelet coefficients. This wavelet based multi-fractal feature along with MR image intensity and a regular fractal feature obtained

using our existing piecewise-triangular-prism-surface-area (PTPSA) method, are fused in segmenting PF tumor and non-tumor regions in brain T1, T2, and FLAIR MR images respectively. We also demonstrate a non-patient-specific automated tumor prediction scheme based on these image features. We experimentally show the tumor discriminating power of our novel multi-fractal texture along with intensity and fractal features in automated tumor segmentation and statistical prediction. To evaluate the performance of our tumor prediction scheme, we obtain ROCs and demonstrate how sharply the curves reach the specificity of 1.0 sacrificing minimal sensitivity. Experimental results show the effectiveness of our proposed techniques in automatic detection of PF tumors in pediatric MRIs.

6915-121, Poster Session

Quantitative integration of magnetic resonance spectroscopy and magnetic resonance imaging in vivo for computer-aided diagnosis of prostate cancer

S. E. Viswanath, P. Tiwari, Rutgers Univ.; M. A. Rosen, Univ. of Pennsylvania; A. Madabhushi, Rutgers Univ.

Recently, in vivo Magnetic Resonance Imaging (MRI) and Spectroscopy (MRS) have emerged as promising new imaging modalities to aid in prostate cancer detection. MRI imagery provides anatomic and structural information of the prostate while MRS data provides functional information in the form of spectra which represent biochemical concentrations of metabolites (such as creatine, choline and citrate) that can be used to differentiate normal tissue from tumor as well as possibly indicate the degree of tumor metabolism. We have previously presented a hierarchical clustering scheme for prostate cancer detection using in vivo MRS data and have recently developed a computer aided segmentation model for use with in vivo MRI data for prostate cancer detection. In this paper we present a novel machine learning scheme to develop a meta-classifier for detecting prostate cancer in vivo by quantitative integration of prostate MRS and MRI data via manifold learning. High dimensional data extracted from the structural MRI and MRS are first non-linearly projected into a lower dimensional space and data integration is obtained by combining the MRS and MRI features in the low dimensional embedding space. Preliminary results of our computer-aided diagnosis scheme on a small cohort of patient data obtained from the multi-site, multi-institutional ACRIN trial, for which corresponding histological ground truth for spatial extent of cancer is known, shows a higher sensitivity (82.1%) and positive predictive value (84.1%) than that obtained from using MRS or MRI alone.

6915-122, Poster Session

Improvement of automatic hemorrhage detection methods using brightness correction on fundus images

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Recently, to develop an automated screening system to analysis ocular fundus images, we have been developing several automated methods for detecting abnormalities. The aim is to develop an automated hemorrhages detection method to help diagnosing diabetic retinopathy. We propose a new method of the pre-processing in the present study. The brightness of fundus image was changed by the original curve with the brightness values of HSV space. In order to emphasize brown regions, gamma correction was processed on the each red, green, and blue-bit image. Then, the histograms of each red, blue, and blue-bit image were extended.

After that, the hemorrhage candidates were detected. The hemorrhages and the blood vessels were brown regions, and their candidates were detected using a double-ring filter based on density analysis. We removed the large candidate as blood vessel. Finally, FPs were removed by using 45 features analysis. To evaluate the new method for detecting hemorrhages, we examined 125 fundus images including 35 images with the hemorrhages and 90 normal images. The sensitivity and specificity for the detection of abnormal cases was 80% and 88%, respectively. Such

results indicate that the new method may improve the performance of our computer-aided diagnosis system for hemorrhages effectively.

6915-123, Poster Session

Quantitative evaluation of humeral head defects by comparison of its left and right features

S. Kawasaki, T. Nakaguchi, N. Ochiai, N. Tsumura, Y. Miyake, Chiba Univ. (Japan)

The top of arm bone (humeral head) defect has been diagnosed subjectively by the clinical experience of the physician. Therefore, it is required to develop a quantitative evaluation method. In this paper, we propose a computer-aided quantitative diagnostic method for evaluating humeral head defects by comparing the shapes of the left and right humeral heads. The proposed method is composed of three steps. In the first step, the contour of humerus is extracted from a set of multi-slice CT images by using thresholding technique and active contour model. In the second step, the three dimensional (3-D) surface model of humerus is reconstructed from extracted contours. In the third step, the reconstructed 3-D shape of left and right humerus is superimposed by using CG techniques, and then the non-overlapped part is recognized as the defect part. This idea is based on the assumption that the left and right of human bone structure is mirror symmetry each other. Finally, the shape of visualized defect part is analyzed by principal component analysis and those obtained principal components and contributions represent the feature of the defect part. In this research, the result of seven sets of shoulder multi-slice CT images is analyzed and evaluated.

6915-124, Poster Session

A concurrent computer-aided detection (CAD) tool for articular cartilage disease of the knee on MR imaging using active shape models

B. Ramakrishna, Univ. of Maryland/Baltimore County; N. Safdar, Univ. of Maryland Medical System; K. M. Siddiqui, VA Maryland Health Care System; C. Chang, Univ. of Maryland/Baltimore County; E. L. Siegel, Univ. of Maryland Medical Ctr.

Osteoarthritis (OA) is the most common form of arthritis and a major cause of morbidity affecting millions of adults in the US and world wide. In the knee OA begins with the degeneration of joint articular cartilage, resulting in femur and tibia coming in contact, causing severe pain and stiffness. There has been extensive research examining 3D MR imaging sequences and automatic/semi-automatic techniques for 2D/3D articular cartilage extraction. However in routine clinical practice the most popular technique still remain radiographic examination and qualitative assessment of joint bone distance. This may be in large part because of a lack of tools that can provide clinically relevant diagnosis in adjunct (in near real time fashion) with the radiologist and which can serve the needs of the radiologists and reduce inter-observer variation. Our work aims to fill this void by developing a CAD application that can generate clinically relevant diagnosis of the articular cartilage damage in near real time fashion. The algorithm features a 2D Active Shape Model (ASM) for the modeling bone-cartilage interface on all the slices of the Double Echo Steady State (DESS) MR sequence, followed by measurement of the cartilage thickness from the surface of the bone, and finally by the identification of regions of abnormal thinness and focal/degenerative lesions. A preliminary evaluation of CAD tool was carried out on 5 cases taken from the Osteoarthritis Initiative (OAI) database (containing about 159 cases). When compared with 2 board-certified musculoskeletal radiologists, the automatic CAD application was able to get segmentation/thickness maps in little over 60 seconds for all of the 5 cases. This observation poses interesting possibilities for increasing radiologist productivity and confidence, improving patient outcomes, and applying more sophisticated CAD algorithms to not only routine orthopedic imaging tasks.

6915-125, Poster Session

Comparison of two algorithms in the automatic segmentation of blood vessels in fundus images

R. W. LeAnder, S. C. Myneni, S. Mokkaapati, S. E. Umbaugh, Southern Illinois Univ.

Fundus images can provide information for detecting and monitoring eye-related diseases to help prevent vision loss. This study compared the effectiveness of two blood vessel extraction algorithms.

Methods: Thirty fundus images were preprocessed by extracting pertinent information from their green bands and by removing noise and enhancing contrast, using a Yp mean filter and a histogram stretch. Each algorithm applied various combinations of morphological filtering and edge detection. Post-processing included smoothing, using an opening operation or arithmetic mean filter and converting the images from color to binary. The algorithms were compared in effectiveness, using ophthalmologists' hand-drawn images, SNR, RMS error and Pratt's Figure of Merit. Results: The major difference between the algorithms is that Algorithm 1 had difficulty with intersections and bifurcations, while extracting most of the major vessels. Algorithm 2 extracted all of the major blood vessels and many of the minor ones. Conclusion: Algorithm 2 was superior in retinal blood vessel extraction.

6915-126, Poster Session

A new registration method with voxel matching technique for temporal subtraction image

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A temporal subtraction image, which is obtained by subtraction of a previous image from a current one, can be used for enhancing interval changes on medical images by removing most of normal structures. One of the important problems in temporal subtraction is that subtraction images commonly include artifacts created by slight differences in the size, shape, and/or location of anatomical structures. In this paper, we developed a new registration method with voxel-matching technique for substantially removing the subtraction artifacts on the temporal subtraction image obtained from multiple-detector computed tomography (MDCT). With this technique, the voxel value in a warped (or non-warped) previous image is replaced by a voxel value within a kernel, such as a small cube centered at a given location, which would be closest (identical or nearly equal) to the voxel value in the corresponding location in the current image. Our new method was examined on 16 clinical cases with MDCT images. Preliminary results indicated that interval changes on the subtraction images were enhanced considerably, with a substantial reduction of misregistration artifacts. The temporal subtraction images obtained by use of the voxel-matching technique would be very useful for radiologists in the detection of interval changes on MDCT images.

6915-127, Poster Session

An image-based retrieval system and a computer-aided diagnosis system for renal cortical scintigraphy images

E. U. Mumcuoglu, F. Nar, Middle East Technical Univ. (Turkey); O. Ugur, F. Bozkurt, M. Aslan, Hacettepe Univ. Medical School (Turkey)

Cortical renal (kidney) scintigraphy images are 2D images (256x256) acquired in three projection angles (posterior, right-posterior-oblique and left-posterior-oblique). These images are used by nuclear medicine specialists to examine the functional morphology of kidney parenchyma. The main visual features examined in reading the images are: size, location, shape and activity distribution (pixel intensity distribution within the boundary of each kidney). Among the above features, activity distribution (in finding scars if any) was found to have the least interobserver reproducibility. Therefore, in this study, we developed an image-based retrieval (IBR) and a computer-based diagnosis (CAD) system, focused on this feature in particular. The developed IBR and CAD algorithms start with automatic segmentation, boundary and landmark detection. Then, shape and activity distribution features are computed. Activity distribution feature is obtained by using the difference of the acquired original image and its best fit Active Shape Model (ASM). In

the training step of ASM, normal patient images are used. Retrieval performance is evaluated by calculating precision and recall. CAD performance is evaluated by specificity and sensitivity. To our knowledge, this paper is the first IBR or CAD system reported in the literature on renal cortical scintigraphy images.

6915-128, Poster Session

Handheld erythema and bruise detector

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Visual inspection of intact skin is commonly used when assessing persons for pressure ulcers and bruises. Melanin masks skin discoloration hindering visual inspection in people with darkly pigmented skin. The objective of the project is to develop a point of care technology capable of detecting erythema and bruises in persons with darkly pigmented skin. Two significant hardware components, a color filter array and illumination system have been developed and tested. The color filter array targets four defined wavelengths and has been designed to fit onto a CMOS sensor. The crafting process generates a multilayer film on a glass substrate using vacuum ion beam splitter and lithographic techniques. The illumination system is based upon LEDs and targets these same pre-defined wavelengths. Together, these components are being used to create a small, handheld multispectral imaging device. Compared to other multi spectral technologies (multi prisms, optical-acoustic crystal and others), the design provides simple, low cost instrumentation that has many potential multi spectral imaging applications which require a handheld detector.

6915-129, Poster Session

Glaucoma diagnosis by mapping macula with Fourier domain optical coherence tomography

O. Tan, A. T. Lu, V. Chopra, R. Varma, Univ. of Southern California; H. Ishikawa, J. S. Schuman, Univ. of Pittsburgh Medical Ctr.; D. Huang, Univ. of Southern California

A new image segmentation method was developed to detect macular retinal sub-layers boundary on newly-developed Fourier-Domain Optical Coherence Tomography (FD-OCT) with macular grid scan pattern. The segmentation results were used to create thickness map of macular ganglion cell complex (GCC), which contains the ganglion cell dendrites, cell bodies and axons. Overall average and several pattern analysis parameters were defined on the GCC thickness map and compared for the diagnosis of glaucoma. Intraclass correlation (ICC) is used to compare the reproducibility of the parameters. Area under receiving operative characteristic curve (AROC) was calculated to compare the diagnostic power. The result is also compared to the output of clinical time-domain OCT (TD-OCT). We found that GCC based parameters had good repeatability and comparable diagnostic power with circumpapillary nerve fiber layer (cpNFL) thickness. Parameters based on pattern analysis can increase the diagnostic power of GCC macular mapping.

6915-130, Poster Session

Linear structure verification for medical imaging applications

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This paper proposes a method for linear-structure (LS) verification in mammography CAD systems that aims at reducing post-classification microcalcification (MCC) false-positives (FP). It is an MCC cluster-driven method that verifies linear structures with a small rotateable band that is centered on a given MCC cluster candidate. The classification status of an MCC cluster candidate is changed if its association with a linear structure is confirmed through LS verification. There are four main identifiable features that are extracted from the rotateable band in the gradient-magnitude and Hough parameter spaces. The LS verification process applies cascade rules to the extracted features to determine if an MCC cluster candidate resides in a linear structure area. The efficiency

and efficacy of the proposed method are demonstrated with results obtained by applying the LS verification method to over hundred cancer cases and over thousand normal cases.

6915-43, Session 9

Human airway measurement from CT images

J. Lee, A. P. Reeves, S. V. Fotin, T. V. Apanasovich, Cornell Univ.; D. F. Yankelevitz, Cornell Medical Ctr.

A wide range of pulmonary diseases, including common ones such as COPD, affect the airways. If the dimensions of airway can be measured with high confidence, the clinicians will be able to better diagnose diseases as well as monitor progression and response to treatment. In this paper, we introduce a method to assess the airway dimensions from CT scans, including the airway segments that are not oriented axially. First, the airway lumen is segmented and skeletonized, and subsequently each airway segment is identified. We then represent each airway segment using a segment-centric generalized cylinder model and assess airway lumen diameter (LD) and wall thickness (WT) for each segment by determining inner and outer wall locations.

The method was evaluated on 14 healthy patients from Cornell screening database who had two scans within a 2 months interval. The corresponding airway segments were located in two scans and measured using the automated method. The total number of segments identified in both scans was 131. When 131 segments were considered altogether, the average absolute change over two scans was 0.31 mm for LD and 0.12 mm for WT, with 95% limits of agreement of [-0.85, 0.83] for LD and [-0.32, 0.26] for WT. The results were also analyzed on per-patient basis, and the average absolute change was 0.19 mm for LD and 0.05 mm for WT. 95% limits of agreement for per-patient changes were [-0.57, 0.47] for LD and [-0.16, 0.10] for WT.

6915-44, Session 9

Computer-aided detection of endobronchial valves

R. A. Ochs, J. G. Goldin, F. G. Abtin, S. Ahmad, Z. Irani, I. da Costa, M. S. Brown, Univ. of California/Los Angeles

The ability to automatically detect and monitor implanted devices may serve an important role in patient care and the evaluation of device and treatment efficacy. The purpose of this research was to develop a system for the automated detection of bronchoscopically implanted devices. METHODS: Volumetric Thoracic CT image data (1.25 - 2.0 mm slice thickness) from 24 subjects scanned at inspiration was acquired retrospectively. As part of a trial for less invasive treatment of emphysema, the subjects were implanted with endobronchial valves (max diameter < 10 mm and length < 20 mm). Seven subjects with 31 devices were used for system development and 17 subjects with 58 devices were reserved for testing. The detection process consisted of two main steps 1) pre-processing and 2) template matching. While the pre-processing is domain specific, the template matching technique is intended to be generic enough for many devices. The template matching used a control-point model of the device rotated at 26 orientations for identifying each device and rejecting false positives (such as calcium deposits). RESULTS: During the initial evaluation, 44 of 58 (76%) of the devices could be correctly detected with 3 false positives. Missed devices occurred when two devices overlapped, false positives occurred as a result of calcification. The results indicate the potential for computers to aid device detection and monitoring. Modifying the initial lung segmentation to cover soft tissue regions near the hilum improved performance during subsequent evaluations.

6915-45, Session 9

Computerized scheme for detection of diffuse lung diseases on CR chest images

R. R. Pereira, Jr., J. Shiraishi, F. Li, Q. Li, K. Doi, The Univ. of Chicago

We have developed a new computer-aided diagnostic (CAD) scheme for detection of diffuse lung disease in computed radiographic (CR) chest images. One hundred ninety nine chest images (59 normals and 140 abnormal with interstitial diseases) were used. The 140 abnormal cases

were classified into three levels of severity (39 mild, 52 moderate, and 49 severe) by an experienced chest radiologist with use of five different patterns, i.e., nodular, nodular-reticular, reticular, air-space opacity, and emphysema. In our computerized scheme, the first moment of the power spectrum, the root mean square variation and the average pixel value were determined for each Region of Interest (ROI) which was automatically selected in the lung fields. The average pixel value and its dependence on the location of the ROI were employed for identifying abnormal patterns due to air-space opacity and emphysema. A rule based method was used for determining four levels of abnormality for each ROI (1: normal, 2: mild, 3: moderate, and 4: severe). The distinction between normal lungs and abnormal lungs with diffuse disease was determined by use of the fraction of abnormal ROIs and the severity of the abnormalities. Preliminary results indicated that the area under the ROC curve was 0.84 for the 49 severe cases, 0.82 for the 101 severe and moderate cases, and 0.80 for all cases. In conclusion, the CAD scheme for detection of diffuse lung diseases based on texture features extracted from CR chest images has the potential to assist radiologists in their interpretation of diffuse lung diseases.

6915-46, Session 9

Extraction and visualization of the central chest lymph node stations

W. E. Higgins, K. Lu, The Pennsylvania State Univ.

Lung cancer remains the leading cause of cancer deaths in the United States and is expected to account for nearly 30% of all cancer deaths in 2007. Central to the lung-cancer diagnosis and staging processes is the assessment of the central chest lymph nodes. This assessment typically requires two major stages: (1) location of the lymph nodes in a three-dimensional (3D) high-resolution volumetric multi-detector computed-tomography (MDCT) image of the chest; (2) subsequent nodal sampling using transbronchial needle aspiration (TBNA). We describe a computer-based system for locating the central chest lymph nodes in a 3D MDCT image. Automated analysis methods are first run that extract the airway tree, airway-tree centerlines, aorta, pulmonary artery, lungs, and major-airway labels. This information provides geometrical and anatomical cues for localizing the major nodal stations. Our system demarcates these stations, conforming to criteria outlined for the Mountain and Wang standard classification systems. Visualization tools within the system then enable the user to interact with these stations to locate visible lymph nodes. Results derived from a set of human 3D MDCT chest images illustrate the usage and efficacy of the system.

6915-47, Session 9

(ST) Reduction of lymph tissue false positives in pulmonary embolism detection

B. S. Ghanem, J. Liang, J. Bi, M. Salganicoff, A. Krishnan, Siemens Medical Solutions USA, Inc.

Pulmonary embolism (PE) is a serious medical condition, characterized by the partial/complete blockage of an artery within the lungs. We have developed a fast yet effective approach for computer aided detection of PE in computed topographic pulmonary angiography (CTPA) [1], which is capable of detecting both acute and chronic PEs, achieving a benchmark performance of 78% sensitivity at 4 false positives (FPs) per volume. By reviewing the FPs generated by this system, we found the most dominant type of FP, roughly one third of all FPs, to be lymph/connective tissue. In this paper, we propose a novel approach that specifically aims at reducing this FP type. Our idea is to explicitly exploit the anatomical context configuration of PE and lymph tissue in the lungs: a lymph FP connects to the airway and is located outside the artery, while a true PE should not connect to the airway and must be inside the artery. To realize this idea, given a detected candidate (i.e. a cluster of suspicious voxels), we compute a set of contextual features, including its distance to the airway based on local distance transform and its relative position to the artery based on fast tensor voting and Hessian "vesselness" scores. Our tests on unseen cases show that these features can reduce the lymph FPs by 59%, while improving the overall sensitivity by 3.4%.

6915-48, Session 9

(ST) Feasibility of quantitative lung perfusion by 4D CT imaging by a new dynamic-scanning protocol in an animal model

Y. Wang, J. G. Goldin, F. G. Abtin, M. S. Brown, M. F. McNitt-Gray, Univ. of California/Los Angeles

PURPOSE: The purpose of this study is to test a new dynamic Perfusion-CT imaging protocol in an animal model and investigate the feasibility of quantifying perfusion of lung parenchyma to perform functional analysis from 4D CT image data. **METHOD:** A novel perfusion-CT protocol was designed with 25 scanning time points: the first at baseline and 24 scans after a bolus injection of contrast material. Post-contrast CT scanning images were acquired with a high sampling rate before the first blood recirculation and then a relatively low sampling rate until 10 minutes after administrating contrast agent. Lower radiation techniques were used to keep the radiation dose to an acceptable level. 2 Yorkshire swine with pulmonary emboli underwent this perfusion-CT protocol at suspended end inspiration. The software tools were designed to measure the quantitative perfusion parameters (perfusion, permeability, relative blood volume, blood flow, wash-in&wash-out enhancement) of voxel or interesting area of lung. The perfusion values were calculated for further lung functional analysis and presented visually as contrast enhancement maps for the volume being examined. **RESULT:** Increased CT temporal sampling rate provides the feasibility of quantifying lung function and evaluating the pulmonary emboli. Differences between areas with known perfusion defects and those without perfusion defects were observed. **CONCLUSION:** The techniques to calculate the lung perfusion on animal model have potential application in human lung functional analysis such as evaluation of functional effects of pulmonary embolism. With further study, these techniques might be applicable in human lung parenchyma characterization and possibly for lung nodule characterization.

6915-49, Session 10

Characterization of pulmonary nodules: effects of size and feature type on reported performance

A. C. Jirapatnakul, A. P. Reeves, A. M. Biancardi, T. V. Apanasovich, Cornell Univ.; D. F. Yankelevitz, C. I. Henschke, Cornell Medical Ctr.

The question of whether size distribution bias of datasets used in the training of automated systems for characterization provides overly optimistic performance was studied in this paper. The performance of two- and three-dimensional features were compared, both including and excluding size, on a dataset of 178 pulmonary nodules. Two classifiers, logistic regression and distance-weighted k-nearest-neighbors (dwwk-NN) were evaluated.

Performance was first measured on the full dataset using leave-one-out. To assess the effect of size-distribution, the performance of a simple size-threshold classifier was measured. For the full dataset, the area under the ROC curve (AUC) of the logistic regression classifier for 2D features with and without size was 0.721 and 0.616 respectively, and for 3D features with and without size, 0.774 and 0.737 respectively. In comparison, the performance using a size-threshold was 0.675. In the second part of the study, the performance was measured on a subset of 46 nodules from the entire subset selected to have a similar size-distribution of malignant and benign nodules. For this subset, performance of the size-threshold was 0.495. For logistic regression, the performance for 2D, with and without size, were 0.578 and 0.478, and for 3D, with and without size, 0.671 and 0.767. Over all the datasets, 3D features offered better performance than 2D features.

This study suggests that in systems for nodule classification, size is responsible for a large part of the reported performance. System performance should be reported with respect to the performance of a size-threshold classifier.

6915-50, Session 10**Use of random process-based fractal measure for characterization nodules and suspicious regions in lung**

M. Acharyya, Siemens Information Systems Ltd. (India); S. Chakravarty, Univ. of Maryland/Baltimore County; J. Stoeckel, Siemens Israel Ltd. (Israel)

The Chest X-ray (CXR) data is a projection image where each pixel of it represents a volumetric integration. Identification of nodules and their characteristics is a difficult task in such images.

Using a novel application of random process-based fractal image processing technique we extract features for nodule characterization. The uniqueness of the proposed technique lies in the fact that instead of relying on apriori information from user as in other random process inspired measures, we translate the random walk process into a feature which is based on its realization values. The Normalized Fractional Brownian (NFB) Motion Model is derived from the random walk process. Using neighborhood region information in an incremental manner we can characterize the smoothness or roughness of a surface. The NFB system gives a measure of roughness of a surface which in our case is a suspicious region (probable nodule). A classification procedure uses this measure to categorize nodule and non-nodule structures in the lung.

The NFB feature set is integrated in a prototype CAD system for nodule detection in chest X-rays. Our algorithm provided a sensitivity of 75.9% with 3.1 FP/image on an independent test set of 50 CXR studies.

6915-51, Session 10**The impact of pulmonary nodule size estimation accuracy on the measured performance of automated nodule detection systems**

S. V. Fotin, A. P. Reeves, Cornell Univ.; C. I. Henschke, D. F. Yankelevitz, Weill Cornell Medical College

The performance of automated pulmonary nodule detection systems is typically qualified with respect to some minimum size of nodule to be detected. Also, an evaluation dataset is typically constructed by expert radiologists with all nodules larger than the minimum size being designated as true positives while all other smaller detected "nodules" are considered to be false positives. In this paper, we consider the negative impact that size estimation error, either in the establishment of ground truth for the evaluation dataset or by the automated detection method for the size estimate of nodule candidates, has on the measured performance of the detection system. Furthermore, we propose a modified evaluation procedure that addresses the size estimation error issue.

The impact of the size estimation error was estimated for a documented research image database consisting of whole-lung CT scans for 509 cases in which 690 nodules have been documented. We compute FROC curves both with and without size error compensation and we found that for a minimum size limit of 4 mm the performance of the system is underestimated by a sensitivity reduction of 5 % and a false positive rate increase of 0.25 per case. Therefore, error in nodule size estimation should be considered in the evaluation of automated detection systems.

6915-52, Session 10**Computer-aided diagnosis: a 3D segmentation method for lung nodules in CT images by use of a spiral-scanning technique**

J. Wang, R. M. Engelmann, Q. Li, The Univ. of Chicago

Accurate segmentation of lung nodules in computed tomography (CT) plays an important role in computer-aided detection, diagnosis, and quantification systems for lung cancer. In this study we developed a simplified and accurate nodule segmentation method in three-dimensional (3-D) CT. First, a volume of interest (VOI) was determined at the location of a nodule. We then transformed the VOI into a two-dimensional (2-D) image by use of a "spiral-scanning" technique, in which a radial line originating from the center of the VOI spirally scanned the

VOI. The voxels scanned by the radial line were arranged sequentially to form a transformed 2-D image. Because the surface of a nodule in 3-D image became a curve in the transformed 2-D image, the spiral-scanning technique considerably simplified our segmentation method and enabled us to obtain accurate results. We employed a dynamic programming technique to delineate the "optimal" curve in the 2-D image, which was transformed back into the 3-D image space to provide the interior of the nodule. The proposed segmentation method was trained on the first and was tested on the second Lung Image Database Consortium (LIDC) datasets. An overlap between nodule regions provided by computer and by the radiologists was employed as a performance metric. Our segmentation method provided relatively accurate results with mean overlap values of 66% and 64% for the nodules in the first and second LIDC datasets, respectively, which represented a higher performance level than those of two existing segmentation methods that were also evaluated by use of the LIDC datasets.

6915-53, Session 10**Comparison of computer-aided diagnosis performance and radiologist readings on LIDC pulmonary nodule dataset**

L. Zhao, M. C. Lee, L. Boroczky, V. Vloemans, Philips Research North America; R. Opfer, Philips Research Europe Hamburg (Germany)

One challenge radiologists facing is determining whether a pulmonary nodule detected in a multi-slice CT scan is benign or malignant. We have developed an image processing and machine learning based computer-aided diagnosis (CADx) method to provide assistance in making such decisions by predicting the likelihood of malignancy of solitary pulmonary nodules.

The uniqueness of our approach is two-fold. First, we have developed 194 image features, with strong capability for discriminating benign and malignant nodules. These image features, combined with patient age, comprise the feature pool. Second, we constructed an ensemble of 1,000 linear discriminant classifiers using 1,000 feature subsets selected from the feature pool using a random selection method. The classification results are combined using a majority voting method to form a decision on the likelihood of malignancy.

We used a dataset of 125 pulmonary nodules for building the classifier ensemble. Validation was performed on the LIDC pulmonary dataset, for which radiologist interpretations were available. We performed the calibration to reduce the differences in the internal operating points and spacing between radiologist rating and the CADx algorithm. Comparing radiologists with the CADx in assigning nodules into four malignancy categories, fair agreement was observed ($\kappa = 0.381$) while binary rating yielded an agreement of ($\kappa = 0.475$), suggesting that CADx can be a promising second reader for use in clinical settings.

6915-54, Session 10**Characteristics of suspicious features in CT lung-cancer screening images**

P. F. Judy, Brigham and Women's Hospital; Y. Kanasaki, Tottori Univ. (Japan); F. L. Jacobson, Brigham and Women's Hospital; C. Del Frate, Univ. degli Studi di Udine (Italy)

The high-frequency of suspicious non-malignant image features limit the use of CT lung-cancer screening of asymptomatic individuals. A reference database of 6 radiologists' localizations of suspicious image features was created. The frequency, sizes, shapes, margins, and degree of calcification of the images features were determined. The database of 6 radiologists reading contained the locations of 614 locations from 27 cases and the frequencies (1 to 6). Forty three percent (263) of the reference database findings had a frequency of 2 or greater and contained 50 findings (8%) reported on 5 or 6 occasions. The fraction findings reported at least twice greater than 4 mm was 28%, while the fraction of findings reported on 5 or 6 occasions was 38%. Twenty three percent of findings reported at least twice were rated as calcified, this fraction increased to 34% findings reported on 5 or 6. The radiologist exam report identified 22% findings reported at least twice, while the CAD system identified 16%. The radiologist exam report

identified 50% findings reported on 5 or 6 occasions, while the CAD system identified 40%. Lung-cancer screening exams using low-dose CT contain numerous features of concern that radiologists may feel require further evaluation. The radiologist exam report missed 80% to 50% of suspicious, retrospectively identified in CT lung cancer images. Many were less than 4 mm. Radiologists can use a lenient criterion in experiments of previously read screening cases.

6915-55, Session 11

Incorporating ensemble techniques in a knowledge-based CAD system: application in mammography

M. A. Mazurowski, J. M. Zurada, Univ. of Louisville; G. D. Tourassi, Duke Univ.

Although ensemble techniques have been investigated in supervised machine learning, their potential with knowledge-based systems is unexplored. The purpose of this study is to investigate ensemble approach with a knowledge-based (KB) CAD system for the detection of masses in screening mammograms. The system is designed to determine the presence of a mass in a query mammographic region of interest (ROI) based on its similarity with a knowledge database of mass and normal cases. Similarity assessment is featureless according to normalized mutual information. Two different approaches of knowledge

database decomposition were investigated to create the ensemble. The first approach was random division of the knowledge database into a pre-specified number of equal size, separate groups. The second approach relied on k-means clustering of the knowledge cases according to common texture features extracted from the ROIs. The ensemble components were fused using a linear classifier. Based on a database of 1820 ROIs (901 masses and 919 and the leave-one-out crossvalidation scheme, the ensemble techniques boosted the performance of the original KB-CAD system ($Az=0.86\pm 0.01$). Specifically, random division resulted in ROC area index of $Az=0.90\pm 0.01$ while k-means clustering provided further improvement ($Az=0.91\pm 0.01$). Although marginally better, the improvement was statistically significant. The superiority of the k-means clustering scheme was robust regardless of the number of clusters. This study supports the incorporation of ensemble techniques with knowledge-based systems in mammography.

6915-56, Session 11

Correlative feature analysis of FFDM images

Y. Yuan, M. L. Giger, H. Li, C. A. Sennett, The Univ. of Chicago

Identifying the corresponding image pair of a lesion is an essential step for combining information from different views of the lesion to improve the diagnostic ability for both radiologists and CAD systems. Because of the non-rigidity of the breasts and the 2D projective property of mammograms, this task is not trivial. In this study, we present a computerized framework that differentiates the corresponding images from different views of a lesion from non-corresponding ones. A dual-stage segmentation method, which employs an initial radial gradient index (RGI) based segmentation and an active contour model, was firstly applied to extract mass lesions from the surrounding tissues. Then various lesion features were automatically extracted from each of the two views of each lesion to quantify the characteristics of margin, shape, size, texture and context of the lesion, as well as its distance to nipple. We employed a two-step method to select an effective subset of features, and combined it with a BANN to obtain a discriminant score, which yielded an estimate of the probability that the two images are of the same physical lesion. ROC analysis was used to evaluate the performance of the individual features and the selected feature subset in the task of distinguishing corresponding pairs from non-corresponding pairs. By using a FFDM database with 124 corresponding image pairs and 35 non-corresponding pairs, the distance feature yielded an AUC (area under the ROC curve) of 0.80 with leave-one-out evaluation, and the feature subset, which includes distance feature, lesion size and lesion contrast, yielded an AUC of 0.86.

6915-57, Session 11

Matching mammographic regions in mediolateral oblique and cranio-caudal views: a probabilistic approach

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In this paper we present a method to match corresponding regions in mediolateral oblique (MLO) and cranio caudal (CC) mammographic views of the breast. Most of the current CAD systems detect suspicious mass regions in individual mammograms. For every possible combination of mass regions, a number of features are calculated, such as the difference in distance of a region to the nipple, a texture similarity measure, the grayscale correlation and the likelihood of malignancy of both regions computed by single view analysis. In contrast to previous research, where Linear Discriminant Analysis was used to discriminate between correct and incorrect links, we are developing a statistical method in which four classes are distinguished, which are defined by the combinations of view (MLO/CC) and pathology (TP/FP) labels. We use distance-weighted k-Nearest Neighbour density estimation method to determine the likelihood of a given region combination given its features. Next, a correspondence score is calculated as the likelihood that the region combination is a TP-TP minus the likelihood that the region combination is a TP-FP. The method was tested on 412 cases with a malignant lesion visible in at least one of the views. In 82.4% of the cases a correct link could be established between the TP detections in both views. In future work, we will use the framework presented here to develop a context dependent region matching scheme, which takes the number and likelihood of possible alternatives into account. It is expected that more accurate determination of matching probabilities will lead to improved CAD performance.

6915-58, Session 11

Concordance of computer-extracted image features with BI-RADS descriptors for mammographic mass margin

B. Sahiner, L. M. Hadjiiski, H. Chan, C. Paramagul, A. Nees, M. A. Helvie, J. Shi, Univ. of Michigan

The purpose of this study was to develop and evaluate computer-extracted features for characterizing mammographic mass margins according to BI-RADS spiculated and circumscribed categories. The mass was automatically segmented using an active contour model. A spiculation measure for a pixel on the mass boundary was defined by using the angular difference between the image gradient vector and the normal to the mass, averaged over pixels in a spiculation search region. For the degree of circumscribed margin (DCM) feature, the angular difference between the principal eigenvector of the Hessian matrix and the normal to the mass was estimated in a band of pixels centered at each point on the boundary, and the feature was extracted from the resulting profile along the boundary. Three MQSA radiologists provided BI-RADS margin ratings for a data set of 285 masses. The features were evaluated with respect to the individual radiologists' characterization using ROC analysis, as well as with respect to that from the majority rule, in which a mass was labeled as spiculated (circumscribed) if it was characterized as such by 2 or 3 radiologists, and non-spiculated (non-circumscribed) otherwise. We also investigated the performance of the features for consensus masses, defined as those labeled as spiculated (circumscribed) or non-spiculated (non-circumscribed) by all three radiologists. When masses were labeled according to radiologists A, B, and C individually, the spiculation feature had an Az value of 0.89 ± 0.03 , 0.84 ± 0.03 , 0.87 ± 0.03 , respectively, while the DCM feature had an Az value of 0.78 ± 0.03 , 0.75 ± 0.03 , and 0.76 ± 0.03 , respectively. When masses were labeled according to the majority rule, the Az values for the spiculation and the DCM features were 0.90 ± 0.02 and 0.80 ± 0.03 , respectively. When only the consensus masses were considered, the Az values for the spiculation and the DCM features were 0.97 ± 0.02 and 0.86 ± 0.03 , respectively. We conclude that the newly developed features had high accuracy for characterizing mass margins according to BI-RADS descriptors.

6915-59, Session 11**The effect of training with SFM images in a FFDM-CAD system**

M. G. Kallenberg, N. Karsssemeijer, Radboud Univ. Nijmegen Medical Ctr. (Netherlands)

The development of CAD systems that can handle Full Field Digital Mammography (FFDM) images is needed, as FFDM is getting more important. In order to develop a CAD system a large database containing training samples is of major importance. However, as FFDM is not yet as widely used as Screen Film Mammography (SFM) it is difficult to collect a sufficient amount of exams with malignant abnormalities. Therefore it would be of great value if the available databases of SFM images can be used to train a FFDM CAD system. In this paper we investigate this possibility.

As we trained our system with SFM images we developed a method that converts the FFDM test images into a SFM-like representation. Key point in this conversion method is the implementation of the characteristic curve which describes the relationship between exposure and optical density for a SFM image. As exposure values can be extracted from the raw FFDM images, the SFM-like representation can be obtained by applying a fitted characteristic curve. Parameters of the curve were computed by simulating the Automatic Exposure Control procedure as implemented in clinical practice.

We found that our FFDM CAD system achieved a case based sensitivity of 70%, 80%, 90%, at 0.06, 0.18, 0.68 FP/image when using SFM-training with 552 abnormal and 810 normal cases, compared to 0.06, 0.25, 1.15 FP/image with FFDM-training with 80 abnormal and 131 normal cases. These results demonstrate that digitized film databases can still be used as part of a FFDM CAD system.

6916-01, Session 1

Fully automatic detection and visualization of patient specific coronary supply regions

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Coronary territory maps, which associate myocardial regions with the corresponding coronary artery that supply them, are a common visualization technique to assist the physician in the diagnosis of coronary artery disease. However, the commonly used visualization, is based on the AHA-17-segment model, which is an empirical population based model. Therefore, it does not necessarily cope with the often highly individual coronary anatomy of a specific patient.

In this paper we introduce a novel fully automatic approach to compute the patient individual coronary supply regions in CTA datasets. This approach is divided in three consecutive steps. In the first step, the aorta is fully automatically located in the dataset with a combination of a hough-transform and a cylindrical model matching approach. Having the location of the aorta, a segmentation and skeletonization of the coronary tree is triggered. In the next step, the three main branches (LAD, LCX and RCA) are automatically labeled based on the knowledge of the pose of the aorta and the left ventricle.

In the last step, the labeled coronary tree is projected on the left ventricular surface, which can afterwards be subdivided into the coronary supply regions based on a voronoi-transform. The resulting supply regions can be either shown in 3D on the epicardial surface of the left ventricle or as a subdivision of a polar map.

6916-02, Session 1

Quantification of carotid arteries atherosclerosis using 3D ultrasound images and area-preserving flattened maps

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Quantitative measurements of the progression (or regression) of carotid plaque burden are important in monitoring patients and evaluating new treatment options. 3D ultrasound (US) has been used to monitor the progression of carotid artery plaques in symptomatic and asymptomatic patients. Different methods of measuring various ultrasound phenotypes of atherosclerosis have been developed. In this work, we extended concepts used in intima-media thickness (IMT) measurements based on 2D images and introduced a metric called 3D vessel-wall-plus-plaque thickness (3D VWT), which was obtained by computing the distance between the carotid wall and lumen surfaces on a point-by-point basis in a 3D image of the carotid arteries. The VWT measurements were then superimposed on the arterial wall to produce the VWT map. Since the progression of plaque thickness is important in monitoring patients who are at risk for stroke, we also computed the change of VWT by comparing the VWT maps obtained for a patient at two different time points. In order to facilitate the visualization and interpretation of the 3D VWT and VWT-Change maps, we proposed a technique to flatten these maps in an area-preserving manner.

6916-03, Session 1

Accelerated circumferential strain quantification of the left ventricle using CIRCOME: simulation and factor analysis

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Circumferential strain of the left ventricle reflects myocardial contractility and is considered a key index of cardiac function. It is also an important parameter in the quantitative evaluation of heart failure. Circumferential compression encoding, CIRCOME, is a novel method in cardiac MRI

to evaluate this strain non-invasively and quickly. This strain encoding technique avoids the explicit measurement of the displacement field and does not require calculation of strain through spatial differentiation. CIRCOME bypasses these two time-consuming and noise sensitive steps by directly using the frequency domain (k-space) information from radially tagged myocardium, before and after deformation. It uses the ring-shaped crown region of the k-space, generated by the taglines, to reconstruct circumferentially compression-weighted images of the heart before and after deformation. CIRCOME then calculates the circumferential strain through relative changes in the compression level of corresponding regions before and after deformation. This technique can be implemented in 3D as well as 2D and may be employed to estimate the overall global or regional circumferential strain. The main parameters that affect the accuracy of this method are spatial resolution, signal to noise ratio, eccentricity of the center of radial taglines and their density. Also, a variety of possible image reconstruction and filtering options may influence the accuracy of the method. This study describes the pulse sequence, algorithm, influencing factors and limiting criteria for CIRCOME and provides the simulated results.

6916-04, Session 1

Automatic selection of an optimal systolic and diastolic reconstruction window for dual source CT coronary angiography

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Purpose: To assess the performance of a motion map algorithm to automatically determine the optimal systolic and diastolic reconstruction window for coronary CT Angiography using Dual Source CT.

Materials and Methods: Dual Source coronary CT angiography data sets (Somatom Definition, Siemens Medical Solutions) from 50 consecutive patients were included in the analysis. Optimal systolic and diastolic reconstruction windows were determined using a motion map algorithm (BestPhase(r), Siemens Medical Solutions). Additionally data sets were reconstructed in 5% steps throughout the RR-interval. For each major vessel (RCA, LAD and LCX) an optimal systolic and diastolic reconstruction window was manually determined by two independent readers using volume rendering displays. Image quality was rated using a five-point scale (1 = no motion artifacts, 5 = severe motion artifacts over entire length of the vessel).

Results: The mean heart rate during the scan was 72.4bpm (± 15.8 bpm). Median systolic and diastolic reconstruction windows using the BestPhase(r) algorithm were at 37.0% and 72.5% RR. The median manually selected systolic reconstruction window was 35.0%, 30.0% and 35.0% for RCA, LAD, and LCX. For all vessels the median observer selected diastolic reconstruction window was 75.0%. Mean image quality using the BestPhase(r) algorithm was 2.4 ± 0.9 for systolic reconstructions and 1.9 ± 1.1 for diastolic reconstructions. Using the manual approach, the mean image quality was 1.9 ± 0.5 and 1.7 ± 0.8 respectively. There was a significant difference in image quality between automatically and manually determined systolic reconstructions ($p < 0.01$) but there was no significant difference in image quality in diastolic reconstructions.

Conclusion: Automatic determination of the optimal reconstruction interval using the BestPhase(r) algorithm is feasible and yields reconstruction windows similar to observer selected reconstruction windows. In diastolic reconstructions overall image quality is similar to the image quality in manually selected reconstruction windows.

6916-05, Session 1

Evaluation of model based blood flow quantification from rotational angiography

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(United Kingdom)

For assessment of cerebrovascular diseases, it is beneficial to obtain three-dimensional (3D) information on vessel morphology and hemodynamics. Rotational angiography is routinely used to determine 3D geometry, and we recently outlined a method to estimate the blood flow waveform and mean volumetric flow rate from images acquired using rotational angiography.

Our method uses a model of contrast agent dispersion to estimate the flow parameters from the spatial and temporal development of the contrast agent concentration, represented by a flow map. Artifacts due to the rotation of the c-arm are overcome by using a reliability map. In this paper, we evaluate our method for the case where an attenuation calibration is not available, which may be the case in clinical practice. Furthermore, we concentrate on the validation of the proposed algorithm, with particular emphasis on the influence of parameters such as the length of the analyzed vessel segment, the frame rate of the acquisition, and the duration of the injection on accuracy.

For the validation, rotational angiographic image sequences from a computer simulation and from a phantom experiment were used. With a mean error of 11.0% for the mean volumetric flow rate and 15.3% for the blood flow waveform from the phantom experiments, we conclude that the method has the potential to give quantitative estimates of blood flow parameters during cerebrovascular interventions which are accurate enough to be clinically useful.

6916-06, Session 2

Multimodality MRI of neurodegenerative diseases (Keynote)

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Traditionally, MRI of the brain has been used to detect visually detectable lesions such as brain tumors, strokes, multiple sclerosis plaques etc. Neurodegenerative diseases (ND) is a class of disorders characterized by slowly progressive loss of brain neurons, usually in the elderly, and includes: Alzheimer's disease (AD), Parkinson's disease (PD), frontotemporal dementia (FTD), epilepsy, and also may include psychiatric disorders such as depression, schizophrenia, and post traumatic stress disorder (PTSD). These are extremely common disorders, which affect millions of patients in the US and cost the economy many hundreds of billions of dollars. For example, AD affects almost 50% of all those over age 80 in the US, and because of the increase in the elderly population, the incidence and prevalence of AD is rapidly growing. This emphasizes the importance of improved methods for diagnosis, early detection, and monitoring the effects of treatment. Nevertheless, none of these NDs are characterized by disease-specific lesions, and gross atrophy detected by eye, only occurs at late stages of the disease. For this reason, NDs have received relatively little attention by the radiology community.

Since neurodegeneration is characterized by neural loss, tissue atrophy is often seen. This has been quantified using tissue segmentation and voxel based methods such as voxel based morphometry. Furthermore, various investigators have used a variety of imaging modalities to study changes in all of these disorders. For the past 20 years, investigators in our group have focused on ND, and the talk today will review our findings using multimodality MRI at 4 Tesla. We use: 1) high resolution T-1 weighted MRI to quantify changes in cortex and hippocampal subfields, 2) T-2 weighted MRI and FLAIR to describe the white matter lesions 3) arterial spin labeled MRI to detect alterations of cerebral blood flow, and we coregister the CBF maps with structural imaging to account for tissue effects 3) diffusion tensor imaging and diffusion spectral imaging to detect changes in white matter integrity 4) susceptibility weighted imaging to detect iron and microbleeds 4) single voxel MRS and MR spectroscopic imaging to determine metabolite changes in brain regions. We utilize a variety of image analysis software packages to analyze each modality, and are working towards a comprehensive multimodality approach. We are also involved in a number of multisite studies including the Alzheimer's Disease Neuroimaging Initiative which involves 800 subjects at 57 sites. Recent examples and results of these studies to investigate normal aging, Alzheimer's disease, frontotemporal dementia, and other NDs will be presented.

6916-07, Session 2

Dynamic fMRI of a decision-making task

M. Singh, W. Sungkarat, Univ. of Southern California

A novel fMRI technique has been developed to capture the dynamics of the evolution of brain activity during the decision-making period in a task called the Iowa Gambling Task, where decisions are made under different levels of risk. The task was presented inside a 3T MRI and a dynamic fMRI study of the approximately 2s period between the beginning and end of the decision-making period was conducted by employing a series of reference functions, separated by 200 ms, designed to capture activation at different time-points within this period. As decision-making culminates with a button-press, the timing of the button press was chosen as the reference ($t=0$) and corresponding reference functions were shifted backward in steps of 200ms from this point up to the time when motor activity from the previous button press became visible. SPM was used to realign, high-pass filter (cutoff 200s), normalize to the Montreal Neurological Institute (MNI) Template using a 12 parameter affine/non-linear transformation, 8mm Gaussian smoothing, and event-related General Linear Model analysis for each of the shifted reference functions. The t-score of each activated voxel was then examined to find its peaking time. A random effect analysis showed prefrontal, parietal and bi-lateral hippocampal activations for the $n=6$ group study ($p<0.05$) peaking at different times during the decision making period.

6916-08, Session 2

Correlations between DTI and FLAIR images reveal the relationships of microscopic and macroscopic white matter degenerations in elderly subjects

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Diffusion tensor imaging (DTI) is effective in detecting whiter matter (WM) microscopic structural alterations, whereas fluid attenuated inversion recovery (FLAIR) exams the macroscopic changes in whiter matter lesions (WML). Although both techniques have been widely used to evaluate WM degenerations associated with aging, dementia, and vascular source diseases, the specific relationship between them remains largely unknown. We present a study aims to address this issue based on the correlation analysis between DTI and FLAIR images acquired from 33 elderly subjects at 4T. Advanced techniques were employed to ensure that both DTI and FLAIR datasets were well processed, spatially normalized and co-registered. The WML volume and intensity were used to correlate the fraction anisotropy (FA) or mean diffusivity (MD) across all the subjects on a voxelwise basis. Our results revealed that significant DTI-WML correlations occur at regions with moderate WML intensities, but no correlations were found in pariventricular regions with the highest intensity in FLAIR. Thus, WM degenerations in WML may be classified according the local DTI-WML correlation and this classification has no direct dependence upon the WML intensity. It may imply that some WM degenerations occur in both macroscopic and microscopic scales whereas other degenerations may happen in only one of the scales, as indicated by the different correlations between DTI and FLAIR measurements. Our data suggest that combined DTI and FLAIR modalities may provide higher specificity in characterizing the WM degenerations in elderly populations than using either of them alone.

6916-09, Session 2

Gender differences in brain development in Chinese children and adolescents: a structural MRI study

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Using optimized voxel-based morphometry (VBM), this study systematically investigated gender differences in brain development through magnetic resonance imaging (MRI) data in 158 Chinese normal children and adolescents aged 7.26 to 22.80 years (mean age 15.03 ± 4.70 years, 78 boys and 80 girls). Gender groups were similar on measures of age, handedness, education level. The customized brain templates,

including T1-weighted image and gray matter (GM)/white matter (WM)/cerebro-spinal fluid (CSF) prior probability maps, were created from all participants. Results showed that total intracranial volume (TIV), global absolute GM and global WM volume in girls were significantly smaller than those in boys. Hippocampus grew faster in girls than that in boys, but amygdala grew faster in boys than that in girls. The rate of regional GM decreases with age was steeper in left superior parietal lobule, bilateral inferior parietal lobule, left precuneus, and bilateral supramarginal gyrus in boys compared to girls, which was possibly related to better spatial processing ability in boys. Regional GM volumes were greater in bilateral superior temporal gyrus, bilateral inferior frontal gyrus and bilateral frontal middle gyrus in girls. Regional WM volumes were greater in left temporal lobe, right inferior parietal and bilateral middle frontal gyrus in girls. The gender differences in temporal and frontal lobe maybe be related to better language ability in girls. These findings may aid in understanding the differences in cognitive function between boys and girls.

6916-10, Session 3

Polyp height and width measurement using topographic height map

J. Yao, S. Frenzt, National Institutes of Health; J. Li, Old Dominion Univ.; R. M. Summers, National Institutes of Health

The height and width of colonic polyps are important characteristics to evaluate the status and malignancy of polyps. We borrow the idea from geographic information systems to employ topographic height maps to compute the polyp height and width. The height map is generated using a ray-casting algorithm through an orthogonal projection. A concentric index is devised to gauge the quality of the height map and is maximized in a multi-scale spiral spherical search for the optimal projection. We then locate the polyp tip and neck using directional height profiles, and derive height and width measurement based on geometrical analysis. We manually measured the height and width of 58 polyps and performed paired t-tests between manual measurement and height map measurement. The test shows that Pearson correlation is 0.742 and $P(T \leq t)$ is 0.01 for height measurement; and Pearson correlation is 0.663 and $P(T \leq t)$ is 0.002 for width measurement.

6916-11, Session 3

Registration of prone and supine colons in the presence of topological changes

J. W. Suh, C. L. Wyatt, Virginia Polytechnic Institute and State Univ.

CT colonography is a minimally-invasive screening technique for colorectal polyps in which X-ray CT images of the distended colon are acquired, usually in the prone and supine positions. Registration of segmented colons from both images will be useful for computer-assisted polyp detection. We have previously presented algorithms for registration of the prone and supine colon when both are well distended and there is a single connected lumen.

However due to inadequate bowel preparation or peristalsis there may be collapsed segments in one or both of the colons resulting in a topological change in the images. Such changes make deformable registration of the colons difficult, and at present there are no registration algorithms which can accommodate them. In this paper we present an algorithm which can perform volume registration of prone/supine colon images in the presence of such topological changes.

6916-12, Session 3

Extraction of teniae coli from CT volumes for assisting virtual colonoscopy

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This paper proposes a method for extracting teniae coli from colonic CT volumes. In CT colonography, two types of CT volumes are taken in prone- and supine-positions. These images are used for preventing misdiagnosis caused by fluid stool. However, since the shape of the colon easily changes, it is difficult to find correspondences between

such two volumes. Radiologists need to carefully read both prone- and supine-position volumes. This imposes heavy loads on radiologists who need to CT volumes for CT colonography. Development of a method for registering prone- and supine-position volumes to assist diagnostic process is strongly expected to be developed for reduction of radiologists' load. This paper shows a fully automated method to extract teniae coli regions, which are one of promising land marks of the colon, from CT volumes. Teniae coli region information would be useful for registering CT volumes taken in prone- and supine-positions. Since teniae coli are observed as sequences of ridge-breaks traversing haustra, they can be extracted by analyzing the positions of haustra. First, we extract haustra regions based on curvatures on the colonic wall. Three-lines passing through gravity centers of haustra are computed. Teniae coli regions are extracted as lines running between these three lines. We applied the proposed method to eight cases of colonic CT volumes. The experimental results showed that the proposed method was able to extract teniae coli satisfactorily for cases where haustra were extracted correctly.

6916-13, Session 3

Efficient seeding and curvature streamline defragmentation for colonic polyp detection

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Many computer aided diagnosis (CAD) schemes have been developed for colon cancer detection using Virtual Colonoscopy (VC). In previous work, we developed an automatic polyp detection method integrating flow visualization techniques, that forms part of the CAD functionality of an existing Virtual Colonoscopy pipeline. We used curvature streamlines to characterize polyp surface shape. Derived streamline features correlated highly with true polyp detections. During further testing with larger numbers of patient data sets, we found that the correlation between streamline features and true polyps could be significantly affected by data noise and our streamline generation technique. The seeding and spacing constraints and CT data noise could lead to streamline fragmentation, which reduced the discriminatory power of our streamline features.

In this paper, we present two major improvements of our curvature streamline generation. First, we adapted our streamline seeding strategy to the local surface properties and made the streamline generation faster. It generates a significantly smaller number of seeds for streamline generation, but still results in a comparable and suitable streamline distribution. Second, based on our observation that longer streamlines are better surface shape descriptors, we improved our streamline tracing algorithm to produce longer streamlines.

Our improved techniques not only offer a more efficient curvature streamline computation, but also guide the streamline geometry to correspond better to colonic surface shape. These two adaptations support a robust and high correlation between our streamline features and true positive detections and lead to better polyp detection results.

6916-14, Session 3

Image-based path planning for automatic virtual colonoscopy navigation

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Virtual colonoscopy (VC) is a noninvasive method for colonic polyp screening, by reconstructing three-dimensional images of the colon using computerized tomography (CT). In virtual colonoscopy fly-through navigation, it is crucial to generate an optimal camera path for efficient clinical examination. In the conventional methods, the centerline of the colon lumen is usually used as the camera path. In order to extract colon centerline, some time consuming pre-processing algorithms must be performed before the fly-through navigation, such as colon segmentation, distance transformation computation, or topological thinning. In this paper, we present an efficient image-based path planning algorithm for automated virtual colonoscopy fly-through navigation without the requirement of any pre-processing. Our algorithm only needs the physician to provide a seed point as the starting camera position

using 2D axial CT images. A wide angle fisheye camera model is used to generate a depth image from the current camera position. Two types of navigational landmarks, curved contours (colon haustral folds) and target regions are extracted from the depth images. Camera position and its corresponding view direction are then determined using these landmarks. For the evaluation, we compared the generated camera path with the colon centerline extracted using a distance field based method. The experimental results show that the generated paths are accurate and increase the user comfort during the fly-through navigation.

6916-16, Session 4

Automated anatomical labeling of bronchial branches using multiple classifiers and its application to bronchoscopy guidance based on fusion of virtual and real bronchoscopy

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This paper presents a method for automated anatomical labeling of bronchial branches (ALBB) extracted from 3D CT datasets. The proposed method constructs classifiers that output anatomical names of bronchial branches by employing the machine-learning approach. We also present its application to a bronchoscopy guidance system. Since the bronchus has a complex tree structure, bronchoscopists easily tend to get disoriented. A bronchoscopy guidance system that assists bronchoscopists is strongly expected to be developed. In such navigation system, automated presentation of anatomical names is quite useful in bronchoscopy guidance. Although several methods for automated ALBB were reported, most of them did consider only variations of branching patterns and did not consider those of running directions. Our method tries to solve such problems by utilizing the machine-learning approach. Actual procedure consists of four steps: (a) extraction of tree structure of bronchial branches from 3D CT datasets for training classifiers, (b) computation of features for each branch, such as length and running direction, (c) construction and training of classifiers with the AdaBoost technique, and (d) automated ALBB by using the constructed classifiers. We applied the proposed method to 42 cases of 3D CT datasets. The constructed classifiers were evaluated by leave-one-out scheme. The experimental results showed that the proposed method can assign correct anatomical names to bronchial branches of 94.4% up to segmental lobe branches. Also, we confirmed presentation of anatomical names of bronchial branches on real bronchoscopic views was quite useful to assist bronchoscopy.

6916-17, Session 4

Integrated system for planning peripheral bronchoscopic procedures

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Bronchoscopy is often performed for diagnosing lung cancer. The recent development of multidetector CT (MDCT) scanners and ultrathin bronchoscopes now enable the bronchoscopic biopsy and treatment of peripheral regions of interest (ROIs). Because the peripheral ROIs are often located several generations within the airway tree, careful planning is required prior to a procedure. The current practice for planning peripheral bronchoscopic procedures, however, is difficult, error-prone, and time-consuming. We propose a system for planning peripheral bronchoscopic procedures using patient-specific MDCT chest scans. The planning process begins with a semi-automatic segmentation of ROIs. The remaining system components are completely automatic, beginning with a new strategy for tracheobronchial airway-tree segmentation. From the airway-tree segmentation, a centerline-analysis method extracts the central axes of the airway tree. The system then uses a new locally-adaptive approach for finding the interior airway-wall surfaces. The system's route-planning component analyzes the data generated in the previous stages to determine an appropriate path through the airway tree to the ROI. Finally, an automated report generator gives quantitative data about the route and both static and

dynamic previews of the procedure. These previews consist of virtual bronchoscopic endoluminal renderings at bifurcations encountered along the route and renderings of the airway tree and ROI at the suggested biopsy location. The system is currently in use for a human lung-cancer patient pilot study involving the planning and subsequent live image-based guidance of suspect peripheral cancer nodules.

6916-18, Session 4

Subject specific finite element deformation modeling from monocular endoscope videos

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Realistic surgical simulation requires both visual and biomechanical fidelity. Despite the advances in computational power in recent years, real-time simulation of a complete and physically accurate tissue model suitable for surgical applications is still a significant challenge. Compromises for the sake of interactivity often imply sacrificing realistic tissue motions. In this paper, a technique is described where representative patient specific deformation can be incorporated into finite element modelling. Time dependant tissue deformation is captured in vivo via video bronchoscopy and estimated using image feature tracking. This motion is factored into rigid and non-rigid components via 2D/3D registration based on bronchoscope video and 3D tomographic reconstruction of the same patient. Non-rigid deformation is decomposed into a linear combination of localised deformations derived via forward simulation of the FEM model to which small regional forces are applied. Through optimisation, the forces are scaled over time to derive a physically plausible deformation without having to invert the finite element equations or minimising a system with a large degree of freedom. Error analysis demonstrates the viability of the method to reproduce deformations similar to that observed in bronchoscope video. Detailed analysis is provided for assessing the robustness of the method in the presence of outliers and missing landmarks.

6916-19, Session 4

Virtually assisted optical colonoscopy

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We present a set of tools used to enhance the optical colonoscopy procedure in a novel manner. In order to better present the colon information to the gastroenterologist performing a conventional (optical) colonoscopy, we undistort the radial distortion of the fisheye view of the colonoscopy. The radial distortion is modeled with a function that converts the fisheye view to the perspective view, where the shape and size of polyps can be more readily observed. The conversion calculates the corresponding position in the fisheye view of each pixel on the perspective image, which is accelerated on the graphics processing unit (GPU) and runs in real-time. We also merge our previous work in computer-aided polyp detection for virtual colonoscopy into the optical colonoscopy environment. The physical colonoscope path in the optical colonoscopy is approximated with the hugging corner shortest path, which is correlated with the centerline in the virtual colonoscopy. With the estimated distance that the colonoscope has been inserted, we are able to provide the gastroenterologist with visual cues along the observation path as to the location of possible polyps. In order to present the information to the gastroenterologist in a non-intrusive manner, we have developed a friendly user interface to enhance the optical colonoscopy without being cumbersome, distracting, or resulting in a more lackadaisical inspection by the gastroenterologist. This work aims at improving both the accuracy and efficiency of the common optical colonoscopy procedure.

6916-20, Session 5

Image-based investigation of hemodynamics and rupture of cerebral aneurysms of a single morphological type: terminal aneurysms

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The relationship between hemodynamics and aneurysmal rupture was investigated in cerebral aneurysms of the same morphology (terminal aneurysms) regardless of their location. Hemodynamics information was derived from image-based computational fluid dynamics (CFD) models with realistic patient-specific anatomies. A total of 41 terminal cerebral aneurysms imaged with 3D rotational angiography were included in this study. The maximum wall shear stress (MWSS) at the aneurysms was recorded and flow patterns were classified into three different categories: B) inflow splits in three secondary jets, one of which enters the aneurysm; C) inflow splits in two secondary jets, one is directed towards one of the outflow segments, the other enters the aneurysm; D) inflow first enters the aneurysm before being redirected towards the outflow segments. It was found that ruptured aneurysms had larger MWSS than unruptured aneurysms. In addition, the group with the largest number of ruptured aneurysms was flow Type C. This group also had the highest average MWSS. For all flow types, the averaged MWSS of the ruptured aneurysms was higher than that of the unruptured aneurysms. The results suggest that aneurysms with high values of peak wall shear stress may be more likely to have ruptured than those with lower wall shear stress magnitudes. In turn, the magnitude of the maximum wall shear stress in the aneurysm is associated to the different manners in which the blood flow in the parent artery splits, enters the aneurysm and bifurcates to the daughter branches.

6916-21, Session 5

Image-based biomechanical modeling of aortic wall stress and vessel deformation: response to pulsatile arterial pressure simulations

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Image-based modeling of cardiovascular biomechanics may be very helpful for patients with aortic aneurysms to predict the risk of rupture and evaluate the necessity of a surgical intervention. In order to generate a reliable support it is necessary to develop exact patient-specific models that simulate biomechanical parameters and provide individual structural analysis of the state of fatigue and characterize this to the potential of rupture of the aortic wall.

The patient-specific geometry used here originates from a CT scan of an Abdominal Aortic Aneurysm (AAA). The computations are based on the Finite Element Method (FEM) and simulate the wall stress distribution and the vessel deformation. The wall transient boundary conditions are based on real time-dependent pressure simulations obtained from a previous computational fluid dynamics study. The physiological wall material properties consider a nonlinear hyperelastic constitutive model, based on realistic ex-vivo analysis of aneurysmal arterial tissue.

The results showed large deformation and complex stress distribution on the AAA wall. The maximum stresses occurred at the systole and are found around the aneurysmal bulge in regions close to inflection points.

Biomechanical modeling based on medical images and coupled with patient-specific hemodynamics allows analysing and quantifying the effects of dilatation of the arterial wall due to the pulsatile aortic pressure. It provides a physical and realistic insight into the wall mechanics and enables predictive simulations of AAA growth and assessment of rupture. Further development integrating endovascular models would help evaluating non-invasively individual treatment strategies for optimal placement and improved device design.

6916-22, Session 5

A new deconvolution approach to perfusion imaging exploiting spatial correlation

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The parts of the human body affected by a disease do not only undergo structural changes but also demonstrate significant physiological (functional) abnormalities. An important parameter that reveals the functional state of tissue is the flow of blood per unit tissue volume or

perfusion, which can be obtained using dynamic imaging methods. One mathematical approach widely used for estimating perfusion from dynamic imaging data is based on a convolutional tissue-flow model. In these approaches, deconvolution of the observed data is necessary to obtain the important physiological parameters within a voxel. Although several alternatives have been proposed for deconvolution, all of them treat neighboring voxels independently and do not exploit the spatial correlation between voxels or the temporal correlation within a voxel over time. These simplistic approaches result in a noisy perfusion map with poorly defined region boundaries. In this paper, we propose a novel perfusion estimation method which incorporates spatial as well as temporal correlation into the deconvolution process. Performance of our method is compared to standard methods using independent voxel processing. Both simulated and real data experiments illustrate the potential of our method.

6916-23, Session 5

Modeling respiratory lung motion: a biophysical approach using finite element methods

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Respiratory dynamics poses a main source of error in radiotherapy of thoracic tumors. Development and optimization of methods to adequately account for breathing motion require detailed knowledge of the dynamics and its impact on e. g. the dose delivered by radiation. Thus, computer aided modeling and model based simulation of respiratory motion gains in importance.

In this paper a biophysical approach for modeling lung motion is described. Main aspects of the process of lung ventilation are identified and outlined as the starting point of modeling. They are formulated as a contact problem of linear elasticity theory. The resulting boundary value problem is solved using Finite Element Methods (FEM). 4D (= 3D+t) CT image data are used to evaluate the modeling approach. Model based three-dimensional vector fields representing respiratory motion are computed for different patients. Simulated motion patterns of inner lung landmarks like prominent bifurcations of the bronchial tree and the tumor mass center are compared with corresponding motion patterns observed in the 4D CT data. The influence of geometrical and biomechanical parameters like mesh quality and values of elasticity constants on the modeling process is investigated.

Differences between model based predicted landmark positions and corresponding landmark positions identified interactively are mostly within the variability of interactive landmark positioning across multiple observers (interobserver variability). The impact on resulting vector fields is fairly small. Outcomes suggest that FEM state an adequate strategy to model aspects of the physiology of breathing.

6916-24, Session 5

Compensated Tikhonov regularization for quantitative perfusion measurements

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Quantification of cerebral blood flow (CBF) and the tissue residue function (R) requires arterial input function (AIF) deconvolution. Currently, the most commonly used deconvolution method is singular value decomposition (SVD), which has shown promise in producing accurate estimations of CBF. Unfortunately, deconvolution introduces unwanted oscillations in the time course of R. In some situations, such as blood flow heterogeneity calculations and bolus dispersion assessments, the actual shape of the residue function is of interest. So far, truncated singular value decomposition (TSVD) has been the gold standard for regularizing residue functions. Some of the disadvantages of this method are the large trade-off between regularization and underestimation of the flow rate, distortion of actual shape of the residue function, and the global instead of local threshold. Considering the non-increasing character of residue functions, Tikhonov regularization could be a suitable option. However, some modifications are necessary. In this research a "compensated Tikhonov" method, using a new regularization matrix based on the statistical structure of residue functions, is suggested. Using L-curve

criteria, regularization parameters are calculated locally for each pixel in the image. Perfusion-based parameters estimated using TSVD, regular, and compensated Tikhonov are compared. Based on simulation results, compensated Tikhonov shows more accurate in preserving the structural shape of the residue function and in estimating the perfusion-related parameters, specially in low SNRs.

6916-25, Session 6

Endovascular image-guided treatment of in-vivo model aneurysms with asymmetric vascular stents (AVS): evaluation with time-density curve angiographic analysis and histology

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In this study we compare the results obtained from Time-Density Curve (TDC) analysis of angiographic imaging sequences with histological evaluation for a rabbit aneurysm model treated with standard stents and new asymmetric vascular stents (AVS) placed by image-guided endovascular deployment.

AVSs are stents having a low-porosity patch region designed to cover the aneurysm neck and occlude blood flow inside. To evaluate AVSs, rabbits with elastase-induced aneurysm model (20) were divided into three groups: the first (10) was treated with an AVS, the second (5) with a non-patch standard coronary stent, and third was untreated as a control (5). We used TDC analysis to measure how much contrast media enters the aneurysm before and after treatment. TDCs track contrast-media-density changes as a function of time over the region of interest in x-ray DSA cine-sequences. After 28 days the animals were sacrificed and the explanted specimens were histologically evaluated. The first group showed an average reduction of contrast flow into the aneurysm of 95% after treatment with an AVS with fully developed thrombus at 28 days follow-up. The rabbits treated with standard stents showed an increase in TDC residency time after treatment and partial-thrombogenesis. The untreated control aneurysms displayed no reduction in flow and were still patent at follow-up.

The quantitative TDC analysis findings were confirmed by histological evaluation suggesting that the new AVS has great potential as a definitive treatment for cerebro-vascular aneurysms and that angiographic TDC analysis can provide in-vivo verification.

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6916-26, Session 6

3D analysis of microvascular architecture of the spleen with ultra-high-resolution for partial splenic embolization

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The purpose of this study is to clarify embolic effects of embolic agents for partial splenic embolization. Partial splenic embolization is a minimally invasive technique for splenomegaly. However, embolic agents have been empirically chosen because embolic effects have never been studied quantitatively. We have constructed a quantitative 3-D analysis system of microvascular architecture. The system has consisted of data acquisition, segmentation, and measurement of diameters of end arterioles. 3-D volumetric data of samples with ultra-high resolution was acquired using a synchrotron radiation CT constructed in SPring-8. Segmented microvascular architecture was obtained applying an adaptive region growing method. This method is a kind of dynamic thresholding to cope with nonuniformity of the voxel density. To recognize end of arterioles, distance map from initial point placed at the root of the major trunk have been generated applying single-seeded coding. Diameters of vasculature are measured using single-seeded clusters which are formed from the

same single-seeded code in the distance map and Euclidean distance transform which measures the minimum distances between each voxel and vascular boundary. Diameters of end arterioles are obtained choosing the maximum value in the result of Euclidean distance transform in the most distant cluster. In this study, we found diameters of embolized end arterioles were ranging from 48 to 72 μm with the analysis system. We have concluded that a quantitative 3-D analysis system have been successfully developed for microvascular architecture. A new approach to establish theoretical basis of embolization therapy with microspheres have been provide owing to the system.

6916-27, Session 6

Segmentation of stentgrafts in the abdominal aorta from ECG-gated CTA data

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Endovascular aortic replacement (EVAR) is an established technique, which uses stentgrafts to treat aortic aneurysms in patients at risk of aneurysm rupture. The long-term durability of these stentgrafts is affected by the stresses and hemodynamic forces applied to them, and may be reflected by the movements of the stentgraft itself during the cardiac cycle. A conventional CT scan (which results in a 3D volume) is not able to visualize these movements. However, applying ECG-gating does provide insight in the motion of the stentgraft caused by hemodynamic forces at different phases of the cardiac cycle.

The amount of data obtained is a factor of ten larger compared to conventional CT, but the radiation dose is kept similar for patient safety. This causes the data to be noisy, and streak artifacts are more common. Algorithms for automatic stentgraft detection must be able to cope with this.

Segmentation of the stentgraft is performed by examining slices orthogonal to the centreline. Regions with high CT-values exist at the locations where the metallic frame penetrates the slice. These regions are well suited for detection and sub-pixel localization. Spurious points can be removed by means of a clustering algorithm, leaving only points on the contour of the stent. We compare the performance of several different point detection methods and clustering algorithms. The position of the stent's centreline is calculated by fitting a circle through these points.

The proposed method can detect several stentgraft types, and is robust against noise and streak artifacts.

6916-28, Session 6

Analysis of anatomic variability in children with low mathematical skills

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Mathematical difficulty affects approximately 5-9% of the population. Studies on individuals with dyscalculia, a neurologically based math disorder, provide important insight into neural correlates of mathematical ability. For example, cognitive theories, neuropsychological studies, and functional neuroimaging studies in individuals with dyscalculia suggest that the bilateral parietal lobes and intraparietal sulcus are central to mathematical performance. The purpose of the present study was to investigate morphological differences in a group of third grade children with poor math skills. We compare population averages of children with low math skill (MD) to gender and age matched controls with average math ability. Anatomical data were gathered with high resolution MRI and four different population averaging methods were used to study the effect of the normalization technique on the results. Statistical results based on the deformation fields between the two groups show the anatomical differences lie in bilateral parietal lobes, right frontal lobe, and left occipital/parietal lobe.

6916-29, Session 6

Computer-aided segmentation and 3D analysis of in vivo MRI examinations of the human vocal tract during phonation

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PURPOSE: To develop, test, and evaluate a 3D segmentation and analysis system for in vivo MRI examinations of the human vocal tract during phonation.

METHOD AND MATERIALS: Six professionally trained speakers, age 22-34y, were examined using a standardized MRI protocol (1.5 T, T1w FLASH, ST 4mm, 23 slices, acq. time 21s). The volunteers performed a prolonged (â%¥21s) emission of sounds of the German phonemic inventory. Simultaneous audio tape recording was obtained to control correct utterance. Scans were made in axial, coronal, and sagittal planes each. Computer-aided quantitative 3D evaluation included (i) automated registration of the phoneme-specific data acquired in different slice orientations, (ii) semi-automated segmentation of oropharyngeal structures, (iii) computation of a curvilinear vocal tract midline in 3D by nonlinear PCA, (iv) computation of cross-sectional areas of the vocal tract perpendicular to this midline. For the vowels /a/, /e/, /i/, /o/, /Ä/, /u/, /y/, the extracted area functions were used to synthesize phoneme sounds based on an articulatory-acoustic model. For quantitative analysis, recorded and synthesized phonemes were compared, where area functions extracted from 2D midsagittal slices were used as a reference.

RESULTS: All vowels could be identified correctly based on the synthesized phoneme sounds. The comparison between synthesized and recorded vowel phonemes revealed that the quality of phoneme sound synthesis was improved for phonemes /a/ and /y/, if 3D instead of 2D data were used, as measured by the average relative frequency shift between recorded and synthesized vowel formants ($p < 0.05$, one-sided Wilcoxon rank sum test).

CONCLUSION: The combination of fast MRI followed by subsequent 3D segmentation and analysis is a novel approach to examine human phonation in vivo. It unveils functional anatomical findings that may be essential for realistic modelling of the human vocal tract during speech production.

6916-30, Session 6

Segmentation of multispectral bladder MR images with inhomogeneity correction for virtual cystoscopy

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Virtual cystoscopy (VC) is a developing noninvasive, safe, and low-cost technique for bladder cancer screening. Multispectral (T1- and T2-weighted) magnetic resonance (MR) images provide a better tissue contrast between bladder wall and bladder lumen comparing with computed tomography (CT) images. The intrinsic T1 and T2 contrast of the urine against the bladder wall eliminates the invasive air insufflation procedure which is often used in CT-based VC. Because earliest stages of bladder lesion development are inside the mucosa with gradual extension into bladder muscle, we propose a new partial volume (PV) segmentation scheme with inhomogeneity correction to extract the bladder lumen and wall for tumor screening by virtual cystoscopy. The proposed PV segmentation algorithm automatically estimates the bias field and segments tissue mixtures inside each voxel of MR images, thus preserving texture information and providing tissue growth tendency between bladder lumen and wall. Experimental results indicate that the present scheme is very promising towards mass screening by virtual cystoscopy means.

6916-32, Session 7

Modelling the pelvic floor for investigating difficulties during childbirth

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Research has suggested that athletes involved in high-intensity sports for sustained periods have a higher probability of experiencing prolonged second stage of labour compared to non-athletes. The mechanism responsible for this complication is unknown but may depend on the relative size or tone of the pelvic floor muscles. Prolonged training can result in enlargement and stiffening of these muscles, providing increased resistance as the fetal head descends through the birth canal during a vaginal birth. On the other hand, recent studies have suggested an association between increased muscle bulk in athletes and higher distensibility. This project aims to use mathematical modelling to study the relationship between the size and tone of the pelvic floor muscles and the level of difficulty during childbirth. We obtained sets of magnetic resonance (MR) images of the pelvic floor region for a female athlete and a female non-athlete. Thirteen components of the pelvic floor were segmented and used to generate finite element (FE) models. The fetal head data was obtained by laser scanning a skull replica and a FE model was fitted to these data. We used contact mechanics to simulate the motion of the fetal head moving through the pelvic floor, constructed from the non-athlete data. A maximum stretch ratio of 3.2 was induced in the muscle at the left lateral attachment point to the pubis. We plan to further improve our modelling framework to include active muscle contraction and fetal head rotations in order to address the hypotheses that there is a correlation between the level of difficulty and the size or tone of the pelvic floor muscles.

6916-33, Session 7

Estimating MR relaxation in a single shot: considerations for estimation accuracy

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Quantitative and spatially accurate $R2^*$ maps from single-shot acquisitions would be valuable for functional MRI and dynamic contrast studies. Addressing this need is SS-PARSE (Single-shot parameter assessment by recovery from signal encoding), a recently introduced MRI technique for mapping magnetization magnitude, frequency, and net transverse decay rate $R2^*$ from a single-shot signal. SS-PARSE uses (a) a single-shot acquisition scheme designed to maximize information content on $R2^*$ (and other local parameters) encoded into the signal, and (b) an inverse solution of the signal equation. Because the signal model used is fundamentally more accurate than the model implicitly used in most current MRI methodology, SS-PARSE maps are inherently free from geometric errors due to off-resonance frequencies. Extension to parallel acquisitions can substantially increase the power of the method. Key performance issues include the nature of the estimation errors, and the choice of estimation algorithm to apply to the signal. We analyze bias and random errors, and demonstrate that both are influenced by the choice of spatial grid at which the parameters are evaluated, and that hexagonal grids are a better choice than Cartesian grids under some circumstances. We use the Cramer-Rao bound to demonstrate that rosette trajectories are fundamentally more effective at encoding local relaxation rate $R2^*$ than are standard multiple-echo scans of the same duration. Also investigated are the pros and cons of estimation algorithms based on conjugate gradient search and projections onto convex sets (POCS). Performance is evaluated using experimental results from phantom and animal studies.

6916-34, Session 7

Three-dimensional reconstruction of the moving mitral valve annulus and mitral valve leaflets from multislice 2D magnetic resonance images acquired using a balanced steady-state free precession imaging pulse sequence

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Accurate geometric assessment of the dynamics of the mitral apparatus before and after mitral valve repair procedures will improve patient selection, surgical evaluation, and long-term patient management. Here, we present an imaging and post-processing solution to provide 3-D reconstructions of the mitral valve annulus and the mitral valve leaflet dynamics. A balanced steady-state free precession magnetic resonance pulse sequence was used to acquire a cine-sequence of 2-D images for a series of parallel left-ventricular long-axis slices prescribed specifically to sample the mitral valve. Post-processing methods were then developed to reconstruct the leaflet surfaces and the mitral valve annulus from these images. First, the contrast between the valve and the blood pool in these images was exploited to extract points on the mitral valve leaflet surfaces using intensity-based curve-tracing tools. Second, for each time frame, the sparse cloud of 3-D leaflet points grouped from all slices was regridged on to a fine mesh and fitted to a surface automatically. The surface was then color-coded to add depth information. Third, for each 2-D slice, two points on the annulus are determined by identifying the fixed ends of the anterior and posterior leaflets. The frame of the annulus is then reconstructed by interpolating these points in 3-D using third-order splines. Finally, for each time frame, the reconstructed leaflet surface and mitral annulus are overlaid on a context image for visual reference. Experiments were performed on normal volunteers and pigs with an induced model of ischemic mitral regurgitation.

6916-35, Session 7

Imaging magnetic nanoparticles using the signal's frequency spectrum

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Current methods of magnetic particle imaging generate a signal by cyclically saturating nanoparticles creating measurable harmonics in the induced magnetization. The sensitivity promises to be competitive with SPECT so molecular imaging is possible. The signal has been localized by saturating the nanoparticles outside a voxel using a strong static magnetic field and sweeping that voxel across the sample to form an image. However, in applications where enough nanoparticles are present, signal can be detected at several higher harmonic frequencies and we show that the distribution of signal between those frequencies allows the signal to be localized. We tested one-dimensional implementations but the methods can be generalized to three dimensions. Two related methods were considered: a spatially varying static magnetic field and a mixture of drive frequencies that varied spatially. The measured signal at different static fields was used to model the response from a sample in a gradient. The other method employed two drive coils tuned to different drive frequencies and mounted on the same axis. The response was measured from a single sample at eight positions along that axis to estimate response function for the reconstruction. Then two identical samples were placed at pairs of locations to test the method. In both cases localization can be achieved using the spectrum of the signal generated. Applications are limited to those where the nanoparticle concentration is sufficiently high that signal can be measured at multiple higher harmonic frequencies; e.g., imaging the distribution of nanoparticles in ferrofluid hyperthermia.

6916-36, Session 7

Fast 3D fluid registration of brain magnetic resonance images

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Fluid registration is widely used in medical imaging to track anatomical changes, to correct image distortions, and to integrate multi-modality data. Fluid mappings guarantee that the template image deforms smoothly into the target, without tearing or folding, even when large deformations are required for accurate matching.

Here we implemented an intensity-based fluid registration algorithm (Christensen et al., 1996), accelerated by using a filter designed in Bro-Nielsen et al. (1996). We validated the algorithm on 2D and 3D geometric phantoms using the mean square difference between the final registered image and target as a measure of the accuracy of the registration. In tests on phantom images with different levels of overlap, varying amounts of Gaussian noise, and different intensity gradients, the fluid method outperformed a more commonly used elastic registration method, both in terms of accuracy and in avoiding topological errors during deformation. We also studied the effect of varying the viscosity coefficients in the viscous fluid equation, to optimize registration accuracy. Finally, we applied the fluid registration algorithm to a dataset of 2D binary corpus callosum images and 3D volumetric brain MRIs from 14 healthy individuals to assess its accuracy and robustness.

6916-37, Session 7

MRI-based noninvasive measurement of intracranial compliance from the relationship between transcranial blood and CSF flows: modeling vs direct approach

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Intracranial compliance (ICC) determines the ability of the intracranial space to accommodate increase in volume (e.g., brain swelling) without a large increase in intracranial pressure (ICP). Therefore, measurement of ICC is potentially important for diagnosis and guiding treatment of related neurological problems. Modeling based approach uses an assumed lumped parameters model of the craniospinal system (CSS) (e.g., RCL circuit), with the net transcranial blood flow as input and craniospinal cerebrospinal fluid (CSF) flow as output. The phase difference between the two is then used to estimate ICC. However, it is not clear whether there is a predetermined relationship between changes in ICC the resulted phase shift. A recently proposed direct approach derives ICC from the ratio of the intracranial volume and pressure changes that occurs naturally with each heart beat. In this study, an RLC circuit model was used to simulate the output, the CSF flow, for a transcranial blood flow measured in vivo by MRI. The affect of ICC on the amplitude and phase of the system were characterized by the system Bode plots. We observed that within the heart rate frequency range, changes in ICC predominantly affected the amplitude of the CSF pulsation and less so the phases shift. This explains the affect of compliance on the maximal change in intracranial volume and CSF pressure gradients used for derivation of ICC by the direct approach [1]. This work further explains why phase shift based techniques are less sensitive to changes in ICC than amplitude based approach.

6916-31, Poster Session

Image-based EPI real time ghost correction

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This paper presents a new, real-time, ghost correction method for echo planar imaging (EPI) that has been implemented using the Imaging Calculation Environment (ICE) on a 3T Siemens MRI System. Conventional methods for correcting EPI image ghost are based on image phase correction or on a reference scan. This new method is also based on image phase correction, but uses a new algorithm for automatic determination of the phase correction, which allows entirely automated operation. With implementation of the new correction method in ICE, ghost-corrected images are automatically generated and loaded into the system's image database immediately after completion of each EPI scan. Experiments showed that this real time ghost correction method consistently reduced the ghost intensity in EPI images and improved overall image quality. On average, the ghost to signal ratio (GSR) improved from 13.0% to 3.2% using the new method

6916-59, Poster Session

Texture-based CAD improves diagnosis for low dose CT colonography

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Computed tomography-based virtual colonoscopy or CT colonography (CTC) currently utilizes oral contrast solutions to differentiate the colonic fluid and possibly residual stool from the colon wall. The enhanced image density of the tagged colonic materials causes a significant partial volume (PV) effect into the colon wall as well as the lumen space (air or CO₂). The PV effect into the colon wall can "bury" polyps of not small size by increasing their image densities to a noticeable level, resulting in false negatives. It can also create false positives when PV effect goes into the lumen space. We have been modeling the image PV effect for mixture-based image segmentation [1-3] and developing text-based computer-aided detection (txCAD) by utilizing the PV mixture-based image segmentation [4]. This work presents a preliminary study of developing txCAD technique and applying it to low dose CTC. A total of 114 studies of asymptomatic patients older than 50, who underwent CTC and then optical colonoscopy (OC) on the same day, were selected from a database for this study. The participating radiologists found ten polyps of greater than 5 mm from a total of 16 OC proved polyps, i.e., a detection sensitivity of 63%. They scored 23 false positives from the database, i.e., a 20% false positive rate. Approximately 70% of the datasets were marked as imperfect bowel cleaning and/or limited by image artifacts. The txCAD detected all the polyps with an average of 2.68 false positives per patient.

6916-60, Poster Session

Glycoprotein expression by adenomatous polyps of the colon

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Colon cancer is the second leading cause of cancer related deaths in the United States. Specificity in diagnostic imaging for detecting colorectal adenomas, which have a propensity towards malignancy, is desired. Adenomatous polyp specimens of the colon were obtained from the mouse model of colorectal cancer called adenomatous polyposis coli-multiple intestinal neoplasia (APCMin). Histological evaluation, by the legume protein Ulex europaeus agglutinin I (UEA-1), determined expression of the glycoprotein e- α -L-fucose. FITC-labelled UEA-1 confirmed overexpression of the glycoprotein by the polyps on fluorescence microscopy in 17/17 cases, of which 13/17 included paraffin-fixed mouse polyp specimens. In addition, FITC-UEA-1 ex vivo multispectral optical imaging of 4/17 colonic specimens displayed over-expression of the glycoprotein by the polyps, as compared to non-neoplastic mucosa. Here, we report the surface expression of e- α -L-fucosyl terminal residues by neoplastic mucosal cells of APC specimens of the mouse. Glycoprotein expression was validated by the carbohydrate binding protein UEA-1. Future applications of this method are the development of agents used to diagnose cancers by biomedical imaging modalities, including computed tomographic colonography (CTC). UEA-1 targeting to colonic adenomas may provide a new avenue for the diagnosis of colorectal carcinoma by CT imaging.

6916-61, Poster Session

Segmentation of colon in tagged CT colonography using adaptive level set method

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Accurate and reliable segmentation of the colon is important for 3D reconstruction, automatic colonic polyp detection and classification. In this paper, we introduce an adaptive level set method for segmenting colon filled with air and opacified fluid in CT colonography. We first use simple thresholding method to remove most of the opacified liquid. Then, closed contours with manual seeds initialization are propagated toward the desired region boundaries through the iterative evolution of an adaptive 3D implicit function. During each iteration, information about

the regions is considered by estimating the parameters of probability density function (PDF). Finally, we evaluate accuracy of the proposed method by computing the overlap between the manual segmented colon and the results segmented by the algorithm. The proposed method has been tested on 10 real tagged CT colonography datasets, which contain approximate 4,500 slices, and the accuracy has achieved 96.06%.

6916-62, Poster Session

Comparison of laterality index of upper and lower limb movement, using brain activated fMRI

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Asymmetry of bilateral cerebral function, i.e. laterality, is an important phenomenon in many brain actions. This asymmetry alters in some clinical conditions. To evaluate brain activation in any limb movement, 10 Male subjects underwent fMRI assessment, while they were asked to move their hands and ankles in a predetermined pattern. The corresponding Blood Oxygenation Level Dependent (BOLD)-signal was characterized by 'Z-stat', being a transformation of t-statistics i.e. dividing the parameter estimate by its standard error. Thus, Regions of Interest (ROIs) were defined for each subject/task separately. The ROIs are major cerebral areas known for motor system including: Primary Motor Cortex(M1), Premotor Cortex(PMC), Thalamus(THA), Basal Ganglia(BG), Cingulate Motor(CMA). Hence, Laterality Index (LI) score, as a representative of lateralization was calculated by the difference of magnitude of the task-induced mean z-stat for equal regions of interest within the contralateral and ipsilateral hemisphere, divided to the summation of these values. Results showed that hand movement activates brain more lateralized in PMC in comparison with lower limb movements. Comparison of dominant versus nondominant limbs showed that lateralization of brain activity during dominant hand movement was significantly greater in M1, PMC and BG in comparison with non dominant hand. In Lower limbs, laterality of brain activation during the dominant and non dominant limb movement did not have any significant difference in any ROIs. These features possibly differentiate hand movements from lower limb joints and this may possibly be due to hand responsibility for precise and fine voluntary movements, whereas lower limb joints are mainly responsible for locomotion, a function which integrates voluntary and automatic bilateral movements.

6916-63, Poster Session

Real time classification of activated brain areas for fMRI-based human-brain-interfaces

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Functional MR imaging (fMRI) enables to detect different activated brain areas according to the performed tasks. However, data are usually evaluated after the experiment, which prohibits intra-experiment optimization or more sophisticated applications such as biofeedback experiments. Using a human-brain-interface (HBI), subjects are able to communicate with external programs, e.g. to navigate through virtual scenes, or to experience and modify their own brain activation, e.g., for reducing emotional stress disorders. These applications require the real-time analysis and classification of activated brain areas. Our paper presents first results of different strategies for real time pattern analysis and classification that enabled to move through a 3D virtual scene in real-time using only thought-based tasks.

6916-64, Poster Session

A study of specific neural substrate for face processing

J. Li, Xidian Univ. (China); J. Tian, Institute of Automation (China); J. Liang, Xidian Univ. (China); H. Zhang, Institute of Automation (China); G. Shi, Xidian Univ. (China)

Recently, there were debates about the neural substrate for face processing, whether the lateral fusiform was involved in processing of

visual expertise and categorization at individual level or specialized only in face processing. Chinese character was taken as the ideal comparison stimuli to reveal the neural substrate for face processing in the present study because of their great similarity to faces. There was a very strong correlation between the activation pattern of face-task versus baseline and character-task versus baseline in the lateral fusiform and face versus character activated the right lateral fusiform much more than character versus face. The results suggest that FFA was a special neural substrate for face processing.

6916-65, Poster Session

An improved algorithm of fiber tractography demonstrates postischemic cerebral reorganization

X. Liu, L. Yao, Beijing Normal Univ. (China); J. Lu, Xuanwu Hospital (China)

In vivo white matter tractography by diffusion tensor imaging (DTI) accurately represents the organizational architecture of white matter in the vicinity of brain lesions and especially ischemic brain. In this study, we suggested an improved fiber tracking algorithm based on TEND, called TENDAS, for tensor deflection with adaptive stepping, which had been introduced a stepping framework for interpreting the algorithm behavior as a function of the tensor shape (linear-shaped or not) and tract history. The propagation direction at each step was given by the deflection vector. TENDAS tractography was used to examine a 17-year-old recovery patient with congenital right hemisphere artery stenosis combining with fMRI. Meaningless picture location was used as spatial working memory task in this study. We detected the shifted functional localization to the contralateral homotypic cortex and more prominent and extensive left-sided parietal and medial frontal cortical activations which were used directly as seed mask for tractography for the reconstruction of individual spatial parietal pathways. Comparing with the TEND algorithms, TENDAS shows smoother and less sharp bending characterization of white matter architecture of the parietal cortex. The results of this preliminary study were twofold. First, TENDAS may provide more adaptability and accuracy in reconstructing certain anatomical features, whereas it is very difficult to verify tractography maps of white matter connectivity in the living human brain. Second, our study indicates that combination of TENDAS and fMRI provide a unique image of functional cortical reorganization and structural modifications of postischemic spatial working memory.

6916-66, Poster Session

Partial volume effect of cingulum tract in diffusion-tensor MRI

N. Cao, B. T. Gold, J. Zhang, Univ. of Kentucky

Diffusion tensor imaging (DTI) represents a promising tool for the early diagnosis of certain brain diseases. Many DTI studies have compared differences in local diffusivity in specific regions of interest between patient and control groups to find possible disease markers. However, local diffusivity results may be influenced by partial volume effects (PVE), particularly in small white matter tracts that border grey matter tissue. Here, we investigated the influence of PVE on local diffusivity measurements in a small but critical white matter tract, the cingulum. Results demonstrated significant variability in PVE that contribute to local diffusivity in the cingulum. Our results highlight the need for careful consideration of PVE when computing diffusivity of small tissues.

6916-67, Poster Session

Fast changing dynamic and high non-stationary electroencephalograph signal analysis during yoga

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Abstract-Electroencephalography (EEG) is the neurophysiologic measurements of the electrical activity of the brain by recording from electrodes placed on the scalp in the cerebral cortex. Altered states of consciousness exhibit subtle EEG changes that must be observed with carefully chosen methodology and signal processing procedures.

Generalized psycho-physiological model of the Self is introduced to point out the possible sources of nervous system excitation that are particularly important in altered states of consciousness. The proposed methodology is based on combination of static and dynamic analysis to characterize underlying neurophysiological states. We developed software tool to support this methodology and provide support for signal processing functions and efficient visualization procedures. Proposed methodology and software environment are used for analysis of brain activities during altered state of consciousness related to the yoga process. We present here obtained results and new parameters in quantitative EEG analysis that can be efficiently used to characterize state of consciousness.

In this research paper we have designed and implemented a new software tool to simplify the complexity of EEG signal based on the digital signal processing parameters like Density estimation, regression estimation, channel properties, event related potential, component activities, data statistics, channel time frequency, component time frequency, channel cross coherence, component cross coherence and Correlation dimension, a wavelet transformation is applied to electroencephalograph records from persons under yoga. This type of analysis is very useful for medical applications, bio-medical research, brain computer interface, Artificial Intelligence, wheelchair This software is used to keep track of the improvement of the persons mind, aging, balance, flexibility, personnel values, mental values, social values, love, sex, knowledge, weight reduction and body fitness. for blocked person, Prosthetic arms & legs, Speech Restoration, Cyberkinetics, Neurosonics, Artificial hippocampus, Ocular implant or artificial retina.

6916-68, Poster Session

Contrast enhanced MRI characterization of the perfusion territories fed by individual coronary arteries in ex-vivo porcine heart

N. M. Szeverenyi, A. Pertsov, B. Searles, Upstate Medical Univ./SUNY

Sudden cardiac death is often caused by ventricular arrhythmias. These arrhythmias are believed to originate from the border zones where tissue was damaged by an ischemic event involving the coronary arteries. It would be valuable to obtain detailed information on the geometry of the perfusion territories fed by individual coronary arteries. MR perfusion imaging on an excised heart can reveal these details and can provide data for electrical modeling. If the heart can be kept viable through the scan, actual electrical measurements can subsequently be made on the same heart.

The right coronary artery (RCA) and left main artery (LM) of an excised porcine heart were cannulated. The heart was suspended from these cannulas and submerged in a container filled with circulating cold cardioplegia solution. Images were obtained on a Philips 1.5T scanner with voxel volumes of 0.25 mm³ following each small bolus injection of Magnevist.

This excised porcine heart model provides high resolution details of cardiac perfusion. The filling pattern and final volume of the RCA perfusion territory were clearly visualized, reaching a consistent final volume of 35% of the entire heart myocardium. The RCA territory was found to have irregular boundaries, which we describe as fingers.

We present the first images of excised whole heart preparations where the irregular boundaries of perfusion territories are described. These irregular borders when mathematically modeled by our group have been shown to propagate arrhythmias. Electrical modeling of the entire heart with these new details will be interesting.

6916-69, Poster Session

Hyperpolarized ³He Magnetic Resonance Imaging of Asthma

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Our objective was to examine subjects with exercise-induced asthma in order to examine whether hyperpolarized (³He) MRI provided a reproducible assessment of regional ventilation defects over short periods of time. Our objective was to evaluate interscan and intra-observer

Hp 3He MRI measurement reproducibility of subjects scanned on 3 occasions over 3 weeks. Magnetic resonance imaging was performed at 3.0Tesla with a custom-built elliptical chest coil specifically designed to image helium gas within the lungs. Ventilation defect scoring and volume measurement performed for six subjects showed that baseline ventilation defect locations were similar at all 3 visits indicating persistence of defects, but the number and size of these differed at each visit.

6916-70, Poster Session

In vivo imaging of superficial femoral artery (SFO) stents for deformation analysis

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We have used high-resolution 3D-imaging to evaluate the deforming forces on superficial femoral artery (SFA) stents in subjects. The SFA is susceptible to the development of atherosclerotic lesions that are typically treated with percutaneous transluminal angioplasty and stent deployment. However, it has been found that these stents have a fracture rate as high as 35%. This is usually accompanied by restenosis and reocclusion². The exact cause for the fracture is unknown and is hypothesized to result from deforming forces due to hip and knee flexion.

A high-resolution (198micron) C-arm CT imaging system (Axiom Artis dTA, Siemens Medical Solutions, Forchheim, Germany) was optimized for imaging SFA stents in humans. The subjects were placed on the imaging table which had a specially constructed extension. Imaging was performed with the leg placed in the straight and bent positions. Projection images obtained during 20s scans with ~200° of rotation of the C-arm were back-projected to obtain 3D volumes.

Using a semi-automatic software developed in-house, the centerline for each reconstructed stent was found and ellipses were fitted to slices normal to it. Image quality was adequate for calculations in 11/13 subjects. Bending the leg was found to shorten the stents in 10/11 cases with the maximum change being 9% (12mm in a 133mm stent). It was extended in one case by 1.6%. The maximum change in ellipse eccentricities was 36% in a case where the stent extended behind the knee. The corresponding deforming forces are being evaluated using phantoms where the exact loading is known.

6916-71, Poster Session

Intuitive parameter-free visualization of tumor vascularization using rotating connectivity projections

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We present an effective and intuitive visualization of the vascularization of a selected tumor in three-dimensional image data (e.g. CT, MR, US). For the differential diagnosis of tumors the degree of vascularization is one important clinical parameter.

Surface renderings of vessel- and tumor-segmentations depend critically on the chosen parameter- and threshold-values for the underlying segmentation. Therefore we use rotating Maximum Intensity Projections (MIPs) of a volume of interests (VOI) around the selected tumor. The MIP does not require specific parameters, and allows much quicker visual inspection in comparison to slicewise navigation, while the rotation gives depth cues to the viewer. Of the vessel network within the VOI, however, not all vessels are connected to the selected tumor, and it is tedious to sort out which adjacent vessels are in fact connected and which are overlaid only by projection. Therefore we suggest a simple transformation of the original image values into connectivity values. In the derived connectedness-image each voxel value corresponds to the lowest image value encountered on the highest possible pathway from the tumor to the voxel. The advantage of the visualization is that no implicit binary decision is made whether a certain vessel is connected to the tumor or not, but rather the degree of connectedness is visualized as the brightness of the vessel. Non-connected structures disappear, feebly connected structures appear faint, and strongly connected structures remain in their original brightness. The visualization does not depend

on delicate threshold values. Promising results have been achieved for pulmonary nodules in CT.

6916-72, Poster Session

Combined registration of 3D tibia and femur implant models in 3D magnetic resonance images

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The most frequent reasons for revision of total knee arthroplasty are loosening and abnormal axial alignment leading to an unphysiological kinematic of the knee implant. To get an idea about the postoperative kinematic of the implant, it is essential to determine the position and orientation of the tibial and femoral prosthesis.

Therefore we developed a registration method for fitting 3D CAD-models of knee joint prostheses into an 3D MR image. This rigid registration is the basis for a quantitative analysis of the kinematics of knee implants.

Firstly the surface data of the prosthesis model are converted into a voxel representation; a recursive algorithm determines all boundary voxels of the original triangular surface data.

Secondly an initial preconfiguration of the implants by the user is still necessary for the following step: The user has to perform a rough preconfiguration of both remaining prostheses models, so that the fine matching process gets a reasonable starting point.

After that an automated gradient-based fine matching process determines the best absolute position and orientation: This iterative process changes all 6 parameters (3 rotational- and 3 translational parameters) of a model by a minimal amount until a maximum value of the matching function is reached.

To examine the spread of the final solutions of the registration, the interobserver variability was measured in a group of testers. This variability, calculated by the relative standard deviation, improved from about 50% (pure manual registration) to 0.5% (rough manual preconfiguration and subsequent fine registration with the automatic fine matching process).

6916-73, Poster Session

Comparative evaluation of physicians' pulmonary nodule detection with reduced slice thickness at CT screening

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With thin and thick section Multi-slice CT images at lung cancer screening, we have statistically and quantitatively shown and evaluated the diagnostic capabilities of these slice thicknesses on physicians' pulmonary nodule diagnosis. To comparatively evaluate the 2 mm and 10 mm slice thicknesses, MSCT images of 360 people were read by six physicians. The reading criteria consisted of nodule for further examination (NFE), nodule for no further examination (NNFE) and no abnormality (NA) case. For reading results evaluation; firstly, cross-tabulation was carried out to roughly analyze the diagnoses based on whole lung field and each lung lobes. Secondly, from semi-automated extraction result of the nodule, detailed quantitative analysis was carried out to determine the diagnostic capabilities of two slice thicknesses. Finally, using the reading results of 2 mm thick image as the gold standard, the diagnostic capabilities were analyzed through the features and locations of pulmonary nodules. The study revealed that both slice thicknesses can depict lung cancer. Thin section may not be effective to diagnose nodules of ≤ 3 mm in size and nodules of ≤ 5 mm in size for thick section. Though thick section is less tiring for reading physicians, it is not good at depicting nodules located at the border of lung upper lobe and which have a pixel size distance of ≤ 5 from the chest wall. The information presented may serve as a useful reference to determine in which particular pulmonary nodule condition the two slice thicknesses can be effectively used for early detection of lung cancer.

6916-74, Poster Session

Evaluation of airway measurements in phantom parenchyma and soft tissue regions

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The purpose of this work was to develop a 3D airway measurement technique that can be initialized at a single point (either automatically or user defined) and to evaluate the performance of the method with varying imaging parameters as well as in parenchyma and soft tissue regions. This approach may have advantages over existing methods that require segmentation of the entire airway branch. METHODS: Rays are cast spherically from the initial measurement point and a range image is created of the distance to the edge of the airway lumen. The trajectory of the airway is estimated from the range image, and can be used to re-construct a 2D slice perpendicular to the airway for cross-sectional measurements. The evaluation phantom consisted of 5 tubes (3.18 to 19.05 mm in diameter and 1.59 to 3.18 mm in wall thickness) embedded in simulated lung parenchyma and soft tissue. Images were acquired at 10 and 100 mAs at three tube orientations and were reconstructed at 0.6 and 1.5 mm slice thicknesses with both smooth and standard reconstruction kernels. RESULTS: The overall diameter and wall thickness accuracy was 0.43 ± 0.19 mm and 0.28 ± 0.15 mm respectively in parenchyma regions and 0.46 ± 0.16 mm 0.49 ± 0.40 mm respectively in the soft tissue regions. The overall accuracy of the trajectory estimate was $0.64 \pm 0.51^\circ$. The proposed technique may allow a potentially larger number of airways to be measured for research and clinical analysis than with current methods.

6916-75, Poster Session

The relation of airway size to lung function

J. K. Leader, B. Zheng, C. R. Fuhrman, F. C. Sciruba, S. C. Park, J. Pu, J. M. Bon, W. Laboon, D. Gur, Univ. of Pittsburgh

Chronic obstructive pulmonary disease may cause airway remodeling, and small airways are the mostly likely site of associated airway flow obstruction. Detecting and quantifying airways of in typical computed tomography (CT) images is limited by spatial resolution. In this study, we examined the association between lung function and airway size. CT examinations and spirometry measurement of forced expiratory volume in one second as a percent predicted (FEV1%) from 240 subjects were used in this study. Airway sections depicted on axial CT images were automatically detected and quantified. Pearson correlation coefficients (PCC) were computed to compare lung function across three size categories: (1) all detected airways, (2) the smallest 50% of detected airways, and (3) the largest 50% of detected airways using the CORANOVA test. The mean number of all airways detected per subject was 117.4 (± 40.1) with mean size ranging from 20.2 to 50.0 mm². The correlation between lung function (i.e., FEV1) and airway morphometry associated with airway remodeling and airflow obstruction (i.e., lumen perimeter and wall area as a percent of total airway area) was significantly stronger for smaller airways ($p < 0.05$). The PCCs between FEV1 and all airways, the smallest 50%, and the largest 50% were 0.519, 0.617, 0.523, respectively, for lumen perimeter and 0.560, 0.584, and 0.514, respectively, for wall area percent. In conclusion, analyzing a set of smaller airways compared to larger airways may improve detection of an association between lung function and airway morphology change.

6916-76, Poster Session

Intramyocardial capillary blood volume estimated by whole body CT: validation by micro-CT

Y. Dong, P. E. Beighley, D. R. Eaker, E. L. Ritman, Mayo Clinic College of Medicine

Background: Fast CT has shown that myocardial perfusion (F) is related to myocardial intramuscular blood volume (Bv) as $Bv = AF + BF^{1/2}$. The goal of this study was to estimate the diameter of AF volume that intravascular components occupied.

Methods: Pigs were placed in an EBCT scanner for a perfusion CT scan sequence over 40 seconds after an IV contrast agent injection.

Intramyocardial blood volume (Bv) and flow (F) were calculated from indicator dilution curves generated from Regions-of-Interest in the LAD-perfused myocardium and LV chamber. Coefficients A and B were estimated over the range of $F=1-5$ ml/g/min. After the CT scan, the LAD was injected with Microfil® contrast agent following which the myocardium was scanned by micro-CT at 20 μ m, 4 μ m and 2.5 μ m cubic voxel resolutions. The Bv of the intramyocardial vessels was calculated for each diameter range (which $d=0-5, 5-10, 10-15, 15-20\mu$ m, etc).

Results: EBCT-derived data was presented as $[A^*F/(A^*F+B^*F^{1/2})]$ so that it could be directly compared the micro-CT value of Bv ($0-d/\Sigma Bv (0-D)$), where $d < D$, D is largest diameter vessel. Micro-CT indicated that the blood in vessels less the 10 μ m in diameter occupied 0.27-0.42, which is in good agreement with EBCT values 0.28-0.48 ($R^2 = 0.96$).

Conclusions: Whole body CT image data obtained during the passage of a bolus of IV contrast agent can provide a measure of the intramyocardial intracapillary blood volume.

6916-77, Poster Session

Validation of semi-automatic segmentation of the left atrium

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Circumferential ablation therapy has become increasingly popular for the treatment of left atrial fibrillation. The effect of this treatment on left atrial morphology, however, is currently not well understood. Initial studies have indicated a decrease in left atrial size with a concomitant decrease in pulmonary vein diameter. In order to effectively study if catheter based therapies affect left atrial geometry, robust segmentations with minimal user interaction are required. In this work, we validate a method to semi-automatically segment the left atrium from computed-tomography scans. The first step of the technique utilizes seeded region growing to extract the entire blood pool including the four chambers of the heart, the pulmonary veins, aorta, superior vena cava, inferior vena cava, and other surrounding structures. Next, the left atrium and pulmonary veins are separated from the rest of the blood pool using an algorithm that searches for thin connections between user defined points in the volumetric data or on a surface rendering. Finally, pulmonary veins are separated from the left atrium using a three dimensional tracing tool. A single user segmented three datasets using both the semi-automatic technique as well as manual tracing. The user interaction time for the semi-automatic technique was approximately 45 minutes per dataset and the manual tracking required approximately four hours per dataset. Several metrics were computed to assess the agreement between the semi-automatic technique and the manual tracing. Overall, the results of the semi-automatic approach were in agreement with those obtained using manual tracing. We are currently working to evaluate inter and intra-rater agreement for both the semi-automatic approach and manual tracing. In addition to validation of our proposed semi-automatic technique, the manual tracing results can serve as a baseline for other left atrial segmentation methodologies.

6916-78, Poster Session

3D segmentation and quantitative analysis of inner and outer walls of thrombotic abdominal aortic aneurysms

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An abdominal aortic aneurysm (AAA) is an area of a localized widening of the abdominal aorta, with a frequent presence of thrombus within the lumen. A ruptured aneurysm can cause death due to severe internal bleeding. Every year, approximately 200,000 people are diagnosed as suffering from AAA in the United States alone, 15,000 of which may have a risk of death from a ruptured aneurysm if not appropriately treated. AAA vessel and thrombus segmentation and its quantitative analysis are of paramount importance for diagnosis, risk assessment, and determination of treatment options. Until now, only a small number of methods for thrombus segmentation and its analysis appeared in the literature. For example, 2-D active shape models (ASMs) were developed offering sufficient accuracy. However, substantial user intervention is

required for slice-by-slice control. While ASMs based on 3-D level-sets promised a decrease in user interaction, the accuracy of the reported segmentation results was inferior. Clearly, a new method offering minimal user interaction and high accuracy is required for thrombus segmentation to become universally adopted. Our thrombus segmentation method is composed of 4 main steps: aortic centerline detection, luminal inner contour segmentation, thrombus outer contour segmentation, and vessel/thrombus morphology analysis. Our segmentation utilizes the power and flexibility of optimal 3-D graph search method in which cost functions for thrombus inner and outer surfaces are based on gradient magnitudes and - for the outer thrombus surfaces, utilize the a priori knowledge about approximately elliptical cross-sectional shape. Quantitative analysis of thrombotic AAAs includes the local cross-sectional areas, thrombus thickness, thrombus volume, vessel curvature index, and lumen/thrombus eccentricity.

6916-79, Poster Session

Assessing influence of conductivity in heart modelling with the aim of studying cardiovascular diseases

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The monodomain method has been widely used to model the electrical activity in cardiac tissue over the past years. Here we present a sensitivity study of a mandatory parameter in the bidomain model, the tissue conductivity, with the aim of measuring to what extent outcomes of a cardiac electrical simulation can be altered. This study is necessary since there is no general agreement on the actual values that should be employed, mainly due to inconsistencies between the few sources of empirical information existent in the literature. Furthermore, obtaining a good estimation of this parameter from either imaging techniques or from empirical measurements on isolated cardiac tissue have proved to be not accurate enough. For this study a 3D biventricular model built from Multi-Detector Computer Tomography has been used where the most relevant electrical structures, as myocardial fiber orientation or Purkinje fiber system, are included. Specific ionic models for normal myocardium and for Purkinje system are taken into account. Finite Element methods are used to solve monodomain equation for a number of different conductivity settings. Comparative results using isochronal maps will be shown in combination with statistical test to measure changes in the sequence of electrical activation in the myocardium, conduction velocities or local activation times (LAT).

6916-80, Poster Session

Measurement of myocardial oxygen consumption with PET-CT using C-11 acetate

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Data were reconstructed with filtered back projection. Semi-automatic ROI were drawn on myocardial walls and LV blood pool and MVO2 parameters (k_1 , k_2) were calculated using 2 compartment kinetic model after metabolic correction.

6916-81, Poster Session

Cone beam CT tumor vasculature dynamic study (murine model)

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Tumor angiogenesis is the process by which new blood vessels are formed from the existing vessels in a tumor to promote tumor growth. Tumor angiogenesis has important implications in the diagnosis and treatment of various solid tumors. In addition, identifying vasculature associated with solid masses and its fluid dynamics are an important indicator of malignant versus benign tumors. Flat panel detector-based

cone beam CT opens up a new way for detection of tumors, and tumor angiogenesis associated with functional CBCT has the potential to provide more information than traditional functional CT due to its greater overall coverage of the volume of interest during the same scanning period and its isotropic high spatial resolution reconstruction resulting in a more accurate 3D volume intensity measurement. A functional study was conducted by using CBCT to determine the degree of the enhancement within the tumor after injecting the contrast agent intravenously. For typical doses of contrast material, the amount of enhancement is proportional to the concentration of this material within the region of interest and the time lapse from contrast injection. A series of images obtained at one location over time allows generation of time-attenuation data from which a number of semi-quantitative parameters, such as enhancement rate, can be determined. An in vivo mouse study was conducted on our prototype CBCT system, and a half scan reconstruction scheme was used to determine the time-intensity curve within the ROI of the mouse tumor. The mouse was implanted with murine breast tumor cells (MCA-4) which were allowed to grow.

6916-38, Session 8

Serial volumetric registration of pulmonary CT studies

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Detailed morphological analysis of pulmonary structures and tissue provided by modern CT scanners is of utmost importance for example in oncological applications both for diagnosis and follow-up. In this case, a patient may go through several tomographic studies along a period of time building up volumetric sets of image data that must be appropriately co-registered in order to be able to track suspicious radiological findings.

The structures or regions of interest may change their position or shape in CT exams acquired at different moments, due to postural, physiologic or pathologic changes, so, the exams should be registered before any follow-up information can be extracted. Postural mismatch along time is practically impossible to avoid when imaging is performed at the limiting spatial resolution.

In this work, we propose a new method for intra-patient registration of pulmonary CT studies, to assist in the management of the oncological pathology. Our method takes advantage of prior segmentation work. In a first step, the pulmonary segmentation is performed and trachea and main bronchi are identified. Then the registration method proceeds with a longitudinal alignment based on lungs morphological features such as the carina position, the pulmonary areas, the centers of mass and the pulmonary transaxial principal axis. The final step corresponds to the transaxial co-registration of the corresponding pulmonary region masks following an iterative optimal search of the affine transformation parameters in order to optimize the similarity metric.

Results with several cases of intra-patient, intra-modality registration along up to 7 time points show this method provides accurate co-registration which is needed for quantitative tracking of lesions and the development of image fusion strategies that may effectively assist the follow-up process.

6916-39, Session 8

Pulmonary artery segmentation and quantification in sickle cell associated pulmonary hypertension

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Pulmonary arterial hypertension is a known complication associated with sickle-cell disease; roughly 75% of sickle cell disease-afflicted patients have pulmonary arterial hypertension at the time of death. This prospective study investigates if a size change in the pulmonary arteries of sickle cell patients could be linked to sickle-cell associated pulmonary hypertension. Pulmonary CT-Angio scans from sickle-cell patients were obtained. Pulmonary CT-Angio studies from patients without sickle-cell anemia were used as negative controls.

First, images were smoothed using anisotropic diffusion. Then, a combination of fast marching and geodesic active contours level sets

were employed to segment the pulmonary artery. An algorithm based on fast marching methods was used to compute the centerline of the segmented arteries. From the centerline, the diameters at the pulmonary trunk and first branch of the pulmonary arteries were measured automatically. Arterial diameters were normalized to the width of the thoracic cavity, patient weight and body surface. Results show that the pulmonary trunk and first right and left pulmonary arterial branches at the pulmonary trunk junction are significantly larger in diameter with increased blood flow in sickle-cell anemia patients as compared to controls (p values of 0.0278 for trunk and 0.0007 for branches). CT with image processing show great potential as a surrogate indicator of pulmonary hemodynamics or response to therapy, which could be an important tool for drug discovery and noninvasive clinical surveillance.

6916-40, Session 8

Active contour approach for accurate quantitative airway analysis

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Chronic airway diseases can cause structural changes in the lungs such as peribronchial thickening and airway dilatation. Multi-detector computed tomography (CT) of the lungs is capable of obtaining detailed near-isotropic images, allowing physicians to diagnose and locate airway abnormalities, adapt treatment, and monitor progress over time. High resolution images promise the ability to obtain quantitative measurements of lumen diameter and airway wall thickness, which would allow standardized assessment. However, due to the sheer number of airways per patient, systematic analysis is infeasible in routine clinical practice without automation. We have developed an automated and real-time method based on active contours to estimate both airway lumen and wall dimensions; the method does not require manual contour initialization but only a starting point on the targeted airway. While the lumen contour segmentation is purely region-based, the estimation of the outer diameter considers the inner wall segmentation as well as local intensity variation in order to anticipate the presence of nearby arteries and exclude them. These properties make the method more robust than the Full-Width Half Maximum (FWHM) approach. Results are demonstrated on a phantom dataset with known dimensions and on a human dataset where the automated measurements are compared with those from two human operators. The average error on the phantom measurements was 0.10mm and 0.14mm for inner and outer diameters, showing sub-voxel accuracy. Similarly, the mean variation from the average manual measurement was 0.14mm and 0.18mm for inner and outer diameters respectively.

6916-41, Session 8

Processing and analysis of CT images for diffuse lung disease in the lung tissue research consortium

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The goal of Lung Tissue Resource Consortium (LTRC) is to improve the management of diffuse lung diseases through a better understanding of the biology of Chronic Obstructive Pulmonary Disease (COPD) and Idiopathic Pulmonary Fibrosis (IPF). Participants are subjected to a battery of tests including tissue biopsies, physiologic testing, clinical history examination, and CT scanning. In addition to the test results, individual investigators can request supplemental data such as radiology reports, pathology reports, and automated image analysis results from the CT data. The LTRC Radiology Core Laboratory (RCL) has developed processing methods to quantify how these diseases manifest in radiographic images. The RCL has implemented a semi-automated method for segmenting the anatomical regions of the lung and airways including the right and left lung, lung lobes, the central and peripheral regions, and the trachea and bronchi. Emphysema volumes are computed using a threshold, and tissue classification is performed to the extent of normal lung, ground glass opacities, "honeycombing" (HC) and "irregular linear" or "reticular" pulmonary infiltrates. Wall thickness measurements of the trachea are also computed. The methods for processing are described. The data is reviewed by an expert radiologist following

processing. To date, over 900 cases have been processed. Analyses are underway to look at the clinical and physiological significance of the imaging features of these diseases. In the future, the quantitative image measures will be correlated to biopsy results to determine if these measurements might be an effective prognostic indicator, or for monitoring of disease progression or response to therapy.

6916-42, Session 8

The influence of reconstruction algorithm on the measurement of airway dimensions using computed tomography

J. C. Wong, James Hogg iCapture Ctr. (Canada); Y. Nakano, Shiga Univ. of Medical Science (Japan) and James Hogg iCapture Ctr. (Canada); H. O. Coxson, N. L. Müller, Vancouver General Hospital (Canada); P. D. Paré, J. C. Hogg, James Hogg iCapture Ctr. (Canada)

The assessment of airway dimensions is important in understanding the pathophysiology of various lung diseases. A number of methods have been developed to measure airways on computed tomography, but no study has been done to validate the different CT scanning techniques, CT scanners, and reconstruction algorithms. In our study, we constructed an artificial "airway" and "lung" phantom using hollow plastic tubes and foam blocks. The phantom was CT scanned using axial or helical techniques, and the images were reconstructed using a very high spatial frequency algorithm, a high spatial frequency algorithm, or a low spatial frequency algorithm. Custom software was then used to analyze the "airways" and measure lumen area (Ai) and "airway" wall area (Aaw). WA% ($WA\% = 100 \times Aaw / (Ai + Aaw)$) was also calculated. The cross-sectional area of the lumen and wall of the plastic tubes were measured using an optical micrometer. CT measurements of airway dimensions were virtually identical, comparing axial and helical techniques, and comparing a single-slice CT scanner to a multi-slice CT scanner. Using the plastic tube measurements as a "gold standard", Ai was estimated better with the very high or high special frequency algorithm (4.1 and 7.4 % error) vs. low special frequency algorithm (10.4% error), Aaw better with the low or high special frequency algorithm (3.8% and 6.1%) vs. very high spatial frequency algorithm (12.9%), and WA% better with the high or low spatial frequency algorithm (3.5% and 5.1%) vs. very high spatial frequency algorithm (7.3%). Based on these results, we recommend the high spatial frequency algorithm for the CT measurement of airway dimensions.

6916-43, Session 9

Hip fracture risk estimation based on bone mineral density of a biomechanically-guided region of interest: a preliminary study

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We aim to define a biomechanically-guided region of interest inside the proximal femur for improving fracture risk prediction based on bone density measurements. The central hypothesis is that by identifying and focusing on the proximal femoral tissues strongly associated with hip fracture risk, we can provide a better densitometric evaluation of fracture risk compared to current evaluations based on anatomically defined regions of interest using DXA or CT. To achieve this, we have constructed a hip statistical atlas of quantitative computed tomography (QCT) images by applying rigid and non-rigid inter-subject image registration to transform hip QCT scans of 15 fractured patients and 15 controls into a common reference space, and performed voxel-by-voxel t-tests between the two groups to identify bone tissues that showed the strongest relevance to hip fracture. Based on identification of this fracture-relevant tissue volume, we have generated a biomechanically-guided region of interest (B-ROI). We have applied BMD measured from this new region of interest to discriminate the fractured patients and controls, and compared it to BMD measured in the total proximal femur. For the femur ROI approach, the BMD values of the fractured patients and the controls had an overlap of 60 mg/cm³, and only 1 out of 15 fractured patients had BMD below the overlap region; for the B-ROI approach, a much narrower BMD overlap region of 28 mg/cm³ was observed, and 11 out of 15 fractured patients had BMDs below the overlap region.

6916-44, Session 9

Determination of the local strains involved in microdamage formation in a three-point bending test of single trabeculae

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As previously reported whitening of bone, undergoing deformation, is linked to microscopical damage. This enables a direct quantitative observation of microdamage formation in video footage captured during micro-mechanical tests. In the presented study we tested single trabeculae from a bovine femur in a three-point-bending geometry and captured video footage of these tests. Whitening was detected in the form of an ellipsoid zone on the tension side on tested trabeculae. Upon formation of a macro-crack, the whitening faded and a whitened zone following the propagating crack tip was seen. Applying the gold standard for microdamage detection, fluorescence labeling and histology, we demonstrate here that whitening is indeed highly correlated to microdamage and that the size of cracks range from sub-micron to the micron range. Given this piece of information, we analyzed the local strains involved in the formation of microdamage. For this purpose we patterned the single trabecula samples with small ink-marks and applied a customized digital image correlation technique on the captured video footage to obtain the local surface strains (2D) involved in microdamage formation. Results indicated that the tensile strain along the long axis of the trabecula correlated best with the whitening zones. Whitening, and thus microdamage, initiated around a local tensile strain of 2.1%, whereas initiation of a macro-crack leading failure occurred at strains of around 16%. Our results allow for the first time to correlate microdamage and local strains directly, which is an important step for the further development of damage predicting bone failure behavior.

6916-45, Session 9

Improved 3D skeletonization of trabecular bone images derived from in vivo MRI

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Independent of overall bone density, 3D trabecular bone (TB) architecture has been shown to play an important role in conferring strength to the skeleton. Advances in imaging technologies such as micro-computed tomography (CT) and micro-magnetic resonance (MR) now permit in vivo imaging of the 3D trabecular network in the distal extremities. However, various experimental factors preclude a straightforward analysis of the 3D trabecular structure on the basis of these in vivo images. For MRI, these factors include blurring due to patient motion, partial volume effects, and measurement noise. While a variety of techniques have been developed to deal with the problem of patient motion, the second and third issues are inherent limitations of the modality. To address these issues, we have developed a series of robust processing steps to be applied to a 3D MR image and leading to a 3D skeleton that accurately represents the trabecular bone structure. Here we describe the algorithm, provide illustrations of its use with both specimen and in vivo micro-MR images, and discuss the accuracy and quantify the relationship between the original bone structure and the resulting 3D skeleton volume.

6916-46, Session 9

Synchrotron radiation micro- and nano-CT methods for 3D quantitative assessment of mechanical relevant ultrastructural properties in murine bone

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Age-related and osteoporotic bone fractures have a devastating effect on morbidity and mortality. Therefore, the study of bone mechanical properties is of vital importance for a better understanding of bone function. It was shown that bone strength is determined not only by bone mass but also bone structure and genetic predisposition. Moreover,

recent results show that ultrastructural bone tissue properties can be linked directly to measures of bone tissue quality and with that, to bone mechanics. For these purposes, we developed different synchrotron radiation (SR)-based micro- and nano-computed tomography (μ CT and nCT) methods, which allowed for the first time to assess ultrastructural bone phenotypes, namely the cannular and cellular network as well as microcracks in unprecedented resolution. Using these μ CT and nCT methods, we studied these phenotypes in murine bone in the light of their genetic predisposition, their interaction with growth hormone as well as their relevance for bone function. These investigations provided particularly strong evidence for a significant influence of the ultrastructural phenotypes on murine bone mechanics. This is for the first time that cannular, cellular, and micromechanical features can be assessed in a truly 3D and non-destructive fashion, allowing also time-lapsed imaging of fracture initiation and propagation. We believe that the assessment of ultrastructural bone phenotypes, in conjunction with bone mechanics, will provide new insights in the assessment of bone quality. We hypothesize that the prediction of bone mechanics can be improved in certain diseases and genetic predispositions by including ultrastructural bone tissue properties accessible using SR μ CT and nCT methods.

6916-47, Session 9

High resolution x-ray imaging of dynamic solute transport in cyclically deformed porous tissue scaffolds

J. Op Den Buijs, K. Lee, S. M. Jorgensen, E. L. Ritman, S. Wang, M. J. Yaszemski, Mayo Clinic College of Medicine

The objective was to develop a method for high-resolution imaging of dynamic solute transport in cyclically deforming porous scaffolds for tissue engineering applications. A biodegradable flexible cubic scaffold with single cylindrical channel was made using a combined 3D printing and injection molding technique. The scaffold was attached to the bottom of a fluid reservoir mounted underneath a compression apparatus placed inside the X-ray scanner. The scaffold was positioned with the channel axis perpendicular to the X-ray beam. The container was filled with glycerin, and a solution of the contrast agent sodium iodide (NaI) in glycerin was injected into the scaffold channel. Intervals of compression cycles ($14.5 \pm 2.1\%$ compression at 1.0 Hz) were applied to the top face of the scaffold. After each interval the compression was temporarily paused to obtain a two-dimensional image at 20 $11/4\text{m}$ pixel resolution. A series of images was also obtained without application of the compression cycles to quantify the effect of passive diffusional removal of NaI from the channel. The average NaI concentration in the channel decreased by 82% after 300 cycles (5 min.) of compression, vs. 40% after 60 min. of passive removal. Spatial profiles of the NaI concentration along the channel axis indicated that compression-induced transport preferentially removed the contrast agent at the pore openings. We conclude that convective transport induced by cyclic mechanical deformation of artificial tissue scaffolds could significantly contribute to the rate and depth of nutrient transport inside the scaffold, as compared to slow diffusive transport alone.

6916-48, Session 10

Combination of model-free and model-based analysis of dynamic contrast enhanced MRI for breast cancer diagnosis

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Dynamic contrast enhancement (DCE) is the leading technique in magnetic resonance imaging for cancer detection and diagnosis. However, there are large variations in the reported sensitivity and specificity of this method that result from the wide range of contrast-enhanced MRI sequences and protocols, image processing methods, and interpretation criteria. Analysis methods can be divided to physiological based models that take into account the vascular and tissue specific features that influence tracer perfusion, and to model free algorithms that decompose enhancement patterns in order to segment and classify different tissue types. Inhere we present a general hybrid method for

analyzing dynamic contrast enhanced images integrating a mathematical, model-free technique with a model derived approach that characterizes tissue microvasculature function. We demonstrate the application of the method for breast cancer diagnosis. A brief description of this approach was recently presented for the diagnosis of prostate cancer. The model free method employed principle component analysis and yielded eigen-vectors of which two were relevant for characterizing breast malignancy. The physiological relevance of the two eigen-vectors was revealed by a quantitative correlation with the model based three time point technique. Projection maps of the eigen-vector that specifically related to the wash-out rate of the contrast agent depicted with high accuracy breast cancer. Overall, this hybrid method is fast, standardized, and yields parametric images characterizing tissue microvascular function. It can improve breast cancer detection and potentially be extended as a computer aided tool for the detection and diagnosis of other cancers.

6916-49, Session 10

An iterative hyperelastic behavior reconstruction for breast cancer assessment

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In breast elastography, breast tissues undergo large compression resulting in significant geometric and structural changes. Such changes lead to significant nonlinear mechanical behavior of the tissue. In this study, an elastography technique is presented where parameters characterizing tissue nonlinear behavior are reconstructed. While such parameters pertaining to tumors can be used for tumor tissue classification necessary for cancer diagnosis, the normal tissue parameters can be used for Finite Element (FE) tissue simulation of clinical procedures such as surgery and needle biopsy. To model the nonlinear behavior, tissues are treated as hyperelastic materials where both material intrinsic nonlinearity and geometric nonlinearity are taken into account. The proposed reconstruction technique uses a constrained iterative inversion method to reconstruct the tissue hyperelastic parameters. Each iteration involves stress calculation followed by hyperelastic parameter updating based on the measured tissue displacement data. For stress calculation, we use a nonlinear FE model. In this research, we applied Yeoh model and second order polynomial model to model the tissue hyperelasticity. In each iteration, a system of ill-conditioned linear system was obtained for parameter updating. To solve this system, we used regularization techniques. To mimic the breast geometry, we used a computational 3D phantom, which comprises of a hemisphere connected to a cylinder. This phantom consists of two types of hyperelastic tissues to mimic adipose and fibroglandular tissues, and a hyperelastic tumor embedded in the fibroglandular tissue. Simulation results show the feasibility of the proposed method in reconstructing the hyperelastic parameters of the tumor tissue with high accuracy.

6916-50, Session 10

Parametric dynamic F-18-FDG PET/CT breast imaging

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This study was undertaken to estimate metabolic tissue properties from dynamic breast F-18-FDG PET/CT image series and to display them as 3D parametric images. Nonlinear curve fitting of activity vs. time based on a realistic two-compartment model was performed for each voxel of the volume. We evaluated which parameters are most suitable to determine the spatial extent and malignancy in suspicious lesions. Dynamic PET studies were performed, each consisting of 50 frames of 1 minute duration. Each consecutive PET image was nonrigidly registered to the first frame using a finite element method (FEM) based model and fiducial skin markers. Curve fitting was accomplished by application of the Levenburg-Marquardt algorithm (LMA) that minimized Chi-squared or maximized the correlation coefficient (R-squared). After implementing LMA, the parameter space was systematically searched to check whether a better fit existed. We established that, especially for breast tissue regions with moderate or low F-18-FDG uptake, a better fit frequently existed. The best-fit parameters, used to create 3D parametric images, included cumulated activity, time-to-maximum activity, maximum activity,

maximum uptake slope, maximum washout slope, Chi-squared, and R2 distribution. We conclude that nonrigid registration followed by voxel-by-voxel based nonlinear fitting to a realistic two-compartment model yields better quality parametric images, as compared to unprocessed dynamic breast PET time series. The maximum uptake slope and the time-to-maximum activity parametric images provide the best delineation of suspicious breast tissue lesions and hyperactive subregions within the lesion that cannot be discerned in unprocessed images.

6916-51, Session 10

Combined thermal-elastic modeling of the normal and tumorous breast

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The abnormal thermogram has been shown to be a reliable indicator of a high risk of breast cancer, but an open question is how to quantify the complex relationships between the breast thermal behaviors and the underlying physiological/pathological conditions. Previous thermal modeling techniques generally did not utilize the breast geometry determined by the gravity-induced elastic deformations arising from various body postures. In this paper, a 3-D finite-element method is developed for combined modeling of the thermal and elastic properties of the breast, including the mechanical nonlinearity associated with large deformations. The effects of the thermal and elastic properties of the breast tissues are investigated quantitatively. For the normal breast in a standing/sitting up posture, the gravity-induced deformation alone is found to be able to cause an asymmetric temperature distribution even though all the thermal/elastic properties are symmetrical, and this temperature asymmetry increases for softer and more compressible breast tissues. For a tumorous breast, we found that the surface-temperature alterations generally can be recognizable for superficial tumors at depths less than 20 mm. Tumor size plays a less important role than the tumor depth in determining the tumor-induced temperature difference. This result may imply that a higher thermal sensitivity is critical for a breast thermogram system when deeper tumors are present, even if the tumor is relatively large. We expect this new method to provide a stronger foundation for, and greater specificity and precision in, thermographic diagnosis, and treatment, of breast tumors.

6916-52, Session 10

Utilization of mammographic complexity for improving risk assessment and cancer detection

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Currently, breast cancer screening protocols are based on a woman's age, but not on other risk factors or on the physical characteristics of her breasts. One commonly cited risk factor is dense breast tissue. This study is part of an effort to provide basic information needed to develop automatically, individualized screening protocols, by clarifying the relationships between age, risk, breast composition, lesion conspicuity, and other factors. In this project, a database was established that includes 227 cancer negative cases and 116 cancer positive cases across a wide range of age groups. In the cancer positive cases, we included a subgroup in which the cancer had been missed in the previous exam. Using our physics based model of breast density, we quantified percentage of breast parenchyma as an index of density. Density distributions and changes over time were analyzed. The most significant finding within this data was a significantly slower density decrease over the time in the cancer positive group than in the cancer negative group, with no overall difference in the density distribution in those two groups. False negative cases were found to be significantly more dense than true positive cases. In addition, our results showed a trend of density decrease with increasing age, which is in agreement with others' widely reported results.

6916-53, Session 11

Model-based segmentation and quantification of subcellular structures in 2D and 3D fluorescent microscopy images

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based approach for segmenting and quantifying GFP-tagged subcellular structures of the Golgi apparatus in 2D and 3D microscopy images. The approach is based on 2D and 3D intensity models, which are directly fitted to the image within 2D circular or 3D spherical regions-of-interest (ROIs). We also propose automatic approaches for the detection of candidates, for the initialization of the model parameters, and for adapting the size of the ROI used for model fitting. Based on the fitting results, we determine statistical information about the spatial distribution and the total amount of intensity (fluorescence) of the subcellular structures. We demonstrate the applicability of our new approach based on 2D and 3D microscopy images.

6916-54, Session 11

Automated analysis of siRNA screens of cells infected by hepatitis C and dengue viruses based on immunofluorescence microscopy images

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We present an image analysis approach as part of a high-throughput microscopy screening system based on cell arrays for the identification of cellular genes involved in Hepatitis C and Dengue virus replication.

Our approach comprises: cell nucleus segmentation, quantification of virus replication level in the neighborhood of segmented cell nuclei, localization of regions with transfected cells, cell classification by infection status, and quality assessment of an experiment and single images. In particular, we propose a novel approach for the localization of regions of transfected cells within cell array images, which combines model-based circle fitting and grid fitting. By this scheme we integrate information from single cell array images and knowledge from the complete cell arrays. The approach is fully automatic and has been successfully applied to a large number of cell array images from screening experiments. The experimental results show a good agreement with the expected behavior of positive as well as negative controls and encourage the application to screens from further high-throughput experiments.

6916-55, Session 11

Dynamic perfusion CT in the evaluation of distal small pulmonary emboli in an animal model

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This study investigates a novel perfusion-CT protocol and technique in accessing the functional impact of distal small pulmonary emboli. 5 Yorkshire swine underwent a new perfusion-CT protocol. Scans were performed pre&post injection of autologous clotted blood as the source of emboli. In the post emboli scans CT images were acquired at suspended end inspiration with 25 time intervals: baseline and 24 scans after bolus injection of 1ml/kg. From perfusion scans two radiologists visually identified 4 visible and non-visualized emboli whose peripheral regions appeared relatively poor perfusion. Then the arteries adjacent to the regions were evaluated. A region of interesting(ROI) was placed in the visually identified poor contrast zones and another in an adjacent region with good enhancement. The functional impact of embolism was characterized by contrast difference between the high and low perfusion ROIs. Perfusion curves were generated based on mean ROI intensity. Wash-in & wash-out enhancement were quantified for each ROI and compared between high and low perfusion ROIs to evaluate

this functional impact. For 4 identified emboli, all high perfusion ROIs demonstrated higher wash-in(83.7 ± 48.1 HU) and wash-out(56.2 ± 44.5 HU) enhancement than low perfusion ROIs. For non-visualized emboli, the perfusion curves for the identified low and apparent perfused regions have the same characteristics as observed in regions with visible emboli. Preliminary data shows perfusion-CT can analyze the perfusion characteristics in different lung regions; peripheral subsegmental emboli do have local effects on perfusion; even vessels in which no visible clot may still present perfusion abnormalities.

6916-56, Session 11

Whole mouse cryo-imaging

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The fluorescence/brightfield, whole mouse Case cryo-imaging system uniquely provides micron resolution and information-rich contrast mechanisms over very large 3D fields of view. The cryo-imaging system consists of a mouse-sized, motorized cryostat, brightfield/fluorescence microscope, and robotic xyz imaging system positioner, all of which are fully automated by a control system. By alternately sectioning and imaging the block face, the system acquires 3D, high-resolution anatomical color as well as cellular and molecular fluorescence images. Cryo-imaging is used in a variety of applications, including mouse and embryo anatomical phenotyping, drug delivery, imaging agents, metastatic cancer, and very high resolution vascular imaging, among many. The system detects fluorescent-reporter-gene labeled cells anywhere in the mouse. For example, in an LLC cell metastatic cancer model, we identified clusters of cells in the liver and adrenal gland. There were 3850 clusters in the adrenal gland, and a histogram of volumes had peaks at integer numbers of cells, indicating the ability to detect single cells. In other experiments, we are evaluating lead fluorescent compounds for imaging myelin in neurodegenerative disease. With 3D cryo-imaging, we can rapidly determine in vivo binding to structures such as corpus callosum and cerebellar myelene tracts, a task well beyond the resolution of in vivo imaging techniques. We believe that cryo-imaging fills the gap between whole animal in vivo imaging and histology, allowing one to image a mouse along the continuum from the mouse -> organ -> tissue structure -> cell -> sub-cellular domains. In this overview, we describe the technology and a variety of exciting applications.

6916-57, Session 11

In vivo and ex vivo imaging of alveolar structure and function using a custom fiber optic laser scanning confocal microscope

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Understanding the structure and function of alveoli in vivo is crucial for understanding the normal and diseased lung. The question of alveolar size and number change through the full breathing cycle remains very incomplete, yet is fundamental for understanding alveolar based diseases.

In this study we image the alveoli of mice in vivo, using a custom fiber optic catheter based laser scanning confocal microscope. The system incorporates a laser scanning system coupled to a 30,000 optic fiber imaging bundle. Using a combination of fluorescent markers including, Fluorescein, PKH26-PCL and Acridine Orange we visualize alveolar airspace, walls, collagen and elastin matrix, resident macrophages and nuclei. Fresh intact mouse lungs were also dynamically imaged ex vivo through a sequence of inspiration and expiration maneuvers and software was developed for automated measurement of alveolar size, wall thickness and alveolar number from the confocal images.

Results show that direct dynamic visualization of alveoli and surrounding structures is possible, with high resolution. Through a combination of fluorescent markers, alveolar walls, nuclei and macrophages are labeled and observed in vivo. The ex vivo data obtained from the fresh intact mouse lungs extends previous studies describing possible recruitment at high pressures, with direct dynamic visualization of the recruitment

and de-recruitment of alveoli in intact fresh mouse lungs. Using the techniques presented in this study there is great promise for advancing our knowledge of the functional unit of the lung, the alveoli; for alveolar mechanics, cell traffic and 3D structural visualization

6916-58, Session 11

Three-dimensional bioluminescent source reconstruction method based on nodes of adaptive FEM

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Small animal molecular imaging has been rapidly developed and applied to biomedical research in recent years. As a new optical molecular imaging modality, bioluminescence tomography (BLT) has become an effective approach for in vivo imaging because it not only can reveal non-invasive molecular and cellular activities directly, but also has high sensitivity and low cost in comparison with other imaging technologies. BLT is used to determine the bioluminescent source distribution inside a small animal or phantom with the boundary measured data. However, BLT is ill-posed for high scattering properties of the biological tissues and the limited boundary detection data. To assure the uniqueness of BLT, adequate a priori knowledge needs to be incorporated, such as optical parameters and anatomical structures of the tissues. Adaptive FEM based on the discretized elements has been introduced into BLT field recently, but the quickly increasing number of elements will reduce the source reconstruction effectiveness greatly along with mesh refinement. In this paper, a BLT reconstruction method based on nodes of adaptive FEM is developed for localizing and quantifying bioluminescent source to solve the above problem, which can improve localization of source and enhance the efficiency of reconstruction. Optical and anatomical information of the tissues are incorporated as a priori knowledge in this method which reduce the ill-posedness of BLT. The performance of this method is tested using homogeneous and heterogeneous mouse chest phantoms and Monte Carlo simulation data. The results show the effectiveness and merits of this approach for BLT.

6917-01, Session 1

An unexpected research career: How a short project became long (The annual Harold L. Kundel, MD, Honorary Lecture)

A. E. Burgess, Harvard Medical School (Retired)

I will describe my 30-year journey through the interesting world of human perceptual limitations when interpreting medical images. I expected a short journey. My earliest research was devoted to developing models for x-ray imaging system components to optimize neuroangiography. This led me to try to understand how to calculate SNR from a human point of view. As it turned out, it took me 5 years to understand how to do proper experiments and performance analysis. The journey consisted of 4 stages. First was muddling about doing mostly wrong things - investigating "bottom-up" models starting at the cornea while using subjective experimental methods. In 1979, I shifted to the "top-down" ideal observer approach to evaluate human performance with white noise images. Two people played important roles here, Horace Barlow and Bob Wagner. I also started using objective (MAFC) experimental methods. In the 1990s I began investigations using filtered noise images - motivated by related work of Jannick Rolland. Finally in 1998, with retirement approaching, I began to use realistic (hybrid) mammograms to investigate mass detection limited by patient structure. The goal was to finally do something that might contribute to understanding of a clinical problem. A number of people have influenced my work - Bob Wagner, Philip Judy, Kyle Myers, Harry Barrett and Craig Abbey to name a few. It has been an exciting 30 years for medical imaging in general. As for perception research, many bright young people have become interested and it will be fun to watch where they take the field.

6917-02, Session 1

Performance changes in lung nodule detection following perceptual feedback of eye movements

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In a previously reported study we demonstrated that expert performance can decline following perceptual feedback of eye movements in the relatively simple radiological task of wrist fracture detection (Donovan et al., 2005). This study was carried out to determine if the same effect could be observed using a more complicated radiological task of identifying lung nodules on chest radiographs. Four groups (n=10 in each group) of observers with different levels of expertise were tested. The groups were naïve observers, 1st year radiography students, 3rd year radiography students and experts. Feedback was presented to the observers in the form of their scan paths and fixations. Half the observers had feedback and half had no perceptual feedback. JAFROC analysis was used to measure observer performance. A repeated measures ANOVA was carried out. There was no significant effect between the pre and post no feedback condition. There was a significant difference between the pre and post feedback condition with a significant improvement following feedback ($F(1,16)=6.6, p=0.021$). Overall the mean percentage improvement was small of 3.3%, with most of the improvement due to the 1st year group where the percentage increase in the figure of merit (FOM) was 8.4% and this was significant ($p<0.05$).

Eye tracking metrics indicate that the expert and naïve observers were less affected by feedback or a second look whereas there were mixed results between the 1st and 3rd year students possibly reflecting the different search strategies used. Perceptual feedback may be beneficial for those early in their training.

6917-03, Session 1

How much agreement is there in the visual search strategy of experts reading mammograms?

C. Mello-Thoms, Univ. of Pittsburgh

We have shown that the eyes of expert breast imagers are attracted

to the location of a malignant mass in a mammogram in less than 2 seconds after image onset. Moreover, the longer they take to visually fixate the location of the mass, the less likely it is that they will report it. We conjectured that this behavior was due to the formation of the initial hypothesis about the image (i.e., 'normal' - no lesions to report, or 'abnormal' - possible lesions to report). This initial hypothesis is formed as a result of a difference template between the experts' expectations of the image and the actual image. Hence, when the image is displayed, the expert detects the areas that do not correspond to their 'a priori expectation', and these areas get assigned weights according to the magnitude of the perturbation. The radiologist then uses eye movements to guide the high resolution fovea to each of these locations, in order to resolve each perturbation. In order to accomplish this task the radiologist uses not only the local features in the area but also lateral comparisons with selected background locations, and this comprises the radiologist's visual search strategy. Eye-position tracking studies seem to suggest that no two radiologists search the breast parenchyma alike, which makes one wonder whether successful models can be developed that accurately reflect the way these experts search these images. In this study we show that there is more to the experts' search strategy than meets the eye.

6917-04, Session 2

Comprehensive evaluation of an image segmentation technique for measuring tumor volume from CT images

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Comprehensive quantitative evaluation of tumor segmentation technique on large scale clinical data sets is crucial for routine clinical use of CT based tumor volumetry. In this paper, we present a systematic validation study of a semi-automatic image segmentation technique for measuring tumor volume from CT images. The segmentation algorithm was tested using clinical data of 200 tumors in 107 patients with liver, lung, lymphoma and other types of cancer. The performance was evaluated using both accuracy and reproducibility. The accuracy was assessed using 7 commonly used metrics that can provide complementary information regarding the quality of the segmentation results. The reproducibility was measured by the variation of the volume measurements from 10 independent segmentations. The effect of disease type, lesion size and slice thickness of image data on the accuracy measures were also analyzed. Our results demonstrate that the tumor segmentation algorithm showed good correlation with ground truth for all four lesion types ($r=0.96, 0.99, 0.94, 0.98, p<0.0001$ for liver, lung, lymphoma and other respectively). The segmentation algorithm can produce relatively reproducible volume measurements on all lesion types (coefficient of variation in the range of 10-20%). Our results show that the algorithm is insensitive to lesion size (coefficient of determination close to 0). Slice thickness has little effect on the performance of the segmentation technique ($p>0.90$). The validation framework used in this paper has the potential to facilitate the development of new tumor segmentation algorithms and assist large scale evaluation of segmentation techniques for other clinical applications.

6917-05, Session 2

Performance study of a globally elastic locally rigid matching algorithm for follow-up chest CT

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A real-time matching algorithm for follow-up chest CT scans can

significantly reduce the workload on radiologists by automatically finding the corresponding location in the first or second scan, respectively. The objective of this study was to assess the accuracy of a fast and versatile single-point registration algorithm for thoracic CT scans.

The matching algorithm is based on automatic lung segmentations in both CT scans, individually for left and right lung. Whenever the user clicks on an arbitrary structure in the lung, the coarse position of the corresponding point in the other scan is identified by comparing the volume percentiles of the lungs. Then the position is refined by optimizing the gray value cross-correlation of a local volume of interest. The algorithm is able to register any structure in or near the lungs, but is of clinical interest mainly in particular with respect to lung nodules and airways.

For validation, CT scan pairs were used in which the patients were scanned twice in one session, using low-dose non-contrast-enhanced chest CT scans (0.75 mm collimation). Between these scans, patients got off and on the table to simulate a follow-up scan. 291 nodules were evaluated. Average nodule diameter was 9.5 mm (range 2.9 - 74.1 mm). Automatic registration succeeded in 95.2% of all cases (277 /291). In successful registered nodules, average registration consistency was 1.1 mm. The real-time matching proved to be an accurate and useful tool for radiologists evaluating follow-up chest CT scans to assess possible tumor growth.

6917-06, Session 2

PET/CT detectability and classification of simulated pulmonary lesions using an SUV correction scheme

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Positron emission tomography (PET) and computed tomography (CT) together are a powerful diagnostic tool, but imperfect image quality allows false positive and false negative diagnoses to be made by any observer despite experience and training. This work investigates PET acquisition mode, reconstruction method and a standard uptake value (SUV) correction scheme on the classification of lesions as benign or malignant in PET/CT images, in an anthropomorphic phantom. The scheme accounts for partial volume effect (PVE) and PET resolution. The observer draws a region of interest (ROI) around the lesion using the CT dataset. A simulated homogenous PET lesion of the same shape as the drawn ROI is blurred with the point spread function (PSF) of the PET scanner to estimate the PVE, providing a scaling factor to produce a corrected SUV. Computer simulations showed that the accuracy of the corrected PET values depends on variations in the CT-drawn boundary and the position of the lesion with respect to the PET image matrix, especially for smaller lesions. Correction accuracy was affected slightly by mismatch of the simulation PSF and the actual scanner PSF. The ROC study resulted in several observations. Using observer drawn ROIs, scaled tumor-background ratios (TBRs) more accurately represented actual TBRs than unscaled TBRs. For the PET images, 3D OSEM outperformed 2D OSEM, 3D OSEM outperformed 3D FBP, and 2D OSEM outperformed 2D FBP. The correction scheme significantly increased sensitivity and slightly increased accuracy for all acquisition and reconstruction modes at the cost of a small decrease in specificity.

6917-07, Session 2

Comparing signal-based and case-based methodologies for CAD assessment in a detection task

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We are investigating the potential for differences in CAD assessment study conclusions when the performance analysis is signal-based (derived from Free-response Receiver Operating Characteristics (FROC) analysis) versus case-based (derived from Receiver Operating Characteristics (ROC) analysis). To consider this question, we utilized reader data from a CAD assessment study based on 100 mammographic background images to which fixed size and fixed intensity Gaussian signals were added, generating a low and high intensity set. The study

thus allowed CAD assessment in two situations: when CAD sensitivity was 1) superior, or 2) equivalent or lower to the average reader. Seven readers participating in the study were asked to review each set using CAD in both second-reader and concurrent modes. Signal-based detection results were analyzed using the area under the FROC curve below 0.5 false positive per image. Case-based decision results were analyzed using the area under the parametric ROC curve. The results were consistent between the signal-based and case-based analyses for the low intensity set, suggesting that CAD in both reading modes can increase reader signal-based detection and case-based decision accuracies. For the high intensity set, the signal-based and case-based analysis suggested different conclusions regarding the utility of CAD, although neither analysis resulted in statistical significance. Further work is underway to better understand the relationships between assessment methodologies and the consistency of the conclusions derived from them.

6917-08, Session 2

Performance evaluation of image processing algorithms in digital mammography

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The purpose is to evaluate the performance of different image processing algorithms in terms of replication of microcalcification clusters in digital mammograms.

Clusters were simulated in "for processing" clinical images. Their positions were selected according to typical locations of breast cancers, while pasted in all types of background (from fatty to dense). The clusters were further characterized by size, contrast and type. The mammograms were selected out of our clinical routine cases and had been acquired with the Siemens Novation DR. The entire dataset consisted of 200 normal images. In half the number of normal images a total of 150 clusters was simulated; the remaining 100 normal images served as true negative input cases. Both abnormal (composite) and normal images were processed with 5 different image processing algorithms: Siemens OpView v1 and Siemens OpView v2, Agfa Musica1, Sectra Sigmoid and IMS Processing 1.2.

Five observers were asked to detect and score the cluster(s) in each image, by means of an in-house developed software tool. The evaluation time per image was recorded for each observer. Free-response receiver operating characteristic (FROC) curves and JAFROC analysis are applied to assess the image processing performance.

The evaluation of the data is on-going. This study is a first step towards a quantitative assessment of image processing in terms of clusters detection in clinical mammograms. Dedicated databases as explored in this study could be a useful tool for manufacturers in order to assess or optimize their algorithms for a clinically relevant task.

6917-09, Session 2

The use of Z3d software in breast MRI to improve sensitivity and specificity in the diagnosis of malignant neoplasms

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This study incorporates the use of z3D software for breast MRI interpretation. There are resultant statistically significant enhancements to image interpretation in terms of lesion detection, morphological feature visualization and kinetic analysis of enhancement characteristics. This retrospective study was drawn from the images generated by 133 breast MRI studies performed between October 2006 and June 2007 at our institution. 26 of these women subsequently underwent breast biopsy. The z3D software offered advanced capabilities in lesion morphological evaluation and a rendered 3-dimensional kinetic map of enhancement features. Also incorporated into the z3D software was BlinkRadiology imaging technology which rapidly alternated the pre and post enhanced images in a way which drew the interpreter's eye to enhancing lesions and therefore improves lesion detection, particularly in the 20-30% of studies which were hampered by motion artifacts. Twenty-four of the

26 (92%) of the breast MRI studies of the women who subsequently underwent biopsy were found to have had significant improvement in overall understanding of the disease process and efficiency in image interpretation using the z3D software. There was better visualization of washout in 20 women (77%), detection of differential areas of washout within individual lesions in 16 (62%), and improvement in lesion detection capabilities in 15 (58%).

6917-10, Session 3

A novel partial area index of receiver operating characteristic (ROC) analysis

T. Wu, H. Huang, G. Du, Siemens Ltd. (China); Y. Sun, Siemens Corporate Research

Appropriate validation of the segmentation algorithms is important for clinical acceptance of the methods. Receiver operating characteristic (ROC) analysis provides the most comprehensive description of the accuracy performance of image segmentation. Total area under an ROC curve (AUC) is widely used as an index of ROC analysis of performance test. However, a large part of the ROC curve is in the clinically irrelevant range, the total area can be misleading in some clinical situation. In this paper, we proposed a partial area index of ROC curves, which measures the segmentation performance in a clinically relevant range decided by learning from subjective ratings. The boundary of the range is defined by a linear cost function of false positive fraction (FPF) and true positive fraction (TPF). The cost factors of FPF and TPF are learned by maximizing the Kendall's coefficient of concordance (KCC) between the partial areas and the subjective ratings. Experiment results show that our method gives a large cost factor on FPF and a small cost factor on TPF on a tumor data set. This is consistent with the fact that a large FPF is generally more difficult to be accepted in tumor segmentation. Our method is able to determine the optimal range for partial area index of ROC analysis, and this partial area index is more appropriate than AUC for evaluation of segmentation performance.

6917-11, Session 3

Investigation of methods for analyzing location specific observer performance data

D. P. Chakraborty, H. Yoon, Univ. of Pittsburgh

We examined the statistical powers of three methods for analyzing FROC data, namely ROC, JAFROC and IDCA. Two classes of "observers" were simulated, (a) a CAD algorithm that reports, on the average, about 10 actually normal initial detections per image, and (b) a human observer who sees, on the average, about 1.3 actually normal suspicious regions per image but does not report all of them. The search model simulator allows specification of the average numbers of normal and abnormal suspicious regions per image and the fraction that are reported, the lesion signal-to-noise-ratio, and includes inter and intra-image correlations. Parameters were chosen to yield 80% and 85% areas under the search model predicted ROC curves corresponding to the two modalities, and 100 normal/abnormal images were considered. The maximal area under the FROC curve was used as the IDCA figure-of-merit. For condition (a) the statistical powers for IDCA, JAFROC and ROC were 87%, 71% and 37%, respectively. For condition (b) the corresponding values were 24%, 29% and 15%, respectively, however the power of JAFROC drops as the number of normal cases is reduced. The slightly superior performance of JAFROC for human observers is due to the relatively larger number of images with no marks, which information is not used in IDCA. We conclude that among the methods investigated, CAD data should be analyzed using IDCA, but JAFROC may be preferable for radiologist data provided the number of normal cases is not too small. The ROC method risks a substantial power penalty and is not recommended for localization studies.

6917-12, Session 3

Comparisons of two agreement measures

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Correlation and prediction accuracy are two measures of agreement for correlated/paired scores (ex. the scores from two doctors reading the same set of images). We investigate the agreement measure PK presented by Smith et al. (1996) that is a generalization of the area under the ROC curve (receiver operating characteristics curve). The generalization allows for polytomous (multi-state) ordinal truth instead of just binary truth, and thus AUC is a special case.

In this work, we compared two agreement measures: the widely used correlation coefficient ρ , and P_k . We have rewritten the estimate of Smith et al. in a form that helps identify its explicit relationship to AUC (the area under the ROC curve) that also allows for continuous data. This expression also helps us to generalize to a reader-averaged agreement measure and a corresponding multi-reader multi-case (MRMC) variance. Additionally, we have investigated how these measures behave in a simulation experiment as we change the intrinsic correlation, number of samples, number of rating levels, and the data quantization scheme. We also investigated different relationships between our test samples (linear and nonlinear) to see how the agreement measures respond. These agreement measures will help investigators developing model observers to compare their models against a human on a case-by-case basis instead of with a summary figure of merit that requires and is limited by binary truth, like AUC. The model observer AUC can equal the human observer AUC, while making very different decisions on a case-by-case basis.

6917-13, Session 3

Three-class ROC analysis: a sequential decision model developed for the diagnostic task of simultaneous dual-isotope myocardial perfusion SPECT imaging

X. He, E. C. Frey, Johns Hopkins School of Medicine

Previously we developed a decision model for three-class ROC analysis where the three classes are treated simultaneously. In this paper, a sequential decision model was developed for the specific three-class task involving simultaneous dual-isotope myocardial perfusion SPECT (MPS) imaging. This sequential decision model was developed based on the fact that sometimes this diagnostic task employs a two-step process. First, the stress (Tc-99m) image is read to determine whether a patient is normal or abnormal based on the presence of defect on the stress image. If a defect is found, the rest (Tl-201) image is then read to determine whether this is a reversible defect or a fixed defect based on the presence of defect on the rest image. In fact, in some protocols, the rest imaging is not performed if there is no defect on the stress image. Therefore, the three-class task is decomposed to a sequence of two two-class tasks. By maximizing the expected utility of both steps of the decision process, the log likelihood ratios were found to provide the optimal ROC surface under the assumption that incorrect decisions have equal utilities under the same hypothesis. The properties of the sequential decision model were then studied. We found that the sequential decision model also shares most of the features of an ROC curve. While this model was developed for the dual-isotope MPS, it may have applications to other similar diagnostic tasks.

6917-14, Session 3

Optimality of a utility-based performance metric for ROC analysis

D. C. Edwards, C. E. Metz, The Univ. of Chicago

We previously introduced a utility-based ROC performance metric, the "surface-averaged expected cost" (SAEC), to address difficulties which arise in generalizing the well-known area under the ROC curve (AUC) to classification tasks with more than two classes. In a two-class classification task, the SAEC can be shown explicitly to be twice the area above the conventional ROC curve (1-AUC) divided by the arclength along the ROC curve. In the present work, we show that for a variety of two-class tasks under the binormal model, the SAEC obtained for the proper decision variable (the likelihood ratio of the latent decision variable) is less than that obtained for the conventional decision variable (i.e., using the latent decision variable directly). We also attempt to justify this result using methods related to the calculus of variations. Numerical studies as well as theoretical analysis suggest that the behavior of the

SAEC is consistent with that of the AUC performance metric, in the sense that the optimal value of this quantity is achieved by the ideal observer.

6917-15, Session 4

Individualized training to address variability of radiologists' performance

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Computer-based tools are increasingly used for the training and continuing professional development of radiologists. We propose an adaptive training system to support individualised learning in mammography, based on a set of real cases, which are annotated with educational content by experienced breast radiologists. The system has knowledge of the strengths and weakness of each radiologist's performance: each radiologist is assessed to compute a profile showing how they perform on different sets of cases, classified by type of abnormality, breast density, and perceptual difficulty. We also assess variability in cognitive aspects of image perception, classifying errors made by radiologists as errors of search, detection or decision. This is a novel element in our approach. The profile is used to select cases to present to the radiologist. The intelligent and flexible presentation of these cases distinguishes our system from existing training tools. The training cases are organised and indexed by an ontology we have developed for breast radiologist training, which is consistent with the radiologists' profile. The radiologist's profile is not statically stored in the system, but it is dynamically updated through the training processes. Hence, the training system is able to select appropriate cases to compose an individualised training path, addressing the variability of the radiologists' performance. A substantial part of the system, the ontology has been evaluated on a large number of cases, and the training system is under implementation for further evaluation.

6917-16, Session 4

Image perception by expert readers as a function of patient skin entrance dose levels in digital radiography

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Diagnostic acceptability is subjective and can be based on professional experience, image processing and image display. In this study, image quality was based on the required clinical criteria, in order to investigate the degree to which patient entrance doses in digital radiography have a measurable effect on diagnostic confidence levels.

Images from a cadaver were acquired and subsequently scored according to diagnostic acceptability with a standard 9-point rating system. Extremity and spine images formed the basis of the image database. Benchmarking was conducted using the standard techniques currently used in daily practice with a Kodak DirectView DR7500 for the specific body part and projection being imaged. Records were kept of kV, mAs, DAP (dose area product), and skin entrance dose readings. Radiographic techniques were stepwise decreased corresponding to decreases in patient skin entrance dose of 75%, 50% and 25% from the benchmarked value for each series of images. 100% corresponded to the benchmarked value for the specific body part and projection. Expert readers were blinded to the dose level and read from properly calibrated diagnostic workstations. Readers could vary the window width and level of each image, and had no time limits imposed.

It was possible to reduce the entrance skin dose to 25% in the case of extremities without compromising the image quality required for diagnosis. It was also determined that when readers were presented the 4 dose level images belonging to a set, more than half of the time the 75% image was rated as the best image.

6917-17, Session 4

Towards perceptually driven image retrieval in mammography: a pilot observer study to assess visual similarity of masses

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Development of a fully automated system retrieving visually similar images is a task that could be helpful as the basis of a computer-assisted diagnostic (CADx) tool in mammography. Our study aims at a better understanding of the concept of visual similarity as it pertains to mammographic masses. Such understanding is a necessary step for building effective perceptually-driven image retrieval systems. In our study we deconstruct the concept of visual mass similarity into three components: similarity of size, similarity of shape, and similarity of margin. We present the results of a pilot observer study to determine the importance of each component when human observers assess the overall similarity of two masses. Seven observers of various expertise participated in the study: 1 highly experienced mammographer, 1 expert in visual perception, 3 CAD researchers, and 2 novices. Each observer assessed the similarity between 100 pairs of mammographic regions of interest (ROIs) depicting benign and malignant masses. Visual similarity was assessed in four categories (shape, size, margin, overall) using a web-based interface and a 10-point rating scale. Preliminary analysis of the results suggests the following. First, there is a moderate agreement between observers in similarity assessment for all mentioned categories. Second, all components substantially affect the overall similarity rating, with mass margin having the highest impact and mass size having the lowest impact relatively to the other factors. These findings varied somewhat based on the observer's expertise. Third, some low-level morphological features extracted from the masses can be used to mimic the overall visual similarity ratings and its specific components.

6917-18, Session 4

Existence and perception of textural information predictive of atypical nevi - a preliminary study

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Texture is known to predict atypicality in pigmented skin lesions. This paper describes an experiment that was conducted to determine 1) if this textural information is present in the center of skin lesions, and 2) how color affects the perception of this information. Images of pigmented skin lesions from three categories were shown to subjects in such a way that only textural information could be perceived; other factors known to predict atypicality were either removed or held constant. These images were shown in both color and grayscale. Each subject assigned a confidence score of atypicality to each image.

The experiment was conducted on 5 subjects of varying backgrounds, including one expert. Each subject's accuracy under each modality was measured by calculating the volume under a 3-way ROC surface (VUS). The modalities were compared using the Dorfman-Berbaum-Metz (DBM) method of ROC analysis, giving a p-value of 0.8611. Therefore the null hypothesis that there is no difference between the predictive power of the modalities cannot be rejected. Also, a two one-sided test of equivalence (TOST) was performed giving a p-value pair of <0.01; strong evidence that the textural information is independent of color.

Additionally, the subjects' accuracies were compared to a set of random readers using the DBM and TOST methods. This was done for accuracies under the color modality, the grayscale modality and both modalities simultaneously. The results (all p-values <0.001) confirm the existence of textural information predictive of atypia in the center of pigmented skin lesions.

6917-19, Session 4

Mass detection on mammograms: signal variations and performance changes for human and model observers

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In this paper, we studied the influence of signal variability on human and model observer performances for a detection task with mammographic backgrounds and computer generated clustered lumpy backgrounds (CLB). We used synthetic yet realistic masses and backgrounds that have been validated by radiologists during previous studies, ensuring conditions close to the clinical situation. Four trained non-physicians observers participated in two-alternative forced-choice (2-AFC) experiments. They were asked to detect synthetic masses superimposed on real mammographic backgrounds or CLB. Separate experiments were conducted with sets of benign and malignant masses. Results under the signal-known-exactly (SKE) paradigm were compared with signal-known-statistically (SKS) experiments. In the latter case, the signal was chosen randomly for each of the 1,400 2-AFC trials (image pairs) among a set of 50 masses with similar dimensions, and the observers did not know which signal was present. The human observers' results were then compared with model observers (channelized Hotelling with Difference-of-Gaussian and Gabor channels) in the same experimental conditions.

Results show that the performance of the human observers does not differ significantly when the masses are superimposed on real images or on CLB with locally matched gray level mean and standard deviation. The performance does not differ significantly between SKE and SKS experiments, when the signals' dimensions do not vary throughout the experiment. However, there is a performance drop when the SKS signals' dimensions vary from 5.5 to 9.5 mm in the same experiment. Noise level in the model observers can be adjusted to reproduce human observers' proportion of correct answers in the 2-AFC task within 5% accuracy for all conditions.

6917-20, Session 4

Weighted perceptual difference model (case-PDM) for MR image quality evaluation

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The perceptual difference model (Case-PDM) is being used to quantify image quality of fast, parallel MR acquisitions and reconstruction algorithms by comparing to slower, full k-space, high quality reference images. To date, most perceptual difference models average a single scalar image quality metric over a large region of interest. In this paper, we create an alternative metric weighted to image features. Spatial filters were applied to the reference image to create edge and flat region images, then weighted and aggregated to create "structural" images which in turn spatially weighted the perceptual difference maps. We optimized the scale of the spatial filters and weighting scheme with an exhaustive search so as to improve the linear correlation coefficient between human ratings and weighted Case-PDM, across a large set of MR reconstruction test images of varying quality. Human ratings were obtained from a modified Double Stimulus Continuous Quality Scale experiment. For 5 different images (3 different brain, 1 cardiac, and 1 phantom images), r values [weighted PDM, average PDM] were improved ([0.96, 0.94], [0.94, 0.91], [0.95, 0.94], [0.97, 0.91], [0.98, 0.97]) in all cases. Our method is robust across subjects and anatomy; that is, scores maintain a high correlation with human ratings even if the test dataset is different from the training dataset.

6917-32, Poster Session

VGC analysis: application of the ROC methodology to visual grading tasks

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To determine clinical image quality in radiography, visual grading of the reproduction of important anatomical landmarks is often used. The rating data from the observers in a visual grading study with multiple scale steps is ordinal, meaning that non-parametric rank-invariant statistical methods are required. However, many visual grading methods incorrectly use parametric statistical methods. This work describes how the methodology developed in receiver operating characteristics (ROC) analysis for characterising the difference in the observer's response to the signal and no-signal distributions can be applied to visual grading data for characterising the difference in perceived image quality between two systems. The method is termed visual grading characteristics (VGC) analysis. In a VGC study, the task of the observer is to rate his confidence about the fulfilment of image quality criteria. Using ROC software, the given ratings for the two systems are then used to determine the VGC curve, which describes the relationship between the proportions of fulfilled image criteria for the two compared systems for all possible decision thresholds. As a single measure of the difference in image quality between the two compared systems, the area under the VGC curve can be used.

6917-33, Poster Session

A method of ROC analysis by applying item response theory (IRT) to results of 1/0 judgments on the presence or absence of abnormal findings in CT image readings

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Purpose: Development of a method of ROC analysis to evaluate both the ability of individual readers to detect abnormal findings and the detectability of abnormal findings in individual cases by applying item response theory (IRT) to the results of 1/0 judgments on the presence or absence of abnormal findings in CT image readings.

Method(s): The validity of the method was verified by the following data and methods. Twenty-four readers searched for abnormal findings in 25 cases for which there were chest CT images with defined abnormal findings. From the 1/0 judgment data for the 25 cases with CT images (column) read by the 24 readers (row), each reader's potential ability to detect the abnormal findings (θ), the rate of "1" judgment by each reader, $P(\theta)$, and the response characteristic curves with the reader as the item were calculated, from which ROC curves that represent the ability of each reader to detect abnormal findings were created. In addition, from the 1/0 judgment data for the 25 cases with CT images (row) read by the 24 readers (column), the detectability of abnormal findings for each CT image (θ) and the rate of "1" judgment by readers, $P(\theta)$, were calculated, from which ROC curves that represent the detectability of the abnormal finding in each case were created.

Results: Present ROC curves were compared with those curves by reader groups in our previous study that were created from 1/0 judgment (SPIE07) and the validity of this method was verified.

New or breakthrough work to be presented

ROC analysis can be performed, even from the 1/0 judgment results of readers by applying item response theory (IRT).

Conclusions: The ability of individual readers to detect abnormal findings and the detectability of abnormal findings in individual cases can be evaluated by ROC analysis by applying item response theory (IRT), even from the 1/0 judgment results of readers.

6917-34, Poster Session

Relations between physical properties of local and global image-based elements and the performance of human observers in lung nodule detection

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Aim: The study aims to help our understanding of the relationship between physical characteristics of local and global image features and the location of visual attention by observers.

Background: Neurological visual pathways are specified at least in part by particular spatial frequency ranges at different orientations. High spatial frequencies, which carry the information of local perturbations like edges, are assembled mainly by foveal vision, whereas peripheral vision provides more global information coded by low frequencies.

Recent visual-search studies in mammography (C Mello-Thoms et al) have shown that observers allocate visual attention to regions of the image depending on: i) spatial frequency characteristics of regions that capture attention and ii) the level of experience of the observer. Both aspects are considered in this study.

Methods: A spatial frequency analysis of postero-anterior chest images containing pulmonary nodules has been performed by wavelet packet transforms at different scales. This image analysis has provided regional physical information over the whole image field on locations both with nodules present and nodules absent.

The relationship between such properties as spatial frequency, orientation, scales, contrast, and phase of localised perturbations has been compared with eye-tracked search strategies and decision performance of observers with different levels of expertise.

Results: The work is in progress and the results of this initial stage of the project will be presented with a critical appraisal of the methods used.

6917-35, Poster Session

Reconstruction filters and contrast detail curves in CT

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In this study, we investigated the effect of CT reconstruction filters in abdominal images of a Rando phantom. A GE Light Speed 4-slice scanner was used to scan the abdomen of an adult anthropomorphic phantom (Rando). Images were reconstructed using four reconstruction filters: (1) soft tissue with the lowest noise; (2) detail (relative noise 1.7); (3) bone (relative noise 4.5); and (4) edge (relative noise 7.7). A two Alternate Forced Choice (AFC) experimental paradigm was used to estimate the intensity needed to achieve 92% correct (i.e., I92%). Four observers measured detection performance for five lesions with size ranging from 2.5 to 12.5 mm for each reconstruction filter. Results from four readers show similar trends with modest inter-observer differences with the measured coefficient of variation of the absolute performance levels of ~22%. All four reconstruction filter investigated (soft tissue, detail, bone, and edge) had similar contrast detail curves, but increasing the noise level always reduced detection performance. If the noise increased by a factor Y%, the average drop in detection performance was approximately 0.2Y%. The key findings of this study are that (a) the Rose model can provide reasonable predictions as to how changes in lesion size affect observer detection; (b) the shape of CT contrast detail curves is essentially the same for all reconstruction filters; (c) changes in reconstruction filter noise can predict qualitative changes in observer detection performance, but are very poor predictors of the quantitative changes of imaging performance.

6917-36, Poster Session

Inter-reader variability in alternate forced choice studies

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zetti, SUNY Upstate Medical Univ.; E. Samei, Duke Univ.; R. L. Laval-lee, M. L. Roskopf, SUNY Upstate Medical Univ.

In this study, we investigated differences in detection performance between eleven observers who each generated a contrast detail curve using CT images. Axial images were obtained of the abdomen of an anthropomorphic newborn phantom on a GE Lightspeed CT scanner (4-slice). An Alternate Forced Choice (AFC) experimental paradigm was used to measure how observer performance changes with lesion size. Lesion sizes ranged from 2.5 to 12.5 mm. Following training, eleven readers generated a single contrast detail curve. Eight readers produced approximately linear contrast detail curves. The remaining three readers required a second order polynomial fit because of reduced performance when detecting the largest (i.e., 12.5 mm) lesion. For the three smallest lesions, the coefficient of variation between the 11 readers was ~11%, which increase with increasing lesion size to ~21% for 12.5 mm lesions. The ratio of the maximum I92% to minimum I92% values is about 1.5 for the smallest sized lesions, and this increases to nearly a factor of two for the 12.5 mm lesion. The combined experimental data show that the slope of the contrast detail curve was -0.46, which may be compared to the value of -1.0 predicted by the Rose model. These results therefore show that factors other than quantum noise are important in the detection of low contrast lesions in this phantom. We conclude that minimizing inter-reader variability in AFC experiments requires the elimination of lesion sizes that cause detection problems in a minority of observers.

6917-37, Poster Session

Mammographic interpretation training: how useful is handheld technology?

Y. Chen, A. G. Gale, H. J. Scott, Loughborough Univ. (United Kingdom)

In the UK a national self-assessment scheme (PERFORMS) for mammographers is undertaken as part of the breast screening programme where individuals annually read especially selected difficult exemplar screening images. From examination of several years of PERFORMS data, problematic mammographic features which film-readers have more difficulty with can be identified. Accordingly, further training can be suggested to improve their performance. Ideally, such training would be on-demand; that is whenever and wherever an individual decides to undertake it. To use a portable device for such a purpose would be attractive on many levels, although currently it is not known whether such technology could be used effectively for such high resolution mammographic images. Previous studies have shown growing possibilities of viewing medical images (e.g. CT, MRI) on PDAs; however these images have fairly low spatial resolution. In this study, we set out to investigate possible factors affecting feasibility of a PDA as a training technology for examining large high resolution mammographic images. Two studies are reported: 20 mammographers examined a series of single mammograms presented on a PDA and rated their confidence in whether an abnormality was present, specifying its location if abnormal. Secondly, a group of technologists examined a series of single mammograms presented at different sizes and resolutions to mimic presentation on a PDA and their eye movements were recorded. The results indicate the possible use of PDAs to show such large high resolution images if suitable HCI techniques are employed. This can then extend the delivery of individualised training.

6917-38, Poster Session

How are false negative cases perceived by mammographers? Which abnormalities are misinterpreted and which go undetected?

H. J. Scott, A. G. Gale, S. Hill, Loughborough Univ. (United Kingdom)

A radiographic 'false negative' or a case which has been 'missed' can be categorised in terms of errors of search (where gaze does not fall upon the abnormality); detection (a perceptual error where the abnormality may be physically 'seen' but remains undetected) and misinterpretation (a perceptual error whereby an abnormality, although detected, is not deemed worthy of further assessment). In this study we aim to investigate perceptual errors in mammographic film-reading and will focus on the later of the two error types, namely errors of misinterpretation and errors

of non-detection. Previous research has shown, on a self-assessment scheme of recent and difficult breast-screening cases, that certain feature types are susceptible to errors of misinterpretation and others to errors of non-detection. This self assessment scheme, 'PERFORMS' (Personal Performance in Mammographic Screening), is undertaken by the majority (at present over 90%) of breast-screening mammographers in the UK Breast Screening Programme. The scheme is completed bi-annually and confidentially - where participants receive immediate and detailed feedback on their performance. Feedback from the scheme includes information detailing their false negative decisions including case classifications (benign or malignant), feature type (masses, calcification, asymmetries, architectural distortions and others) and case perception error (percentage of misinterpretation and percentage of non-detection). Results from a recent round of PERFORMS (n=500), revealed that certain feature types had significantly higher percentages of error overall (including architectural distortion and calcification), and that these feature types also showed significant differences for error type. Implications for real life screening practice are discussed.

6917-39, Poster Session

Measurement of visual strain in radiologists

E. A. Krupinski, A. Johns, The Univ. of Arizona; K. S. Berbaum, The Univ. of Iowa

While the great strides in medical imaging have real and definite advantages, calculating the associated costs in the practice of radiology cannot ignore diagnostic accuracy. Digital displays offer less contrast than film and reduced spatial resolution, information used by the visual system to regulate image focus, single vision, and direction of gaze. This may strain the oculomotor system of the radiologist and reduce diagnostic accuracy. Our overall hypothesis is that the current practice of radiology produces oculomotor fatigue that reduces diagnostic accuracy. One step towards testing this hypothesis is to measure visual strain. We are doing this by measuring visual accommodation of radiologists before and after diagnostic viewing work. Preliminary results indicate that near-viewing accommodation is degraded in the afternoon after reading digitally displayed images all day compared to near-viewing accommodation prior to the day's reading. Far-viewing accommodation is, as expected, less affected by a day's viewing of radiographic images. The next series of studies will measure the impact of fatigue on diagnostic accuracy using a series of bone fracture images and a series of chest nodule CT images. It is expected that diagnostic accuracy will be impacted as radiologists' visual systems fatigue.

6917-40, Poster Session

Learning from others: effects of viewing another person's eye movements while searching for chest nodules

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We report a study that investigated whether experienced and inexperienced radiographers benefit from knowing where another person looked during pulmonary nodule detection. Twenty-four undergraduate radiographers (1 year of experience) and 24 postgraduate radiographers (5+ years of experience) searched 42 chest x-rays for nodules and rated how confident they were in their decisions. Eye movements were also recorded. Performance was compared across three within-participant conditions: (1) free search-where radiographers could identify nodules as normal; (2) image preview-where radiographers were first shown each chest x-ray for 20 seconds before they could then proceed to mark the location of any nodules; and (3) eye movement preview-which was identical to image preview except that the 20 second viewing period displayed an overlay of the real-time eye movements of another radiographer's scanpath for that image. For this preview condition half of each group were shown where a novice radiographer looked, and the other half were shown where an experienced radiologist looked. This was not made known to the participants until after the experiment. Performance was assessed using JAFROC analysis. Both groups of radiographers performed better in the eye movement preview

condition compared with the image preview or free search conditions, with inexperienced radiographers improving the most. We discuss our findings in terms of the task-specific information interpreted from eye movement previews, task difficulty across images, and whether it matters if radiographers are previewing the eye movements of an expert or a novice.

6917-41, Poster Session

Assembling a prototype resonance electrical impedance spectroscopy system for breast tissue signal detection: preliminary assessment

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Using electrical impedance spectroscopy (EIS) technology to detect breast abnormalities has been attracting research interests for decades. In this study, we explore a new and unique resonance frequency based EIS technology to measure breast tissue EIS signals in vivo, which aims to be more sensitive to small tissue changes. Through collaboration between our group and a commercial company, a prototype REIS system has been assembled and preliminary signal acquisition has commenced. This REIS system has two detection probes mounted in the two ends of a Y-shape support device with separation of 60mm. During REIS measurement, one probe touches the nipple and the other touches to an outer point of the breast. The electronic system continuously generates multiply frequency electrical pulse sweeps ranging from 100 to 4100 kHz. The maximum electric voltage and the current applied to the probes are 1.5V and 30mA, respectively. Once a "record" command is entered, the output EIS sweeps are recorded every 12 seconds until a "stop" recording command is received. We have collected REIS measurements from 150 women, which include 58 biopsy cases, 78 screening negative cases, and other recalled cases (for additional imaging procedures). We measured eight REIS signal features of each breast and applied a multi-feature based artificial neural network (ANN) to classify between abnormal (biopsy) and normal (non-biopsy) breasts. The ANN performance is evaluated using a leave-one-out based validation method and ROC analysis. We conducted two experiments. The first experiment classified between 58 abnormal breasts and 58 normal breasts acquired from 58 women each having one breast underwent biopsy. The second experiment classified between 58 abnormal breasts acquired from the biopsy cases and 58 normal breasts acquired from screening negative cases. The areas under ROC curves are 0.679 ± 0.033 and 0.606 ± 0.035 for the first and the second experiment, respectively. The preliminary results demonstrate that (1) it is feasible to apply REIS technology to identify women with highly suspicious breast lesions and (2) the electromagnetic asymmetry between two breasts may be more sensitive to detect the abnormal cases. To further improve the REIS system performance, we are currently designing a new REIS system with multiple detection probes and testing new REIS feature analysis methods.

6917-42, Poster Session

Perceptual assessment of multiple stent deployment

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Coronary stents are an important tool in interventional cardiology for the treatment of coronary artery disease. These small wire mesh cylinders are deployed as a part of a balloon angioplasty procedure and used to support the vessel during recovery and tissue remodeling. For extensive disease, including diffuse or multiple arterial plaques, multiple contiguous stents may be used to cover a larger region of vasculature. The placement of multiple coronary stents requires fine judgments of distance between a deployed stent and stent/guidewire assembly to be deployed in order to achieve continuous coverage without a gap or overlap between the two. These judgments are made difficult by limited system resolution, noise, relatively low contrast of the deployed stent, and stent motion during the cardiac cycle. In this work we investigate some of the perceptual issues associated with this task. In particular, we assess the effect of frame rate and number of frames used in a sequence on the accuracy of

stent placement. To investigate these issues we use real X-ray coronary angiograms as backgrounds along with guidewire and stent assemblies imaged separately with lucite for similar beam attenuation. Stents and guidewire assemblies are embedded in the angiograms by adding optical densities. Realistic motion is rendered by synchronizing to vascular features in each image.

6917-43, Poster Session

An automated system for the analysis of peri-prosthetic osteolysis progression

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The purpose of this work is to evaluate the performance of a computer based analysis system aimed at the quantitative detection of changes in hip osteolytic lesions in subjects with hip implants. The computer system is based on the supervised segmentation of a baseline x-ray computed-tomography (CT) scan and an automated segmentation of a follow-up CT scan using an object based tracking algorithm. The segmentation process outlines the pelvic bone and lesions present in the pelvis. The size and CT density of the osteolytic lesions are computed in both baseline and follow-up segmentations and the change in both these quantities are evaluated. The system analysis consisted of the direct comparison of the quantitative results obtained from an expert manual segmentation to the quantitative results obtained using the automated system on 20 subjects. The system bias was evaluated by performing forwards and backwards analysis of the CT data. Furthermore, the stability of the proposed tracking system was compared to the variability of the manual tracking. The results show that the system enhances the human ability to detect changes in lesions size and density regardless of the inherent observer variability in the definition of the baseline manual segmentation.

6917-44, Poster Session

Performance assessment of multifrequency processing of ICU chest images for enhanced visualization of tubes and lines

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Portable chest radiography is the most frequently performed radiographic procedure in the intensive care unit (ICU). Tube and line visualization, identifying the tip locations and following the course of endotracheal tubes, nasogastric tubes, venous catheters, etc., from captured images is one of the most frequently performed clinical tasks. ICU chest radiographs usually have less image quality than those produced from standard chest radiography because anti-scatter grids are often not used to reduce excessive x-ray scatter. The contrast of the tubes and lines in the ICU images are poor and often very difficult to perceive by the clinicians. An image processing method has been developed to enhance ICU chest images for tube and line visualization. This method is based on multifrequency processing, i.e., the input image is decomposed into different spatial frequency bands, and those bands that contain the tube and line signals are individually enhanced by nonlinear boosting functions.

A total of 50 computed radiography (CR) images from 10 ICU patients were evaluated. The patient cases were randomly selected from a large database of 1100 ICU patients with a total of 9600 images. The CR images were first processed with default image processing parameters as those used in clinical settings, and then the images were processed with the method for tube and line enhancement. Three ICU clinicians evaluated the image pairs, which were displayed side-by-side on two 3MP diagnostic-quality monitors with the image window/level function enabled. Questions were asked as to the clinicians' ability to identify the tip location and their ability to follow the course of the tubes and lines using a five-point rating scale. Data indicates that the method greatly improves the visualization of tubes and lines. The processing offers an alternative view for clinicians, in addition to the standard image produced, for improved image-review efficiency.

6917-45, Poster Session

Steady-state sweep visual evoked potential processing denoised by wavelet transform

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Visually evoked potential (VEP) is a very small electrical signal originated in the visual cortex in response to periodic visual stimulation. Sweep-VEP is a modified VEP procedure used to measure grating visual acuity in non-verbal and preverbal patients. This biopotential is buried in a large amount of electroencephalographic (EEG) noise and movement related artifact. The signal-to-noise ratio (SNR) plays a dominant role in determining both systematic and statistic errors. The purpose of this study is to present a method based on wavelet transform technique for filtering and extracting steady-state sweep-VEP. Counter-phase sine-wave luminance gratings modulated at 6 Hz were used as stimuli to determine sweep-VEP grating acuity thresholds. The amplitude and phase of the second-harmonic (12 Hz) pattern reversal response were analyzed using the fast Fourier transform after the wavelet filtering. The wavelet transform method was used to decompose the VEP signal into wavelet coefficients by a discrete wavelet analysis to determine which coefficients yield significant activity at the corresponding frequency. In a subsequent step only significant coefficients were considered and the remaining was set to zero allowing a reconstruction of the VEP signal. This procedure resulted in filtering out other frequencies that were considered noise. Numerical simulations and analyses of human VEP data showed that this method has provided higher SNR when compared with the classical recursive least squares (RLS) method. An additional advantage was a more appropriate phase analysis showing more realistic second-harmonic amplitude value during phase brake.

6917-46, Poster Session

A strategy to optimize CT pediatric dose with a visual discrimination model

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Technological developments of computed tomography (CT) have led to a drastic increase of its clinical utilization, creating concerns about patient exposure. To better control dose to patients, we propose a methodology to find an objective compromise between dose and image quality by means of a visual discrimination model.

A GE LightSpeed-Ultra scanner was used to perform the acquisitions. A QRM 3D low contrast resolution phantom (QRM - Germany) was scanned using CTDIvol values in the range of 1.7 to 103 mGy. Raw data obtained with the highest CTDIvol were afterwards processed to simulate dose reductions. Noise realism of the simulations was verified with normalized noise power spectra (NNPS) and standard deviation measurements.

Patient images were acquired according to Diagnostic Reference Levels (DRL) proposed in Switzerland. Noise reduction was then simulated as for the QRM phantom, to obtain five different CTDIvol levels, down to 3.0 mGy.

Image quality of phantom images was assessed with the Sarnoff JNDmetrix visual discrimination model and compared to an assessment made by means of ROC methodology, taken as a reference. For patient images a similar approach was taken but using as reference the Visual Grading Analysis (VGA) method.

A relationship between Sarnoff JNDmetrix and ROC results was established for low contrast detection in phantom images, demonstrating that the Sarnoff JNDmetrix can be used for qualification of images with highly correlated noise. Patient image qualification showed a threshold of conspicuity loss only for children over 35 kg.

6917-47, Poster Session

Assessment of scanning model observers with hybrid SPECT images

H. C. Gifford, P. H. Pretorius, M. A. King, Univ. of Massachusetts Medical School

The purpose of this work is to test methods of applying scanning linear model observers in order to predict human-observer lesion-detection performance with hybrid images. Hybrid images consist of clinical backgrounds with simulated abnormalities. The basis for this investigation was detection and localization of solitary pulmonary nodules (SPN) in SPECT lung images, and our overall goal was to determine the extent to which detection of SPN could be improved by proper modeling of the acquisition physics during the iterative reconstruction process.

Towards this end, we conducted human-observer localization ROC (LROC) studies to optimize the number of iterations and the postfiltering of four rescaled block-iterative (RBI) reconstruction strategies with various combinations of attenuation correction (AC), scatter correction (SC), and system-resolution correction (RC). This observer data was then used to evaluate several scanning human-model observers. Forms of the channelized Hotelling (CH) and channelized nonprewhitening (CNPW) model observers were tested with a set of three difference-of-Gaussian channels. A typical 'background-known-exactly' (BKE) task formulation overstated the knowledge that human observers had about the hybrid images. We will discuss results based on modifications of the BKE paradigm that preserved some degree of structural noise in the detection task. Results from adding internal-noise mechanisms to the scanning observers will also be presented.

6917-48, Poster Session

SPECT image system optimization using ideal observer for detection and localization

L. Zhou, G. R. Gindi, Stony Brook Univ.

We consider the problem of optimizing collimator characteristics for a simple emission tomographic imaging system. We use the performance of two different ideal observers to carry out the optimization. The first ideal observer applies to signal detection when signal location is unknown and background is variable, and the second ideal observer (one proposed previously by our group) to the more realistic task of signal detection and localization with signal location unknown and background variable. The two observers operate on sinogram data to deliver scalar figures of merit AROC and ALROC, respectively. We considered three different collimators that span a range of efficiency-resolution tradeoffs. Our central question is this: For optimizing the collimator in an emission tomographic system, does adding a localization requirement to a detection task yield an efficiency-resolution tradeoff that differs from that for the detection-only task? Our simulations with a simple SPECT imaging system show that as the localization requirement becomes more stringent, the optimal collimator shifts from a low-resolution, high efficiency version toward higher resolution, lower efficiency version. We had previously observed such behavior for a planar pinhole imaging system. In our simulations, we used a simplified model of tomographic imaging and a simple model for object background variability. This allowed us to avoid the severe computational complexity associated with ideal-observer performance calculations. Thus the more realistic task (i.e. localization included) resulted for this case in a different optimal collimator.

6917-49, Poster Session

Computerized observers for optimizing simulated x-ray imaging chain

I. Son, B. Yazici, Rensselaer Polytechnic Institute

This study develops and demonstrates a realistic X-ray imaging simulator with computerized observers to maximize lesion detectability and minimize patient exposure. A software package, ViPRIS, incorporating two computational patient phantoms, has been developed for simulating x-ray radiographic images. A tomographic phantom, VIP-Man, constructed from Visible Human anatomical color images is used

to simulate the scattered portion using the ESGnrc Monte Carlo code. The primary portion of an x-ray image is simulated using the projection ray-tracing method through the Visible Human CT data set.

To produce a realistic image, the software simulates quantum noise, blurring effects, lesions, detector absorption efficiency, and other imaging artifacts. The primary and scattered portions of a x-ray chest image are combined to form a final image for computerized observer studies and image quality analysis. Absorbed doses in organs and tissues of the segmented VIP-Man phantom were also obtained from the Monte Carlo simulations.

Approximately 25,000 simulated images and 2,500,000 data files were analyzed using computerized observers. Hotelling and Laguerre-Gauss Hotelling observers are used to perform various lesion detection tasks.

Several model observer tasks were used including SKE/BKE, MAFC, and SKEV. The energy levels and fluence at which the minimum dose required to detect a small lesion were determined with respect to lesion size, location, and system parameters.

6917-50, Poster Session

Noise reduction effect in super-high resolution LCDs using independent sub-pixel driving technology

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We have developed and reported a super-high resolution liquid crystal display (SH-LCD) using a new resolution enhancement technology of independent sub-pixel driving (ISD) that utilizes three sub-pixels included in each pixel element. This technology realizes three-times resolution enhancement of monochrome LCDs, and improves the depiction ability of detailed shape such as micro-calcifications of a mammography and bone structures. Furthermore, the ISD technology brings not only resolution enhancement but also noise reduction effect by high-resolution data sampling in displaying clinical images. In this study, we describe the efficacy of the newly developed LCDs from the noise power spectrum measurement (NPS) and the perceptual comparison of phantom images and clinical images. A 15 mega-pixel (MP)SH-LCD out of a 5MP LCD, a 9MP SH-LCD out of a 3MP LCD and a 6MP SH-LCD out of a 2MP LCD were used for the measurement and evaluation. In the NPS measurements, the noise of all the SH-LCDs was improved obviously. The improvement degree of the NPS varied according to the matrix size, and the 6MP LCD showed maximum improvement. In the perceptual evaluation of the quality-control phantom images and the low-contrast images of the micro-calcifications of the mammography, all the SH-LCDs provided higher performance than conventional LCDs. These results proved that the SH-LCDs using the ISD technology had the excellent ability to display the high-quality clinical images.

6917-51, Poster Session

Mammography workstation design: reducing the risk of musculoskeletal disorders

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In the UK Breast Screening Programme there is a growing transition from film to digital mammography, and consequently a change in mammography workstation ergonomics. This paper investigates the effect of the change for radiologists including their comfort, likelihood of developing musculoskeletal disorders (MSD's), and work practices. Three workstation types were investigated. At the first workstation films were read from a roller viewer. At the second workstation, digital mammograms were read from a double LCD screen and prior mammograms (from the previous screening round) read from a roller viewer. Finally at the third workstation digital mammograms were read from a double LCD screen with no hard copy used. To ascertain the risk of developing MSD's, mammographers were video-taped whilst conducting work sessions at each of the workstations. The video was analysed using the Rapid Upper Limb Assessment (RULA) postural analysis tool in conjunction with analysis of Reach Envelopes, and Body Part Discomfort charts. The latter

two instruments were completed by the mammographer before and after each session. To analyse the effect of workstation type on radiologist work practices, comparisons of the number of fixations per case on the prior mammograms were made at the three workstations. This showed how the level of use of prior mammograms can vary depending on the medium in which they are displayed. Recommendations for best practice both during and after the changeover to digital technology are made as a result of these findings.

6917-52, Poster Session

Influence of monitor characteristics on the signals detection present in the mammographic phantom image

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Objective: The objective of this study was to compare the detection of microcalcifications and fibers on phantom images based on monitor readings versus analog image readings. **Materials and Method:** 180 films were obtained with 3 different mammographic equipment under different exposure conditions and digitized using the Lumiscan75 scanner. It was used the ALVIM statistical phantom (4,5cm) and this phantom with 2 acrylic plates of 1cm (6,5cm). The software named QuallM was developed to manager the images and the database which storage the specialist's readings allowing using digital tools. The images are displayed on 4 monitors: CRT Philips 19" (2,9Mpixels/8bits), CRT Philips 22" (3,0Mpixels/8bits), LCD Clinton (3,0Mpixels/10bits) and LCD Barco (5,0Mpixels/14bits). The same analog films were also displayed on the view box special to mammograms (3200cd/m²) and these readings were taken as reference. The software generates on real time Kappa values to microcalcification and fibers detection, histogram, ROC curve and true/false positive parameters. **Results:** Barco monitor reading produced superior results when compared with all the others suggesting that there weren't losses in the digitalizing process. Clinton monitor readings were similar the view box results and superior on both Philips monitors when compared the detection of objects on phantom images (6,5cm). Only for images of 4,5cm the specialist performance using Philips 22" was comparable to view box and Clinton results. **Conclusions:** It was possible to verify that the spatial and contrast resolution have influenced on the reading performance of specialists, suggesting as relevant to know more about the performance on mammograms detection.

6917-53, Poster Session

Radiological image presentation requires consideration of human adaptation characteristics

N. O'Connell, National Univ. of Ireland/Dublin (Ireland); R. J. Toomey, M. F. McEntee, Univ. College Dublin (Ireland); J. T. Ryan, P. C. Brennan, National Univ. of Ireland/Dublin (Ireland)

Radiological image details are best discriminated at luminance levels to which the eye is adapted. Recommendations that ambient light conditions are matched to overall monitor luminance to encourage appropriate adaptation are based on an assumption that clinically-significant regions within the image match average monitor brightness. The current work tests this assumption. Three image-types were considered: postero-anterior (PA) chest; PA wrist; computerised tomography (CT) of the head. Luminance levels for clinically-significant regions were measured at: hilar region and peripheral lung (chest); distal radius (wrist); supra-ventricular grey matter (CT head). Average monitor luminances were calculated from measurements at the midpoint of 16 equally sized regions of the display face plate with a calibrated photometer at 3 ambient light levels, 0, 100 and 400 lux. Thirty samples of each image-type were employed, resulting in a total of over 6,000 measurements. Results demonstrate that average monitor luminances varied from clinically-significant values by up to a factor of 4, 2 and 6 for chest, wrist and CT head images respectively. Values for the hilum of the chest and distal radius were higher than average monitor levels, whilst the reverse was the case for the peripheral lung and CT brain. Increasing ambient light had little impact on the differences seen. The results demonstrate that clinically important radiological information for common radiological examinations is not being presented to the viewer in a way that facilitates optimised adaptation and subsequent interpretation. The importance of image-

processing algorithms focussing on clinically-significant anatomical regions instead of radiographic projections is highlighted.

6917-54, Poster Session

Searching in axial and 3D CT visualizations

P. W. Phillips, D. J. Manning, Univ. of Cumbria (United Kingdom); T. Crawford, Lancaster Univ. (United Kingdom); D. Burling, St. Marks Hospital (United Kingdom); C. Tam, A. Taylor, Lancaster Royal Infirmary (United Kingdom)

Traditional diagnostic modalities have been, for the most part, static two-dimensional images displayed on film or a computer screen. More recent diagnostic modalities are solely computer-based and consist of large datasets of multiple images. Image perception and visual search using these new modalities are complicated by the need to interact with the computer in order to navigate through the data.

This paper reports the late-breaking results from two small studies into visual search within two types of CT Colonography (CTC) visualisations.

The twelve novice observers in the study were taking part in a weeklong course in CTC and were tested at the beginning and end of the course. A number of expert observers were also recorded. The two visualisations used in the study were 2D axial view and 3D colon flythrough. In both cases, searching was performed by inspecting the colon wall, but by two distinct mechanisms. The axial study recorded observer eye-gaze and image navigation in a CTC axial view. The search strategy was to follow the lumen of the colon and detect abnormalities in the colon wall. The observer used the physical computer interface to navigate through the set of axial images to follow the wall. The 3D flythrough study recorded observer eye-gaze whilst watching a recording of a computed flight through the lumen. Unlike the axial view there was no computer control, so inspection of the colon surface was dictated by the speed of flight through the colon.

6917-21, Session 5

Image splitting techniques for a dual layer high dynamic range LCD display

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Liquid crystal displays (LCD) are replacing analog film in radiology and permit to reduce diagnosis times. Their typical dynamic range, however, can be too low for some applications, and their poor ability to reproduce low luminance areas represents a critical drawback. The black level of an LCD can be drastically improved by stacking two liquid crystal panels in series. In this way the global transmittance is the pointwise product of the transmittances of the two panels and the theoretical dynamic range is squared. Such a high dynamic range (HDR) display also permits the reproduction of a larger number of gray levels, increasing the bit depth of the device. The two panels, however, are placed at a small distance one from each other due to mechanical constraints, and this introduces a parallax error when the display is observed off-axis. A complex, spatially-adaptive algorithm is therefore necessary to generate the images used to drive the two panels.

In this paper, we describe the characteristics of a prototype dual-layer HDR display and discuss the issues involved in the image splitting algorithms. We propose some solutions and analyze their performance, giving a measure of the capabilities and limitations of the device.

6917-22, Session 5

Detection of low contrast test patterns on an LCD with different luminance and illuminance settings

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The DICOM part 14 grayscale standard display function provides one way of harmonizing image appearance under different monitor luminance settings. This function is based on ideal observer conditions where the eye is always adapted to the target luminance and thereby also at peak

contrast sensitivity. Clinical workstations are however often submitted to variations in ambient light due to a sub-optimal reading room light environment. Also, clinical images are inhomogeneous and low-contrast patterns must be detected even at luminance levels that differ from the eye adaptation level. All deviations from ideal luminance conditions cause the observer to detect patterns with reduced eye sensitivity but the magnitude of this reduction is unclear.

A method to display well-defined sinusoidal low-contrast test patterns on an LCD has previously been developed and was used in this study. The observers were exposed to light from three different areas:

- 1) The test pattern covering approximately 2x2 degrees
- 2) The remaining of the display surface
- 3) Ambient light from outside the display area covering most of the observer's field of view.

By adjusting the luminance from each of these three areas, two major effects can be quantified. The first effect is similar to Barten's f-factor where the target luminance differs from the observer's adaptation level while the second effect concerns the influence of areas outside the display area.

6917-23, Session 5

Visual adaptation: softcopy image contribution to the observer's field of view

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Purpose: Detection of low-contrast details is highly dependent on the adaptation state of the eye. It is important therefore that the average luminance of the observer's field of view (FOV) matches those of softcopy radiological images. This study establishes the percentage of FOV filled by workstations at various viewing distances.

Methods: Five observers stood at viewing distances of 20, 30 and 50cm from a homogenous white surface and were instructed to continuously focus on a fixed object at a height-appropriate level. A dark indicator was held at this object and then moved steadily until the observer could no longer perceive it in his/her peripheral vision. This was performed at 0°, 90°, 180° and 270° clockwise from the median sagittal plane. Distances were recorded, radii calculated and observer and mean FOV areas established. These values were then compared with areas of typical high and low specification workstations.

Results: Individual and mean FOVs were 7660, 15463 and 30075cm² at viewing distances of 20, 30 and 50cm respectively. High and low specification monitors with respective areas of 1576.25 and 921.25cm² contributed between 5 to 21% and 3 to 12% respectively to the total FOV depending on observer distance. Limited inter-observer variances were noted.

Conclusions: Radiology workstations typically comprise between only 3 and 21% of the observer's FOV. This demonstrates the importance of measuring ambient light levels and surface reflection coefficients in order to maximise adaptation and observer's perception of low contrast detail and minimise eye strain.

6917-24, Session 5

Achieving consistent color and consistent grayscale presentation for digital color displays in medical imaging

H. Roehrig, The Univ. of Arizona; J. Fan, GE Healthcare; W. J. Dallas, The Univ. of Arizona

Color displays are increasingly used for medical imaging, replacing the traditional monochrome-displays in radiology for multi-modality applications, 3D representation applications, etc. Color displays are also used increasingly because of wide spread application of Tele-Medicine, Tele-Dermatology and Digital Pathology. At this time, there is no concerted effort for calibration procedures for this diverse range of color displays in Telemedicine and in other areas of the medical field.

Using a colorimeter to measure the display luminance and chrominance properties as well as some processing software we developed a first attempt to a color calibration protocol for the medical imaging field.

While the processing software mentioned is rather simple in our first attempts, it can be rather complicated. Fundamentally it is based on Matrix transformations.

The main purpose of color calibration is to allow accurate display of images whose pixel colors are specified in terms of their CIE XYZ tristimulus values (or convertible to tristimulus values from their chromaticity coordinates and luminance values). Each display device has fixed color primaries, and in turn, a fixed color gamut. The color gamut of a display refers to the envelope of colors that this display device can generate and is defined by the triangle formed by the chromaticity coordinates of the three display primaries. The color gamut varies from display to display, and many LCD displays have larger color gamuts than that of CRT displays. However, even displays produced from the same manufacturing line will not have identical color gamuts. This means that when one digital color image is displayed on two different color displays, they may look different because of the different color gamut of the two displays.

6917-25, Session 5

A model observer for the assessment of display temporal characteristics

H. Liang, A. Badano, U.S. Food and Drug Administration

Most assessments of display performance are limited to studying display quality for static images. However, dynamic scenes constitute a large fraction of medical images and are becoming more widespread due to the increase in the number of images to be interpreted. The image quality of a dynamic scene is affected by both the display's temporal response and the human visual system's temporal response. We propose to use a model observer with temporal sensitivity to understand the effect of high image browsing speeds in medical displays. We use a 3D cluster lumpy background to study the effect of different browsing speeds calculated with liquid crystal display (LCD) temporal response measurements established in our previous work. The image set is then analyzed by the model observer. This allows us to quantify the effect of slow temporal response of medical LCDs on the performance of the anthropomorphic observer. Slow temporal response of the display device affects the lesion contrast and the observer performance. Limitations in the human visual system also compromise the image quality when the browsing speed is large. This methodology, after validation with human observers, could be used to study limits for the rendering speed of large volumetric image datasets (from CT, MR, or tomosynthesis) read in stack-mode.

6917-26, Session 6

Model observers to predict human performance in LROC studies of SPECT reconstruction using anatomical priors

A. Lehovich, H. C. Gifford, M. A. King, Univ. of Massachusetts Medical School

We investigate the use of linear model observers to predict human performance in a localization ROC (LROC) study. The task is to locate gallium-avid tumors in simulated SPECT images of a digital phantom. Our study is intended to find the optimal strength β of smoothing priors incorporating various degrees of anatomical knowledge. Our models have access to the noise-free reconstructions, and use area under the ROC curve to predict human area under the LROC curve. We used two models, the non-prewhitening matched filter (NPWMF) and the channelized nonprewhitening (CNPW). The CNPW model does a poor job of predicting human performance. The NPWMF model does a somewhat better job, but still does not qualitatively capture the human results.

6917-27, Session 6

Optimizing breast-tomosynthesis acquisition parameters with scanning model observers

H. C. Gifford, Univ. of Massachusetts Medical School; C. S. Didier, Univ. of Massachusetts Medical School and Univ. of Massachusetts/Lowell; M. Das, S. J. Glick, Univ. of Massachusetts Medical School

In digital breast tomosynthesis (DBT), multiple x-ray projections obtained over a limited angular range are reconstructed to produce a three-dimensional (3D) volume. This process can be a means of reducing the structural masking effects associated with conventional mammography, and there has been considerable interest in optimizing acquisition and reconstruction parameters associated with DBT. We are currently evaluating the use of scanning model observers for this purpose. This abstract reports on a limited optimization of the number of projection views that has been performed on the basis of detection and localization of masses within the fibroglandular tissue of a mathematical phantom. Both 'background-known-exactly' (BKE) and 'quasi-BKE' (QBKE) tasks were considered. The latter attempts to heuristically account for imperfect observer knowledge of the structural noise in an image, and as such is an alternative to 'background-known-statistically' (BKS) tasks. Future work will aim to evaluate the usefulness of the model-observer predictions in terms of human-observer performance.

6917-28, Session 6

Markov-chain Monte Carlo for the performance of a channelized-ideal observer in detection tasks with non-Gaussian lumpy backgrounds

S. Park, U.S. Food and Drug Administration; E. W. Clarkson, The Univ. of Arizona

The Bayesian ideal observer is optimal among all observers, providing a quantitative measure of diagnostic performance of an imaging system for binary detection tasks. Therefore, this observer should be used for image quality assessment whenever possible. However, computation of ideal-observer performance is difficult because this observer requires the full description of statistical properties of the signal-absent and signal-present data, which are often unknown in tasks involving complex backgrounds. Furthermore, the dimension of the integrals that need to be calculated for the observer is huge. To estimate ideal-observer performance in detection tasks with non-Gaussian lumpy backgrounds and Gaussian signals, a Markov-chain Monte Carlo (MCMC) method was developed [Kupinski et al. JOSA A 2003], but this method has a disadvantage of long computation times. In an attempt to reduce the computation load and still approximate ideal-observer performance, we [Park et al. JOSA A 2007 and Witten et al. SPIE 2008] investigated a channelized-ideal observer (CIO) in similar tasks with Laguerre-Gauss channels and singular vectors of a linear imaging system, respectively. We found that singular vectors most relevant to the signal image are highly efficient and more efficient than Laguerre-Gauss. However, in that work, an extension of the Kupinski MCMC [Park et al. JOSA A 2007] was used for calculating the performance of the CIO and it did not reduce the computational burden. In the current work, we propose a novel MCMC method to speed up the computation of the CIO using the singular vectors. Our new MCMC samples from the channel space unlike the aforementioned MCMCs sampling from the image space. Preliminary results show that the new MCMC enables the fast computation of the CIO, providing good estimates of the performance of the CIO.

6917-29, Session 6

Singular vectors of an imaging system matrix as efficient channels for the ideal observer in detection tasks involving non-Gaussian distributed lumpy images

J. M. Witten, Univ. of Maryland/College Park and U.S. Food and Drug Administration; S. Park, K. J. Myers, U.S. Food and Drug Administration

The Bayesian ideal observer sets an upper bound for diagnostic performance of an imaging system in binary detection tasks. Thus, this observer should be used for image quality assessment whenever

possible. However, it is difficult to compute ideal-observer performance because the probability density functions of the data required for the observer are often unknown in tasks involving complex backgrounds. Furthermore, the dimension of the integrals that need to be calculated for the observer is huge. To attempt to reduce the dimensionality of the problem and still approximate ideal-observer performance, we previously investigated a channelized-ideal observer (CIO) with Laguerre-Gauss channels for detecting a Gaussian signal at a known location in non-Gaussian lumpy images [Park et al. JOSA A 2007]. While the CIO with Laguerre-Gauss channels could approximate ideal-observer performance within error bars, depending on the channel and background parameters, there still was a gap between the mean performance of the ideal observer and the CIO. Moreover, it is not clear how to choose efficient channels for the ideal observer. In the current work, we investigated the use of singular vectors of a linear imaging system as efficient channels for the ideal observer in the same tasks. Singular value decomposition of the imaging system was performed to obtain its singular vectors. Singular vectors most relevant to the signal and background images were chosen as candidate channels. Preliminary results indicate that the singular vectors are not only more efficient than Laguerre-Gauss channels, but also they are highly efficient for the ideal observer. The results further demonstrate that singular vectors strongly associated with the signal image are the most efficient channels.

6917-30, Session 6

Comparison of variable and fixed focal length cone beam CT in diagnostic imaging

S. J. LaRoque, J. Bian, E. Y. Sidky, X. M. Pan, The Univ. of Chicago

We present a task-based method for objectively comparing estimates of lesion properties from different scan configurations in helical cone-beam CT (CBCT). This method will be used to assess whether variable focal length CBCT scans provide a significant improvement in estimating lesion position and size relative to fixed focal length CBCT in diagnostic applications. Using a simple 2D example, we assess the likelihood that the measured data are a result of a given parameter estimate using a maximum-likelihood estimator, and

explore the likelihood space using a Markov chain Monte Carlo method. We demonstrate that this method provides objective comparisons of estimation performance for different data weightings in the reconstruction for the specific task considered. Results of our 3D CBCT study will help to address whether variable focal length CT can provide significantly better estimates of lesion position and size relative to a fixed focal length scan of the same duration in diagnostic CT.

6917-31, Session 6

Cone-beam CT image reconstruction with a straight-line trajectory optimized on a SKE/BKE detection task

E. Y. Sidky, S. J. LaRoque, X. M. Pan, The Univ. of Chicago

In the past few years there has been rapid development of exact reconstruction algorithms for cone-beam CT (CBCT) using a variety of x-ray source scanning trajectories. Exact CBCT algorithms have been developed for the helical scan as well as a host of other trajectories such as circle plus line, saddle, and variable pitch helical scans. Although the analytic theory for CBCT is now well-developed, not much work has been put into minimizing the impact of inconsistencies in the cone-beam projection data due to, for example, noise. Such studies may be important for developing reconstruction algorithms that efficiently utilize the dose delivered to the subject. In order to improve image quality in CBCT reconstruction, it is necessary for the algorithm to take into account the redundancy in the cone-beam projection data. In this work, we derive a useful expression for this data redundancy for a straight-line x-ray source trajectory. From this expression, a family of exact CBCT image reconstruction algorithms are derived. The selection of the optimal algorithm is based on its performance on a signal-known-exactly/background-known-exactly detection task.

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6918-01, Session 1

Three-dimensional display, stereo and beyond

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With the advent of large, high-quality stereo display monitors and high-volume 3-D image acquisition sources, it is time to revisit the use of 3-D display for diagnostic radiology.

Stereo displays may be goggled, or goggle-less; we consider only goggle-less technologies. Commercial LCD flat-screen 3-D goggle-less monitors typically rely on one of two techniques: Blocked perspective, Integral photography

On the acquisition modality side, MRI and CT provide 3-D data sets. However, helical/spiral CT with multi-row detectors and multiple x-ray sources provides a monsoon of data. Presenting and analyzing this large amount of potentially dynamic data will require advanced presentation techniques.

We begin with a very brief review the two stereo-display technologies. These displays are evolving beyond presentation of the traditional pair of views directed to fixed positions of the eyes to multi-perspective displays. At differing head positions, the eyes are presented with the proper perspective pairs corresponding to viewing a 3-D object from that position. In addition, we will look at some of the recent developments in computer-generated holograms or CGH's. CGH technology differs from the other two technologies in that it provides a wave-optically correct reproduction of the object.

We then move to examples of stereo-displayed medical images and examine some of the potential strengths and weaknesses of the displays. We have installed a commercial stereo-display in our laboratory and are in the process of generating stereo-pairs of CT data. We are examining, in particular, preprocessing of the perspective data.

6918-02, Session 1

Dual energy CT: how to best blend both energies in one fused image

C. D. Eusemann, Siemens Medical Solutions (Germany); D. R. Holmes III, Mayo Clinic; B. T. Schmidt, T. G. Flohr, Siemens Medical Solutions (Germany); R. A. Robb, C. H. McCollough, D. M. Hough, J. E. Huprich, M. H. Wittmer, H. Siddiki, J. G. Fletcher, Mayo Clinic

In x-ray based imaging techniques, attenuation depends on the type of the tissue scanned and the average energy level of the x-ray beam, which can be adjusted via the x-ray tube's KV setting. Conventional Computed Tomography (CT) imaging uses one kV value, usually 120kV. Dual energy CT uses two different energies (e.g. 80kV & 140kV) by running two X-ray sources simultaneously at different energies to obtain two datasets with different attenuation characteristics. This difference in attenuation levels allows for classification of the elemental chemical composition of the tissues. In addition, the different energies have a great impact on the contrast resolution and noise characteristics of the two energy data sets. 80kV images provide far greater contrast resolution than 140kV but have the limitation that they are noisier. The additional information with dual-energy CT may provide additional diagnostic information to the physician, but the question arises on how to best illustrate it. In conventional single energy CT, patient data is presented to the physicians using very well understood organ specific window and level sets. In dual energy CT, images are currently fused into a single dataset using a commercially-available linear mixing of 70% 140kV and a 30% 80kV mixing ratio. This ratio provides a good representation of the data, but due to the linear nature of the blending, the benefits of each dataset are partially offset by the drawbacks (such as the noise). This research evaluates a variety of organ specific linear and non-linear mixing algorithms in the attempt to optimize the blending of both the low and high kV information in a way that visualizes the benefits of both energies in a single image. Upon blinded review by subspecialized abdominal radiologists, unique, tunable, non-linear mixing algorithms were felt to outperform linear, fixed mixing for a variety of different organs and pathologies of interest.

6918-03, Session 1

Java-based volume rendering

R. Cheng, National Institutes of Health; A. Bokinsky, Geometric Tools, Inc.; P. F. Hemler, Hampden-Sydney College and National Institutes of Health; E. S. McCreedy, M. J. McAuliffe, National Institutes of Health

In recent years the number and utility of 3D rendering frameworks has grown substantially. A quantitative and qualitative evaluation of the capabilities of a subset of these systems is important to determine the applicability of these methods to specific medical visualization tasks. Libraries evaluated in this paper include the Java3D API, JOGL (Java OpenGL API), a multi-histogram software-based rendering method, and the WildMagic visualization libraries. Volume renderer implementations using each of these frameworks were developed using the platform-independent Java programming language. In addition, all four frameworks were implemented or ported to the Java language thereby allowing a complete Java based solution. Quantitative performance measurements (frames per second, memory usage) were used to evaluate the strengths and weaknesses of each renderer implementation.

6918-04, Session 1

Anatomical equivalence class based complete morphological descriptor for robust image analysis and abnormality detection

S. Baloch, C. A. Davatzikos, Univ. of Pennsylvania

Groupwise registration and statistical analysis of medical images are of fundamental importance in computational anatomy, where healthy and pathologic anatomies are compared relative to their differences with a common template. Accuracy of such approaches is primarily determined by the ability to find perfectly conforming shape transformations, which is rarely achieved in practice due to algorithmic limitations arising from biological variability. Amount of the residual information not reflected by the transformation is, in fact, dictated by template selection and is lost permanently from subsequent analysis. In general, an attempt to aggressively minimize residual results in biologically incorrect correspondences, necessitating a certain level of regularity in the transformation at the cost of accuracy.

In this paper, we introduce a framework for groupwise registration and statistical analysis of biomedical images that optimally fuses the information contained in the diffeomorphism and the residual to achieve completeness of representation. Since the degree of information retained in the residual depends on transformation parameters such as the level of regularization, and template selection, our approach consists of forming an equivalence class for each individual, thereby representing them via nonlinear manifolds embedded in high dimensional space. By employing a minimum variance criterion and constraining the optimization to respective anatomical manifolds, we proceed to determine their optimal morphological representation. A practical ancillary benefit of this approach is that it yields optimal choice of transformation parameters, and eliminates respective confounding variation in the data. Resultantly, the optimal signatures depend solely on anatomical variations across subjects, and lead to more accurate diagnosis through pattern classification.

6918-05, Session 1

Transfer function design for Fourier volume rendering and implementation using GPU

C. Cheng, Y. Ching, National Chiao Tung Univ. (Taiwan)

Volume rendering is a common technique for volume visualization. Given a set of $N \times N \times N$ volume data, the traditional volume rendering methods need $O(N \times N \times N)$ rendering time and thus are not considered real-time rendering methods. The FVR (Fourier Volume Rendering), that takes advantage of the Fourier slice theorem, takes $O(N \times N \times \log N)$ rendering time once the Fourier Transform of the volume data is available.

Thus the FVR is favor of designing a real-time rendering algorithm with a preprocessing step. The FVR has the disadvantages that resampling in the frequency domain causes replicas in the spatial domain and the method for designing a transfer function is not obvious. In this paper, we report that by using the spatial domain zero-padding and tri-linear filtering could reduce the replicas to the least possible in spatial domain. To design the transfer function, we present a method that the user specifies a transfer function using a Bézier curve first. Based on the linear combination property of the Fourier transform and Bézier curve equation, the Fourier transform of the volume rendered result can be obtained by adding the weighted frequency domain signals. That mean, once the transfer function is given, we don't have to recomputed the Fourier transform of the volume data after the transfer function applied. It still takes time to $O(N \times N \times \log N)$ generate the rendered result after the transfer function applied. These computations can be parallelized by using the GPU processors.

6918-06, Session 2

Registration of a needle-positioning robot to high-resolution 3D ultrasound and computed tomography for image-guided interventions in small animals

A. C. Waspe, J. C. Laceyfield, D. W. Holdsworth, A. Fenster, Roberts Research Institute (Canada) and Univ. of Western Ontario (Canada)

Preclinical research often requires the delivery of biological substances to specific locations in small animals. Guiding a needle to targets in small animals with an error $< 200 \mu\text{m}$ requires accurate registration. We are developing techniques to register a needle-positioning robot to high-resolution three-dimensional ultrasound and computed tomography small animal imaging systems. Both techniques involve moving the needle to predetermined robot coordinates and determining corresponding needle locations in image coordinates. Registration accuracy will therefore be affected by the robot positioning error and is assessed by measuring the target registration error (TRE). A point-based registration between robot and micro-ultrasound coordinates was accomplished by attaching a fiducial phantom onto the needle. A TRE of $145 \mu\text{m}$ was achieved when moving the needle to a set of robot coordinates and registering the coordinates to needle tip locations determined from ultrasound fiducial measurements. Registration between robot and micro-CT coordinates was accomplished by injecting barium sulfate into tracks created when the robot withdraws the needle from a phantom. Points along cross-sectional slices of the segmented needle tracks were determined using an intensity-weighted centroiding algorithm. A minimum distance TRE of $194 \pm 18 \mu\text{m}$ was achieved by registering centroid points to robot trajectories using the iterative closest point (ICP) algorithm. Simulations, incorporating both robot and ultrasound fiducial localization errors, verify that robot error is a significant component of the experimental registration. Simulations of micro-CT to robot ICP registration similarly agree with the experimental results. Both registration techniques produce a TRE $< 200 \mu\text{m}$, meeting design specification.

6918-07, Session 2

Image registration for CT and intra-operative ultrasound data of the liver

N. Papenberg, Univ. zu Lübeck (Germany); T. Lange, Charité Universitätsmedizin Berlin (Germany); J. Modersitzki, Univ. zu Lübeck (Germany); P. M. Schlag, Charité Universitätsmedizin Berlin (Germany); B. Fischer, Univ. zu Lübeck (Germany)

The paper is concerned with image registration algorithms for the alignment of computer tomography (CT) and 3D-ultrasound (US) images of the liver. The necessity of registration arises from the surgeon's request to benefit from the planning data during surgery. The goal is to align the planning data, derived from pre-operative CT-images, with the current US-images of the liver acquired during the surgery. The registration task is complicated by the fact, that the images are of a different modality, that the US-images are severely corrupted by noise, and that the surgeon is looking for a fast and robust scheme. To guide and support the registration, additional pairs of corresponding landmarks are prepared. We will present two different approaches for registration. The first one is based on the pure alignment of the landmarks using thin

plate splines. It has been successfully applied in various applications and is now transmitted to liver surgery. In the second approach, we mix a volumetric distance measure with the landmark interpolation constraints. In particular, we investigate the promising normalized gradient field

distance measure. We use data from actual liver surgery to illustrate the applicability and the characteristics of both approaches. It turns out that both approaches are suitable for the registration of multi-modal images of the liver.

6918-08, Session 2

Intraoperative adaptation and visualization of preoperative risk analyses for oncologic liver surgery

C. Hansen, MeVis Research GmbH (Germany); S. Schlichting, Univ. Schleswig-Holstein (Germany); S. Zidowitz, A. Köhn, M. Hindennach, MeVis Research GmbH (Germany); M. Kleemann, Univ. Schleswig-Holstein (Germany); H. Peitgen, MeVis Research GmbH (Germany)

Tumor resections from the liver are complex surgical interventions. With recent planning software, risk analyses based on individual liver anatomy can be carried out preoperatively. However, additional tumors within the liver are frequently detected during oncological interventions using intraoperative ultrasound. These tumors are not visible in preoperative data and their existence may enforce changes to the resection strategy. We propose a new method that allows an intraoperative risk analysis adaptation by merging newly detected tumors with a preoperative risk analysis. To determine the exact positions and sizes of these tumors we make use of a navigated ultrasound-system. A fast XML-based communication protocol enables our application to exchange crucial data with this navigation system during an intervention.

A further motivation for our work is to improve the visual presentation of a moving ultrasound plane within a complex, interweaving three-dimensional planning model including vascular systems, tumors and organ surfaces. In case the ultrasound plane is located inside the liver, occlusion of the ultrasound plane by the planning model is an inevitable problem for the applied visualization technique. Our system allows the surgeon to focus on the ultrasound image while perceiving context-relevant planning information. To improve orientation ability and distance perception, we include additional depth cues through new illustrative visualization algorithms.

Preliminary evaluations confirm that in case of intraoperatively discovered tumors a risk analysis adaptation is beneficial for precise liver surgery. Our new GPU-based visualization approach provides the surgeon with a simultaneous visualization of planning models and navigated 2D ultrasound data while minimizing occlusion problems.

6918-09, Session 2

Adaptive visualization for needle guidance in RF liver ablation: taking organ deformation into account

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Interventional procedures on deformable organs pose difficulties for the radiologists when inserting the probe towards a lesion. The deformation due to the breathing makes a reliable and automated alignment of the interventional 2D CT-Fluoro to the pre-interventional 3D CT-Volume very challenging. Such alignment is highly desirable since, during the intervention, the CT-Volume brings more information as it is enhanced with contrast agent and has a higher resolution than the CT-Fluoro slice. A reasonable solution for the alignment is obtained by employing a robust optimization technique. However, since we would like to help the needle guidance towards the lesion, due to the involved deformation, a single slice of the 3D CT-Volume is not satisfactory.

The main contribution of this paper consists in visualizing slices of the 3D CT-Volume that are resulting from the out-of-plane motion parameters along weighted isosurfaces in the convergence basin of the similarity function used during the alignment. This visualization copes with the uncertainty in estimating the deformation and brings much

more information than a single registered slice. Three experienced interventional radiologists were consulted and their evaluation clearly highlighted that such visualization unfolding the neighborhood with the belonging structures, like vessels and lesion spread, will help the needle guidance.

6918-10, Session 2

Visualization tool for improved accuracy in needle placement during percutaneous radio-frequency ablation of liver tumors

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The European research network "Augmented reality in Surgery" (ARIS*ER) developed a system that supports percutaneous radio frequency ablation of liver tumors. It is based on the software framework "Studierstube" and has been developed at TU Graz. The prototype system runs on a liver phantom and has been assembled at the Interventional Centre in Oslo. The system provides interventionists, during placement and insertion of the RFA needle, with information from pre-operative CT images and real-time tracking data. Based on an analysis of intra-operative tasks (user-medical image interactions), a visualization tool has been designed at TU Delft. It aims to support exploration of the abdomen, planning of needle trajectory and insertion of the needle in the most efficient way.

This work describes a first evaluation of the system, where user performances and induced workload of two visualization concepts of the tool - needle view and user view - are compared. After being introduced to the system, ten subjects performed three needle placements with both concepts. Task fulfillment rate, time for completion of task, special incidences, accuracy of needle placement, and subjective as well as objective workload ratings were recorded and analyzed.

The results show ambiguous results with beneficial and less favorable effects on user performance and workload of both concepts. Effects depend on characteristics of intra-operative tasks as well as on task complexities depending on tumor location. The results give valuable input for the next design steps.

6918-11, Session 2

Development of preoperative liver and vascular system segmentation and modeling tool for image-guided surgery and surgical planning

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Image-guided liver surgery (Linasy device, Pathfinder Therapeutics, Inc., Nashville, TN) requires a user-oriented, easy-to-use, fast segmentation and preoperative surgical planning system. This system needs to build liver models displaying the liver surface, tumors, and the vascular system of the liver. Tools that currently exist to perform these functions are too time-consuming, required well-trained professionals, and do not contain an export to the Linasy system. A robust and efficient tool for this purpose was developed and evaluated. For the liver surface or other bulk shape organ segmentation, the delineation was conducted on multiple slices of a CT image volume with a region growing algorithm. This algorithm incorporates both spatial and temporal information of a propagating front to advance the segmenting contour. The user can reduce the number of delineation slices during the processing by using interpolation. Our findings showed that up to 1 cm can be interpolated between delineations. The acceptable interpolation distance depended on the smoothness of the liver over the interpolated region. Comparing our liver segmentation results on to those from MeVIS (Bremen, Germany), the average overlap percentage was 94.55%. For portal and hepatic vein segmentation, three-dimensional region growing based on image intensity was used. All second generation branches can be identified without time-consuming image filtering and manual editing. The two veins are separated by using mutually exclusive region growing. The tool can be used to conduct segmentation and modeling of the liver, veins, and other organs and prepare data export to the Linasy within one hour.

6918-12, Session 3

From pre-operative cardiac modeling to intra-operative virtual environments for surgical guidance: an in vivo study

C. A. Linte, Robarts Research Institute (Canada) and Univ. of Western Ontario (Canada); M. Wierzbicki, Grand River Regional Cancer Ctr. (Canada); J. Moore, C. Wedlake, Robarts Research Institute (Canada); A. D. Wiles, Robarts Research Institute (Canada) and Univ. of Western Ontario (Canada); D. Bainbridge, Univ. of Western Ontario (Canada); T. M. Peters, Robarts Research Institute (Canada) and Univ. of Western Ontario (Canada)

As part of an ongoing theme in our laboratory on reducing morbidity during minimally-invasive intracardiac procedures, we developed a computer-assisted intervention system that provides safe access inside the beating heart and sufficient visualization to deliver therapy to intracardiac targets while maintaining the quality of the procedure. Integrating pre-operative information, 2D trans-esophageal ultrasound for real-time intra-operative imaging, and surgical tool tracking using the NDI AuroraTM magnetic tracking system in an augmented virtual environment, our system allows the surgeons to navigate instruments inside the heart in spite of the lack of direct target visualization. This work focuses on further enhancing intracardiac visualization and navigation by supplying the surgeons with detailed 3D dynamic cardiac models constructed from high-resolution pre-operative MR data and overlaid onto the intra-operative imaging environment. Here we report our experience during an in vivo intra-cardiac procedure on a porcine subject. A feature-based registration technique previously explored and validated in our laboratory was employed for the pre-operative to intra-operative mapping. This registration method is suitable for {it in vivo} interventional applications as it involves the selection of easily identifiable landmarks, while ensuring a good alignment of the pre-operative and intra-operative surgical targets. The resulting augmented reality environment fuses the pre-operative cardiac model with the intra-operative real-time US images with a ~ 5 mm accuracy for structures located in the vicinity of the valvular region. Therefore, we strongly believe that our augmented virtual environment significantly enhances intracardiac navigation of surgical instruments, whereas on-target detailed manipulations are performed under real-time US guidance.

6918-13, Session 3

Object identification accuracy under ultrasound enhanced virtual reality for minimally invasive cardiac surgery

A. D. Wiles, C. A. Linte, Univ. of Western Ontario (Canada) and Robarts Research Institute (Canada); J. Moore, C. Wedlake, Robarts Research Institute (Canada); T. M. Peters, Univ. of Western Ontario (Canada) and Robarts Research Institute (Canada)

A 2D ultrasound enhanced virtual reality surgical guidance system has been under development for some time in our lab now. The new surgical guidance platform has been shown to be effective in both the laboratory and clinical settings, however, the accuracy of the tracked 2D ultrasound has not been investigated in detail in terms of the applications for which we intend to use it (i.e. mitral valve replacement and atrial septal defect closure). This work focuses on the development of an accuracy assessment protocol specific to the assessment of the calibration methods used to determine the rigid transformation between the ultrasound image and the tracked sensor. We also examine the various accuracy related parameters associated with different styles of ultrasound transducers such as focal region, beam width, etc. Specifically, we test a Z-bar phantom calibration method and a phantomless calibration method; and we also compare the accuracy of tracking ultrasound images from transthoracic, transesophageal, intracardiac and laparoscopic ultrasound transducers. This work provides a fundamental quantitative description of the accuracy that can be obtained with this new surgical guidance system.

6918-14, Session 3

Coregistered volumetric true 3D ultrasonography in image-guidance neurosurgery

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Intraoperative ultrasound (iUS) is an important neuronavigational aid in image-guided open cranial neurosurgeries because of its low cost, easy implementation and real time image acquisition. The use of iUS for brain shift compensation during the course of surgery is maximized when coregistered with preoperative magnetic resonance images (pMR) of the patient's head to improve the delineation of parenchymal structures, due to the image noise, poor soft tissue contrast, artifacts and limited feature localization accuracy in iUS. Two dimensional iUS (2DiUS) is currently the leading ultrasonic imaging tool used in the operating room (OR). However, gaps of imaging planes and limited sampling in 2DiUS result in an incomplete imaging of the internal anatomical structure of interest (e.g., tumor). In this paper, we investigated and evaluated the use of a coregistered true three-dimensional iUS (3DiUS) generated from a broadband matrix array transducer (X3-1) on a Phillips iU22 intelligent Ultrasound System. This 3DiUS system is able to provide full 3D sampling over the tumor volume with high resolution dicom images directly achieved from the ultrasound system without the need for free-hand sweeping or 3D reconstruction. Comparing with coregistered 2DiUS (e.g. curved array transducer C8-5) in terms of image quality, sampling and acquisition time, we show that 3DiUS provides improved tumor sampling and enhances integration into the surgical workflow, and holds promise for routine use in the OR.

6918-15, Session 3

Electromagnetic tracking system for minimal invasive interventions using a C-arm system with CT option: first clinical results

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Evaluation of a novel navigation system with electromagnetic tracking (EMT) in clinical routine.

Methods: The navigation system (CAPPa IRAD EMT, CAS innovations, Germany) consists of a PC with appropriate navigation software, the AURORA tracking system (NDI, Canada) and needles equipped with small coils in their tips for EMT navigation. After patient positioning, a 3D C-arm data set of the anatomic region of interest is acquired. The images are reconstructed and the 3D data set is directly transferred to the navigation system. Image loading and the image-to-patient registration are performed automatically. For image acquisition, a C-arm system with DynaCT option (Axiom Artis, Siemens Medical Solutions, Germany) was used. We performed different clinical applications, i.e. biopsies in the abdomen and spine, discographies, radio frequency ablations (RFA) and occlusion of arteries.

Results: All interventions were carried out without any complication. After a single planning scan the radiologists were able to place the needle in the desired anatomic region. During needle feed 2D imaging was performed only in a few cases for control reasons. For RFA of spine tumors more than one needle was positioned sequentially based on a single planning scan. The time between planning and final needle positioning was reduced in all cases compared to conventional methods. Moreover, the number of control scans was reduced tremendously. The deviations of the needle to the planned target were less than 5 mm.

Conclusion: The use of angiographic CT images in combination with EMT navigation systems allows a wide field of minimal invasive percutaneous interventions.

6918-16, Session 3

3D ultrasound guidance system for needle placement procedures

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This paper presents an ultrasound guidance system for needle placement procedures. The system integrates a real-time 3D ultrasound transducer with a 3D localizer and a tracked needle to enable real-time visualization of the needle in ultrasound. The system uses data streaming to transfer real-time ultrasound volumetric images to a separate workstation for visualization. The multi-planar reconstructions of the ultrasound volume are computed at the workstation using the tracking information, allowing for real-time visualization of the needle in ultrasound without aligning the needle with the transducer. The system simplifies the procedure and reduces the skill-level and training needed to perform accurate needle placements. The physician can therefore focus on the needle placement procedure without paying extra attention to aligning the needle with the ultrasound image plane. In addition, the physician has real-time visual feedback of the needle and the target even before the needle enters the patient's skin and the ultrasound image, allowing the surgery to be easily, safely and accurately planned. The superimposed needle can also greatly improve the poor visualization of the needle in the ultrasound image. Since the needle is not inserted through any fixed needle channel, the physician can enjoy full freedom of selecting the needle's orientation or position. No cumbersome accessories are attached to the ultrasound transducer, allowing the physician to use all his/her experience with regular ultrasound transducers.

6918-17, Session 4

Maximum likelihood estimation of the distribution of target registration error

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Accuracy is an important issue in the rigid-body point-based registration algorithms. The accuracy depends on the level of the noise that perturbs registering data sets. The noise in the data sets arises from the fiducial (point) localization error (FLE) that can have different isotropic or anisotropic distributions for each point in the data sets. The presence of FLE in the data sets leads to an imperfect registration. To compute the accuracy of the performed registration, an error measure is defined as the target registration error (TRE)-- the distance after registration between a pair of corresponding points which is not used in the registration process. In this paper, we derive an approximation of the distribution of TRE; we utilize the Maximum Likelihood function to estimate the registration parameters and their variances when FLE has different isotropic or anisotropic distributions for each point in the data sets. The variances are then used in a closed-form solution for TRE, previously presented by the authors, to derive the distribution of TRE. We demonstrate that the derived distribution of TRE matches the one obtained by numerical simulations.

6918-18, Session 4

A system for finding a 3D target without a 3D image

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We present here a framework for a system that tracks one or more 3D anatomical targets without the need for a preoperative 3D image. Multiple 2D projection images are taken using a tracked, calibrated fluoroscope. The user manually locates each target on each of the fluoroscopic views. A least-squares minimization algorithm triangulates the best-fit position of each target in the 3D space of the tracking system: using the known projection matrices from 3D space into image space, we use matrix minimization to find the 3D position that projects closest to the located target positions in the 2D images. A tracked endoscope, whose projection geometry has been pre-calibrated, is then introduced to the operating field. Because the position of the targets in the tracking space is known, a rendering of the targets may be projected onto the endoscope view, thus allowing the endoscope to be easily brought into the target vicinity

even when the endoscope field of view is blocked, e.g. by blood or tissue. An example application for such a device is trauma surgery, eg, removal of a foreign object. Time and scheduling considerations may prohibit the acquisition of a 3D image, such as a CT scan, which is required for traditional image guidance systems; it is however advantageous to have 3D information about the target locations available, which is not possible using fluoroscopic guidance alone.

6918-19, Session 4

Feasibility of 3D tracking of surgical tools using 2D single-plane x-ray projections

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Fluoroscopy is frequently used for image-guidance, however its planar images provide limited information about the location of the surgical tools or targets in three-dimensional space. A modified and iterative form of the projection-Procrustes technique has demonstrated the ability to accurately determine three-dimensional positions and orientations of known sparse objects from a single, perspective projection. We assess the feasibility of applying this technique to the tracking of surgical tools by measuring its precision and accuracy through in vitro experiments. Two phantoms were fabricated to perform this assessment: a grid plate phantom with numerous point-targets at regular distances from each other; and a sparse object used as a surgical tool phantom. Two-dimensional planar radiographs of the phantoms were acquired using an image intensifier based Siemens Multistar C-arm x-ray unit. The weighted-centroids of the fiducials projected onto the planar radiographs were calculated using an automated segmentation and localization algorithm. The tip of the surgical tool phantom was localized in three-dimensions from a single-perspective x-ray projection using the iterative form of the projection-Procrustes technique. The accuracy of the localization is measured by comparison of the Euclidean distances between calculated phantom tip locations with the known dimensions of the grid plate phantom. Precision was determined through a set of repeated measures on several projection images acquired with the phantoms in a static position. The three-dimensional root-mean-square error of localizing the phantom tool tip was 0.23 mm. The two-dimensional root-mean-square precision of localizing the sparse objects from the projection images was 0.018 mm.

6918-20, Session 4

Automatic extraction of the mid-sagittal plane using an ICP variant

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Precise knowledge of the mid-sagittal plane is important for the assessment and correction of several deformities. Furthermore, the mid-sagittal plane can be used for the definition of standardized coordinate systems such as pelvis or skull coordinate systems. A popular approach for mid-sagittal plane computation is based on the selection of anatomical landmarks located either directly on the plane or symmetrically to it. However, the manual selection of landmarks is a tedious, time-consuming and error-prone task, which requires great care. In order to overcome this drawback, previously it was suggested to use the iterative closest point (ICP) algorithm: After an initial mirroring of the data points on a default mirror plane, the mirrored data points should be registered iteratively to the model points using rigid transforms. Finally, a reflection transform approximating the cumulative transform could be extracted. In this work, we present an ICP variant for the iterative optimization of the reflection parameters. It is based on a closed-form solution to the least-squares problem of matching data points to model points using a reflection. In experiments on CT pelvis and skull datasets our method showed a better ability to match homologous areas.

6918-21, Session 4

The distribution of registration error of a fiducial marker in rigid-body point-based registration

R. Balachandran, J. M. Fitzpatrick, Vanderbilt Univ.

Many image-guidance surgical systems rely on rigid-body, point-based registration of fiducial markers attached to the patient. Marker locations in image space and physical space are used to provide the transformation that maps a point from one space to the other. Target registration error (TRE) is known to depend on the fiducial localization error (FLE), and the fiducial registration error (FRE) of a set of markers, though a poor predictor of TRE, is a useful predictor of FLE. All fiducials are typically weighted equally for registration purposes, but is also a common practice to ignore a marker at position r by zeroing its weight when its individual error, $FRE(r)$, is high in an effort to reduce TRE. The idea is that such markers are likely to have been compromised, i.e., perturbed badly between imaging and surgery. While ignoring a compromised marker may indeed reduce TRE, the expected effect of ignoring an uncompromised marker is to increase TRE. There is unfortunately no established method for deciding whether a given marker is likely to have been compromised. In order to make this decision, it is necessary to know the probability distribution $p(FRE(r))$, which has not been heretofore determined. With such a distribution, it may be possible to identify a compromised marker and to adjust its weight in order to improve the expected TRE. In this paper we derive an approximate formula for $p(FRE(r))$ accurate to first order in FLE. We show by means of numerical simulations that the approximation is valid.

6918-22, Session 4

A new method of automatic landmark tagging for shape model construction via local curvature scale

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Segmentation and modelling of organs is a difficult task requiring very often the use of model-based approaches, such as Active Shape Model (ASM), which have proved to be powerful tools for medical image segmentation and understanding. To build the model, we need an annotated training set representing correspondences among shapes. Manual positioning of landmarks is a tedious, time-consuming, and error prone task, and almost impossible in the 3D space. To overcome some of these drawbacks, we devised an automatic method based on the notion of c-scale, a new local scale concept. For each boundary element b , the arc length of the largest homogeneous curvature region connected to b is estimated as well as the orientation of the tangent at b . With this shape description method, we can automatically locate mathematical landmarks selected at different levels of detail. The method avoids the use of landmarks for the generation of the mean shape. The selection of landmarks on the mean shape is done automatically using the c-scale method. Then, these landmarks are propagated to each shape in the training set, defining this way the correspondences among the shapes. The method is evaluated on 40 MRI foot data sets, the object of interest being the talus bone. The results show that, for the same number of landmarks, the proposed method is more compact than manual annotation, yet, it places landmarks roughly at locations similar to those selected by a human operator. This method is applicable to spaces of any dimensionality, although we have focused in this paper on 2D shapes.

6918-23, Session 5

Ultrasound calibration using intensity-based image registration: for application in cardiac catheterization procedures

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We present a novel method to calibrate a 3D ultrasound probe which has a 2D transducer array. By optically tracking a calibrated 3D probe we are able to produce extended field of view 3D ultrasound images. Tracking also enables us to register our ultrasound images to other tracked and calibrated surgical instruments or to other tracked and calibrated imaging devices. Our method applies rigid intensity-based image registration to three or more ultrasound images. These images can either be of a simple phantom, or could potentially be images of the patient. In this latter case we would have an automated calibration system which required no phantom, no image segmentation and was optimized to the patient's ultrasound characteristics i.e. speed of sound. We have carried out experiments using a simple calibration phantom and with ultrasound images of a volunteer's liver. Results are compared to an independent gold-standard. These showed our method to be accurate to 1.5mm using the phantom images and 1.6mm using the liver data, which is slightly better than the traditional point-based calibration method (1.7mm in our experiments).

6918-24, Session 5

Augmented reality image guidance for minimally invasive

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We present a novel system for image guidance in totally endoscopic coronary artery bypass (TECAB). A key requirement is the availability of 2D-3D registration techniques that can deal with non-rigid motion and deformation. Image guidance for TECAB is mainly required before the mechanical stabilization of the heart, thus the most dominant source of non-rigid deformation is the motion of the beating heart.

To augment the images in the endoscope of the da Vinci robot, we have to find the transformation from the coordinate system of the preoperative imaging modality to the system of the endoscopic cameras.

In a first step we build a 4D motion model of the beating heart. Intraoperatively we can use the ECG or video processing to determine the phase of the cardiac cycle. We can then take the heart surface from the motion model and register it to the stereo endoscopic images of the da Vinci robot using 2D-3D registration methods. We are investigating robust feature tracking and intensity-based methods for this purpose.

Images of the vessels available in the preoperative coordinate system can then be transformed to the camera system and projected into the calibrated endoscope view using two video mixers with chroma keying. It is hoped that the augmented view can improve the efficiency of TECAB surgery and reduce the conversion rate to more conventional procedures.

6918-25, Session 5

Image-based mass-spring model of mitral valve closure for surgical planning

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Surgical repair of the mitral valve can be difficult even for skilled surgeons. A surgical planning system based on patient-specific medical images that allows surgeons to simulate and compare potential repairs could greatly improve surgical success rates. The mathematical model of mechanics used to close the valve must be able to detect and resolve self-collisions, to handle the complex boundary conditions imposed by the chords

tethering the valve, and to compute the closed state quickly. We have developed a system for generating a triangulated mesh of the valve surface based on volumetric image data of the opened valve. We then compute the closed position of the mesh using a mass-spring model of dynamics. The triangulated mesh is produced by fitting an isosurface to the volumetric image data, and boundary conditions, including the valve annulus and chord endpoints, are determined from the image data using a graphical user interface. In the mass-spring model, every side of each triangle is treated as a linear spring, and every side shared by two triangles is treated as a bending spring, with parameters that represent

material properties derived from experimental studies. Chords are treated as nonlinear springs, and self-collisions are detected using 3-d bounding boxes and triangle intersection. We represented the mitral valve with 361 nodes joined by 419 triangles and 22 chords, and this model exhibited rapid valve closure, with realistic self-collision handling and effects of chords.

6918-26, Session 5

Image-based physiological monitoring of cardiac function

C. S. Maier, Siemens Corporate Research and Deutsches Krebsforschungszentrum (Germany); M. Bock, W. Semmler, Deutsches Krebsforschungszentrum (Germany); C. H. Lorenz, Siemens Corporate Research

A new framework for image based physiological cardiac monitoring based on repeated imaging of critical slice locations in an interventional MRI environment is proposed. The aim of this work is to provide a method of detecting pathological changes in the left ventricular (LV) myocardial wall motion where the standard method of using the ECG for monitoring is not possible due to distortions by the magnetic field. First MRI LV short axis images are acquired for different phases of the cardiac cycle over RR intervals. Then LV contours are detected based on an established segmentation algorithm. The contour's Fourier Descriptors are calculated to classify myocardial wall into two classes contracted or not contracted. The classifier is trained during an initial observation period before a pathological change might occur during an intervention. A contour rejected by the classifier using the unconditional, predictive probability of the contour's observation vector as confidence measure is interpreted as a pathological change in the LV myocardial wall motion. To evaluate the performance of the classifier a simple model is introduced for simulating the contours of a pathological, ischemic, LV myocardial wall. The overall performance of the classifier on 516 samples based on healthy volunteer images and 3096 simulated ischemic samples yielded a mean classification error for supervised training of 5.7% and for unsupervised training of 8.7%.

6918-27, Session 5

Enhanced cardio vascular image analysis by combined representation of results from dynamic MRI and anatomic CTA

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The diagnosis support in the field of coronary artery disease (CAD) is very complex due to the numerous symptoms leading to the final diagnosis. MRI and CTA are on their way to replace invasive catheter angiography. Thus, there is a need for sophisticated software tools that present the different analysis results, and correlate the anatomical and dynamic image information. We introduce a new software assistant for the combined result visualization of MRI and CTA images. Therefore, we developed a dedicated concept for the structured presentation of original data, result masks from the segmentation, and individual findings. For each of them we define a class hierarchy and assign suitable interaction functions. To this end, user guidance is coupled as closely as possible with available data, supporting a straightforward workflow design. Our analysis results are extracted from two previously developed software assistants, providing coronary artery analysis and measurements, function analysis as well as perfusion and late enhancement data investigation. To make distinctive features and according measurements accessible, we have to extend their functionality. Thus, we introduce a finding concept, which directly relates suspicious positions to the underlying data. The application of registration methods and the AHA 17-segment model in our new software assistant enables the coupling of local findings to positions in all datasets. Furthermore, sophisticated visualization in 2D and 3D and interactive bull's eye plots facilitate a correlation of the coronary stenoses and the physiology. The software has been evaluated on 20 patient datasets.

6918-28, Session 6

Robo-surgeon: combining medical imaging and mechanical models to automate surgery (Keynote)

R. D. Howe, Harvard Univ.

Current surgical robots are teleoperated: the surgeon must specify every move of the instruments. By combining medical imaging and mechanical models, we can envision methods for automating much of soft tissue surgery. Interactive image processing will identify the target anatomy. Mechanical models can be created from these images, so that the outcome of different instrument motions can be compared using model predictions. Robotic instruments will then execute the optimum approach, using real-time image processing and modeling for guidance. Automating surgery will require new developments in image processing, mechanical model generation, and real-time control. These new techniques will be immediately useful for enhancing today's image-guided procedures, in such areas as neurosurgery, needle-based procedures, and intracardiac surgery.

6918-29, Session 6

Biomechanical modelling for breast image registration

A. W. C. Lee, V. Rajagopal, J. Chung, P. M. F. Nielsen, M. Nash, The Univ. of Auckland (New Zealand)

Breast cancer is a leading cause of death in women. Tumours are usually detected by palpation or X-ray mammography followed by further imaging, such as MRI or ultrasound. The ultimate aim of this research is to develop a biophysically-based computational tool that will allow accurate collocation of features (such as suspicious lesions) across multiple imaging views and modalities in order to help clinicians in the diagnosis of breast cancer. We have developed a computational framework for generating subject-specific, 3D, finite element models of the breast. MR images were obtained of the breast under gravity loading and neutrally buoyant conditions. Neutrally buoyant images, obtained whilst immersing the breast in water, were used to estimate the unloaded state of the breast (for present purposes, we have assumed that the densities of water and breast tissue are similar). These images were segmented to isolate the breast tissues and a tricubic Hermite finite element mesh was fitted to the digitised data points in order to produce a customised breast model. The model was deformed in accordance with finite deformation elasticity theory, to predict the gravity loaded state of the breast in the prone position. The unloaded breast images were embedded into the reference model and warped based on the predicted deformation. In order to analyse the accuracy of the model predictions, image comparison metrics, such as mutual information, cross-correlation and histogram-based comparison measures, were used to compare the warped, resampled images with the clinical images of the prone gravity loaded state. A biomechanical image registration tool of this kind will aid radiologists to provide more reliable diagnosis and localisation of breast cancer.

6918-30, Session 6

Development of an anthropomorphic breast software phantom based on region growing algorithm

C. Zhang, P. R. Bakic, A. D. A. Maidment, The Univ. of Pennsylvania Health System

In radiography, breast phantoms have been widely used for optimization of imaging modalities, as well as for evaluation of image post-processing algorithms. The realism of such generated synthetic images depends on methods for simulation of 3D breast anatomical structures. We present here a novel algorithm for computer simulation of breast anatomy as an extension of our software breast phantom. The breast phantom includes the skin, adipose tissue, fibroglandular tissue, and the matrix of Cooper's ligaments. The simulation approach is based upon a region growing procedure; adipose compartments are grown with different speed and orientation, starting from a selected set of seed points. The region growing algorithm provides more compact volume coverage and more realistic appearance of the simulated phantom images. We were able to simulate a wide range of phantoms with different cup size, tissue glandularity, or compartment size distribution, thus covering the breast

anatomical variety. An accompanying abstract presents our results of finite element modeling of breast phantom deformation and simulation of tomosynthesis acquisition and reconstruction.

6918-31, Session 6

A deformation model for non-rigid registration in image-guided kidney surgery

R. Ong, S. D. Herrell III, M. I. Miga, R. L. Galloway, Jr., Vanderbilt Univ.

In order to facilitate the removal of tumors during partial nephrectomies, an image-guided surgery system may be useful. This system would require a registration of the physical kidney to a pre-operative image volume; however, it is unclear whether a rigid registration would be sufficient. One possible source of non-rigid deformations is the clamping of the renal artery during surgery and the subsequent outflow of blood. In order to explore this issue, a model of kidney deformation was developed based on Biot's consolidation model. The model was tested on a resected human kidney in which the renal artery and vein and ureter were clamped. CT and laser range scanner images of the kidney were obtained before and after the deformation caused by unclamping, and fiducials embedded on the surface of the kidney allowed the deformation to be tracked. The accuracy of the kidney model was assessed by comparing the predicted to the fiducial-tracked displacements.

6918-32, Session 7

Recognition of risk situations based on endoscopic instrument tracking and knowledge-based situation modeling

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Minimally invasive surgery has gained significantly in importance over the last decade due to the numerous advantages on patient-side. The surgeon has to adapt special operation-techniques and deal with difficulties like the complex hand-eye coordination, limited field of view and restricted mobility. To alleviate these constraints we propose to enhance the surgeon's capabilities by providing a context-aware assistance using augmented reality techniques. In order to generate a context-aware assistance it is necessary to recognize the current state of the intervention using intraoperatively gained sensor data and a model of the surgical intervention. In this paper we present the recognition of risk situations, the system warns the surgeon if an instrument gets too close to a risk structure. The context-aware assistance system starts with an image-based analysis to retrieve information from the endoscopic images. This information is classified and a semantic description is generated. This description is used to recognize the current state and launch an appropriate AR visualization. In detail we present an automatic vision-based instrument tracking to obtain the positions of the instruments. Situation recognition is performed using a knowledge representation based on a description logic system. Two augmented reality visualization programs are realized to warn the surgeon if a risk situation occurs.

6918-33, Session 7

Three-dimensional bronchial simulator: automatic generation of volumetric CT images for assessment of bronchial parameter quantification methods

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The problem of quantifying bronchial parameter from multi-detector computed tomography (MDCT) data has been highly studied in medical research. While the developed methods have been tested and validated on cylindrical computer/physical phantoms or by experimented radiologists on in-vivo/in-vitro CT image data, today there is no established ground truth enabling to compare the different results. This paper proposes an original approach allowing to simulate CT image acquisitions of realistic 3D bronchus-vessel configurations

starting from mesh models of perfectly known parameters, with easily modifiable geometry and topology according to different pathology characteristics. The bronchial simulator platform, BSCT3D, is composed of several modules: 1) 3D model generation of bronchus inner and outer wall surfaces of different calibers, shapes and orientations, 2) texture volume creation corresponding to the lung parenchyma including or not blood vessels, 3) simulation of CT image acquisition mimicking the scanning process. The proposed model generation method relies on the construction of a consistent 2-manifold surface of branching structure with given medial axis and local radii. First, a coarse triangular mesh is created by connecting polygonal cross-sections along the medial axis. The model is then refined and locally deformed in the surface normal direction under specific force constraints which stabilize its evolution at the level of the input radii. By generating a pathology-specific database, BSCT3D will contribute to the building of a test-bed for bronchial parameter quantification. BSCT3D is currently used to lead various validations of existing approaches with respect to the clinical objective of airway wall remodeling assessment.

6918-34, Session 7

Visual enhancement of facial tissue in endoscopy

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A colon resection, necessary in case of colon cancer, can be performed minimally invasively by laparoscopy. Before the affected part of the colon can be removed, however, the colon must be mobilized. A good technique for mobilizing the colon is to use Gerota's fascia as a guiding structure, i.e. to dissect along this fascia, without harming it. The challenge of this technique is that Gerota's fascia is usually difficult to distinguish from other tissue.

In this paper, we present an approach to enhance the visual contrast between fatty tissue covered by Gerota's fascia and uncovered fatty tissue, and the contrast of both structures to the remaining soft tissue in real time (25 frames per second). As fasciae are whitish transparent tissues, they cannot be identified by means of their color itself. Instead, we found that their major difference is the color saturation. To enhance their visible contrast, we applied a non-linear transformation to the saturation.

An off-line evaluation was carried out consulting two specialists in laparoscopic colon resection. We presented them four scenes from two different interventions in which our enhancement was applied together with the original scenes. These scenes did not only contain situations where Gerota's fascia had to be found, but also situations where aerosol from ultrasonically activated scissors inhibited the clear vision, or situations where critical structures such as the ureter or nerves had to be identified under fascial tissue. The surgeons stated that our algorithm clearly offered an information gain in all of the presented scenes so the colon mobilization could be carried out easier, faster, and safer. Moreover, the algorithm did not hamper the view in case of appearing aerosol or the visibility of an ureter or nerves.

6918-35, Session 7

A navigation system using projection images of laparoscopic instruments and a surgical target with improved image quality

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We propose the projector-based augmented reality (PBAR) system using projection images of laparoscopic instruments and a surgical target for laparoscopic surgery. Furthermore, three methods are adopted for improved quality of projection images: 1) Compensation for body motion of a patient. 2) High accurate calibration method. 3) Size reduction of the system. The two kinds of the dry lab experiments are conducted to validate the significance of the proposed system for safe and smooth forceps insertion.

6918-36, Session 7

An evaluation environment for respiratory motion compensation in navigated bronchoscopy

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For exact orientation inside the tracheobronchial tree, clinicians would greatly profit from a navigation system for bronchoscopy. Such an image guided system giving the ability to show the current position of a bronchoscope (an instrument to inspect the inside of the lung) or a catheter within the tracheobronchial tree, would significantly improve orientation inside the complex airway structure and the depth of insertion into it. A major challenge for a bronchoscopy navigation system is respiratory motion. Recently more and more developments of navigated bronchoscopy systems use the tracheobronchial centerline as a constraint to compensate for respiratory motion or to correct distorted position information of an electromagnetic tracking system. But the performance of this constraint has not been evaluated yet. We developed an evaluation environment which simulates a random insertion of a tracking sensor into a tracheobronchial tree, adding electromagnetic noise and distortion similar to an operation room table, and harmonic respiratory motion to the tracked position. With this environment a high number of insertion tracks can be created and used to optimize methods for minimizing the electromagnetic tracking error and compensating respiratory movement. The authors encourage other researchers to use this evaluation environment to test different correction and estimation algorithms for navigated bronchoscopy.

6918-37, Session 7

Robust distortion correction of endoscope system

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Endoscopic images suffer from a fundamental spatial distortion due to the wide angle design of the endoscope lens. This barrel-type distortion is an obstacle for subsequent Computer Aided Diagnosis (CAD) algorithms and needs to be corrected. Various methods and research models for the barrel-type distortion correction have been proposed and studied. For industrial applications, a stable, robust method with high accuracy is required to calibrate the different types of endoscopes in an easy of use way. The correction area shall be large enough to cover all the regions that the physicians need to see. In this paper, we present our endoscope distortion correction procedure which includes data acquisition, distortion center estimation, distortion coefficients calculation, and look-up table (LUT) generation. We investigate different polynomial models used for modeling the distortion and propose a new one which provides correction results with better visual quality. The method has been verified with four types of colonoscopes. The correction procedure is currently being applied on human subject data and the coefficients are being utilized in the subsequent 3D reconstruction project of colon.

6918-38, Session 7

Method for radiometric calibration of an endoscope's camera and light source

W. E. Higgins, L. Rai, The Pennsylvania State Univ.

An endoscope is a commonly used instrument to perform minimally invasive visual-examination of the tissues inside the body. A physician uses the endoscopic video images to identify tissue abnormalities. The images, however, are highly dependent on the optical properties of the endoscope and its orientation and location with respect to the tissue structure. The analysis of endoscopic video images is therefore purely subjective. Studies suggest that the fusion of endoscopic video images (providing color and texture information) with virtual endoscopic views (providing structural information) can be useful for assessing various pathologies, for several applications: (1) surgical simulation, training, and pedagogy; (2) the creation of a database for pathologies; and (3) the building of patient-specific models. Such a fusion requires both geometric and radiometric alignment of endoscopic video images in the texture space. Inconsistent estimates of texture/color of the tissue

surface results in seams when multiple endoscopic video images are combined together. This paper (1) identifies the endoscope-dependent variables to be calibrated for objective and consistent estimation of surface texture/color and (2) presents an integrated set of methods to measure them. Results show that the calibration method can be successfully used to estimate objective color/texture values for simple planar scenes and significantly reduce seams when used for constructing a mosaic. Uncalibrated endoscopes performed very poorly for the same tests.

6918-61, Poster Session

Validation of the use of photogrammetry to register pre-procedure MR images to intra-procedure patient position for image-guided cardiac catheterization procedures

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A hybrid x-ray and magnetic resonance imaging system (XMR) has been proposed as an interventional guidance strategy for cardiovascular catheterization procedure. However, very few hospitals can benefit from the XMR system because of its high cost and limited availability. In this paper we describe a new guidance strategy for cardiovascular catheterization procedure. In our technique, intra-operative patient position is estimated by using a chest surface constructed from a photogrammetry system. The chest surface is then registered with the same surface derived from pre-procedure magnetic resonance (MR) images. The catheterisation procedure can therefore be guided by a roadmap derived from the MR images. Patients were required to hold the breath at end expiration during MRI acquisition. The quality of the chest surface images is usually high enough to allow the chest surface to be extracted automatically. The surface matching accuracy is improved by using a robust trimmed iterative closest point (ICP) matching algorithm, which is especially designed for incomplete surface matching. Compared to the XMR system, the proposed guidance strategy is low cost and easy to set up. Experimental data were acquired from 6 volunteers and 1 patient. The patient data were collected during an electrophysiology procedure. In 6 out of 7 subjects, the experimental results show our method is accurate in term of reciprocal residual error (range from 1.66mm to 3.75mm) and consistent (closed-loop TREs range from 1.49mm to 3.55mm). For one subject, trimmed ICP failed to find the optimal transform matrix (residual = 4.89, TRE = 9.32) due to the poor quality of the photogrammetry-reconstructed surface. More studies are being carried on in clinical trials.

6918-62, Poster Session

Evaluation of the use of multimodality skin markers for the registration of pre-procedure cardiac MR images and intra-procedure x-ray fluoroscopy images for image guided cardiac electrophysiology procedures

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This paper presents the evaluation of the use of multimodality skin markers for the registration of cardiac MR image data to x-ray fluoroscopy data for guidance of cardiac electrophysiology procedures. The approach was applied to 3 patients undergoing pulmonary vein (PV) isolation for treatment of paroxysmal atrial fibrillation. Skin markers were affixed to the patients' chest and used to register pre-procedure cardiac MR image data to intra-procedure fluoroscopy data. Registration errors were assessed using contrast angiograms of the left atrium that were

available in 2 out of 3 cases. A clinical expert generated "gold standard" registrations by adjusting the registration manually. Target registration errors (TREs) were computed using points on the PV ostia. Ablation locations were computed using biplane x-ray imaging. Registration errors were further assessed by computing the distances of the ablation points to the registered left atrial surface for all 3 patients. The TREs were 6.0 & 3.1mm for patients 1 & 2. The mean ablation point errors were 6.2, 3.8, & 3.0mm for patients 1, 2, & 3. These results are encouraging in the context of a 5mm clinical accuracy requirement for this type of procedure. We conclude that multimodality skin markers have the potential to provide anatomical image integration for x-ray guided cardiac electrophysiology procedures, especially if coupled with an accurate respiratory motion compensation strategy.

6918-63, Poster Session

Epicardial ablation guidance using coronary arterial models and live fluoroscopic overlay registrations

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Knowledge of patient-specific cardiac anatomy is required for catheter-based ablation in epicardial ablation procedures such as ventricular tachycardia (VT) ablation interventions. In particular, knowledge of critical structures such as the coronary arteries is essential to avoid collateral damage. In such ablation procedures, ablation catheters are brought in via minimally-invasive subxiphoid access. The catheter is then steered to ablation target sites on the left ventricle (LV). During the ablation and catheter navigation it is of vital importance to avoid damage of coronary structures.

Contrast-enhanced rotational X-ray angiography of the coronary arteries delivers a 3D impression of the anatomy during the time of intervention. Vessel modelling techniques have been shown to be able to deliver accurate 3D anatomical models of the coronary arteries.

To simplify epicardial navigation and ablation, we propose to overlay coronary arterial models, derived from rotational X-ray angiography and vessel modelling, onto real-time X-ray fluoroscopy. In a preclinical animal study, we show that overlay of intra-operatively acquired 3D arterial models onto X-ray allows placement of ablation lesions at a safe distance from coronary structures. Example ablation lesions have been placed based on the model overlay at distances between 5-10mm of artery structures.

6918-64, Poster Session

Four-chamber surface model from segmented cardiac MR

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This paper presents a novel method for the generation of a four-chamber surface model from segmented cardiac MRI. The method has been tested on 3D short-axis cardiac magnetic resonance images with strongly anisotropic voxels in the long-axis direction. It provides a smooth triangulated surface mesh that closely follows the endocardium and epicardium. The surface triangles are close-to-regular and their number can be preset. The input to the method is the segmentation of each of the four cardiac chambers. The same algorithm is independently used to generate the surface mesh of the epicardium and of the endocardia of the four cardiac chambers. For each chamber, a sphere that includes the chamber is centered at its barycenter. A triangulated surface mesh with almost perfectly regular triangles is constructed on the sphere. The number of vertices and triangles of the mesh can be preset. Then, the Laplace equation is solved over the region bounded by the segmented chamber surface and the sphere. Finally, each vertex from the triangulated mesh on the sphere is mapped from the sphere to the chamber surface by following the gradient flow of the solution of the Laplace equation. The proposed method was compared to the marching cubes algorithm. The proposed method provides a smooth mesh of the heart chambers despite the strong voxel anisotropy of the 3D images. This is not the case for the marching cubes algorithm, unless the mesh

is significantly smoothed. However, the smoothing of the mesh shrinks it, which makes it a less accurate representation of the chamber surface. The second advantage is that the mesh triangles are more regular for the proposed method than for the marching cubes algorithm. Finally, the proposed method allows for a finer control of the number of triangles than the marching cubes algorithm.

6918-65, Poster Session

MR-guided catheter-based excitation emission optical spectroscopy for in vivo tissue characterization

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Excitation emission spectroscopy (EES) has been used in the past to characterize many different types of tissue [1-3]. This technique involves the use of multiple excitation wavelengths with a complete optical spectrum being sampled for each, yielding an excitation-emission matrix (EEM). Using EES it is possible to determine the presence of more than one optical contrast agent since these dyes tend to have characteristic spectra that can be separated [4]. Furthermore, the extra information contained in the EEM can be used to determine relative fluorescent dye concentrations.

In this work, we demonstrate an excitation-emission spectrometer specifically designed for use in conjunction with MR. The EES is applied with an in-suite control setup that permits real-time navigation, utilizing active MR tracking catheters, and providing a platform for MR-guided tissue characterization. The setup can be applied for in vivo interrogation in both interstitial (e.g. cancer) and intravascular procedures (e.g. atherosclerosis and plaque).

6918-66, Poster Session

Investigation of new flow modifying endovascular image-guided interventional (EIGI) techniques in patient-specific aneurysm phantoms (PSAPs) using optical imaging

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Effective minimally invasive treatment of cerebral bifurcation aneurysms is challenging due to the complex and remote vessel morphology. An evaluation of endovascular treatment in a phantom involving image-guided deployment of new asymmetric stents consisting of polyurethane patches placed to modify blood flow into the aneurysm is reported. The 3D lumen-geometry of a patient-specific basilar-artery bifurcation aneurysm was derived from a segmented computed-tomography dataset. This was used in a stereolithographic rapid-prototyping process to generate a mold which was then used to create any number of exact wax models. These models in turn were used in a lost-wax technique to create transparent elastomer patient-specific aneurysm phantoms (PSAP) for evaluating the effectiveness of asymmetric-stent deployment for flow modification. Flow was studied by recording real-time digitized video images of optical dye in the PSAP and its feeding vessel. For three asymmetric stent placements: through the basilar into the right-posterior communicating artery, through the basilar into the left-posterior communicating artery, and the combination using two stents, the greatest deviation of flow streamlines away from the aneurysm occurred for the combination stent deployment. Flow was also substantially affected by variations of inflow angle into the basilar artery, resulting in alternations in washout times as derived from time-density curves. Evaluation of flow in the PSAPs with real-time optical imaging can be used to determine new EIGI effectiveness and to validate computational-fluid-dynamic calculations for EIGI-treatment planning and contrast-media flow results from x-ray angiographic procedures.

6918-67, Poster Session

Developing patient-specific anatomic models for validation of cardiac ablation guidance procedures

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Image-guided cardiac ablation has the potential to decrease procedure times and improve clinical outcome for patients with cardiac arrhythmias. There are several proposed methods for integrating patient-specific anatomy into the cardiac ablation procedure; however, these methods still require thorough validation. One of the primary challenges in validation is determining ground truth as a standard for comparison. Some validation protocols have been developed for animal models and in patients; however, these methods can be costly to implement and may increase the risk to patients. We have developed an approach to building patient-specific anatomic models at a low-cost in order to validate the guidance procedure without introducing additional risk to the patients. Using a pre-procedural CT, the blood pool of the left and right atria of a patient are segmented manually. In addition, several anatomical landmarks are identified in the image data. The segmented atria and landmarks are converted into a polygonalized model which is used to build a thin-walled patient-specific blood pool model in a stereo-lithography system. Thumbscrews are inserted into the model at the landmarks. The entire model is embedded in a platinum silicone material which has been shown to have tissue-mimicking properties with regards to ultrasound. Once the pliable mold has set, the blood pool model is extracted by dissolving the material. The resulting physical model correctly mimics a specific patient anatomy with embedded fiducials which can be used for validation experiments. The patient-specific anatomic model approach may also be used for pre-surgical practice and training of new interventionalists.

6918-68, Poster Session

Detection and characterization of lymph node on MR colorectal images

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Colorectal cancer is the second most common cause of death in Western countries. It is often curable by chemoradiotherapy and/or surgery; however, accurate staging has a significant impact on patient management and outcome. Numerous clinical reports attest to the fact that staging is not currently satisfactory, and so more precise methods are required for effective treatment. The three major components of disease staging are tumour size; whether or not there is distal metastatic spread; and the extent of lymph node involvement. Of these, the latter is currently by far the hardest to quantify, and it is the subject of this paper. Lymph nodes are distributed throughout the mesorectal fascia that envelops the colorectum. In practice, they are detected and assessed by clinicians using properties such as their size and shape. We are not aware of any previous image analysis approach for colorectal images that makes this subjective approach more scientific.

To aid precise staging and surgery, we have developed a method that characterises lymph nodes by extracting implicit properties as computed from (T2 weighted) magnetic resonance colorectal images. We first learn the probability density function (PDF) of the intensities of the mesorectal fascia and find that it closely approximates a Gaussian distribution. The parameters of a Gaussian, fitted to the PDF, were estimated and the mean intensity of a lymph node candidate was compared with it. The fitting provides an explicit criterion for a region to be classed as a lymph node: namely, it is an outlier of the Gaussian distribution.

As a key part of this process, we need to segment the boundaries of the mesorectal fascia, which is enclosed by two closed contours. Clinicians recognise the outer contour as thin edges. Since the thin edges are often ambiguous and disconnected, differentiating them from neighbouring tissues is a non-trivial problem; the surrounding tissues have no significant difference from the mesorectal fascia in both intensity and texture. We employed a level set method to segment three sets of objects: the mesorectal fascia, the colorectum and lymph node candidates. We found in our experiments that level set methods performed better for our purpose than other commonly used segmentation methods. Our segmentation results led us to build a PDF and to use it for the criterion

that we propose. The results of numerous clinical cases are summarised in the paper.

6918-69, Poster Session

Dynamic dosimetry and edema detection in prostate brachytherapy - a complete system

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Purpose: Brachytherapy (radioactive seed insertion) has emerged as one of the most effective treatment options for patients with prostate cancer, with the added benefit of a convenient outpatient procedure. The main limitation in contemporary brachytherapy is faulty seed placement, predominantly due to the presence of intra-operative edema (tissue expansion). Though currently not available, the capability to intra-operatively monitor the seed distribution, can make a significant improvement in cancer control. We present such a system here.

Methods: Intra-operative measurement of edema in prostate brachytherapy requires localization of inserted radioactive seeds relative to the prostate. Seeds were reconstructed using a typical non-isocentric C-arm, and exported to a commercial brachytherapy delivery system. Technical obstacles for 3D reconstruction on a nonisocentric C-arm include pose-dependent C-arm calibration; distortion correction; pose estimation of C-arm images; seed reconstruction; and C-arm to TRUS registration.

Results: In precision-machined hard phantoms with 40-100 seeds and soft tissue phantoms with 45-87 seeds, we correctly reconstructed the seed implant shape with an average 3D precision of 0.35 mm and 0.24 mm, respectively. In a DoD Phase-1 clinical trial on 6 patients with 48-82 planned seeds, we achieved intra-operative monitoring of seed distribution and dosimetry, correcting for dose inhomogeneities by inserting an average of 4.17 (1-9) additional seeds. Additionally, in each patient, the system automatically detected intra-operative seed migration induced due to edema (mean 3.84 mm, STD 2.13 mm, Max 16.19 mm).

Conclusions: The proposed system is the first of a kind that makes intra-operative detection of edema (and subsequent re-optimization) possible on any typical non-isocentric C-arm, at negligible additional cost to the existing clinical installation. It achieves a significantly more homogeneous seed distribution, and has the potential to affect a paradigm shift in clinical practice. Large scale studies and commercialization are currently underway.

6918-70, Poster Session

Comparative assessment of optical tracking systems for soft tissue navigation with fiducial needles

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In this paper, we compare two optical tracking systems with regard to their suitability for soft tissue navigation with fiducial needles: The Polaris system with passive markers (Northern Digital Inc. (NDI); Waterloo, Ontario, Canada), and the MicronTracker 2, model H40 (Claron Technology, Inc.; Toronto, Ontario, Canada). We introduce appropriate tool designs and assess the tool tip tracking accuracy under typical clinical light conditions in a sufficiently sized measurement volume. To assess the robustness of the tracking systems, we further evaluate their sensitivity to illumination conditions as well as to the velocity and the orientation of a tracked tool. While the Polaris system showed robust tracking accuracy under all conditions, the MicronTracker was highly sensitive to the examined factors.

6918-71, Poster Session

Method for evaluating compatibility of commercial Electromagnetic (EM) catheter tracking systems with surgical and imaging tables

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Electromagnetic (EM) tracking systems have been successfully used in ENT, cranial, and spine applications for several years. Catheter sized EM systems have also been used in tightly controlled cardiac mapping and pulmonary applications. These EM systems have the benefit of not requiring a line-of-sight between devices. Ferrous metals or conductive materials that are dynamically brought into the EM working volume may impact the tracking performance. Effective methods for detection of this EM field distortion and flagging the results are generally well known. Objects that have a static relationship to a tracking system can be compensated for.

New commercial EM catheter tracking systems offer opportunities for expanded image-guided procedures. It is important to know and understand how well these systems perform with different surgical brand tables and ancillary equipment. By their design and intended use, they will be utilized intracorporeally and therefore be in closer range to the surgical tables.

Our goal was to define a simple and portable process that could be used to estimate the EM tracker accuracy, and to vet a large number of popular surgery and imaging tables that are used in the United States and abroad.

6918-72, Poster Session

Automatic needle segmentation in 3D ultrasound images using 3D improved Hough transform

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In this paper, we propose a new automated technique, the 3D Improved Hough Transform (3DIHT) algorithm, to automatically segment a needle in a 3D ultrasound images. The 3DIHT algorithm is based on the coarse-fine search strategy and the representation $(\Phi, \theta, \rho, \alpha)$ of lines in 3D space, and is described below. Firstly, the 3D US image is cropped to discard portions of the 3D US image, which do not contain the needle or have the high gray value background structures, according to the information about the rough orientation and insertion point of the needle when the needle is inserted manually, or with a motorized mechanical device under computer control. Secondly, we used a coarse-fine search strategy in image space to segment needles in 3D US images. At the coarse stage, the optimal image resolution was determined by minimizing the computational complexity of the 3D Hough Transform (3DHT) method. In the lower resolution 3D US image, the needle was segmented quickly by using 3DHT without any prior information of the needle, and the approximate orientation and position $(\Phi', \theta', \rho', \alpha')$ of the needle were found. At the fine stage, the 3DHT was used to detect needles accurately and quickly while the parameter ranges were set to be the vicinity of $(\Phi', \theta', \rho', \alpha')$. The algorithm was evaluated by using wagger phantoms. The average segmentation position deviations were less than 1mm and angular deviations were much less than 2. The average computational time measured on Pentium D 2.80GHz PC computer was less than 2s.

6918-73, Poster Session

Low-cost respiratory motion tracking system for PET/CT

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INTRODUCTION: Lung cancer is the cause of more than 150,000 deaths annually in the United States. Early and accurate detection of lung tumor with Positron Emission Tomography has enhanced lung tumor diagnosis. However, respiratory motion during the imaging period of PET results in the reduction of accuracy of detection due to blurring of the images.

METHODS: For tracking the chest motion, an optical laser tracking system is designed which tracks the motion of a patterned card placed on the chest by illuminating the pattern with two structured light sources, generating 8 positional markers. The position of markers is used to determine the vertical, translational, and rotational motion of the card. Information from the markers is used to decide whether the breath is normal or abnormal. The system is developed with an inexpensive web-camera and low-cost laser pointers. The experiments are carried

out using a dynamic phantom developed in-house, to simulate chest movement with different amplitudes and breathing periods.

RESULTS: Motion of the phantom was tracked by the developed system and a pressure transducer to validate the system. The studies showed a correlation of 96.6% between the respiratory tracking waveforms by the two systems, demonstrating the capability of the system.

CONCLUSION: The system tracks motion in 3 dimensions. It also demonstrates the ability to track the sliding motion of the patient in the direction parallel to the bed and provides the potential to stop the PET scan in case of such motion.

6918-74, Poster Session

Effects of sensor orientation on AC electromagnetic tracking system accuracy in a CT scanner environment

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The purpose of this study was to examine the effects of different sensor orientation on the positional accuracy of an AC electromagnetic tracking system, the second generation NDI Aurora, within a CT scanner environment. A three-axis positioning robot was used to move three electromagnetically tracked needles above the CT table throughout a 30cm by 30cm axial plane sampled in 2.5cm steps. All three needle tips were held within 2mm of each other, with the needle axes orthogonally located in the +x, +y, and +z directions of the Aurora coordinate system. The corresponding position data was captured from the Aurora for each needle and was registered to the positioning system data using a rigid body transformation minimizing the least squares L2-norm. For all three needle orientations, the largest errors were observed farthest from the field generator and closest to the CT table. However, the 3D distortion error patterns were different for each needle, demonstrating that the sensor orientation has an effect on the positional measurement of the sensor. This suggests that the effectiveness of using arrays of reference sensors to model and correct for metal distortions may depend strongly on the orientation of the reference sensors in relation to the orientation of the tracked device. In an ideal situation, the reference sensors should be oriented in the same direction as the tracked needle.

6918-75, Poster Session

Assessment of the potential for catheter heating during MR imaging

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There is an increasing interest in using MR imaging as a means of guiding endovascular procedures due to MR's unparalleled soft tissue characterization capabilities and its ability to assess functional parameters such as blood flow and tissue perfusion. In order to evaluate the potential safety risk of catheter heating, we performed in vitro testing where we measured heat deposition in sample non-ferrous 5F catheters ranging in length from 80cm - 110cm within a gel phantom. To identify the conditions for maximum heat deposition adjacent to catheters, we measured [1] the effect of variable immersed lengths, [2] the effect of variable SAR, and [3] whether heating varied along the catheter shaft. Net temperature rise per scan and initial rate of temperature rise were determined for all configurations. The temperature recordings clearly and consistently demonstrated the correlations between MR scanning under the three variable conditions and heat deposition. Our overall maximum heating condition, which combined the maximum heating conditions of all three variables, was modest (<10C/min), but well above the temperature response of the gel well away from the catheter. Reduced SAR acquisitions effectively limited these temperature rises, and RF exposure levels of 0.2W/kg produced little detectable temperature change over the 2 minute MR acquisitions studied here. A combination of SAR limits and imaging duty cycle restrictions appear to be sufficient to permit MR imaging in catheterized patients without concern for thermal injury.

6918-76, Poster Session

3D transrectal ultrasound prostate biopsy using a mechanical imaging and needle-guidance system

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The prostate biopsy procedure is currently limited to using 2D transrectal ultrasound (TRUS) imaging to guide the biopsy needle. Being limited to 2D causes ambiguity in needle guidance and provides an insufficient record in cases of prostate re-biopsy. We have developed a multi-jointed mechanical device, which supports a commercially available TRUS probe and integrated needle guide for precision prostate biopsy. The device is fixed at the base, allowing the joints to be manually manipulated while fully supporting its weight throughout its full range of motion. Means are provided in order to track the potential needle trajectory and display this trajectory on a corresponding TRUS image, allowing the physician to aim the needle-guide at predefined targets within the prostate thus, allowing for true 3D navigation. The tracker has been designed for use with several end-fired transducers that can be rotated about the longitudinal axis of the probe in order to generate 3D images. Using the system, 3D TRUS prostate images can be scanned and reconstructed in less than 10 seconds. The tracker reduces most of the user variability from conventional hand-held probes that render them unsuitable for precision biopsy, while preserving the user familiarity and procedural workflow. Testing on a prostate phantom, biopsy needles were guided to within 2 mm from their targets and the 3D location of the biopsy core was recorded to within 3 mm of "truth". The 3D TRUS biopsy system is designed for easy clinical integration.

6918-77, Poster Session

Phantom evaluation of an image-guided navigation system based on electromagnetic tracking and open source software

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We have developed an image-guided navigation system using electromagnetically-tracked tools, with potential applications for abdominal procedures such as biopsies, radiofrequency ablations, and radioactive seed placements. We present the results of two phantom studies using our navigation system. In the first study, a physician and medical resident performed a total of 18 targeting passes in the abdomen of an anthropomorphic phantom based solely upon image guidance. The distance between the target and needle tip location was measured based on confirmatory scans which gave an average of 3.56 mm. In the second study, three foam nodules were placed at different depths in a gelatin phantom. Ten targeting passes were attempted in each of the three depths. Final distances between the target and needle tip were measured which gave an average of 3.00 mm. In addition to these targeting studies, we discuss our refinement to the standard four-quadrant image-guided navigation user interface, based on clinician preferences. We believe these refinements increase the usability of our system while decreasing targeting error.

6918-78, Poster Session

Robotically assisted ultrasound interventions

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The goal of this work is to develop a robotic system to assist the physician in minimally invasive ultrasound interventions. In current practice, the physician must manually hold the ultrasound probe in one hand and manipulate the needle with the other hand, which can be difficult. To assist the physician, the robot should not only be capable of providing the spatial movement needed, but also be able to control the contact force between the ultrasound probe and patient. We are developing a

prototype system based on a six degree of freedom parallel robot. The system will provide high bandwidth, precision motion, and force control. The requirements, design concept, and prototype status are presented in this abstract.

6918-79, Poster Session

Intraoperative identification of tip position of bronchoscope using 3D CT images and fluoroscope images

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In lung cancer diagnosis, tumors found by CT examination are biopsied using a bronchoscope. However, it is sometime difficult for surgeons to reach at the target position when it is locating in peripheral positions. In such a case, a fluoroscopy is taken perioperatively to confirm the location of the tip of the bronchoscope. However, the accuracy of such position estimation is limited. We propose a method for specifying the 3D position of the bronchoscope using a 3D CT image and two directional X-ray images acquired perioperatively. The flow of the guide of bronchoscope insertion is as follows: Some fiducial markers are first put on the body of the patient. CT image of the patient is then acquired just before the bronchoscope insertion. Whenever the position of the tip of bronchoscope or forces is required, fluoroscope images are taken and the location is identified and registered to the CT image and shown it.

We first investigated the relationship between fiducial markers location and the estimation accuracy through computer simulation. Based on the computer simulation, a volunteer experiment with fiducial markers at optimum positions was performed. As a result, good accuracy of 2.5mm was achieved.

6918-80, Poster Session

Point-cloud-to-point-cloud technique on tool calibration for dental implant surgical path tracking

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Dental implant is one of the most popular methods of tooth root replacement used in prosthetic dentistry. Computerize navigation system on a pre-surgical plan is offered to minimize potential risk of damage to critical anatomic structures of patients. Dental tool tip calibrating is basically an important procedure of intraoperative surgery to determine the relation between the hand-piece tool tip and hand-piece's markers. With the transferring coordinates from preoperative CT data to reality, this parameter is a part of components in typical registration problem. It is a part of navigation system which will be developed for further integration. A high accuracy is required, and this relation is arranged by Point-cloud-to-point-cloud rigid transformations and singular value decomposition (SVD) for minimizing rigid registration errors. In earlier studies, commercial surgical navigation systems from, such as, BrainLAB and Materialize, have flexibility problem on tool tip calibration. Their systems either require a special tool tip calibration device or are unable to change the different tool. The proposed procedure is to use for pointing device or hand-piece to touch the point on the pivot and the transformation matrix is calculated every time when it moves to the new position while the tool tip stays at the same point. The experiment acquired on the information of tracking device, image acquisition and image processing algorithms. The key success is that point-to-point-cloud requires only 3 post images of tool to be able to converge to the minimum errors 0.77%, and the obtained result is correct in using the tool holder to track the based line displayed in graphic animation.

6918-81, Poster Session

A real-time ultrasound calibration system with automatic accuracy control and incorporation of ultrasound beam thickness

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This paper presents a novel freehand ultrasound (US) calibration system

and its thorough validation results. Such calibration is typically required to construct a 3D image of the patient's anatomy from a set of 2D US images. Most of the current calibration techniques concern primarily with precision and accuracy, which is well justified if the procedure is conducted in a laboratory setup; however, for computer-assisted surgery applications that may require a calibration task inside the operating room (OR), many other important aspects, such as ease of use, automatic and real-time operation, sterilization and cost effectiveness, have to be considered besides accuracy. We have developed a real-time freehand ultrasound calibration system, with automatic accuracy control and incorporation of quantitative US section beam thickness. The system encompasses several essential elements that are crucial for a practical OR usage: (1) a calibration phantom that achieves high accuracy, while maintaining a simple, sterilizable and low-maintenance design with a great potential for large-scale, cost-effective manufacturing; (2) a real-time calibration system that demands no human interference; (3) an automatic error retrieval and accuracy control mechanism; (4) a quantitative evaluation and incorporation of effective US elevation beam width to improve the calibration precision. Extensive validations were conducted to thoroughly investigate the accuracy, robustness, and performance of the proposed calibration system. Our results have demonstrated that the system is able to consistently and robustly achieve high calibration accuracy with real-time performance and efficiency.

6918-82, Poster Session

A buyer's guide to electromagnetic tracking systems for clinical applications

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When choosing an electromagnetic tracking system (EMTS) for image-guided procedures, it is desirable for the system to be usable for different procedures and environments. Several factors influence this choice. To date only one of these has been studied extensively, the susceptibility of electromagnetic tracking systems to distortions caused by ferromagnetic materials. In this paper we provide a more comprehensive overview of the factors that should be taken into account when choosing an EMTS. These factors include: 1) accuracy and stability of the reported transformations; 2) system ergonomics including the possibilities for placing the electro-magnetic field generator, the size of its working volume, and its effect on the use of imaging devices during the procedure; 3) available sensor sizes, affecting the ability to embed them into tools, and the information provided by the sensors, either translation and rotation without knowledge of the rotation around the sensor axis (5D), or the complete transformation (6D). We evaluate the Aurora EMTS (Northern Digital Inc., Waterloo, Ontario, Canada) and the 3D Guidance EMTS with flat field generator (Ascension Technology Corp., Burlington, Vermont, USA) in two clinical environments. We show that these systems are applicable to specific procedures or in specific environments, but that, currently, neither are optimal for all environments and procedures we evaluated.

6918-83, Poster Session

Visual servoing of a laser ablation based cochleostomy

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The aim of this approach is a defined, visually camera controlled and navigated laser based bone removal on the promontorium of the inner ear. A precise and minimally traumatic opening procedure of the cochlea for the implantation of electronic hearing aids is mandatory. The destruction of the membrane lining the inner ear can lead to damages of organ functions (e.g. deafness or vertigo). A precise tissue removal by a laser bone ablation system is investigated. In the borehole for the cochleostomy the pulsed laser beam is guided automatically over the bone by using a two mirror galvanometric scanner. The ablation process is controlled by visual servoing. For the detection of the boundary layers

of the inner ear the ablation area is monitored by a color camera. The grabbed pictures were analyzed by image processing and the results control the laser ablation process. This publication describes the whole system with the used image processing algorithms and the concept for the resulting distribution of the single laser pulses. The complete system is tested with human cochlea in ex-vivo studies. Further developments will lead to save intraoperative openings of the cochlea by a robot based surgical laser instrument.

6918-84, Poster Session

Real-time deformable modeling using global mass-spring medial structure and local finite elements with double-float GPU acceleration

P. Huang, L. Gu, J. Zhang, H. Zhou, D. He, X. Yu, J. Song, Z. Yan, S. Lv, J. Liu, Shanghai Jiao Tong Univ. (China)

Real-time simulation of soft-tissue deformation is one of the most difficult challenges in virtual surgery, because of the dilemma requirements of immediate interactivity and realistic simulation. In this paper, we propose a hybrid method to win this challenge by introducing a multi-level modeling technique.

To achieve the real-time requirement of realistic deformable modeling, it is necessary to employ the acceleration techniques such as GPU computing for FEM and efficient modeling such as hybrid structures in a virtual surgery simulation system.

In this paper, we present a novel deformable model on linear or nonlinear deformation of soft tissue based on global Mass-Spring Medial Structure and local Finite Elements with double-float GPU acceleration. The most important advantage of our model is its ability to achieve an interactive frame update rate for the dynamical deformable result in minimal surgical simulation for kidney and blood vessel cases on standard PC machine.

This research is achieved through two novel methods. In the first place, the major calculation work in the Conjugate Gradient solver for deformation is migrated from the CPU to the contemporary GPU to promote the calculation. Experiments have been given to show the feasibility and efficiency of the method.

Secondly, it is to apply the hybrid structures of deformable models, by mainly calculating the volumetric deformation in the local operation part while merely computing the global deformation by Mass-Spring Medial Representation method.

As an example in order to simulate the minimal surgery, we have developed a deformable human kidney and vessel model generated from the medical dataset, with the result of rapid computation procedure.

6918-85, Poster Session

Virtual surgery planning for breast reconstruction using mass-spring deformable modeling and centerline bending

W. Chen, L. Gu, P. Huang, Y. Jin, H. Xu, J. Dong, Shanghai Jiao Tong Univ. (China)

Those who are suffering from the breast cancer may have to excise the one with cancer and it becomes necessary for them to take the reconstruction surgery. A method to a virtual breast reconstruction with Deep Inferior Epigastric Perforator (DIEP) flap surgery is proposed in this paper.

In order to calculate the shape, volume and the depth of the flap, we measure the healthy side of the breast and take the following steps:

- 1) input MRI data of the patient's another breast which is healthy;
- 2) get the virtual 3D mesh data of the healthy breast using balloon segmentation and butterfly smooth algorithm and establish triangle mesh on breast surface;
- 3) flatten the triangulated skin of breast using deformable model, map the 3D mesh data onto the 2D mesh data;
- 4) calculate the centerline of the flattened mesh data, which is 2D, via binary image skeleton extract algorithm, map the line to the points which

are in the mesh data and smooth the line;

5) stretch the centerline until it is straight and reset the coordinates;

6) the points on the centerline have been modified and the balance is broken, calculate the shape of the flap via rebalancing the Mass-Spring model.

Other methods such as mesh smoothing and cutting of triangulated surface are also introduced.

6918-86, Poster Session

Finite element model for nonrigid motion analysis and its application in temporal registration of breast images

Y. Qiu, Univ. of South Florida

Images taken by various techniques are often obtained under entirely different tissue configurations, compression, orientation or body position. Hence, some form of spatial non rigid transformation of image data is required so that the tissues are represented in an equivalent configuration. We proposed Finite Element Method (FEM) based strategy for correspondence identification between image features identified in two view mammography taken at different time. The algorithms modeled breast compression during mammography and allowed for correspondence recovery of 2D features found in two views and reconstruction of their 3D locations.

Our experiment results showed that the Finite Element Model could reasonably predict lesion correspondence in temporal pairs. A dataset containing 7 patient data has been built and tested with different models constructed using Finite Element Method. Our test results showed that the proposed simulation can be used in analysis of breast positioning, compression, and image acquisition parameters.

We have presented a deformable model based method to improve feature registration between temporal mammographic views. The advantage of using a 3D finite element model is that nonrigid breast deformation can be computed accurately, which is lacking in 2D registration methods. We devised a stepwise incremental approach to simulate plates motion, which enables us to model large breast deformation through a series of static equilibrium calculation. We also employed an adaptive meshing technique to reduce the computational cost. The use of MRIs of the same patient to build a finite element model further ensures the registration quality. The proposed modeling approach holds great promise in both early breast cancer diagnosis and the subsequent surgery planning.

Our initial work showed that our finite element method increased the sensitivity to temporal pathological changes. With lesion correspondence, our finite element method could be used to suppress technical variations (e.g., mammogram positioning or compression) and to emphasize genuine alterations in the breast.

6918-87, Poster Session

Modeling the influence of the VV delay for CRT on the electrical activation patterns in absence of conduction through the AV node

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Epidemiological investigations have determined that 0.04% of the population suffers from a degree of atrioventricular (AV) block. The palliative treatment in the last years for third degree AV block has involved Cardiac Resynchronization Therapy (CRT) since patients experience more clinical improvement in the long term than with dual chamber devices. Still, some patients' hemodynamic function does not significantly benefit from the therapy's potential. A better understanding of the basis for optimizing the VV delay will help increase the number of responders. In our work a finite element model of the left and right ventricles was generated from an atlas of the heart. The electrical activity was simulated with the electrophysiological solver CARP, using the Ten Tusscher et al. ionic model for the working myocardium, and the DiFrancesco-Noble for Purkinje fibres. The model is representative of a patient with no dilated or ischemic cardiomyopathy. The simulations were set for different VV delays and pre-activations (RV pre-activated and LV pre-activated). To

optimize the solution, simulations are compared against the His-Purkinje network activation (normal physiological conduction), and interventricular septum activation (as collision point for the two wave fronts). The results are analyzed using isochronal maps of late activation times (LATs) and LV's 17 segment model for regional activation times. Correlation coefficient and RMS error are used to establish comparisons between simulation cases. The results of this study contribute to gain insight on the VV delay and how its adjustment can decrease the number of non-responders in CRT and optimize the treatment.

6918-88, Poster Session

Mutual-information-corrected tumor displacement using intraoperative ultrasound for brain shift compensation in image-guided neurosurgery

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Intraoperative ultrasound (iUS) has emerged as a practical neuronavigational tool for brain shift compensation in image-guided tumor resection surgeries. The use of iUS is optimized when coregistered with preoperative magnetic resonance images (pMR) of the patient's head. However, the fiducial-based registration alone does not necessarily optimize the alignment of internal anatomical structures deep in the brain (e.g., tumor) between iUS and pMR, due to errors from the fiducial-based registration, US scan-head calibration and even possible brain shift at the very start of surgery (i.e., before dural opening). In this paper, we investigated and evaluated an image-based re-registration scheme maximizing the normalized mutual information (nMI) between iUS and pMR to improve tumor boundary alignment using the fiducial registration as a starting point for optimization. We show that this scheme significantly ($p < 0.001$) reduces tumor boundary misalignment pre-durotomy. The same technique was employed to measure tumor displacement post-durotomy, and the locally measured tumor displacement was assimilated into a biomechanical model to estimate the whole-brain deformation. Our results demonstrate that the nMI re-registration pre-durotomy is critical for the fidelity of the measured tumor displacement, with significantly improved model response at the craniotomy when compared with stereopsis data independent from tumor registration. This automatic and computationally efficient (< 2 min) re-registration technique is feasible for routine clinical use in the operating room (OR).

6918-89, Poster Session

Simulation of tomosynthesis images based on an anthropomorphic software breast tissue phantom

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The aim of this work is to provide a simulation framework for generation of synthetic tomosynthesis images, to be used for evaluation of future developments in the field of tomosynthesis. An anthropomorphic software tissue phantom was previously used in a number of applications for evaluation of acquisition modalities and image post-processing algorithms for mammograms. This software phantom has been extended for similar use with tomosynthesis. The new features of the simulation framework include a finite element deformation model to obtain realistic mammographic deformation and projection simulation for a variety of tomosynthesis geometries. The resulting projections are provided in DICOM format to be applicable for clinically applied reconstruction algorithms. Examples of simulations, using parameters of a currently applied clinical setup, are presented. The overall simulation model is generic, allowing multiple degrees of freedom to cover anatomical variety in the amount of glandular tissue, degrees of compression, material models for the breast tissues, and tomosynthesis geometries.

6918-90, Poster Session

Interactive modeling and simulation of peripheral nerve cords

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This paper contributes to the modeling, simulation and visualization of peripheral nerve cords. Until now, only sparse data sets of nerve cords can be found. In addition this data has not been used in simulators yet, because it is only static. To recreate the anatomical structure of peripheral nerve cords we propose a hierarchical tree data structure where each node represents a nerve branch. The shape of nerve segments itself is approximated by spline curves. Interactive modeling allows for the creation and editing of control points which are used for branching nerve sections, calculating spline curves and editing spline representations via cross sections. Furthermore the control points can be attached to different anatomic structures. Through this approach nerve cords deform in accordance to the movement of the connected structures, e.g., muscles or bones. As a result we have developed an intuitive modeling system that runs on desktop computers and in immersive environments. It allows anatomical experts to create movable peripheral nerve cords for articulated virtual humanoids. Direct feedback of changes induced by movement or deformation is achieved by visualization in real-time. The techniques and the resulting data are already used for medical simulators.

6918-91, Poster Session

A fast stereo matching algorithm for 3D reconstruction of internal organs in laparoscopic surgery

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In this paper, we propose a fast stereo matching algorithm for 3D reconstruction of internal organs using a stereoscopic laparoscope. Stoyanov et al. proposed a technique that recovers the 3D depth of internal organs from the images of a stereoscopic laparoscope. In this conventional technique, the dense stereo correspondence was solved based on the registration of the whole image regions in order that the 3D depth of internal organs can be densely recovered. However, the calculation cost of this technique was very high since the registration of whole image regions requires multidimensional optimization. In this paper, we propose an algorithm using a local-region based registration method considering the similarity of stereo images taken by stereoscopic laparoscope. The local-region based registration requires only low dimensional optimization. Therefore, its calculation cost is significantly low. We evaluated the calculation cost of the proposed algorithm using a stereoscopic laparoscope and abdominal models of human body. We also evaluated the accuracy of the algorithm using a 3D laser scanner and abdominal models. The result showed that the proposed algorithm can significantly reduce the calculation cost with a little accuracy degradation of 3D depth.

6918-92, Poster Session

Preliminary investigation of the inhibitory effects of mechanical stress in tumor growth

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In the past years different models have been formulated to explain the growth of gliomas in the brain. The most accepted model is based on a reaction-diffusion equation that describes the growth of the tumor as two separate components- a proliferative component and an invasive component. While many improvements have been made to this basic model, the work exploring the factors that naturally inhibit growth is insufficient. It is known that stress fields affect the growth of normal tissue. Due to the rigid skull surrounding the brain, mechanical stress might be an important factor in inhibiting the growth of gliomas. A realistic model of glioma growth would have to take that inhibitory effect into account. In this work a mathematical model based on the reaction-diffusion equation was used to describe tumor growth, and the affect

of mechanical stresses caused by fluid pressure and the mass effect of tumor cells was studied. An initial tumor cell concentration with a Gaussian distribution was assumed and tumor growth was simulated for two cases- one where growth was solely governed by the reaction-diffusion equation and second where mechanical stress inhibits growth by affecting the diffusivity. All the simulations were performed in one dimension using the finite difference method. The results of simulations show that the proposed mechanism of inhibition could have a significant affect on tumor growth predictions. This could have implications for varied applications in the imaging field that use growth models, such as registration and model updated surgery.

6918-93, Poster Session

MITK-based segmentation of co-registered MR data for patient-specific regional anesthesia simulation

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With a steadily increasing indication, regional anesthesia (RA) is still trained directly on the patient. To develop a virtual reality (VR)-based simulation, a patient model is needed containing several tissues, which have to be extracted from individual magnet resonance imaging (MRI) volume datasets. Due to the given modality and the different characteristics of the single tissues, an adequate segmentation can only be achieved by using a combination of segmentation algorithms.

In this paper, we present a framework for creating an individual model from a MRI scan of the patient. Our work is split into two parts. At first, an easy-to-use and extensible tool for handling the segmentation task on arbitrary datasets is provided. The key idea is to let the user create a segmentation for the given subject by running different processing steps in a purposive order and store them in a segmentation script for reuse on new datasets. For data handling and visualization, we utilize the Medical Imaging Interaction Toolkit (MITK), which is based on the Visualization Toolkit (VTK) and the Insight Segmentation and Registration Toolkit (ITK). The second part is to find suitable algorithms and respectively a script for a differentiating segmentation of the tissues required by the RA simulation. For this purpose, a fuzzy c-means clustering algorithm combined with mathematical morphology operators and a geometric active contour-based approach is chosen. The segmentation process itself aims at operating with minimal user interaction, and the gained model fits the requirements of the simulation.

6918-94, Poster Session

Dynamic lung tumor phantom coupled with chest motion

M. del Valle, M. Z. Goryawala, A. J. McGoron, Florida International Univ.

Introduction: Motion artifacts have always been a non-desired effect in the field of Medical Imaging, thus emerging technologies have always tried to find ways to ameliorate the damaging effects of image blurring caused by motion. Most of these new technologies required the use of phantoms as a means of precise, repeatable and controllable source of motion for testing initial prototypes.

Design: A dynamic lung tumor phantom coupled with chest motion was designed. The phantom consists of linear actuators. The complete design, excluding the actuators was built in house out of acrylic material with a low attenuation factor making it ideal for PET studies. The linear actuator is a stepper motor coupled to a lead screw which translates rotational motion into linear displacement at a rate of .0254 mm/step. The system is driven by a PIC microcontroller that allows the user to select different tumor motion parameters, and it is capable of performing 3D motion.

Evaluation: The phantom is capable of providing lung tumor and chest position with an accuracy of 1.3 μ m in the axis of motion, as well as displacement of up to 52 mm with maximum velocities of 21.59 mm/sec.

Conclusion: This design has proven to be suitable for simulating

lung tumor motion in PET studies, as well as testing motion tracking algorithms. However it is not limited by any means to the aforementioned, and can be possibly used in studies dealing with gated radiotherapy.

6918-95, Poster Session

Atlas-based segmentation of deep brain structures using non-rigid registration

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Deep brain structures are frequently used as targets in neurosurgical procedures. However, the boundaries of these structures are often not visible in clinically used MR and CT images. Techniques based on anatomical atlases and indirect targeting are used to infer the location of such targets intraoperatively. Initial errors of such approaches are typically a few millimeters, which is not negligible since they are comparable to the target size. E.g. subthalamic nucleus is approximately 4x6 mm in the axial plane and the radius of globus pallidum internus is approximately 4 mm, both of which are used as targets in deep brain stimulation surgery. To increase the initial localization accuracy of deep brain structures we have developed an atlas-based segmentation method that can be used during the surgery planning. The atlas is a high resolution MR head scan of a healthy volunteer with nine deep brain structures manually segmented. The quality of the atlas image allowed for the segmentation of the deep brain structures, which is not possible from the clinical MR head scans. The subject image is non-rigidly registered to the atlas image using thin plate splines to represent the transformation and normalized mutual information as a similarity measure. The obtained transformation is used to map the segmented structures from the atlas to the subject image. We tested the approach on five subjects. The quality of the atlas-based segmentation was evaluated by visual inspection of the third and lateral ventricles, putamena, and caudate nuclei, which are visible in the subject MR images. The agreement of these structures for the five tested subjects was approximately 1 to 2 mm.

6918-96, Poster Session

Automatic initialization for 3D bone registration

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In image-guided bone surgery, sample points collected from the bone surface are registered to the pre-operative CT model using well-known methods such as Iterative Closest Point (ICP). Proper initialization of the surface points is critical for successful registration. The initial alignment is normally carried out manually due to high risk of the optimization algorithm getting trapped in a local minimum.

In this paper, we present an automatic method that initially aligns the surface sample points of pelvis with the CT model. The main idea is to exploit a mean shape of the pelvis created from a large number of CT scans as the prior knowledge to guide the initial alignment. The CT model is first aligned with the mean shape using the bilateral symmetry of the pelvis and the similarity of multiple projections. Incorporating the information about the protocol of the data collection, the sample surface points are aligned with the pelvis mean shape. This will, in turn, lead to initial alignment of the sample points with the CT model.

The experiment using dry pelvis bone shows that the method can align the randomly dislocated datasets with average closest distance error of 3.29 mm. This alignment was close enough for the standard ICP to register the datasets. In addition, CT/US data has been collected from a cadaver, and analysis of the collected data is in progress.

6918-97, Poster Session

Accurate and reproducible semi-automatic liver segmentation using haptic interaction

E. Vidholm, M. Golubovic, S. Nilsson, I. Nyström, Uppsala Univ. (Sweden)

In this work, we describe and evaluate a semi-automatic method for liver segmentation in CT images using a 3D interface with haptic feedback

and stereo graphics.

Recently, we reported our fast semi-automatic method using fast marching segmentation. Four users performed initialization of the method for 52 datasets by manually drawing seed regions directly in 3D using the haptic interface.

Here, we evaluate our segmentation method by computing accuracy based on newly obtained manual delineations by two radiologists for 23 datasets. We also show that by performing subsequent segmentation with an interactive deformable model, we can increase segmentation accuracy.

Our method shows high reproducibility compared to manual delineation. The mean precision for the manual delineation is 89% while it is 97% for the fast marching method. With the subsequent deformable mesh segmentation we obtain a mean precision of 98%. To assess accuracy, we construct a fuzzy “true” segmentation by averaging the manual delineations. The mean sensitivity for the fast marching segmentation is 93% and the specificity is close to 100%. When we apply deformable model segmentation we get a sensitivity increase of three percentage points while the high specificity is maintained. The mean interaction time for the deformable model is 1.5 minutes.

We present a fully 3D liver segmentation method where high accuracy and precision is efficiently obtained via haptic interaction in a 3D user interface. Our method makes it possible to avoid time-consuming manual delineation, which otherwise is a common option prior to, e.g., hepatic surgery planning.

6918-98, Poster Session

Continuous endoscopic guidance via interleaved video tracking and image-video registration

W. E. Higgins, L. Rai, The Pennsylvania State Univ.

Endoscopic needle biopsy is a common procedure for early lung-cancer detection. This procedure uses two steps: (1) 3D computed-tomography (CT) chest image analysis, to plan and choose a biopsy site; (2) live endoscopy, to perform the biopsy. We present an image-based method for endoscopic guidance that combines the “real” endoscopic video world and the 3D CT-based “virtual” world in a continuous process. The method interleaves periodic CT-video registration with endoscopic video motion tracking to enable near real-time guidance of endoscopy. Results demonstrate the robustness of the method for both phantom and human lung-cancer cases. We also illustrate the method when integrated into a complete system for the image-based planning and guidance of endoscopy.

6918-99, Poster Session

Advanced 2D-3D registration for endovascular aortic interventions: addressing dissimilarity in images

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In the current clinical workflow of minimally invasive aortic procedures navigation tasks are performed under 2D or 3D angiographic imaging. Many solutions for navigation enhancement suggest an integration of the preoperatively acquired computed tomography angiography (CTA) in order to provide the physician with more image information and reduce contrast injection and radiation exposure. This requires exact and robust registration algorithms that align the CTA volume to the intraoperative 2D or 3D images. Additional to the real-time constraint, the registration accuracy should be independent of image dissimilarities due to varying presence of medical instruments and contrast agent. In the preoperative CTA volume the aorta is contrasted and no medial instrument is visible. Intraoperatively, however, contrast agent is injected very rarely and the navigation is mostly done by fluoroscopy imaging. Furthermore, medical instruments used during the procedure are also displayed inside the images. In this paper, we propose efficient solutions for image-based 2D-3D and 3D-3D registration that reduce the dissimilarities in two ways. First

dissimilarities are detected and segmented either inside the CTA volume or the intraoperative images. Then, adaptive weights are introduced into the 2D-3D registration process. For the 3D-3D registration, dissimilarities are erased by interpolation preprocessing. Experiments and evaluations are conducted on real patient data.

6918-100, Poster Session

Location constraint based 2D-3D registration of fluoroscopic images and CT volumes for image-guided EP procedures

R. Liao, Siemens Corporate Research; N. Xu, Vanderbilt Univ.; Y. Sun, Siemens Corporate Research

Presentation of detailed anatomical structures via 3D Computed Tomographic (CT) volumes helps visualization and navigation in electrophysiology procedures (EP). Registration of the CT volume with the online fluoroscopy however is a challenging task for EP applications due to the lack of discernable features in fluoroscopic images. In this paper, we propose to use the coronary sinus (CS) catheter in bi-plane fluoroscopic images and the coronary sinus in the CT volume as a location constraint to accomplish 2D-3D registration. Two automatic registration algorithms are proposed in this study, and their performances are investigated on both simulated and real data. It is shown that compared to registration using mono-plane fluoroscopy, registration using bi-plane images results in substantially higher accuracy in 3D and enhanced robustness. In addition, compared to registering the projection of CS with the 2D CS catheter, it is more desirable to reconstruct a 3D CS catheter from the bi-plane fluoroscopy and then perform a 3D-3D registration. Quantitative validation based on simulation and visual inspection on real data demonstrates the feasibility of the proposed workflow in EP procedures.

6918-102, Poster Session

Left atrium segmentation for atrial fibrillation ablation

R. Karim, R. Mohiaddin, D. Rueckert, Imperial College London (United Kingdom)

Segmentation of the left atrium is vital for pre-operative assessment of its anatomy in radio-frequency catheter ablation (RFCA). RFCA is commonly used for treating atrial fibrillation. In this paper we present an automatic approach for segmenting the left atrium and its pulmonary veins from MR angiography (MRA) data sets. We also present an approach for automatic recognition of left atrial body from the segmented atrium. The segmentation algorithm is based on the notion that in MRA the atrium becomes connected to surrounding structures via partial volume affected voxels and narrow vessels, the atrium can be separated if these regions are characterized and identified. The blood pool, obtained by subtracting the pre- and post-contrast scans, is first segmented using a region-growing approach. The segmented blood pool is then subdivided into disjoint subdivisions based on its Euclidean distance transform. These subdivisions are then merged automatically starting from a seed point and stopping at points where the atrium connects to a neighboring structure. The resulting merged subdivisions produce the segmented atrium. Measuring the size of the pulmonary vein ostium is vital for selecting the optimal Lasso diameter. We present a second technique for automatically identifying the atrial body from segmented left atrium images. The separating surface between the atrial body and the pulmonary veins gives the ostia locations and can play an important role in measuring their diameters. The technique relies on multi-scale eigenvalue analysis of the second-order local information (i.e. Hessian). Results have been presented on 20 patient MRA datasets.

6918-103, Poster Session

Left atrium segmentation for planning atrial fibrillation ablation

R. Karim, Imperial College London (United Kingdom); R. Mohiaddin, National Heart and Lung Institute (United Kingdom); D. Rueckert, Imperial College London (United Kingdom)

Segmentation of the left atrium is vital for pre-operative assessment of its

anatomy in radio-frequency catheter ablation (RFCA). RFCA is commonly used for treating atrial fibrillation. In this paper we present an automatic approach for segmenting the left atrium and the pulmonary veins from MR angiography (MRA) data sets. We also present a technique for automatic identification of left atrial body from the segmented atrium. The blood pool, obtained by subtracting the pre- and post-contrast scans, is first segmented using a region-growing approach. The segmented blood pool is then subdivided into disjoint subdivisions based on its Euclidean distance transform. These subdivisions are then merged automatically starting from a seed point and stopping at points where the atrium connects to a neighbouring structure. The resulting merged subdivisions produce the segmented atrium. Measuring the size of the pulmonary vein ostium is vital for selecting the optimal catheter diameter. Identifying the atrial body can automate this process. The separating surface between the atrial body and the pulmonary veins gives the ostia locations and thus play an important role in measuring their diameters. Our technique for left atrial body identification relies on multi-scale eigenvalue analysis of the second-order local information (i.e. Hessian). Results have been presented on 20 patient MRA datasets.

6918-104, Poster Session

A hybrid method for reliable registration of digitally reconstructed radiographs and kV x-ray images for image-guided radiation therapy for prostate cancer

Y. Song, Memorial Sloan-Kettering Cancer Ctr.; X. Huang, Lehigh Univ.

Prostate cancer is the most common tumor site treated with intensity modulated radiation therapy (IMRT). However, due to patient and organ motions, patient's physiological changes, and different daily fillings in the bladder and rectum, the prostate's position can change significantly. Without a proper guiding technique, this could result in overdosing the critical organs and underdosing the target. Therefore, image-guided localization of the prostate must be performed prior to each treatment, leading to the development of a new radiation treatment modality, the image-guided radiation therapy (IGRT). One form of IGRT is to implant three gold seed markers in the prostate gland to serve as a fixed reference system in the prostate.

In this paper, we present an efficient and automated method for registering digitally reconstructed radiographs (DRR) and kV X-ray images of the prostate with high accuracy using a hybrid method. Our technique relies on both internal fiducial markers (i.e. gold seed markers) implanted in the prostate and a robust, hybrid 2D registration method based on our previous work of salient-region based image registration. The registration procedure consists of several novel steps. Validation experiments are performed to register DRR and kV X-ray images in PA or lateral views and the results are jointly reviewed by experienced radiation oncologists and radiation oncology physicists. The registration technique improves not only the efficiency, but also the accuracy of the DRR/kV X-ray registration and is a viable and practical choice for routine pre-treatment patient setup verification for IGRT treatment.

6918-105, Poster Session

Efficient fiber clustering using parameterized polynomials

J. Klein, H. Stuke, MeVis Research (Germany); B. Stieltjes, German Cancer Research Ctr. (Germany); O. Konrad, H. K. Hahn, H. Peitgen, MeVis Research (Germany)

In the past few years, fiber clustering algorithms have shown to be a very powerful tool for grouping white matter connections tracked in DTI images into anatomically meaningful bundles. They improve the visualization and perception, and could enable robust quantification and comparison between individuals. However, most existing techniques perform a coarse approximation of the fibers due to the high complexity of the underlying clustering problem or do not allow for an efficient clustering in real time. In this paper, we introduce new algorithms and data structures which overcome both problems. The fibers are represented very precisely and efficiently by parameterized polynomials defining the x-, y-, and z-component individually. A two-step clustering method determines possible clusters having a Gaussian distributed structure within one component and, afterwards, verifies their existences

by principal component analysis (PCA) with respect to the other two components. As the PCA has to be performed only n times for a constant number of points, the clustering can be done in linear time $O(n)$, where n denotes the number of fibers. This drastically improves on existing techniques, which have a high, quadratic running time, and it allows for an efficient whole brain fiber clustering. Furthermore, our new algorithms can easily be used for detecting corresponding clusters in different brains without time-consuming registration methods. We show a high reliability, robustness and efficiency of our new algorithms based on several artificial and real fiber sets that include different elements of fiber architecture such as fiber kissing, crossing and nested fiber bundles.

6918-106, Poster Session

Memory-efficient 3D multiresolution image enhancement and processing

R. Albers, Technische Univ. Eindhoven (Netherlands); E. Suijs, Philips Medical Systems Nederland (Netherlands); P. H. N. de With, Technische Univ. Eindhoven (Netherlands)

The recent interest in multi-resolution techniques for image representation and analysis can be attributed to the advantage of hierarchical processing with intelligent interlayer communication, and for obtaining access to a certain spatial or frequency scale. Despite the recent advances in off-the-shelf computing technology, fast execution of scale-based algorithms has not improved due to the continuous increase of algorithm complexity and resolution of medical images. Full storage of 3D image sets is not possible within common processor architectures, thereby relying on a background memory. Because memory bandwidth is a scarce parameter, we will focus on methods for bandwidth optimization at the processor-chip level within multiprocessor systems. We use a practical model of the computing, memory and cache read/write procedures to derive formulas for which we can optimize the mapping of data into the memory and cache for different configurations. A substantial performance improvement is realized by a new memory-communication model that incorporates the data-dependencies of the image-processing functions. More specifically, bandwidth optimization and minimization is achieved by implementing two measures: (1) breaking down the algorithm such that the processing gets a locality that fits with the cache size of the processor, and (2) addressing and organizing the data prior to processing in such a way that memory traffic is minimized.

For the experiments, we have concentrated particularly on image enhancement and noise reduction for 3D X-ray data sets. First experimental results show a bandwidth reduction of 40-50% compared to straightforward implementations. In the full paper, we will report on more extensive experiments. We are convinced that with the introduction of new memory-rich processing algorithms such as segmentation and motion analysis, the gains will be significantly higher.

6918-107, Poster Session

Interactive tissue separation and visualization with dual-energy data on the GPU

F. Vega-Higuera, B. Krauss, Siemens Medical Solutions (Germany)

Dual-Energy CT makes it possible to separate the contributions of different linear X-ray attenuation coefficients and hence materials in the CT image itself. Thereby, standard dual-energy tissue classification techniques perform a so called material analysis in a pre-processing step. The resulting material maps can then be used to perform explicit segmentation of anatomical structures such as osseous tissue in case of bone removal algorithms. As a drawback, information about tissue classes included in the scan must be known beforehand in order to choose the appropriate material analysis algorithms.

In this paper, we propose direct volume rendering (DVR) with bidimensional transfer functions (2DTF) as a tool for interactive and intuitive exploration of dual energy scans. Thereby, adequate visualization of the dual energy histogram provides the basis for easily identifying different tissue classes inside the tomographic data. Transfer functions are interactively adjusted over the dual energy histogram where the x- and y-axis correspond to the 80 kV and 140kV intensities respectively. GPU implementation makes it possible to precisely fine-tune transfer functions with real time feedback in the resulting visualization. Additionally, high

quality visualizations are obtained with per fragment filtering and post interpolative dual energy tissue classification. Moreover, interactive histogram exploration makes it possible to create adequate dual energy transfer functions without previous knowledge about existing tissue classes and with no pre-processing other than loading volume data to the GPU memory. Overall, this method allows rapid 3D examination of dual energy data for implicit tissue segmentation.

6918-108, Poster Session

Fast, high-quality volume visualization for 3D medical imaging

A. D. Kalvin, Akimbo Technologies; A. F. Laine, T. Song, Columbia Univ.

The two major volume visualization methods used in biomedical applications are Maximum Intensity Projection (MIP) and Volume Rendering (VR), both of which involve the process of creating a set of 2D projections from a 3D image.

Based on the fact that the inverse of this process (i.e. a transformation from 2D projections to a 3D image) is simply the standard tomographic image reconstruction transformation, we have developed a new method for very fast, high-quality volume visualization of 3D biomedical images.

This new method uses the 2D projections acquired by the scanner, obviating the need for the two computationally expensive steps of (i) reconstructing the 3D image from 2D projection data, and (ii) computing the set of 2D projections from the reconstructed 3D image

Another benefit of this new method is improved visualization quality, since both steps (i) and (ii) degrade the quality of the original projection data; an unavoidable consequence of step (i) is the introduction of "image reconstruction noise", and in step (ii) calculating rays projections through the 3D volume generally involves interpolation of the original sample data, which further degrades data quality.

For this paper, we focus on 3D tomographic images, and on MIP visualization. However we note that this method can be extended as for use with 3D MRI data (by transforming the raw MRI k-space data into 2D projection data), and Direct Volume Rendering (by computing transfer functions, shading etc. directly in projection space).

6918-109, Poster Session

Gaussian weighted projection for visualization of cardiac calcification

X. Chen, Case Western Reserve Univ. and Xi'an Jiaotong Univ. (China); R. C. Gilkeson, Univ. Hospitals Case Medical Ctr. and Case Western Reserve Univ.; B. Fei, Case Western Reserve Univ. and Univ. Hospitals of Cleveland

At our institution, we are using dual-energy digital radiography (DEDR) as a cost-effective screening tool for the detection of cardiac calcification. We are evaluating DEDR using CT as the gold standard. We are developing image projection methods for the generation of digitally reconstructed radiography (DRR) from CT image volumes. Traditional visualization methods include maximum intensity projection (MIP) and average-based projection (AVG) that have difficulty to show cardiac calcification. Furthermore, MIP can over estimate the calcified lesion as it displays the maximum intensity along the projection rays regardless of tissue types. For AVG projection, the calcified tissue is usually overlapped with bone, lung and mediastinum. In order to improve the visualization of calcification on DRR images, we developed a Gaussian-weighted projection method for this particular application. We assume that the CT intensity values of calcified tissues have a Gaussian distribution. We then use multiple Gaussian functions to fit the intensity histogram. Based on the mean and standard deviation parameters, we incorporate a Gaussian weighted function into the perspective projection and display the calcification exclusively. Our digital and physical phantom studies show that the new projection method can display tissues selectively. In addition, clinical images show that the Gaussian-weighted projection method better visualizes cardiac calcification than either the AVG or MIP method and can be used to evaluate DEDR as a screening tool for the detection of coronary artery diseases.

6918-110, Poster Session

Interactive multi-modality display environment with photographic overlay enhancement for epilepsy surgical planning

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We describe an interactive multimodality display environment, which combines anatomic CT, MRI, functional MRI images and photographs taken during surgical procedures, to provide comprehensive localization information regarding epilepsy seizure foci and the surrounding context. Our environment incorporates several unique features, including GPU-accelerated volume rendering and image fusion, versatile GPU-based clipping of volumetric images, and the ability to enhance the information delivered to the surgeon by fusing a direct (photographic) view of the surgical field with the volumetric image. We employ direct volume rendering for the fusion of multiple volumes using GPU-accelerated ray casting. In addition, to expose the internal structures during volume fusion, we have developed user interaction tools that enable the surgeon to explore the fused volume using clipping-cube and cutaway clipping schemes. The fusion of intra-operative images onto the image volume allows enhanced visualization of the surgical procedure sites within the surgical planning environment. These techniques have been implemented as Visualization Toolkit (VTK) classes using the OpenGL fragment shading program and Python modules, and have been successfully implemented within our surgical planning environment "EpilepsyViewer". The results and performance of our GPU-based approach are compared with similar techniques in VTK, demonstrating that the use of the GPU can greatly accelerate visualization and enable increased flexibility of the system in the operating room. The result of photo overlay shows good correspondence between the intra-operative images and the pre-operative image model. This environment can also be extended for use in other neurosurgical planning tasks.

6918-111, Poster Session

The architecture and performance of CAVASS

G. J. Grevera, St. Joseph's Univ.; J. K. Udupa, D. Odhner, Y. Zhuge, A. Souza, Univ. of Pennsylvania

The development in our group of the concepts within CAVASS and its progenitor 3DVIEWNIX dates back to the 1970s. Since then, a series of software packages for Computer Assisted Visualization and Analysis (CAVA) of images have been developed and distributed by our group. CAVASS, an open source system, is the latest in this series, and represents the next major incarnation of 3DVIEWNIX. It incorporates four groups of operations: Image Processing, Visualization, Manipulation, and Analysis. Its key features are: (1) most major CAVA operations incorporated; (2) very efficient algorithms/implementations; (3) parallelized algorithms for computationally intensive operations; (4) parallel implementation on a cluster of PCs; (5) interface to other systems such as CAD/CAM software, ITK, VTK, and statistical packages; (6) easy to use GUI. In this paper, we describe the architecture, GUI, interface with other systems, and parallelization strategy of CAVASS. We present the results of comparing the implementation of a host of common visualization and image processing operations in CAVASS with ITK. Our conclusions are based on assessing performance by utilizing a regular (6 MB), large (241 MB), and super (873 MB) 3D image data sets. CAVASS is considerably more efficient than ITK/VTK for computationally intensive operations. It can deal with considerably larger data sets than ITK/VTK. It is easy and ready to use in applications since it provides an easy to use GUI. The users can easily build a cluster from ordinary inexpensive PCs and reap the full power of CAVASS inexpensively compared to expensive multiprocessing systems which are less efficient for CAVA operations.

6918-112, Poster Session

High-quality anatomical structure enhancement for cardiac image dynamic volume rendering

Q. Zhang, R. A. Eagleson, G. Guiraudon, T. M. Peters, Roberts Research Institute (Canada)

Direct ECG-gated beating heart volume rendering is an important component in the procedure of cardiac disease diagnosis and therapy planning as it supplies surgeons with spatial insight of the heart inner anatomical structure and its functional behaviours. Usually most clinical applications tend to focus upon a particular set of structures or problems, so some embedded anatomical features in the whole medical volume are of special importance for the intracardiac interventions. Uniform transfer function generally cannot effectively distinguish these fine structures because of the lack of spatial information. Explicit segmentation is a very powerful way to approach this problem, which usually yields a single binary segmentation mask label for each voxel in the anatomical volume of interest (AVOI), and these labels are used to determine the transfer function (TF) utilized for adjusting the AVOI display. However, this is a post-classification (PostC) procedure, which cannot effectively eliminate the high-frequency artifacts introduced by the nonlinear TF. In addition, the 3D texture based rendering algorithm is usually used to accelerate the visualization speed, which further degrades the result image quality and increases the aliasing artifacts at the adjacent subvolume boundaries. In this paper, we introduce several new approaches to address this problem. A three-channel binary mask volume is first created from explicit segmentation, and a Gauss filter is utilized to smooth its boundaries. Next, both the source and the mask volume are loaded to the GPU shader, where raycasting algorithm is employed for 3D rendering calculation. Different TFs are created for each channel of the mask volume and the source volume respectively. Unlike the classic methods addressing this problem, which use the mask volume as an index for TF selection and an artifact-inherent PostC algorithm is employed for the optical mapping, we utilize a noise eliminated post color-attenuated classification (PCAC) algorithm to classify each channel of the mask volume and the source volume simultaneously. A multiple texture fetching is performed at each sampling step along the casting ray, and the fetched values are blended together using a compositing formula with a novel boundary color adjustment technique for artifacts elimination. Therefore, our approach produces high-quality anatomical feature enhanced cardiac images with artifact-eliminated AVOI boundaries in real-time.

6918-113, Poster Session

A new visualization method for 3D head MRA data

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In this paper, we propose a new visualization method for head MRA data which supports the user to easily determine the positioning of MPR image or MIP image based on the blood vessel network structure (the anatomic location of blood vessels). This visualization method has following features: (a) the blood vessel (cerebral artery) network structure in a head MRA data is portrayed the 3D line structure; (b) the MPR images or MIP images are combined with the blood vessel network structure and displayed in a 3D visualization space; (c) the positioning of MPR or MIP is decided based on the anatomic location of blood vessels; (d) The image processing and drawing can be operated at real-time without a special hardware accelerator. As a result, we believe that our method is available to position MPR images or MIP images related to the blood vessel network structure. Moreover, we think that the user using this method can obtain the 3D information (position, angle, direction) of both these images and the blood vessel network structure.

6918-114, Poster Session

Multispectral image enhancement for H&E stained pathological tissue specimens

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The presence of a liver disease such as cirrhosis can be determined by examining the proliferation of collagen fiber from a tissue slide stained

with special stain such as the Masson's trichrome(MT) stain; MT stain highlights the difference between collagen fiber and smooth muscle which are both stained the same in an H&E stained tissue slide. In this paper we show that with multispectral imaging the difference between collagen fiber and smooth muscle can be visualize even from an H&E stained image. In the method M KL vectors are derived using the spectral data of those H&E stained tissue components which can be easily differentiated from each other, i.e. nucleus, cytoplasm, red blood cells, etc. and based on the spectral residual error of fiber weighting factors are determined to enhanced spectral features at certain wavelengths. Results of our experiment demonstrates the capability of multispectral imaging to delineate tissue structures with subtle colorimetric difference and its advantage compared to the conventional RGB imaging systems in this aspect.

6918-39, Session 8

Evaluation of motion compensation approaches for soft tissue navigation

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Organ motion was quantified and motion compensation strategies for soft-tissue navigation were evaluated in a porcine model. Organ motion due to patient repositioning, and respiratory motion during ventilated breathing were quantified. Imaging was performed on a 16-slice CT scanner. Organ motion due to repositioning was studied by attaching 7 external skin fiducials and inserting 7 point fiducials in the livers of ventilated pigs. The pigs were imaged repeatedly in supine and decubitus positions. Registrations between the images were obtained using either all external fiducials or 6 of the 7 internal fiducials. Target registration errors (TRE) were computed by using the leave-one-out technique. Respiratory organ motion was studied by inserting 7 electromagnetically (EM) tracked needles in a pig liver, one serving as a target, the remaining six serving as reference needles. In addition, 6 EM tracked skin fiducials, 5 passive skin fiducials, and one dynamic reference tracker were attached. Registrations were obtained using three different methods: Continuous registration with the tracking data from internal and external tracked fiducials, and one-time registration using the passive skin fiducials and a tracked pointer with dynamic reference tracking. The TRE for registering images obtained in supine position after an intermittent decubitus position ranged from 3.3 mm to 24.6 mm. Higher accuracy was achieved with internal fiducials (mean TRE = 6.4 mm) than with external fiducials (mean TRE = 16.7 mm). During respiratory motion, the mean TRE was 1.6 and 5.4 mm when using internal and external tracked fiducials, respectively, and 5.2 mm using dynamic reference tracking.

6918-40, Session 8

Real-time respiratory motion tracking: roadmap correction for hepatic artery catheterizations

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Nowadays, hepatic artery catheterizations are performed under live 2D X-ray fluoroscopy guidance, where the visualization of blood vessels requires the injection of contrast agent. The projection of a 3D static roadmap of the complex branches of the liver artery system onto 2D fluoroscopy images can aid catheter navigation and minimize the use of contrast agent. However, the presence of a significant hepatic motion due to patient's respiration necessitates a real-time motion correction in order to align the projected vessels. The objective of our work is to introduce dynamic roadmaps into clinical workflow for hepatic artery catheterizations and allow for continuous visualization of the vessels in 2D fluoroscopy images without additional contrast injection. To this end, we propose a method for real-time estimation of the apparent displacement of the hepatic arteries in 2D fluoroscopy images. Our approach approximates respiratory motion of hepatic arteries from the catheter motion in 2D fluoroscopy images. The proposed method consists of two main steps. First, a filtering is applied to 2D fluoroscopy

images in order to enhance the catheter and reduce the noise level. Then, a part of the catheter is tracked in the filtered images using template matching. A dynamic template update strategy makes our method robust to deformations. The accuracy and robustness of the algorithm are demonstrated by experimental studies on 22 simulated and 4 clinical sequences containing 330 and 571 image frames, respectively.

6918-41, Session 8

A technique for respiratory motion correction in image-guided cardiac catheterization procedures

A. P. King, King's College London (United Kingdom) and University College London (United Kingdom); R. Boubertakh, K. L. Ng, Y. Ma, King's College London (United Kingdom); P. Chinchapatnam, G. Gang, Univ. College London (United Kingdom); T. Schaeffter, King's College London (United Kingdom); D. J. Hawkes, Univ. College London (United Kingdom); R. Razavi, K. S. Rhode, King's College London (United Kingdom)

This paper presents a technique for compensating for respiratory motion and deformation in an augmented reality system for cardiac catheterisation procedures. The technique uses a subject-specific affine model of cardiac motion which is quickly constructed from a pre-procedure magnetic resonance (MR) scan. Respiratory phase information is acquired during the procedure by tracking the motion of the diaphragm in real-time X-ray images. This information is used as input to the model which uses it to predict the position of structures of interest during respiration. 3-D validation of the technique is performed on 4 volunteers and 4 patients using a leave-one-out test on manually identified anatomical landmarks in the MR scan, and 2-D validation is performed by using the model to predict the respiratory motion of structures of the heart which contain catheters that are visible in X-ray images. The technique is shown to reduce 3-D registration errors due to respiratory motion from up to 15mm down to less than 5mm, which is within clinical requirements for many procedures. 2-D validation improved accuracy from 14mm to 2mm. In addition, we use the affine model to analyse the effects of different types of breathing on the motion and deformation of the heart, specifically increasing the breathing rate and depth of breathing. Our findings suggest that the accuracy of the model is reduced if the subject breathes in a different way during model construction and application. However, models formed during deep breathing may be accurate enough to be applied to other types of breathing.

6918-42, Session 8

Respiratory signal generation for retrospective gating of cone-beam CT images

S. Wiesner, Technische Univ. München (Germany); Z. R. Yaniv, Georgetown Univ.

We are currently investigating the acquisition of 4D cone-beam CT data using retrospective gating of the X-ray projection images. This approach requires a respiratory signal that is synchronized with image acquisition. To obtain such a signal we propose to use a spherical fiducial attached to the patient's skin surface such that it is visible in the images. A region of interest containing the fiducial is manually identified in an initial image and is then automatically detected in all other images. Subsequently, we perform an approximate spatial (3D) reconstruction of the marker location from its 2D locations. Finally, we compute a respiratory signal by projecting the 3D points onto the major axis estimated via principle component analysis. As this respiratory signal was obtained from the fiducial location in each of the images it is implicitly synchronized with image acquisition. We evaluate the robustness of our fiducial detection using an anthropomorphic respiratory phantom. To evaluate the quality of the estimated respiratory signal we use a motion platform that follows the respiratory motion obtained by tracking the skin surface of a volunteer. We show that our method generates a respiratory signal that is in phase with the ground truth signal, but suffers from inaccuracies in amplitude close to the anterior-posterior imaging setup where the primary direction of motion is perpendicular to the image plane. Thus, our method should only be used for phase based retrospective gating.

6918-43, Session 8

Preoperative brain shift: case studies

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In successful surgery, the neurosurgeon's objectives are threefold: (1)reach the target, (2)remove it, and (3)preserve eloquent tissue surrounding it. Surgical Planning (SP) consists in identifying optimal access route(s) to the target based on anatomical references and constrained by functional areas. Preoperative images are essential input in Multi-modal Image Guided NeuroSurgery (MIGNS) systems and update of these images, with precision and accuracy, is crucial to approach the anatomical reality in the operating room (OR). Intraoperative brain deformation has been previously identified by many research groups and related update of preoperative images has been also studied. We present three case studies with tumors accompanied with edema and where corticosteroids were administered and monitored during a preoperative stage [t0,t1=t0+10 days]. In each case we observed a significant change in the region of interest (ROI) and in anatomical references around it. This preoperative brain shift could induce error for localization during intervention (time tS) if the SP is based on the t0 preoperative images. We computed volume variation, distance maps based on closest point (CP) for different components of the ROI, and displacement of mass center (CM) of the ROI. The matching between sets of homologous landmarks from t0 to t1 was performed by an expert (X.M.). The estimation of the landmarks displacements showed significant deformations around the ROI (landmarks shifted with mean of 3.90±0.92 mm and maximum of 5.45 mm for one case resection). The CM of the ROI moved about 6.92 mm for one biopsy. Accordingly, there was a sizable difference between SP based at t0 vs SP based at t1, up to 7.95 mm for localization of reference access in one resection case. When compared to the typical MIGNS system accuracy (2 mm), it is recommended that preoperative images be updated within the interval time [t1,tS] in order to minimize the error correspondence between the anatomical reality and the preoperative data. This should help maximize the accuracy of registration between the preoperative images and the patient in the OR.

6918-44, Session 9

Incorporating electromagnetic tracking into respiratory correlated imaging for high precision radiation therapy

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It is well established that respiratory motion has significant effects on lung tumor position, and incorporation of this uncertainty increases the normal lung tissue irradiated. Respiratory correlated CT, obtained by oversampling images throughout the respiratory cycle based on an external surrogate, is increasingly being used for radiation therapy planning. Cone beam CT is being used to obtain cross sectional imaging at the time of therapy for accurate patient set-up. However, it is not possible to obtain cross sectional respiratory correlated imaging throughout the course of radiation, leaving residual uncertainties. Recently, implantable passive transponders (Calypso(r) Medical Technologies) have been developed which are currently FDA-cleared for prostate use only and can be tracked via an external electromagnetic array in real-time, without the use of ionizing radiation. A visualization system needs to be developed to quickly and efficiently utilize both the dynamic real-time point measurements with the previously acquired volumetric data. We have created such a visualization system by incorporating the respiratory correlated imaging and the individual transponder locations into the Image Guided Surgery Toolkit (IGSTK.org). The tool already allows quick, qualitative verification of the differences between the measured transponder position and the imaged position at planning and will support quantitative measurements displaying uncertainty in positioning.

6918-45, Session 9

Fiducial movement in lung CT images after CyberKnife stereotactic radiosurgery

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To track respiratory motion during CyberKnife stereotactic radiosurgery in the lung, several (three to five) cylindrical gold fiducials are implanted near the planned target volume (PTV). Since these fiducials remain in the human body after treatment, we hypothesize that tracking fiducial movement over time may correlate with the tumor response to treatment and pulmonary fibrosis, thereby serving as an indicator of treatment success. In this paper, we investigate fiducial migration in 24 patients through examination of computed tomography (CT) volume images at four time points: pre-operative, three, six, and twelve month post-operative. We developed a MATLAB based GUI environment to display the images, identify the fiducials, and compute our performance measure.

After we semi-automatically segmented and detected fiducial locations in CT images of the same patient over time, we identified them according to their configuration and introduced a relative measure to detect their migration. We found that the migration tended to result in a movement towards the fiducial center of the radiated tissue area (indicating tumor regression) and may potentially be linked to the patient prognosis.

6918-46, Session 9

Visualizing anatomic changes over multi-day radiotherapy treatments

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We present a method for visualizing changes in serial 3d medical image sets, such as those gathered over a multi-day radiotherapy treatment. For clinical application of multi-day therapy, it is important to understand the changing shape and spatial relationship of the target to other anatomic structures. Our automatic scene composition method uses partial segmentations of the data to guide a feature driven clipping algorithm. The data is filtered according to the segmentations into a ranked feature volume, from which a view-dependent clip-mask is computed. Our clipping algorithm is based on a novel object-order volume shadowing algorithm rather than ray casting, so it is amenable to hardware acceleration. The clipped data is further modulated by contours from the source and target segmentations, allowing clinicians to focus and contextualize the visualization in different ways to understand a variety of different anatomic relationships over space and time.

6918-47, Session 9

Radiation therapy simulation and planning with magnetic resonance images

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We present a system which allows for use of magnetic resonance (MR) images as primary RT workflow modality alone and no longer limits the user to computed tomography data for radiation therapy (RT) planning, simulation and patient localization. The single steps for achieving this goal are explained in detail.

For planning two MR data sets, MR1 and MR2 are acquired sequentially. For MR1 a standardized sequence is used enhancing bony anatomy. The sequence for MR2 is chosen to get optimal contrast for the target and organs at risk for each individual patient. Both images are naturally in registration, neglecting elastic soft tissue deformations. The planning software first automatically extracts skin and bony anatomy from MR1. The user can semi-automatically delineate target structures and organs at risk based on MR1 and MR2, associate all segmentations with MR1 and create a plan in the coordinate system of MR1. Projections similar to digitally reconstructed radiographs (DRR) enhancing bony anatomy are calculated from the MR1 directly and can be used for iso-center

definition and setup verification. Furthermore we present a method for creating a Pseudo-CT data set which assigns electron densities to the voxels of MR1 based on the skin and bone segmentations. The Pseudo-CT is then used for dose calculation.

Results from first tests under clinical conditions show the feasibility of the completely MR based workflow in RT for necessary clinical cases. It needs to be investigated in how far geometrical distortions influence accuracy of MR-based RT planning.

6918-48, Session 9

Phase impact factor: a novel parameter for determining optimal CT phase in 4D radiation therapy treatment planning for mobile lung cancer

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Due to respiratory motion, lung tumor can move up to several centimeters. If respiratory motion is not carefully considered during the radiation treatment planning, the highly conformal dose distribution with steep gradients could miss the target. To address this issue, the common strategy is to add a population-derived safety margin to the gross tumor volume (GTV). However, during a free breathing CT simulation, the images could be acquired at any phase of a breathing cycle. With such a generalized uniform margin, the planning target volume (PTV) may either include more normal lung tissue than required or miss the GTV at certain phases of a breathing cycle. Recently, respiration correlated CT (4DCT) has been developed and implemented. With 4DCT, it is now possible to trace the tumor 3D trajectories during a breathing cycle and to define the tumor volume as the union of these 3D trajectories. The tumor volume defined in this way is called the internal target volume (ITV). In this study, we introduced a novel parameter, the phase impact factor (PIF), to determine the optimal CT phase for intensity modulated radiation therapy (IMRT) treatment planning. A minimum PIF will yield a minimum probability for the GTV to move out of the ITV during the course of an IMRT treatment, providing a minimum probability of a geometric miss. Once the CT images with the optimal phase were determined, an IMRT plan with three to five co-planner beams was computed and optimized using the inverse treatment planning technique.

6918-49, Session 9

Efficient framework for deformable 2D-3D registration

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Extracting the rigid body transformation between the x-ray and CT imaging coordinate systems can be done through 2D-3D registration of the x-ray images and volumetric CT. The drawback of such approach is the rigidity assumption on the imaged object which is not valid for most of the patient cases. In this paper, we are proposing a technique that performs the 2D-3D registration and also extracts deformations due to various respiratory phases apparent from of the CT and x-ray acquisitions: 2D-3D registration problem is difficult since the observation space is of lower dimension compared to the sought after parameter space. This difficulty is even more apparent if we are dealing with deformations, which are parameterized in 3D, but observed and detected in the 2D projections images: In order to deal with this problem, during a preparation/learning phase, we acquire multiple sets of 4D CT data sets. Using a grid based free form deformable registration algorithm non-rigidly register them to a single chosen CT data set. By doing this we have established a control point grid within our 'base volume' which have a distribution of deformation (i.e., control point movement) across various patients and various breathing phases. Each projected ray through this so-called distribution volume generates a profile, which depicts the nature of the deformation or movements along that ray. This motion distribution profile is parameterized and used with the proposed algorithm: In the first phase of 2D-3D registration, we perform rigid matching and in the second phase, we account for deformations. Prior to the deformable 2D-3D registration, we non-rigidly register the CT volume to the prior 'base volume', in order to be able to assign the deformation distributions to the new grid. We then generate digitally reconstructed radiographs (DRR) using a GPU and compare the results with the corresponding x-

ray image. Local 2D motion component computed based on generated DRR and x-ray image is used to apply the learnt deformation profile to the original CT volume and re-render a new DRR. This iterative process is performed until convergence. The on the fly deformation and rendering of the volume is implemented efficiently using GPUs, making it possible to perform the registration in a reasonable time.

6918-50, Session 10

Detection and visualization of endoleaks in CT data for monitoring of thoracic and abdominal aortic aneurysm stents

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In this paper we present an efficient algorithm for the segmentation of the inner and outer boundary of aortic aneurysms (TAA & AAA) in computed tomography angiography (CTA) acquisitions. The aneurysm segmentation includes two steps: At first the inner boundary is segmented based on a grey level model with two thresholds. Second a modified active contour model approach with initialization based on the available inner boundary segmentation is used for the more complicated problem of the outer boundary segmentation. An opacity image, which aims at enhancing important features while reducing spurious structures, is calculated from the CTA images and employed to guide the deformation of the model. In addition, the active contour model is extended to prevent intersections of the inner and outer boundary and keep the outer boundary in a distance given by the thrombus thickness to the inner boundary. Based upon the segmentation results, the aneurysm size is measured for each centerline point on the orthogonal multiplanar reformatting (MPR) plane. Furthermore a three-dimensional TAA or AAA model is reconstructed from the set of segmented contours, and the presence of endoleaks is detected and highlighted in suitable visualization way. The implemented method has been evaluated on nine clinical CTA data sets. Results are demonstrated for CTA with variations in anatomy and location of the pathology.

6918-51, Session 10

Coronary CT angiography: IVUS image fusion for quantitative plaque and stenosis analyses

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Rationale and Objective: Due to the limited temporal and spatial resolution, the coronary CT angiographic image quality is not (yet) optimal for robust and accurate quantitative stenosis analyses, and plaque differentiation and quantification. By combining the higher resolution IVUS images with CT images, a detailed representation of the coronary arteries can be provided in the CT images.

Methods: The matching of the two vessel representation is carried out in three steps. First, vessel segments are matched using anatomical landmarks in cylindrical projection images. Second, the landmarks are aligned in cross-sectional vessel images. In the third step the semi-automatically detected IVUS lumen contours are matched to the CTA data, using manual interaction and using automatic registration methods.

Results: The IVUS-CTA fusion tool facilitates the unique view of the high resolution IVUS segmentation of the outer vessel wall and lumen-plaque transitions on the CT images. The cylindrical projection of the CMPR image decreases the analysis time for the matching with vessel segments with 50 percent. The automatic registration of the cross-vessel views decreases the analyses time with as much as 85 percent.

Conclusions: The fusion of IVUS images and their segmentation results with coronary CT angiographic images provide a detailed view of the lumen and vessel wall coronary arteries. The automatic fusion tool makes

such a registration feasible in clinical studies and for the development and validation of analysis tools.

6918-52, Session 10

Quantification of the aortic arch morphology in 3D CTA images for endovascular aortic repair (EVAR)

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We introduce a new model-based approach for the segmentation and quantification of the aortic arch morphology in 3D CTA images for endovascular aortic repair (EVAR). The approach is based on a 3D analytic intensity model for thick vessels, which is directly fitted to the image. Based on the fitting results we compute the (local) 3D vessel curvature and torsion as well as the relevant lengths not only along the 3D centerline but particularly along the inner and outer contour. These measurements are important for pre-operative planning in EVAR applications.

We have successfully applied our approach using ten 3D CTA images and have compared the results with ground truth obtained by a radiologist.

It turned out that our approach yields accurate estimation results. We have also performed a comparison with a commercial vascular analysis software.

6918-53, Session 10

In-vivo endovascular image guided interventions (EIGI) using the high-sensitivity micro-angiographic fluoroscope (HS-MAF)

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Advances in catheter technology and remote actuation of finer minimally invasive EIGI devices demand improved x-ray imaging technology. The new x-ray HS-MAF detector offers high resolution and real-time image guidance capabilities greatly exceeding those of commercially available detectors. The HS-MAF consists of a 300 μm CsI input phosphor on a micro-channel-plate light image intensifier (LII), coupled by a minifying fiber-optic taper to a CCD camera. The HS-MAF detector features a 1024X1024 array 35 μm pixels, 12 bit depth, 30 fps frame-rate, and 4 cm diameter field of view. The LII has a large variable gain which enables usage at very low exposures characteristic of fluoroscopy as well as higher exposures for angiography. The custom software allows real-time image acquisition, display, and storage using roadmapping and DSA modes. To evaluate the new detector, a set of in-vivo experimental interventions involving placement of specially designed endovascular stents were carried out under guidance of both the new detector and a standard x-ray image intensifier (XII). Fluoroscopy and angiography were used to assess and then treat aneurysms created in rabbits. The image guided interventions under control with the HS-MAF detector were superior to those with the XII. The markers, endovascular device structures, and vessel geometry were better identified with the new detector. The experimental EIGI procedures demonstrate that the high resolution HS-MAF detector can vastly improve the accuracy of localization and tracking of devices such as guidewires, catheters and stents. (Partial support: NIH grants R01NS43294, R01EB002873; Toshiba MSC, and Abbott Corp.).

6918-54, Session 10

Automated determination of optimal angiographic viewing angles for coronary artery bifurcations from CTA data

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For optimal diagnosis and treatment of lesions at coronary artery

bifurcations using x-ray angiography, it is of utmost importance to determine proper angiographic viewing angles. Due to the increasing use of CTA as a first line diagnostic tool, 3D CTA data is more frequently available before x-ray angiographic procedures take place. Motivated by this, we propose to use available CTA data for the determination of patient specific optimal x-ray viewing angles.

A semi-automatic iterative region growing scheme is developed for the segmentation of the coronary arterial tree. From the segmented arterial tree, a complete hierarchical surface and center line representation, including bifurcation points, is automatically obtained. The optimal viewing angle for a selected bifurcation is determined as the view rendering the least amount of foreshortening and vessel overlap.

For 83 bifurcation areas, viewing angles were automatically determined. First, the sensitivity of the method to patient positioning in the x-ray system was studied. Next, the automatically determined angles were both quantitatively and qualitatively compared with angles determined by two experts.

The method was found not to be sensitive to the positioning of the patient in the angiographic x-ray system. In 95% of the cases our method produced a clinically usable view (mean score of 8.4 out of 10) as compared to 98% for the experts (mean score of 8.7). Our method produced angiographic views with significantly less foreshortening (mean difference of 10 percentage points) than the angiographic views set by the experts.

6918-55, Session 11

Accuracy analysis of an image-guided system for vertebroplasty based on electromagnetic tracking of instruments

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Vertebroplasty is a minimally invasive procedure in which bone cement is pumped into a fractured vertebral body that has been weakened by osteoporosis, long-term steroid use, or cancer. In this therapy, a trocar (large bore hollow needle) is inserted through the pedicle of the vertebral body which is a narrow passage and requires great skill on the part of the doctor to avoid going outside of the pathway. In clinical practice, this procedure is typically done using 2D x-ray fluoroscopy. To investigate the feasibility of providing 3D image guidance, we developed an image-guided system based on electromagnetic tracking and our open source software platform the Image-Guided Surgery Toolkit (IGSTK). The system includes path planning, interactive 3D navigation, and dynamic referencing.. This paper will describe the system and our initial evaluation.

6918-56, Session 11

Optimization of spine surgery planning with 3D templating tools

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The current standard of care for patients with spinal disorders involves a thorough clinical history, physical exam, and imaging studies. Simple radiographs provide a valuable assessment but prove inadequate for surgery planning because of the complex 3-dimensional anatomy of the spinal column, and the close proximity of the neural elements, large blood vessels, and viscera. Currently, clinicians still use primitive techniques such as paper cutouts, pencils, and markers in an attempt to analyze and plan surgical procedures. 3-D imaging studies are routinely ordered prior to spine surgeries but are currently limited to generating simple, linear and angular measurements from 2-D views orthogonal to the central axis of the patient. Complex spinal corrections require more accurate and precise calculation of 3-D parameters such as lengths, angles, levers, and pivot points within individual vertebra. We have developed a clinician friendly spine surgery planning tool which incorporates rapid oblique reformatting of each individual vertebra, followed by interactive templating for 3-D placement of implants. The template placement is

guided by the simultaneous representation of multiple 2-D section views from reformatted orthogonal views and a 3-D rendering of individual or multiple vertebrae enabling superimposition of virtual implants. These tools run efficiently on desktop PCs typically found in clinician offices or workrooms. A preliminary study conducted with Mayo Clinic spine surgeons using several actual cases suggests significantly improved accuracy of pre-operative measurements, which is expected to increase spinal procedure efficiency and safety, and reduce time and cost of the operation.

6918-57, Session 11

2D/3D registration with the CMA-ES method

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We propose a new method for 2D/3D registration and report its experimental results. The method uses the Covariance Matrix Adaptation Evolution Strategy (CMA-ES) as the optimization technique to find the spatial correspondence between the 2D and 3D data robustly, accurately and efficiently. To evaluate the alignment between the two data of different dimensions, 2D Digitally Reconstructed Radiographs (DRRs) are generated from the 3D data and a hardware-accelerated technique, named Adaptive Slice Geometry Texture Mapping (ASGTM), is used to speed-up the generation process. Three bone phantoms of different sizes and shapes were used to test our method: a long femur, a large pelvis, and a small scaphoid. First, experiments were performed using CT and simulated fluoroscope of the phantoms. Next, CT and real fluoroscope of the femur phantom were used to examine the method's behaviours in surgical environment. The results were compared with our previously published results for two other methods, i.e. a commonly used simplex-based method, and our previously proposed Unscented Kalman Filter (UKF) based method. The results show that, while operating with the same order of computation complexity as the two compared methods, the new method consistently achieves the largest capture range and the best accuracy. Furthermore, it has an advantage over the robust UKF-based method in the sense that it requires less number of control parameters and is less sensitive to the parameters' initial values.

6918-58, Session 11

Acetabular rim and surface segmentation for hip surgery planning and dysplasia evaluation

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Knowledge of the acetabular rim and surface can be invaluable for hip surgery planning and dysplasia evaluation. The acetabular rim can also be used as a landmark for registration purposes. At the present time acetabular features are mostly extracted manually at great cost of time and human labor. Using a recent level set algorithm that can evolve on the surface of a 3D object represented by a triangular mesh we automatically extracted rims and surfaces of acetabulae. The level set is guided by curvature features on the mesh. It can segment portions of a surface that are bounded by a line of extremal curvature (ridgeline or crestline). The rim of the acetabulum is such an extremal curvature line. Our material consists of eight hemi-pelvis surfaces. The algorithm is initiated by putting a small circle (level set seed) at the center of the acetabular surface. Because this surface distinctively has the form of a cup we were able to use the Shape Index feature to automatically extract an approximate center. The circle then expands and deforms so as to take the shape of the acetabular rim. The results were visually inspected. Only minor errors were detected. The algorithm also proved to be robust. Seed placement was satisfactory for the eight hemi-pelvis surfaces without changing any parameters. For the level set evolution we were able to use a single set of parameters for seven out of eight surfaces.

6918-59, Session 11

A simulator for surgery training: optimal sensory stimuli in a bone pinning simulation

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Currently available low cost haptic devices allow inexpensive surgical training with no risk to patients. Major drawbacks of lower cost devices include limited maximum feedback force and the incapability to expose occurring moments. Aim of this work was the design and implementation of a surgical simulator that allows the evaluation of multi-sensory stimuli in order to overcome the occurring drawbacks.

The simulator was built following a modular architecture to allow flexible combinations and thorough evaluation of different multi-sensory feedback modules. A Kirschner-Wire tibial fracture fixation procedure was defined and implemented as a first test scenario. A set of computational metrics has been derived from the clinical requirements of the task to objectively assess the trainee's performance during simulation.

Sensory feedback modules for haptic and visual feedback have been developed, each in a basic and additionally in an enhanced form. First tests have shown that specific visual concepts can overcome some of the drawbacks coming along with low cost haptic devices. The simulator, the metrics and the surgery scenario together represent an important step towards a better understanding of the perception of multi-sensory feedback in complex surgical training tasks. Field studies on top of the architecture can open the way to riskless and inexpensive surgical simulations that can keep up with traditional surgical training.

6918-60, Session 11

CT and MR image fusion for CSF leak diagnosis

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The diagnosis of cerebrospinal fluid (CSF) leak using MR images alone is difficult, mostly due to the inherently poor bony information on MR images. While CT images show bones much more exquisitely, they lack the soft tissue contrast that is important for detecting CSF leak. We proposed a method to semi-automatically fuse the CT and MR images of the same patient to combine the complementary information from each modality, which we believe will help with the diagnosis and surgical planning for patients with CSF leak. In the first step of the proposed method, a user identifies three roughly corresponding points (landmarks) on both the CT and MR images. A graphical user interface (GUI) was implemented that allows the user to quickly navigate through the images by reslicing the volumes interactively. After finding the CT and MR slices at approximately the same anatomical position, the user place the markers to represent the same spatial location. A total of three landmarks are required. In the second step, a generalized Procrustes method is used to compute an initial transformation that aligns the CT and MR images, which is then optimized using mutual information based image registration. The CT image are transformed to the same spatial location as the MR images using the optimal transformation found, and the bony masks determined from thresholding CT images are blended with MR images using alpha-composition. The resultant fusion images are saved as DICOM images that can be imported to PACS for further viewing. A fusion viewer was implemented that allows the user to visually inspect the fusion images. Initial results suggest that CT/MR fusion images are superior to unprocessed CT and MR images in diagnosing CSF leak, and a formal evaluation is being planned to assess the efficacy of fusion images in clinical cases.

6919-01, Session 1

How HL7 version 3 is used at the Sahlgrenska University Hospital to exchange information with a central archive

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This paper describes how the integration between one of the RIS-systems (Adapt) in VGR and the infobroker in the central archive is implemented. The project was presented in 2006 with the title Building an IT Healthcare Enterprise by taking the standards to the limits and sometimes beyond that. The Adapt RIS is used by the Sahlgrenska University Hospital (SU) in Gothenburg and consist of 8 different radiology departments.

The implementation is based on HL7 version 3 and the message exchange is based on Web Services. The base of the RIS-system was developed in the beginning of the 1990:s by a company that no longer exists. SU has always been able to modify the system by changing the source code and we have been responsible for the system-development since late 1990s.

We are using IBM Informix Dynamic Server that is running on a Solaris-based cluster with additional software from Veritas/Symantec. The communication is planned to be 2-way. Our RIS-system transfers order promises, various status updates during the workflow and finally reports with various statuses. Our system will be able to receive requests and reports from the broker. The broker in turn receives these messages from other hospitals in VGR (Vastra Gotalands Regionen).

We use Axis2 to generate skeleton java-code based on WSDL- and XSD-files that defines the Web Services. Axis2 is an Open Source software that is developed as a part of the Apache project. Eclipse is a development environment for Java that we use and it is also open source. Apache Tomcat is the application server that we use to receive messages from the infobroker.

6919-02, Session 1

A taxonomy and evaluation of free non-diagnostic DICOM software tools

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A variety of software exists to interpret DICOM files and display them as individual images or volume rendered objects. Some of them offer further processing and analysis features. The surveys that have been published so far are not up-to-date anymore, and neither a detailed description of the software functions nor a comprehensive comparison is given. This survey aims at classification of freely available, non-diagnostic DICOM software into "volume renderer" and "image viewer", and at comparison of software with respect to the following aspects:

1. Performance: such as data loading, transfer functions, sliced views, pre-built models for volume rendering, and viewing, exporting, and processing for image viewers;
2. Robustness: some software tools may misinterpret some datasets or, even worse, fail to read them, possibly resulting in program crash;
3. Usability: such as usage, documentation, and speed;
4. Portability: regarding the operation systems Windows, Unix, and Mac;
5. Miscellaneous: to describe other issues like source availability, support, etc.

Based on our study, a user who is not familiar with DICOM software can efficiently and effectively find that one most adequately addressing his needs. In this abstract, we reviewed five software packages exemplarily: Julius, 3D Slicer, DicomWorks, MIPAV and Osiris. On acceptance, the complete results on about twenty software tools will be provided in the full paper.

6919-03, Session 1

Integrating DICOM structure reporting (SR) into the medical imaging informatics data grid

J. Lee, J. R. Documet, B. J. Liu, Univ. of Southern California

The Medical Imaging Informatics Data Grid developed at the USC Image Processing and Informatics Laboratory enables medical images to be shared securely between multiple imaging centers. Current applications include an imaging-based clinical trial setting where multiple field sites perform image acquisition and a centralized radiology core performs image analysis, often using computer-aided diagnosis tools (CAD) that generate a DICOM-SR to report their findings and measurements. As more and more CAD tools are being developed in the radiology field, the generated DICOM Structure Reports (SR) holding the key radiological findings and measurements that are not part of the DICOM image need to be integrated into the existing Medical Imaging Informatics Data Grid with the corresponding imaging studies. We will discuss the significance and method involved in adapting DICOM-SR into the Medical Imaging Informatics Data Grid. The result is a Data Grid repository from which users can send and receive DICOM-SR objects based on the imaging-based clinical trial application. The services required to extract and categorize information from the structured reports will be discussed, and the workflow to store and retrieve a DICOM-SR file into the existing Data Grid will be shown.

6919-04, Session 1

A DICOM-RT radiation oncology ePR with decision support utilizing a quantified knowledge base from historical data

J. R. Documet, B. J. Liu, A. H. T. Le, Univ. of Southern California; M. Y. Y. Law, The Hong Kong Polytechnic Univ.

During the last 2 years we have been working on developing a DICOM-RT ePR (Electronic Patient Record) with decision support that will allow physicists and radiation oncologists to reduce the turnaround time for the planning of cancer cases. This ePR allows offline treatment dose calculations and plan evaluation, while at the same time compare and quantify treatment planning algorithms using DICOM-RT objects. The ePR framework permits the addition of visualization, processing, and analysis tools, which combined with the core functionality of reporting, importing and exporting of medical studies, creates a very powerful application that can improve the efficiency while planning cancer treatments.

6919-05, Session 1

Brokerage mechanism proposal for teleradiology studies distribution

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The purpose of this work is to present a broker that automates (most of) administrative procedures associated with nighthawk radiology institutions that act as brokers between buyers (institutions where the exams are performed) and suppliers (radiologists that perform the reading of the exam), firstly by optimizing the match between buyers and suppliers of the service and, from there on, by alleviating the associated administrative work before and after the reading is done.

On top of that, the broker complies with (present and expected future) regulatory requirements in place in the European Union for this kind of services. It is also compliant to a set of clinical requirements issued by the clinicians, namely in the field of anonymity and data protection, as well as in specific workflows, such as being able to enable workgroup in oncological case-studies.

From the technical side, it is able to pass clinical and administrative information, such as historical clinical records and details on the case to be studied, among multiple PACS systems that are not directly interconnected.

6919-06, Session 2**A web-accessible content-based cervicographic image retrieval system**

Z. Xue, L. R. Long, S. K. Antani, National Library of Medicine; J. Jeronimo, National Cancer Institute; G. R. Thoma, National Library of Medicine

Content-based image retrieval (CBIR) is the process of retrieving images by directly using image visual characteristics. In this paper, we present a prototype system implemented for CBIR for a uterine cervix image (cervigram) database.

This cervigram database is a part of data collected in a multi-year longitudinal effort by the National Cancer Institute (NCI), and archived by the National Library of Medicine (NLM), for the study of the origins of, and factors related to, cervical precancer/cancer. Users may access the system with any Web browser. The system is built with a distributed architecture which is modular and expandable; the user interface is decoupled from the core indexing and retrieving algorithms, and uses open communication standards and open source software. The system tries to bridge the gap between a user's semantic understanding and image feature representation, by incorporating the user's knowledge. Given a user-specified query region, the system returns the most similar regions from the database, with respect to attributes of color, texture, and size. Experimental evaluation of the retrieval performance of the system on "ground-truth" test data illustrates its feasibility to serve as a possible research tool to aid the study of the visual characteristics of cervical neoplasia.

6919-07, Session 2**Retrieving clinical cases through a concept space representation of text and images**

S. Ebadollahi, D. E. Johnson, IBM Thomas J. Watson Research Ctr.; M. Diao, Georgia Institute of Technology

Retrieving clinical cases, consisting of text notes and images of various modalities, is important both for clinical decision support and educational purposes. Unfortunately each single medium (text or image) is by itself insufficient for effective case retrieval. Text does not convey the subtle information embedded in the associated medical images and images do not represent the clinician's observations. Hence, the information extracted from both media should be combined to improve the accuracy and usability of multimodal medical records retrieval.

We employ a 'modality-anatomy' semantic representation of diagnostic images, and link their contents to the associated text notes at the semantic level. The choice of semantic concepts rests on the fact that observations are often based on specific modalities and are grounded in anatomy. Each multimodal record is mapped into a collection of points in the 'modality-anatomy' based semantic concept space. Queries, consisting of a text query and example images, are also mapped to this space. The projection to a semantic space is doubly interesting: 1) It captures high-level concepts important for medical retrieval from the low-level visual content of images; 2) It provides a framework for a unified semantic concept space enabling a potential uniform representation of information from heterogeneous data sources (text, image, etc.). Such a representation will ease the navigation between different information modalities, i.e., run an image based search from a text query or a text based search from an image query.

Our results demonstrate the effectiveness of using semantic concept space in multimodal medical image retrieval.

6919-08, Session 2**Local versus global texture analysis for lung nodule image retrieval**

R. D. Datteri, Gonzaga Univ.; D. S. Raicu, J. D. Furst, DePaul Univ.

In medical images overlap often occurs making it difficult to identify different anatomical structures using intensity alone; texture therefore is valuable in the analysis, interpretation, and retrieval of lung nodules.

The goal of our research study is to present a comparison between the

different texture models Gabor filters, Markov Random Field (MRF), global and local co-occurrence. For comparison purposes we utilized Manhattan, Euclidean, and Chebychev for one-dimensional feature vectors (global co-occurrence) while for two-dimensional feature comparison (local co-occurrence, Gabor filters, and MRF) we utilized the similarity measures Chi-Square, and Jeffrey-Divergence. Local co-occurrence contains many different variable aspects in its design that can considerably change the success of its results. An examination of local co-occurrence's variables is discussed. We then evaluate the feature models with respect to the radiologists' annotations and, separately, to whether or not the returned image belongs to the same nodule.

All of the discussed texture models are presented in the context of our previous Content-Based Image Retrieval System (CBIRS)[1]. BRISC utilizes the Lung Image Database Consortium (LIDC) database. We have found that Gabor and Markov texture descriptors produce the best retrieval results regardless of the nodule size, number of retrieved items or similarity metric with an average precision of 88%. Global co-occurrence performed the worse at 44% precision yet when co-occurrence was performed locally (Local co-occurrence) the precision results improved to 64%. When we evaluated our system utilizing the radiologists' annotations the differences in the results were minimal.

6919-09, Session 2**RadSearch: a RIS/PACS integrated query tool**

S. Tsao, P. Moin, J. R. Documet, K. Wang, B. J. Liu, Univ. of Southern California

Radiology Information Systems (RIS) contain a wealth of information that can be used for research, education, and practice management. However, the sheer amount of information available makes querying specific data difficult and time consuming. Previous work has shown that a clinical RIS database and its RIS text reports can be extracted, duplicated and simply indexed for searches while complying with HIPAA and IRB requirements (Desjardins). Work has also been done on parsing the radiology text reports (Taira). This project's intent is to provide a sophisticated software tool, the RadSearch Toolkit, to seamlessly search the radiology text report for key terms and retrieve studies associated with a RIS query from the Picture Archiving and Communication System (PACS) automatically. This toolkit will be integrated with the Study Management Tool (SMT) system that allows study distribution via Personal Digital Assistant (PDA), Short Message Service (SMS) or any other workstation with access to broadband internet or intranet. The SMT system has been implemented at two clinical sites (St John's Health Center, Santa Monica, CA & Health Consultation Center II, USC Keck School of Medicine, Los Angeles, CA) for over four years. This powerful combination will be especially useful in the academic setting where researchers can search for studies with specific, multiple criteria as well as allow teaching files to be quickly and effectively created from the search results. These tasks could not be done nearly as efficiently before the creation of the RadSearch Toolkit because (1) RIS systems do not index radiology reports and are not searchable (2) current radiology report search software are not integrated with PACS.

6919-11, Session 2**Grid-enabled mammographic auditing and training system**

M. H. Yap, A. G. Gale, Loughborough Univ. (United Kingdom)

Effective use of new technologies to support healthcare initiatives is important and current research is moving towards implementing secure grid-enabled healthcare provision. In the UK, a large-scale collaborative research project (GIMI: Generic Infrastructures for Medical Informatics), which is concerned with the development of a secure IT infrastructure to support very widespread medical research across the country, is underway. In the UK, there are some 109 breast screening centers and a growing number of individuals (circa 650) nationally performing approximately 1.5 million screening examinations per year. At the same, there is a serious, and ongoing, national workforce issue in screening which has seen a loss of consultant mammographers and a growth in specially trained technologists and other non-radiologists. Thus there is a need to offer effective and efficient mammographic training so as

to maintain high levels of screening skills. Consequently, a grid based system has been proposed which has the benefit of offering very large volumes of training cases that the mammographers can access anytime and anywhere. A database, spread geographically across three university systems, of screening cases is used as a test set of known cases. The GIMI mammography training system first audits these cases to ensure that they are appropriately described and annotated. Subsequently, the cases are utilized for training in a grid-based system which has been developed. This paper briefly reviews the background to the project and then details the ongoing research. In conclusion, we discuss the contributions, limitations, and future plans of such a grid based approach.

6919-12, Session 3

PACS in the clinical context: past, present, and future (Keynote)

D. Avrin, Univ. of California/San Francisco

PACS, and other radiology and clinical information systems are well "beyond the chasm." Yet for users in the trenches today, one hears constant complaints and suggestions of how these systems could be more helpful, easier to use, better integrated, and smarter. This is in spite of the high quality and powerful products available from a wide range of vendors. One becomes particularly aware of the shortcomings when practicing radiology within the context of a clinical enterprise.

In order to chart a productive path for the future, it will be helpful to explore the history of PACS development and deployment, to understand how we arrived at where we are today. We will explore the "requirements and specifications" that affect the role of medical imaging in the broader clinical context. Particular technologies and standards that have potential for creative solutions will be identified.

A survey of current projects in development from North America and Europe that offer creative solutions will be reviewed. Particular focus will be placed upon vendor process for inclusion in product, integration of systems, and smart user interfaces. The impact of IT on the entire workflow process of medical imaging, its relationship to the broader enterprise, quality of interpretation, and patient safety will be examined.

6919-13, Session 3

A classification framework for lung tissue categorization

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1. DESCRIPTION OF PURPOSE

Interpreting high-resolution computed tomography (HRCT) images of the chest showing patterns associated with interstitial lung diseases (ILDs) is time-consuming and requires experience. ILDs are a heterogeneous group of around 150 illnesses. Images play an important role in the diagnosis. Computerized HRCT analysis can provide quick and precious information for emergency radiologists and other non-chest specialists¹. 2. In this study, the abilities of five common classifiers to discriminate several lung tissue patterns are evaluated. This work is part of a content-based HRCT retrieval system for a multimedia database of ILDs with annotated image series and associated clinical data³.

2. METHOD(S)

The dataset used is part of an internal database of ILD cases³, 4 containing HRCT images with slice thickness of 1mm and annotated regions performed by two radiologists. 843 regions of interest (ROIs) from healthy and five pathologic lung tissue patterns commonly found in HRCT images were used for training and testing the classifiers (see Table 1). Texture features used to describe the images are grey-level histograms in Hounsfield Units and quincunx wavelet frame (QWF) coefficients with B-spline wavelets⁵. 6. Classifier implementations are taken from the open source Java library Weka⁷, 8.

3. RESULTS

The classifiers evaluated are Support Vector Machines (SVM), k-Nearest Neighbor (k-NN), Multilayer Perceptron, Naive Bayes, Tree with C4.5. The attributes were normalized in order to give equivalent weight to each feature.

The SVM classifier constitutes the best trade-off between the error rate on the training set and generalisation; the ability to classify ROIs correctly from images of new patients. The latter was integrated into a software for classification of ROIs directly in DICOM images (Figure 1).

4. NEW OR BREAKTHROUGH WORK TO BE PRESENTED

Evaluation of the classifiers is based on a high-quality dataset taken from clinical routine as well as discriminant features. The diagnostic aid tool is easy to integrate into the PACS with the same interface and offers the possibility to add clinical data from the electronic patient record.

5. CONCLUSIONS

The classifier belongs to the core of a computer-aided diagnosis system involved in the decision taking process.

Since SVM were designed to avoid overfitting of training samples, using them to classify medical images with much heterogeneity is adapted.

6919-14, Session 3

Seeing through the window: pre-fetching strategies for out-of-core image processing algorithms

R. Pinho, K. J. Batenburg, J. Sijbers, Univ. Antwerpen (Belgium)

Scientific data files have been increasing in size during the past decades. In the medical field, for instance, magnetic resonance imaging and computer aided tomography can yield image volumes of several gigabytes. While secondary storage (hard disks) increases in capacity and its cost per megabyte slumps over the years, primary memory (RAM) can still be a bottleneck in the processing of huge amounts of data. This represents a problem for image processing algorithms, which often need to keep in memory the original image and a copy of it to store the results. Operating systems optimize memory usage with memory paging and enhanced I/O operations. Although image processing algorithms usually work on neighbouring areas of a pixel, they follow pre-determined paths through the image and might not benefit from the memory paging strategies offered by the operating system, which are general purpose and unidimensional. Having the principles of locality and pre-determined traversal paths in mind, we developed an algorithm that uses multi-threaded pre-fetching of data to build a disk cache in memory. Using the concept of a window that slides over the data, we predict the next block of memory to be read according to the path followed by the algorithm and asynchronously pre-fetch such block before it is actually requested. While other out-of-core techniques reorganize the original file in order to optimize reading, we work directly on the original file. We demonstrate our approach in different applications, each with its own traversal strategy and sliding window structure.

6919-15, Session 4

Automated bone age assessment of older children using the radius

S. Tsao, A. Gertych, A. Zhang, B. J. Liu, H. K. Huang, Univ. of Southern California

The Digital Hand Atlas in Assessment of Skeletal Development is a project funded by the National Institute of Health's National Institute of Biomedical Imaging and Bioengineering (NIBIB). The project includes a completed collection of 1,400 normal hand X-rays of children between the ages of 0-18 years of age for training of a computer aided diagnosis (CAD) algorithm for automated Bone Age Assessment of children. Bone Age Assessment is used as an index of skeletal development for detection of growth pathologies that can be related to endocrine, malnutrition and other disease types. Previous work at the Image Processing and Informatics Lab (IPILab) allowed the bone age CAD algorithm to accurately assess bone age of children from infancy to 15 years of age using the Phalanges as well as the Carpal Bones. At the older ages (15-19 years of age) the Phalanges as well as the Carpal Bones are fully developed and do not provide well-defined features for

accurate bone age assessment. Therefore integration of the Radius as a region of interest (ROI) is greatly needed and will significantly improve the ability to accurately assess the bone age of older children. An integrated Bone Age CAD will use the Phalanges, Carpal Bones and Radius to form a robust method for automatic bone age assessment throughout the entire age range (0-19 years of age).

6919-16, Session 4

Content-based image recognition for digital radiographs

H. Luo, Carestream Health, Inc.; J. Luo, Eastman Kodak Co.

Before a radiographic image is sent to a picture archiving and communications system (PACS), its projection information needs to be correctly identified at capture modalities to facilitate image archive and retrieval. Currently, annotating radiographic images is manually performed by technologists. Although it can be accomplished in a few seconds, the accumulated time spent and the cost required for a large number of radiographs can be substantial. To address this issue, an automatic image recognition method is developed. It first detects the most indicative region in a radiograph for image recognition, then extracts a set of visual features from the region. Based on these features, a family of classifiers, each which is trained for a specific projection, is employed to determine the most appropriate projection for the image. The method has been tested on a large number of clinical images and has shown excellent robustness and efficiency.

6919-17, Session 4

The design and implementation of decision support tools of proton beam therapy treatment planning for brain cancer patients

A. H. T. Le, Univ. of Southern California

Last year, we presented methodology to perform knowledge-based medical imaging informatics research on specific clinical scenarios where brain tumor patients are treated with Proton Beam Therapy (PT). In this presentation, we demonstrate the design and implementation of quantification and visualization tools to develop the knowledge base for therapy treatment planning based on DICOM-RT-ION objects. Proton Beam Therapy (PT) is a particular treatment that utilizes energized charged particles, protons, to deliver dose to the target region. Similar to traditional Radiation Therapy (RT), complex clinical imaging and informatics data are generated during the treatment process that guide the planning and the success of the treatment. Therefore, an Electronic Patient Record (ePR) System has been developing to standardize and centralize clinical data and properly distribute data throughout the treatment duration. To further improve treatment planning process, we developed a set of decision support tools with data mining capacity to improve QA process in treatment planning process. One such example is a tool to assist in the planning of stereotactic PT cases where CT and MR images need to be analyzed simultaneously during treatment plan assessment. These tools are add-on features for DICOM standard ePR system of brain cancer patients and improve the clinical efficiency of PT treatment planning. Additional outcome data collected for PT cases are included in the overall DICOM-RT-ION database design as knowledge to enhance outcomes analysis for future PT adopters.

6919-18, Session 4

Web-based computer-aided-diagnosis (CAD) system for bone age assessment (BAA) of children

A. Zhang, J. Uyeda, S. Tsao, L. Vachon, B. J. Liu, H. K. Huang, Univ. of Southern California

Bone age assessment (BAA) of children is a clinical procedure frequently performed in pediatric radiology to evaluate the stage of skeletal maturation based on a left hand and wrist radiograph. The most commonly used standard: Greulich and Pyle (G&P) Hand Atlas was developed 50 years ago and exclusively based on Caucasian population. Moreover, inter- & intra-observer discrepancies using this method create a need of an objective and automatic BAA method. A digital hand atlas

(DHA) has been collected with 1,400 hand images of normal children from Asian, African American, Caucasian and Hispanic descends. Based on DHA, a fully automatic, objective computer-aided-diagnosis (CAD) method was developed. Adapted to specific population, CAD method achieved high BAA accuracy.

To bring DHA and CAD method to the clinical environment as a useful tool in assisting radiologist to achieve higher accuracy in BAA, a client-server system with direct connection to a clinical site is designed as a novel clinical implementation approach for online and real time BAA. The core of the system, a CAD server receives the image from clinical site, processes it by the CAD method and finally, generates report. A web service publishes the results and radiologists at the clinical site can review it online within minutes.

This prototype can be easily extended to multiple clinical sites and will provide the foundation for broader use of the CAD system for BAA.

6919-19, Session 4

Texture versus shape analysis for lung nodule similarity in computed tomography studies

M. N. Muhammad, Bryn Mawr College; D. S. Raicu, J. D. Furst, E. Varutbangkul, DePaul Univ.

With the aim of reducing the radiologists' subjectivity and the high degree of inter-observer variability, Content-based Image Retrieval (CBIR) systems have been proposed to provide visual comparisons of a given lesion to a collection of similar lesions of known pathology. In this paper, we present the effectiveness of shape features versus texture features for calculating lung nodules' similarity in Computed Tomography studies. In our study, we used eighty-five cases of thoracic Computed Tomography (CT) data from the Lung Image Database Consortium (LIDC). To encode the shape information, we used the eight most commonly used shape features for pulmonary nodule detection and diagnosis by existent CAD systems. For the texture, we used co-occurrence, Gabor, and Markov features implemented in our previous CBIR work. Our preliminary results give low overall precision results for shape compared to texture, showing that shape features are not effective by themselves at capturing all the information we need to compare the lung nodules.

6919-20, Session 4

Role of Computer Aided Detection (CAD) Integration: Case Study with Meniscal and Articular Cartilage CAD applications

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In this paper we investigate the role of integrating the computer-aided detection (CAD) algorithms for automatic detection of meniscal tears and articular cartilage injuries of the knees into a single application. This integration is believed to improve the diagnosis accuracy of the individual CAD algorithms owing to the correlation between meniscal tears and articular cartilage injuries. For the case of meniscal cartilage, automated segmentation of sagittal T1-weighted MR imaging sequences of the knee and detection of tears was performed in two stages. The first stage consists of region of Interest (ROI) selection, slice selection (automatic), binarization, and enforcing shape constraints. The second stage is a 2 step process consisting of scoring of the slices for potential tears using two newly introduced metrics 'breakability' and 'degeneracy' and generation of the final recommendation regarding whether the meniscus is torn or normal. For the case of articular cartilage, we generate clinically relevant diagnosis of the articular cartilage damage in near real time fashion. The algorithm features a 2D Active Shape Model (ASM) for the modeling bone-cartilage interface on all the slices of the Double Echo Steady State (DESS) MR sequence, followed by measurement of the cartilage thickness from the surface of the bone, and finally the identification of regions of abnormal thinness and focal/degenerative lesions. These CAD algorithms are integrated into a single application and the correlation between meniscal tears and articular cartilage injuries is used to improve the final diagnosis results of the individual algorithms. Preliminary results from the integrated application are encouraging and more comprehensive test are being planned.

6919-10, Poster Session

Content based image retrieval applied to contrast enhancing brain tumors

H. Z. Tameem, S. Dube, U. Sinha, Univ. of California/Los Angeles

This work focuses on image retrieval utilizing Principal component analysis (PCA) and Linear discriminant analysis (LDA) techniques for brain tumors from Magnetic Resonance (MR) studies. The research has been broken into three stages. Stage 1 consists of developing the PCA and LDA algorithms to be used for content based image retrieval (CBIR) systems. Stage 2 consists of evaluation of PCA and LDA algorithms on synthetic tumor images with added noise and shading artifacts. Stage 3 consists of tailoring the algorithm specifically for automated detection and content based retrieval system of MR contrast enhancing tumors matching a given query image. The algorithm has been developed and tested successfully for synthetic tumor images and actual contrast enhanced tumors. We hope to integrate the PCA and LDA algorithms to perform an indexing of the tumor shapes derived from actual MR images. Two relevant indices: size and location will also be used to index the data.

6919-37, Poster Session

A novel multidimensional medical image display framework based on VTK

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We propose a novel framework that integrates different rendering methods by utilizing the pipeline mechanism of Visualization Toolkit (VTK) and can display MIP and MPR synchronously with most freedom by allowing users to configure viewpoint freely and to shift between different patterns unlimitedly. Through the pipeline mechanism, the same image data source can be applied to different visualization algorithms. Thus, we apply the same volumetric data to volume rendering as MIP and planar rendering as MPR at same time. Any manipulation on the volume may have effect on all the display patterns. Furthermore, we design a novel MPR rendering technology, Free-MPR, which renders the section plane freely against the change of viewpoint immediately by using the plane object in VTK that is able to cut the volume anywhere. When changing the display pattern from MIP to MPR, we just need to delete current MIP object and pass all the attributes to the new-built MPR object keeping the volume data intact. Transformations are similar among all the patterns. Besides, the framework can be easily applied to medical workstation or Web-based network applications since it is provided as a plug-in that can be integrated conveniently. This software framework is developed on the platform of Visual C++ 6.0 and VTK 5.0, and is offered as a DLL that can be plug into image workstations or provided as web service.

6919-38, Poster Session

A novel strategy to access high resolution DICOM medical images based on JPEG2000 interactive protocol

Y. Tian, W. Cai, J. Sun, J. Zhang, Shanghai Institute of Technical Physics (China)

The demand for sharing medical information has kept rising. However, the transmission and displaying of high resolution medical images are limited if the network has a low transmission speed or the terminal devices have limited resources. In this paper, we present an approach based on JPEG2000 Interactive Protocol (JPIP) to browse high resolution medical images in an efficient way. We design and implement an interactive image communication system with client/server architecture and integrate it with Picture Archiving and Communication System (PACS). JPEG2000 offers many features to support interactive access to large images. These include highly efficient compression, resolution scalability, quality scalability and spatial random access. With the JPIP protocol, a client can make simple requests which identify the resolution, quality and Window Of Interest (WOI) and download selected portions of the JPEG2000 code-stream instead of downloading and decoding the entire code-stream. We compared different JPEG2000 compression

parameters, such as precincts and tiles, resolution numbers and precinct size, and found that precinct-based method was more flexible than tile-based method and five resolutions with 32_32 precinct was a appropriate choice considering both storage capacity and communication efficiency. In our interactive image communication system, the client firstly requests a low resolution image to preview, and then selects a WOI to display in high quality. After receiving a request from a client, the server downloads the requested image from the PACS server and then replies the client by sending the appropriate code-stream. Many mechanism such as cache management, database management and memory management are adopted in this system to enhance the communication efficiency. We also used JPIP in a PDA-based wireless medical system in which large medical images can be transmitted through wireless network and be displayed on the lower resolution screen of a PDA in an efficient way.

6919-41, Poster Session

Database construction for small lung nodule using high-resolution three-dimension CT image

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We have been developing quantitative analysis algorithm that extracts features of small lung nodules such as morphology, interface, internal structure and surroundings. The study of method to schematize nodules quantitatively based on these features is advancing. We conduct the statistical comparison survey to find out the relationship between features and benign nodules, malignant ones, recurrence, reason of death etc. in the nodules schematization processing. We need to use clinical pathology diagnosis result and information of after-operation search and features as data for research, but data is huge. The construction of data management environment using database is necessary for efficient use of data. The processing of comparison between features and clinical pathology diagnosis result, information of after-operation pursuit using database make the efficient schematization processing of nodules possible. Besides, if we systemize that flow, we think that more efficient nodules schematization processing can be realized and effective quantitative image diagnosis is possible. So we perform database design and implementation of supposed systematization of nodule schematization processing.

6919-42, Poster Session

Integration of a research CBIR system into radiological routine

T. M. Deserno, I. Bezrukov, B. Fischer, B. Ott, H. Schubert, RWTH Aachen (Germany)

In this work, a concept for coupling of our system for image retrieval in medical applications (IRMA) with hospital information systems is presented. The coupling is realized by a module that communicates with radiology information system (RIS), picture archiving and communication system (PACS) over DICOM and HL7 protocols. The integration is designed such that a failure of IRMA does not affect the routine operation of the other systems. A first application of the coupling is the improvement of prefetching by including additional images selected as similar by the IRMA system.

6919-43, Poster Session

Development of a mobile HIS/PACS workstation to assist critical cardiac patients in an intensive care unit

M. A. Gutierrez, I. A. Cestari, G. Hamamoto, S. Bacht, M. d. S. Rebelo, J. E. M. Silva, Instituto do Coração do Hospital das Clínicas (Brazil)

The goal of the current study is to describe the experience of the Heart Institute (InCor) in the implementation of a mobile HIS/PACS workstation to assist critical cardiac patients in an Intensive Care Unit (ICU). The system was developed as part of our efforts in to construct a complete HIS/PACS solution to all clinical activities. Recently, mobile devices connected to a WiFi network were incorporated, providing the same

functionalities of common desktop counterpart. However, the use of commercially devices like PDAs and PocketPCs presented a series of problems that are more emphasized in the ICUs 1) low autonomy of the batteries (less than 1 hour), which need constant recharges; 2) low robustness of the devices; 3) insufficient display area not enough to show medical images and vital signals; 4) data entry remains a major problem and imposes an extra time consumption to the staff; 5) high cost when fully equipped with WiFi connection, optical reader to access bar codes and memory.

Based in our lessons of using mobile devices, we developed a mobile kart (MedKart) to access the HIS and PACS systems, with all resources and an ergonomic and practical design to be used by physicians and nurses inside the ICU. The system fulfills the requirements to assist, in the point-of-care, critical cardiac patients in Intensive Care Units. The whole solution permits the access and distribution of medical information at the bed-side and the integration in a consistent and secure environment, without the need to switch between different applications.

6919-44, Poster Session

Computer-aided diagnosis workstation and network system for chest diagnosis based on multislice CT images

H. Satoh, Tokyo Health Care Univ. (Japan)

Multi-helical CT scanner advanced remarkably at the speed at which the chest CT images were acquired for mass screening. Mass screening based on multi-helical CT images requires a considerable number of images to be read. It is this time-consuming step that makes the use of helical CT for mass screening impractical at present. To overcome this problem, we have provided diagnostic assistance methods to medical screening specialists by developing a lung cancer screening algorithm that automatically detects suspected lung cancers in helical CT images a coronary artery calcification screening algorithm that automatically detects suspected coronary artery calcification and a vertebra body analysis algorithm for quantitative evaluation of osteoporosis likelihood using mobile helical CT scanner for the lung cancer mass screening. We have also developed electronic medical recording system and new internet system for the community health in two or more regions by using the Virtual Private Network router with new communication protocol, Biometric fingerprint authentication system and Biometric face authentication system for safety of medical information. Based on these diagnostic assistance algorithm, we have developed a new computer-aided workstation and regional medical network system that can display suspected lesions three-dimensionally in a short time. The results of this study indicate that our computer-aided diagnosis workstation and network system can increase diagnostic speed, diagnostic accuracy and safety of medical information.

6919-45, Poster Session

Using Eclipse RCP for the contextual image viewer

R. A. Moreno, S. S. Furuie, Instituto do Coração do Hospital das Clínicas (Brazil)

The transition of a development prototype to a product is a challenging task. There are several shortcomings of a prototype such as the difficulty of deployment to the client, configuration issues and memory usage. The Eclipse RCP is a platform for development that offers many advantages such as: multiplatform nature; small memory footprint usage and extensible architecture. In this work we present the use of the Eclipse Rich Client Platform (RCP) as the basis for the deployment of a Contextual Medical Image Viewer. The Contextual Viewer is a concept of interface for medical/clinical information visualization that uses different contexts to enhance the user's capability and experience. We present the contextual viewer for X-Ray Angiographic images, based on Eclipse RCP that can use information from two different sources. We conclude that the Eclipse RCP is a promising platform for final-user quality software, improving the Contextual Medical Image Viewer features.

6919-46, Poster Session

Bone age assessment in Hispanic and Asian children: digital hand atlas versus the Greulich and Pyle (G&P) atlas

J. R. F. Fernandez, A. Zhang, S. Tsao, Univ. of Southern California

Bone age assessment is most commonly performed with the use of the Greulich and Pyle (G&P) book atlas, which was developed in the 1950s. Because the United States population is not as homogenous as that used by Greulich and Pyle in the 1950s, the G&P atlas may not be as applicable in clinical practice in the present. A digital hand atlas based on 1,400 hand ages of children of different racial backgrounds (Caucasian, African American, Hispanic, and Asian) aged 0-18 years was collected from Children's Hospital Los Angeles. Diagnostic radiologists will perform reads on Hispanic and Asian pediatric hand and wrist computed radiography images using either the G&P pediatric radiographic atlas or the Children's Hospital Los Angeles Digital Hand Atlas (DHA) as reference. The order in which atlas is used (G&P followed by DHA or vice versa) for each image will be prepared before actual reading begins. Statistical analysis of the results will then be performed to determine if a discrepancy exists between the two readings.

6919-21, Session 5

An adaptable XML-based approach for scientific data management and integration

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Increased complexity of scientific research poses new challenges to scientific data management. Meanwhile, scientific collaboration is becoming increasingly important, which relies on integrating and sharing data from distributed institutions. We develop SciPort, a Web-based platform on supporting scientific data management and integration based on a central server based distributed architecture, where researchers can easily collect, publish, and share their complex scientific data across multi-institutions. SciPort provides an XML based general approach to model complex scientific data by representing them as XML documents. The documents capture not only hierarchical structured data, but also images and raw data through references. In addition, SciPort provides an XML based hierarchical organization of the overall data space to make it convenient for quick browsing. To provide generalization, schemas and hierarchies are customizable with XML-based definitions, thus it is possible to quickly adapt the system to different applications. While each institution can manage documents on a Local SciPort Server independently, selected documents can be published to a Central Server to form a global view of shared data across all sites. By storing documents in a native XML database, SciPort provides high schema extensibility and supports comprehensive queries through XQuery. By providing a unified and effective means for data modeling, data access and customization with XML, SciPort provides a flexible and powerful platform for sharing scientific data for scientific research communities, and has been successfully used in both biomedical research and clinical trials.

6919-22, Session 5

Design and implementation of GRID-based PACS in a hospital with multiple imaging departments

J. Zhang, Y. Yang, J. Sun, J. Jin, Shanghai Institute of Technical Physics (China); J. Feng, Huadong Hospital (China)

Usually, there were multiple PACSs running in enterprise healthcare environment, and there were urgent demand to integrate the multiple PACSs together to provide patient-oriented imaging services for enterprise collaborative healthcare. In this presentation, we gave the design method of developing grid-based PACS to integrate multiple PACSs. The grid-based PACS was designed with service-oriented

architecture (SOA) and consists of three level components: PACS interfacing module, grid agent node and grid master node. The PACS interfacing modules connect to traditional PACS servers or image repositories data center with DICOM communication. The grid agent nodes couple the PACS interfacing modules and master nodes together through Web services and provide public image communication services to the consumers such as traditional PACS workstations, Web-based image viewers or EPR clients. The grid master nodes coordinate the cooperative operation of grid agent nodes and provide grid services to the internal components and out side components of the grid-based PACS. The grid-based PACS functions as a middleware between the traditional PACS archiving servers and workstations or image viewing clients and provide DICOM image communication and WADO services to the end users. The images can be stored in distributed multiple archiving servers, but can be managed with central mode. The grid-based PACS has auto image backup and disaster recovery services and can provide best image retrieval path to the image requesters based on the optimal algorithms. The designed grid-based PACS has been implemented in Shanghai Huadong Hospital and been running for two years smoothly.

6919-23, Session 5

Implementation and use of a web-based interface for confidential communication of data between the clinical and research environments

P. H. Bland, G. E. Laderach, C. R. Meyer, Univ. of Michigan Health System

Policies and regulations in the current health care environment have impacted the manner in which patient data - especially protected health information (PHI) - are handled in the clinical and research settings. Specifically, it is now more challenging to obtain de-identified PHI from the clinic for use in research while still adhering to the requirements dictated by the new policies and regulations. To meet this challenge, we have designed and implemented a novel web-based interface that uses a workflow model to manage the communication of data (for example, biopsy results) between the clinic and research environments without revealing PHI to the research team or associated research identifiers to the clinical collaborators. At the heart of the scheme is a web application that coordinates message passing between researchers (in general, the requesters of de-identified PHI) and clinical collaborators (who have access to PHI) by use of a protocol that protects confidentiality. The web application works in conjunction with a de-identifying DICOM image receiver and a relational database. We describe the design requirements of the messaging/communication protocol, as well as implementation details of the web application and its associated database. We conclude that this scheme provides a useful communication mechanism that facilitates clinical research while maintaining confidentiality of patient data.

6919-24, Session 5

Performance benchmarking of liver CT image segmentation and volume estimation

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In recent years more and more computer aided diagnosis (CAD) systems are being used routinely in hospitals. Image-based knowledge discovery plays important roles in many CAD applications, which will be integrated into the next generation PCAS systems. Robust medical image segmentation tools are essential for such discovery in many CAD applications. This paper presents a platform with necessary tools for performance benchmarking for algorithms of liver segmentation and volume estimation used for liver transplantation planning. It includes an abdominal CT image database (DB), annotation tools, a ground truth DB, statistical 2D and 3D atlases, and performance measure protocols. The proposed architecture is generic and can be used for other organs and imaging modalities. In the current study, approximately 60 sets of abdominal CT images with normal livers (no focal lesion) have been collected and a user-friendly annotation tool is developed to generate

ground truth data, including 2D contours of liver, two kidneys and spinal cord. A number of liver segmentation algorithms, including 2D atlas-based segmentation and 3D probabilistic atlas-based segmentation, will be evaluated based on the platform. We target to increase the CT scans to about 200 sets in the near future, also plan to make the databases available to medical imaging research community. Preliminary benchmark results from the liver segmentation algorithms which make use of statistical knowledge extracted from the abdominal CT image DB will be reported.

6919-25, Session 5

Assuring image authenticity within a data grid using digital signature embedding and a HIPAA-compliant auditing system

J. Lee, J. R. Documet, B. Guo, T. Mo, B. J. Liu, Univ. of Southern California

A Data Grid for medical images has been developed at the Image Processing and Informatics Laboratory, USC. The primary benefits of a Medical Imaging and Informatics Data Grid are distribution and fault-tolerance of medical imaging studies. Its functions as a virtual DICOM storage repository over the Internet to promote multi-institution and international healthcare collaboration. Although proper configuration is required to setup up each grid-access-point, the challenge of image security during transmission of private DICOM images across a public domain is still unresolved. This paper takes steps toward achieving image transfer security within the Data Grid by utilizing DICOM image authentication and HIPAA-compliant auditing toolkits installed at each grid-access-point node. The 3-D lossless digital signature embedding procedure involves embedding a private 64 byte signature into each original DICOM image, whereby on the receiving end the signature can be extracted and verified following the DICOM transmission. This digital signature method was developed and tested at the IPILab. The auditing portion of the system uses a federated database that logs all transmission and authentication events at each grid-access-point. The auditing toolkit, also known as the HIPAA-Compliant Auditing System (H-CAS), is installed at the local grid-access-point to extract log messages from local grid-access-points. It utilizes syslog, a client-server standard for log messaging over an IP network, to send messages to the H-CAS centralized database. By integrating digital image signatures and centralized logging capabilities, DICOM image authenticity can be guaranteed within the Medical Imaging and Informatics Data Grid.

6919-26, Session 6

Improved display calibration algorithm for wide viewing angle DICOM GSDF compliance

T. R. L. Kimpe, C. Marchessoux, Barco N.V. (Belgium)

LCDs suffer from viewing angle dependency, meaning that characteristics of LCDs change with viewing angle. DICOM GSDF calibration and corresponding quality checks typically take place for on-axis viewing. However, users will use the display for a broad range of viewing angles. Several studies have shown that when calibration is done for on-axis viewing then the display is not accurately complying with the DICOM GSDF standard when viewing off-axis.

To overcome this problem solutions have been suggested whereby the position of the user is tracked in real-time and the configuration/characteristics of the display is changed accordingly. In this way the user will always perceive the display as being calibrated independently of the viewing angle. However, this method requires an expensive user tracking method and cannot be used for multiple viewers at the same time.

This paper presents another solution: we adapt the DICOM GSDF calibration algorithm to have inherent robustness against change of viewing angle. This new method also has the advantage that it is a very cheap solution that does not require additional hardware such as head tracking. In addition it also works for multiple viewers.

A validation has been done by means of a 5 Mega Pixel medical display. Results show that it is possible to double the range of viewing angles (18° instead of 9°) for which the display is within the 10% tolerance as defined in the DICOM GSDF standard. This result is very useful because users typically will use their displays also for off-axis viewing angles.

6919-27, Session 6

Display methods for adjustable grayscale and luminance depth

A. Xu, A. Saha, U.S. Food and Drug Administration; G. Guarnieri, G. Ramponi, Univ. degli Studi di Trieste (Italy); A. Badano, U.S. Food and Drug Administration

We explore the calibration of a high luminance range, dual-layer, liquid crystal display (LCD) prototype. The operation of the prototype is done by splitting high luminance resolution image into two 8-bit depth components and sending these images to each of two liquid crystal panels stacked over the backlight module. By interpolation of a small set of luminance data gathered using a specialized luminance probe, the look-up table of gray level pairs of front/back layer LCD and the corresponding luminance values can be generated. To display images, we fit an extended DICOM model to the interpolated luminance table which is adjustable for gray level and luminance depth. A dynamic look up table (DLUT) in which for each luminance there are several gray level pair candidates is generated. We show results for one possible calibration strategy involving the pair selection criterion. By selecting the pair from the DLUT that maximizes back-layer smoothness, the images with arbitrary gray level and luminance depth can then be displayed with equal perceptual distance between luminance levels, while minimizing parallax effects. Other possible strategies that minimize glare and noise are also described. The result can be used for high luminance range display performance characterization and for the evaluation of its clinical significance.

6919-28, Session 6

The effect of increased ambient lighting on detection accuracy in uniform and anatomical backgrounds

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Under typical dark conditions found in reading rooms, a reader's pupils will contract and dilate as the eye gaze intermittently shifts between the high luminance monitor and the darker background wall, resulting in increased visual fatigue and the degradation of diagnostic performance.¹ A controlled increase of ambient lighting may, however, minimize these adjustments and potentially improve reader comfort and detection ability.^{2, 3} This presentation details results from two psychophysical studies designed to determine the effect of a controlled ambient lighting increase on observer detection of subtle objects and lesions viewed on a DICOM-calibrated medical-grade LCD. The first study examined the effect of increased ambient lighting on detection of subtle objects embedded within a uniform background, while the second study examined observer detection performance of subtle cancerous lesions in mammograms and chest radiographs. In both studies, observers were presented with images under a dark room condition (1 lux) and an increased room illuminance level (50 lux) such that the luminance level of the diffusely reflected light from the background wall was approximately equal to that of the displayed image. Observer detection performance under each room illuminance condition was then compared. Identification of subtle objects embedded within the uniform background improved from 59% to 67% with increased illuminance. Furthermore, detection time decreased slightly with additional illuminance. Preliminary results from the anatomical image study revealed that the detection of subtle lesions remains constant under increased ambient lighting. The results support a controlled increase of ambient lighting without concern about compromising diagnostic efficacy.

6919-29, Session 6

Rapid prototyping of clinical software assistants

J. Rexilius, H. Peitgen, MeVis Research GmbH (Germany)

Computer assistance in image-based diagnosis and therapy are continuously growing fields that have gained importance in several medical disciplines. Today, several free and commercial tools are available. However, only few are routinely applied for diagnosis support and treatment planning in clinical practice. Especially tools that provide a flexible support of the whole design process from development

and evaluation to the actual deployment in a clinical environment are missing.

In this work, we introduce a categorization of the design process into different types and fields of application. To this end, we propose a novel framework that allows for flexible and efficient design of clinically valuable software assistants. A multi-layered architecture separates the functionality into application-specific components and core tasks. A standardized interface facilitates the communication between the different layers. Several components for data- and workflow-management provide a generic functionality that can be customized on the developer and the user level. Dedicated assistance is also implemented for efficient clinical workflow integration (PACS integration). Furthermore, we have developed methods to support the integration of image data and processing results from clinical tools into algorithmic developments. A flexible handling of image processing and visualization methods is offered through the utilization of a visual programming and rapid prototyping platform. Several software prototypes have already been designed based on our framework, and are in use at different clinical sites. In this work, we discuss the development of a new assistant for multispectral brain tumor segmentation. Our results show the potential of our approach.

6919-30, Session 6

ImTK: an open source multi-center information management toolkit

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The Information Management Toolkit (ImTK) Consortium effort is an open source effort to develop robust, freely available tools that meet the information management needs of basic, clinical, and translational research. An open source framework and agile programming methodology supports rapid software development while an open architecture encourages interoperability across different environments. The ISIS Center is implementing the ImTK prototype data sharing network to simulate a multi-center environment based on a federated data access model. This will include the development of software tools that enable efficient exchange, sharing, management, and analysis of multimedia medical information such as clinical information, images, and bioinformatics data from multiple data sources. The ImTK data environment is built on open source software methods in an open architecture and data model implementation that complies with existing standards such as DICOM, HL7, and the technical framework and workflow defined by the IHE Information Technology Infrastructure initiative, mainly the Cross Enterprise Document Sharing (XDS) specifications.

6919-31, Session 6

The workflow and procedures for automatic integration of a computer-aided diagnosis workstation with a clinical PACS with real world examples

A. H. T. Le, Univ. of Southern California

Digital Imaging and Communications in Medicine (DICOM) has standardized structure report (SR) to fully support both conventional free-text reports and structured information, thus enhancing the precision, clarity, and value of clinical documents. The SR standard provides the capacity to link key images, region of interest within images, and measurement as result of Computer-Aided Diagnosis (CAD) process. Accordingly, SR bridges the traditional gap between CAD and PACS. Last year we presented an open and universal CAD-PACS integration toolkit that could seamlessly integrate standalone Computer-Aided Diagnosis (CAD) workstations with a clinical PACS based on Structure Report (SR) and IHE Post-Processing. In this presentation, we illustrate the workflow and procedures of CAD-PACS integration by showing examples from some available CAD applications using the toolkit. This proper integration will improve usage of these CAD applications for more accurate analysis and faster assessment in the clinical decision-making process.

6919-32, Session 7

Integration of implant planning workflows into the PACS infrastructure

M. Gessat, Univ. Leipzig (Germany); G. Strauss, Univ. Hospital Leipzig (Germany); O. Burgert, Univ. Leipzig (Germany)

The integration of imaging devices, diagnostic workstations, and image servers into Picture Archiving and Communication Systems (PACS) had an enormous effect on the efficiency of radiology workflows. The standardization of the information exchange between the devices with the DICOM standard was an essential precondition for that development.

Surgical planning procedures are usually contained in monolithic assistance systems and make use of a proprietary data exchange. Because of this, devices are usually not interoperable. Each system brings with it its own dedicated mechanism for communication and data exchange between its components. The unification of interfaces into a standardized communication system across and between clinical centers is expected to be an enabling development for clinical assistance systems in the interventional disciplines.

In this paper we propose the inclusion of implant planning systems into the PACS infrastructure. We propose a generic information model for the patient specific selection and positioning of implants from a repository according to patient image data. The information models are based on clinical workflows from ENT, cardiac, and orthopedic surgery as well as technical requirements derived from different use cases and systems.

We show an exemplary implementation of the model based on DICOM and the MAF Framework for an application in ENT surgery, the selection and positioning of a stapes implant in the middle ear. An implant repository is stored in the PACS using an experimental implementation of the Common Surface Mesh Module currently developed to extend DICOM.

6919-33, Session 7

A general framework for data streaming in the digital operating room

R. Mayoral, A. Vazquez, O. Burgert, Univ. Leipzig (Germany)

The situation today in most operating theaters is characterized by a large number of highly specialized but isolated surgical-assist systems. Integration of these systems into a complete solution is the key to maximize their usefulness and cost-effectiveness through optimization of the data flow and reuse of existing hardware. Goal of the integration is the creation of a distributed assist system by connecting multiple independent components using standard protocols for communication and data exchange. Required surgical functionalities are created by combining the appropriate components.

This distributed assist system brings about fundamental changes in the nature of the data flow among individual components. Today, components tend to exchange more-or-less independent and complete units of information which they process once the complete data set has arrived. However, with distributed functionalities and tighter integration necessary to complete a surgical process, increased continuous data transfer and processing will be required. To handle this type of data transmission, the system will have to support streaming of continuous data.

We present a general framework for the integration of data streaming into the Digital Operating Room. The approach presented provides a two level system in which the management and supervision of the data producing and consuming devices is independent of the actual mechanisms used to transmit the data. This approach allows the use of multiple transmission technologies and infrastructure specially adapted to the specific needs of the streamed data.

6919-34, Session 7

Automatic real-time capture and segmentation of endoscopy video

S. R. Stanek, W. Tavanapong, J. S. Wong, Iowa State Univ.; J. Oh, The Univ. of Texas M.D. Anderson Cancer Ctr.; P. C. de Groen, Mayo Clinic

Endoscopy is a medical technology used to inspect the inner surface of organs such as the colon. During endoscopic inspection of the colon or colonoscopy, a tiny video camera generates a video signal, which is displayed on a monitor for manual interpretation by physicians. In practice, these images are not typically captured, which may be attributed by lack of tools for automatic capturing, automatic analysis of important contents, and quick and easy access to these contents. However, this lack of tools is being addressed by recent research efforts. This paper presents the description and evaluation results of novel software that automates the capture of all images of a single colonoscopy into a single digitized video file. The system uses metrics based on color and motion over time to determine whether the images are derived from inside a single patient. During testing our system extracted 173 videos totaling 70 hours of endoscopic video, out of 230 hours of raw video, with a segment-based sensitivity of 100% and specificity of 99%. No procedures were missed. Two video files contained only a non-patient video signal. The features of our system are robust enough to be suitable for day-to-day use in medical practice.

6919-35, Session 7

Workflow in interventional radiology: uterine fibroid embolization (UFE)

D. Lindisch, Georgetown Univ.; T. Neumuth, O. Burgert, Univ. Leipzig (Germany); K. R. Cleary, Georgetown Univ.

The purpose of this study was to complete a workflow analysis of the Uterine Fibroid Embolization (UFE) procedure. UFE is a minimally invasive procedure for the treatment of painful fibroids in women. We developed an ontology for analyzing this procedure by identifying four phases: pre-procedure, procedure, post-procedure, and between procedures. For each phase a number of specific steps were identified. The workflow editor developing by the University of Leipzig was customized to record the phase, the step, and an actor carrying out the steps. The actors were identified as the attending radiologist, a fellow, an assistant, a scrub nurse, and a nurse. Data from 27 cases was recorded and both the procedure times and time spent actually doing the embolization were identified. The procedure times were between 1:21 (hour: minutes) and 2:21. The embolization time was a relatively small portion of the total time. This was intended as a pilot study and further data analysis is ongoing.

6919-36, Session 7

Integration of a real-time video capture component to the open source image-guided surgery toolkit IGSTK

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The image-guided surgery toolkit (IGSTK) [1] is an open source C++ library that provides basic components required for developing image-guided surgery applications. While the initial version of the toolkit has been released, some additional functionality is required for certain applications. Since an image-guided surgery system may need to import real-time intraoperative data, we are adding a video grabber component to make a video stream accessible through IGSTK. The data imported may be real-time ultrasound for either viewing a 2D ultrasound slice in a 2D window or 3D scene or for 3D ultrasound reconstruction. Furthermore the video grabber component can be used to import data from other intraoperative video sources such as endoscopy. For correct placement of the video stream relative to the patient an interaction with the IGSTK tracker component is necessary, and the visualization will depend on existing and future visualization components of IGSTK. Several aspects must be decided during the design phase: 1) the interaction with existing and future IGSTK components; 2) the functions of the component; and 3) the layout of the internal IGSTK state machine. This paper describes the video grabber component design and presents example applications using the video grabber component.

6920-01, Session 1

Beamformer post-processing for improved spatial resolution and SNR

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We present a method of improving the performance of any beamformer by forming an optimal weighted linear combination of the beamformer outputs in order to satisfy signal-to-noise and spatial resolution criteria. Depending on the characteristics of the first beamformer, improvements in both properties are possible, but in all cases a trade-off between spatial resolution and SNR is achievable.

If the model of an ultrasound system is well characterized and over-determined then inverse filter image reconstruction minimizes the mean squared reconstruction error. Noise sensitivity however, makes diagonal loading necessary, exchanging noise robustness for reduced spatial resolution. A quadratic constrained least squares approach can be used on a pixel-by-pixel basis to maximize the pixel signal energy in relation to unwanted energy, in the form of noise and interference from other scatterers. By shaping the QCLS weight vectors, mainlobe shape versus SNR tolerance is explicitly specified. This provides additional degrees of freedom over prior inverse filter approaches, and has been shown to work with several primary beamformers, including delay-and-sum, coarse delay-and-sum, and spatially matched filtering. When this method is used with the delay and sum beamformer, for the same mainlobe width, sidelobes can be reduced by ~10dB, whilst increasing SNR by 3dB. Similarly, with a 33% narrower mainlobe, sidelobes can be reduced by ~6dB at a cost of a 14dB reduction in SNR.

6920-02, Session 1

Medical ultrasound digital beamforming on a massively-parallel processing array platform

P. Y. Chen, M. Butts, B. Budlong, Ambric, Inc.

Digital beamforming has been widely used in modern medical ultrasound instruments. Flexibility is one of the key advantages of digital beamformers over the traditional analog approach. Unlike analog delay lines, digital delay can be programmed to implement new ways of beam steering without hardware modification. Digital beamformers can also realize dynamic focusing by tracking the depth and focusing the receive beam as the depth increases. By constantly updating an element weight table, a digital beamformer can support the dynamic increase of aperture size with depth to maintain constant lateral resolution and reduce sidelobe noise. Because of the high I/O bandwidth and processing requirements, most ultrasound digital beamformers have been implemented in ASICs and FPGAs, which are designed as hardware.

This paper introduces the implementation of a digital beamformer on a massively parallel processing array (MPPA) platform, which is programmed in software. The system consists of a host PC and a PCI Express-based beamformer accelerator with an Am2045 MPPA chip and 512 Mbytes of external memory. Am2045 has 336 asynchronous RISC-DSP processors that communicate and coordinate through a configurable structure of channels, using a self-synchronizing communication protocol.

This paper presents the memory organization and data access methods used to implement digital delays on the MPPA. It describes the computing resource allocation and inter-processor communication structure in realizing beamforming parallelism, and presents the performance results of this sample implementation. At the end of this paper it identifies the key challenges in 3D beamforming, and explores the possible approaches in meeting these challenges on the MPPA platform.

6920-03, Session 1

Real-time implementation of the echo signal processing and digital scan conversion for medical ultrasound imaging with a single TMS320C6416 DSP

C. Lee, H. Sohn, Sogang Univ. (South Korea); D. Han, LG Electronics Inc. (South Korea); T. Song, Sogang Univ. (South Korea)

Software implementation of a medical ultrasound imaging system using commercial DSPs (Digital Signal Processor) has advantages over FPGA- or ASIC-based system in development cost and time. The authors have developed a full software-based ultrasound scanner consisting of a typical analog front-end block and a DSP system. In this work, we present efficient methods for software realization of an echo processor to perform all the ultrasound signal processing functions following the receive beamforming. For implementation with a single TMS320C6416 DSP, the most computationally demanding functions such as dynamic filtering, quadrature demodulation, decimation, magnitude calculation, and log compression are implemented using modified algorithms and structures optimized to best match the DSP architecture for fast computation. The DSC (digital scan converter) is realized with an LUT for generating memory addresses and interpolation coefficients for each display point. The LUT table is stored in a single external SDRAM so that the internal DSP memory can be fully utilized by the DSP core to maximize the processing speed. The possible memory stall that can be caused by the external memory access is removed by properly employing the enhanced direct memory access channels. Experimental results show that the proposed implementation can support up to 4kHz PRF (pulse repetition frequency) when the input data rate is 40 MHz.

6920-04, Session 1

C-mode reflection ultrasound images using PE-CMOS sensor: a preliminary study

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In this paper, we investigated the potential of using a PE-CMOS sensor based ultrasound system for the detection of bone fractures. The C-mode imaging system used in this study consists of four major components: (1) a 5MHz plane wave transducer, (2) a beamsplitter, (3) a compound acoustic lens system, and (4) a state-of-the-art piezoelectric based complementary metal oxide semiconductor (PE-CMOS) array detector (Model I400, made by Imperium Inc., MD).

In the C-mode reflection geometry, the detected ultrasound energy from an object is mainly attributed to the reflected primary beam intensity and the back-scattering intensity. To generate ultrasound images, a large area source transducer is excited with a spike or tone burst pulse. The wave travels through the beamsplitter where half of the beam goes through and is lost and the other half goes onto the target. The target portion reflects ultrasound energy and goes through the beamsplitter again where it is focused onto the imaging array with a set of F/1 acoustic lenses.

We have fabricated such a prototype and performed a pilot study to demonstrate the feasibility for imaging bone surface in a reflective geometry. A traumatized pork rib with tissues remaining intact was imaged by the C-mode ultrasound camera set up in the pulse-echo mode (reflective geometry) using a plane wave transducer operating at 5 MHz. In addition, a de-scatter process was added to enhance the image quality. In the preliminary study, hair-line bone fractures ~400 microns were detected. With the latest development of PE-CMOS sensor array, it is believed that this new ultrasound system can produce high-quality and high-resolution speckle-free ultrasound image for clinically investigating of bone fracture without radiation.

6920-05, Session 1

A new ultrasound phased array applicator to treat prostate cancer using hyperthermia

A. Talaat-Ibrahim, Alexandria Univ. (Egypt)

The effect of array geometry on the steering performance of ultrasound phased arrays is examined theoretically, in order to maximize array performance under the given anatomical constraints. This paper evaluates the performance of arrays with spherical and cylindrical geometry, determined by using computer simulations of the pressure fields produced at various extremes of steering. The spherical segment arrays were truncated for insertion into the rectum, and contained either

annular or linear elements. The cylindrical arrays were either flat or had a variable curvature applied along their length. Fields were computed by dividing the array elements into many point sources. The effectiveness of an array configuration when steered to a particular focal location was assessed by defining a parameter, G , as the ratio of the intensity at the desired focus to the maximum intensity of any unwanted lobes. The performance of truncated spherical arrays with annular elements was evaluated for focal steering along the array axis (in depth, in the z direction). When steered 15 mm toward the source, these truncated spherical annular arrays exhibited excellent performance, with G 5.7 for arrays containing more than 10 elements. Similarly, the spherical arrays with linear elements performed well when steered along the array axis to the same degree, with G 7 (for element widths up to 3), though many more array elements were required. However, when these arrays were steered 15 mm laterally, along the length of the prostate (the y direction), the value for G fell below 1 for element widths greater than about 1.6. It was found that the cylindrical arrays performed much better for y -direction steering (G 4, for 60 mm arrays with an element width of 1.75), but their performance was poorer when steered in the z direction ($G > 4$ for an element width of 1.5). In order to find a compromise between these extremes, a curved cylindrical array was examined, which was a cylindrical array with additional curvature along its length. These curved cylindrical arrays yielded performance between that of spherical linear arrays and cylindrical arrays, with better steering along the y direction than the spherical arrays and better z -direction steering than the cylindrical arrays.

6920-06, Session 2

An ideal observer approach to beamforming

C. K. Abbey, Univ. of California/Santa Barbara; N. Nguyen, M. F. Insana, Univ. of Illinois at Urbana-Champaign

Many signal processing issues in ultrasonic imaging can be viewed as attempts to focus signal energy while preserving the diagnostic information they contain. We have been developing a task-based ideal-observer approach to signal processing with the goal of better understanding the factors that influence the transfer of diagnostic information and improving signal processing algorithms for optimal transfer. We treat the scattering medium as a Gaussian random field with non-uniform variance that encodes the properties necessary for accurate task performance. Using measured point-spread functions for a given system we propagate the scattering statistics through to various stages of the acquisition process along with acquisition noise. In this work we focus on the role of beamforming in this process. We measure the efficiency of information transfer by evaluating the ideal observer acting on individual receive elements versus the ideal observer acting on beamformed echo signals. Optimal beamforming strategies suggested by the analysis are approximated by applying spatial filtering techniques to fixed-focus echo data. These results are compared with a standard dynamic-receive beamformer.

6920-07, Session 2

Globally optimized Fourier finite-difference method for ultrasound breast imaging

L. Huang, K. M. Hanson, Los Alamos National Lab.; C. Li, N. Duric, Karmanos Cancer Institute; Y. Quan, Stanford Univ.

Ultrasound reflectivity imaging can play an important role in breast cancer detection and diagnosis, but its imaging quality and resolution needs to be significantly improved for heterogeneous breasts. The imaging quality and resolution depend on both the accuracy of heterogeneous breast sound-speed models and the accuracy of numerical methods for inward continuation of ultrasound wavefields. We develop a globally optimized Fourier finite-difference method for ultrasound reflectivity imaging. Our new method provides an optimized accuracy for efficient inward continuation of ultrasound wavefields. Its computational efficiency is 1-2 orders of magnitude faster than finite-difference time-domain wave-equation methods. The globally optimized method is based on one-way wave backpropagation in the frequency-wavenumber and frequency-space domain. It contains a finite-difference term in addition to a split-step Fourier propagator (that is used for ultrasound reflectivity imaging

by Huang and Quan, SPIE Medical Imaging, 2007). The coefficients in the finite-difference term are obtained using an optimized scheme that minimizes errors of ultrasound propagation in heterogeneous breasts. The accuracy analysis indicates that the globally optimized method is much more accurate than the split-step Fourier method. We apply the optimized method to ultrasound breast data and the results demonstrate that it can produce high-resolution and high-quality ultrasound reflectivity images.

6920-08, Session 2

Discrete echo signal modelling of ultrasound imaging systems

M. Chen, C. Zhang, Nanyang Technological Univ. (Singapore)

In this paper, a new discrete model representing the pulse-tissue interaction in the medical ultrasound scanning and imaging process is developed. The model is based on discretizing the acoustical wave equation in terms of convolution between the input ultrasound pulses and the tissue mass density and ultrasound propagation velocity inside tissue. Such a model can provide a useful means for high quality ultrasound image formation.

Most existing models used for ultrasound imaging are based on frequency domain transform. A disadvantage of the frequency domain transform is that it is only applicable to shift-invariant models. Thus it has ignored the shift-variant nature of the original acoustic wave equation where the ultrasound propagation velocity and mass density distributions are spatial-variant factors. The discretized frequency domain model also obscures the ultrasound propagation velocity and mass density representations of the tissue, which may mislead the physical understanding and interpretation of the image obtained. Moreover, only the classical frequency domain filtering methods have been applied to the frequency domain model for acquiring some tissue information from the scattered echo signals. These methods are non-parametric and require a prior knowledge of frequency spectra of the transmitted pulses.

Our proposed model is in terms of discrete, multidimensional, shift-variant convolution equations with the transmitted pulse pressure as the input, the measurement data of the echo signals as the output, and functions of the ultrasound propagation velocity and mass density distributions as shift-variant parameters that can be readily identified from input-output measurements. It represents the spacial and time domain pulse-tissue scattering process, that overcome the limitations of the frequency domain methods. Experiments are carried out for validating the model using real ultrasound radio frequency data collected from ULTRASONIX(r) Sonix RP.

6920-09, Session 2

Clinical breast imaging using sound-speed reconstructions of ultrasound tomography data

C. Li, N. Duric, Karmanos Cancer Institute; L. Huang, Los Alamos National Lab.

To improve clinical breast imaging, a new ultrasound breast imaging device (CURE) has been designed and built at Karmanos Cancer Institute, Wayne State University. The CURE device has a ring array of transducers, which allows recording of both reflection and transmission ultrasound signals. To extract the sound-speed information from the breast data acquired by CURE, we develop an ultrasound computer tomography algorithm, which can reconstruct sound-speed parameters of the breast using the transmission information. This study describes our reconstruction algorithm and its in vivo applications to data from ~150 patients. Images of sound-speed suggest that it is possible to measure variations in the sound-speed of 5 m/s. An apparent correlation with mammograms suggests that the sound-speed can be used to discriminate between various types of soft tissues. Moreover, ultrasound sound-speed tomography, in combination with attenuation and reflectivity images, has the potential to improve diagnostic imaging for breast cancer detection.

6920-10, Session 2

Three-dimensional PSF analysis for arbitrary transducer geometries and SAFT-based image reconstruction

G. F. Schwarzenberg, H. Gemmeke, N. V. Ruiters, Forschungszentrum Karlsruhe (Germany)

The point spread function (PSF) of an imaging system can be used as a measure for imaging performance or image quality. For an ultrasound based system the PSF is usually spatially variable and depends on several system parameters. Our current 3D imaging system for ultrasound computer tomography (USCT) consists of a rotatable cylinder with approx. 2000 ultrasound transducers. 3D images are reconstructed by means of synthetic aperture focusing technique (SAFT). No analytical solution exists for determining the spatially varying PSF for arbitrary geometries. To optimize the next generation setup of our system the 3D PSF has to be analyzed for different system parameters, at arbitrary positions and for arbitrary transducer apertures.

This work demonstrates a fast numerical approach for approximating the 3D PSF for arbitrary transducer geometries including the beam pattern of the ultrasound transducers, a directional point scatterer model, damping of the breast and arbitrary pulse shapes. The approach does not rely on time consuming image reconstructions; it only considers the geometric aspects of the SAFT imaging process. The spatially varying PSF of the current cylindrical geometry is analyzed under idealized conditions (point sources, no damping, and isotropic scattering) and compared to the new results of the PSF analysis. The differences are significant and show the necessity to take the system specific parameters into account for a realistic performance evaluation of the imaging systems.

6920-12, Session 3

New developments in molecular imaging with micro-ultrasound and contrast agents (Keynote)

F. S. Foster, Univ. of Toronto (Canada)

This year the Nobel prize for medicine was given to 3 scientists for the discovery of genetic knock-out techniques for the mouse. The next major project following the sequencing of the genome is the coordinated and systematic knocking out of each of the mouse's ~ 30,000 genes and the discovery of the phenotypes associated with these mutations. The National Institutes of Health and other international organizations are betting 100's of millions of dollars that this will lead to critical discoveries needed along the path to better healthcare. Imaging will play a major role in this enterprise. This presentation will focus on what high frequency micro-ultrasound brings to the table. The principles of this technology will be described and applications in the area of cardiovascular and cancer research will be outlined. The recent introduction of high frequency contrast agents has further expanded potential for micro-ultrasound to perform functional and targeted molecular imaging in disease models and interventional studies. The current state of the art in high frequency contrast imaging of the mouse will be examined. Examples of functional imaging of inflammation, cardiovascular disease, and tumour microcirculation will be used to illustrate the potential and limitations of the current technology. Potential for molecular imaging will be explored in a melanoma xenograft model in which the expression pattern of VEGFR-2 is studied. Performance improvements will require optimization of the microbubbles themselves, a better understanding of microbubble interactions at high frequencies in both the bound and unbound state, and improved capabilities for nonlinear excitation. Photoacoustic imaging may also offer significant opportunities to further expand the range of matrix and intracellular targets for micro-ultrasound. Speculation on the future of micro-ultrasound technology and applications will be discussed.

6920-13, Session 3

Implanting ultrasound devices: techniques and tips

D. H. R. Vilkomerson, T. Chilipka, J. Bogan, DVX LLC; J. Blebea, R. Choudry, J. Wang, M. Salvatore, V. Rotella, K. Soundararajan, Temple Univ.

Using medical implants to wirelessly report physiological data is a rapidly growing area. Ultrasound is well-suited for implants -- it requires little power, and has almost no interaction with the body. We report here on techniques we have developed in our experience gained in implanting over a dozen Doppler ultrasound flow-measuring implants in dogs.

The goal of this development is an implant that energizes a 20 MHz Doppler diffraction-grating transducer system, either by external command or by internal timetable, then record digitized Doppler real and imaginary channels, and finally transmits the data to a bed-side (or here, kennel-side) monitor for evaluation.

After outlining the overall operation of the system, we will concentrate on three areas where special techniques are required: biocompatibility, to prevent the body from reacting to its invasion; energy-use minimization, to provide long-life to a small battery-powered system; and simultaneous data transmission, to obey stringent FCC and FDA rules (Medical Implant Communications Service) on spectral use and power output.

We will also provide some useful tips for device developers, e.g. where to place signal connectors exiting a dog's body from being chewed, scratched, or rubbed off (a crucial problem in device development).

6920-14, Session 3

Improvement of signal-to-noise ratio by a new high contrast imaging method combining amplitude modulation and pulse inversion techniques

N. Maikusa, T. Fukami, Y. Tamura, T. Yuasa, T. Akatsuka, Yamagata Univ. (Japan)

The second harmonic and subharmonic components, the frequencies of which are twice and one half the fundamental frequencies, are included in echoes from contrast agents. An imaging method, which employs a second harmonic (second harmonic imaging), is widely used in medical diagnoses. On the other hand, subharmonic is expected to provide a higher contrast between biological tissues and blood flow because echo signals are generated only from blood containing the contrast agents. However, the subharmonic component echo signal power from contrast agents is relatively low. This has resulted in little progress in the field of subharmonic imaging. In this study, we have proposed a new imaging method using amplitude-modulated waves as transmitted waves combined with the pulse inversion method to enhance subharmonic echo signals. We set two optimal frequencies including the modulated waves, F1 and F2, so that the subharmonic frequency of F1 and the second harmonic frequency of F2 may result in the same value. This allows a more powerful signal at the frequency band because the second harmonic and subharmonic components are integrated. We compared the subharmonic component from contrast agents, Levovist. As a result, the echo power of the subharmonic component was enhanced by approximately 4.7 dB more than the conventional method.

6920-15, Session 4

Cardiac phase detection in intravascular ultrasound images

M. M. S. Matsumoto, Aeronautics Institute of Technology (Brazil) and Univ. de São Paulo (Brazil); P. A. Lemos, Univ. de São Paulo (Brazil); T. Yoneyama, Aeronautics Institute of Technology (Brazil); S. S. Furuie, Univ. de São Paulo (Brazil)

Image gating is a problem related to image modalities which involve quasi-periodic moving organs. Therefore, during intravascular ultrasound (IVUS) examination, there is cardiac movement interference. This project aims to obtain gated images based on the images themselves. This would allow the reconstruction of 3D coronaries with temporal accuracy for any cardiac phase, which is an advantage over the ECG-gated acquisition that shows a single one. It is also important for retrospective studies, as in existing IVUS databases there are no additional reference signals (ECG). From the images, we calculated signals based on average intensity (AI), and, from consecutive frames, average intensity difference (AID), cross-correlation coefficient (CC) and mutual information (MI). The process includes a wavelet-based filter step and ascendant zero-cross detection in order to obtain the phase information. Firstly, methodology was tested in simulated images, with different speckle noise levels, contrast and

patient's random characteristics. We tested 90 sequences with 1025 frames each, 480x480 pixel resolution images and acquisition rate of 30 frames/s. The results from simulated images have shown that our method was able to achieve more than 95.0% of true positives and less than 2.3% of false positives ratio, for all signals. Afterwards, we tested in a real examination, with 897 frames, with ECG as gold-standard. In this preliminary case, we achieved 97.4% of true positives (CC and MI), and 2.5% of false positives. Furthermore, the methodology presented is independent from settings such as thresholds. For future works, methodology should be tested in wider range of IVUS examinations.

6920-16, Session 4

Evaluation of a level set segmentation method for cardiac ultrasound images

Y. Yue, H. D. Tagare, Yale Univ. School of Medicine

This paper evaluates the quality of segmentation achieved by a level set evolution strategy call Tunneling Descent. Level sets often evolve to find a local minimum of an energy function. We compare the quality of the level set segmentation with the segmentation achieved by (1) simulated annealing (with three different cooling schedules), and (2) random sampling, and (3) three experts (manual segmentation). Simulated annealing and random sampling offer global minimization. A comparison of the local level set minimum with a global minimum is important for many applications. This is especially true of ultrasound segmentation where ultrasound speckle can introduce many local minima which trap the level set.

The quality of the segmentation is compared for 21 clinically-obtained images. The comparison is carried out using two performance measures: the amount by which the global minimizers can further decrease the level set energy, and the Hausdorff distance between the segmentations themselves. The results show that level set segmentation is within one ultrasound resolution cell of the global minimum. The results also show that the level set segmentation is quite close to manual segmentation.

6920-17, Session 4

Detection of artery interfaces: a real-time system and its clinical applications

F. Faita, V. Gemignani, E. Bianchini, Consiglio Nazionale delle Ricerche (Italy); C. Giannarelli, L. Ghiadoni, Univ. di Pisa (Italy); M. Demi, Consiglio Nazionale delle Ricerche (Italy) and Esaote SpA (Italy)

Analyzing the artery mechanics is a crucial issue because of its close relationship with several cardiovascular risk factors, such as hypertension and diabetes.

Moreover, the most part of the work can be carried out by analyzing image sequences obtained with ultrasounds, that is with a non-invasive technique which allows a real-time visualization of the observed structures. In this topic, therefore, an accurate temporal localization of the main vessel interfaces becomes a central task for which the manual approach should be avoided since such a method is rather unreliable and time consuming.

Real-time automatic systems are advantageously used to automatically locate the arterial interfaces. The automatic measurement reduces the inter/intra-observer variability with respect to the manual measurement which unavoidably depends on the experience of the operator. The real-time visual feedback, moreover, guides physicians when looking for the best position of the ultrasound probe, thus increasing the global robustness of the system.

The automatic system which we developed is a stand-alone video processing system which acquires the analog video signal from the ultrasound equipment, performs all the measurements and shows the results in real-time. The localization algorithm of the artery tunics is based on a new mathematical operator (the first order absolute moment) and on a pattern recognition approach.

Various clinical applications have been developed on board and validated through a comparison with gold-standard techniques: the assessment of intima-media thickness, the arterial distension, the flow-mediated dilation and the pulse wave analysis. With this paper, the results obtained on clinical trials are presented.

6920-18, Session 4

Estimation of cardiac functional parameters from contrast-enhanced echocardiography video sequences by spatio-temporal clustering

P. P. Bansod, U. B. Desai, Indian Institute of Technology (India); N. J. Burkule, Asian Heart Institute and Research Ctr. (India)

We present a spatio-temporal Density Based Clustering algorithm (ST-DBSCAN) for the estimation of cardiac functional parameters in short axis (SAX) contrast echocardiographic image sequences. A semiautomatic method is also proposed for segmentation of left ventricle in SAX videos, which uses this clustering algorithm and at the same time requires minimal expert intervention. Expert is required to specify candidate points of the contour only in the first frame of the sequence. The initial contour is approximated by fitting an ellipse in the region defined by the points specified. This region is identified as the principal cluster corresponding to the left ventricular cavity. In contrast echo images, this region is characterized by bright points approximately in the centre of the acoustic window. Later the density based clustering was applied for regularization on the initial contour. We have extended the DBSCAN algorithm for incorporating the temporal information from the adjacent frames during the segmentation process. This ensures temporal continuity in the contours by accommodating the drop outs in the individual frames due to imaging modality. The cardiac functional parameters are evaluated after the segmentation of endocardial contour in all the frames of the video sequence over one full cardiac cycle. The algorithm developed was applied to 10 data sets from different patients and the results were validated by comparing computer generated boundaries and parameters to those manually outlined by one expert. The maximum error in the contours detected was ± 2.9 mm. The functional parameter estimation was within 10 percent of that determined by human expert. The spatio-temporal clustering algorithm proposed in this paper offers an efficient semiautomatic segmentation of heart chambers in 2D contrast echocardiography sequences.

6920-19, Session 4

A new fringeline-tracking approach for ultrasound color Doppler imaging phase unwrapping

A. A. Saad, Univ. of Washington and Philips Medical Systems; L. G. Shapiro, Univ. of Washington

Ultrasound color Doppler imaging is a powerful non-invasive diagnostic tool for many clinical applications. Many imaging artifacts hinder the quantification of the color Doppler images, the most important of which is the aliasing artifact. In this work we will address the color Doppler aliasing problem and present a recovery methodology for the true flow velocities from the aliased ones. This paper documents the need for a phase unwrapping algorithm for use in ultrasound color Doppler image analysis. It describes a new phase-unwrapping algorithm. Experiments have been performed on both in-vitro flow-phantom data and in-vivo human blood flow data. In addition to the qualitative assessment of the results, a quantitative assessment approach was developed to measure the success of the results.

6920-20, Session 4

Automatic detection of blood versus non-blood regions on intravascular ultrasound (IVUS) images using wavelet packet signatures

A. Katouzian, Columbia Univ.; B. Baseri, Univ. of Medicine and Denistry of New Jersey; S. G. Carlier, E. E. Konofagou, A. F. Laine, Columbia Univ.

Intravascular ultrasound (IVUS) is the most reliable imaging modality that is widely employed in the cardiac interventional procedures. It provides morphologic as well as pathologic information of the occluded plaques throughout the coronary arteries. In this paper, we present a new technique using wavelet packet analysis to differentiate between blood and non-blood regions on the IVUS images. We utilized the multi-channel texture segmentation algorithm based on the discrete wavelet packet frames (DWPF). A k-mean clustering algorithm was deployed to

partition the extracted textural features into blood and non-blood in an unsupervised fashion. Finally, the geometric and statistical information of the segmented regions were used to estimate the closest set of pixels to the lumen border and a spline curve was fitted to the set. Our algorithm will be helpful in delineating the lumen border automatically and more reliably prior to the process of plaque characterization, especially for 40 MHz catheters in which appearance of the red blood cells makes the border detection more challenging even manually. Experimental results are shown and they are quantitatively compared with manually traced borders by an expert. It is concluded that our two dimensional (2D) algorithm, which is independent of the cardiac and catheter motions, performs well in both in-vivo and in-vitro cases.

6920-21, Session 5

Adaptive spatial compounding for improving ultrasound images of the epidural space on human subjects

D. Tran, R. N. Rohling, A. A. Kamani, The Univ. of British Columbia (Canada); V. Lessoway, BC Women's Hospital and Health Ctr. (Canada); K. Hor, The Univ. of British Columbia (Canada)

Administering epidural anesthesia can be a difficult procedure, especially for inexperienced physicians. The use of ultrasound imaging can help by showing the location of the key surrounding structures: the ligamentum flavum and the lamina of the vertebrae. The anatomical depiction of the interface between ligamentum flavum and epidural space is currently limited by speckle and anisotropic reflection. Previous work on phantoms showed that spatial compounding with non-rigid registration can improve the depiction of these features. This paper describes the development of an updated compounding algorithm and results from a clinical study. Average-based compounding may obscure anisotropic reflectors that only appear in one image, so a median-based compounding technique is developed. In order to reduce the computational cost of the registration process, a linear prediction algorithm is used to reduce the search space for registration. The algorithms are tested on 20 human subjects. Comparisons are made among the reference image plus combinations of different compounding methods, warping and linear prediction. The linear gradient of the bone surfaces, the Laplacian of the ligamentum flavum, and the SNR and CNR are used to quantitatively assess the visibility of the features in the processed images. The results show a significant improvement in quality when median-based compounding with warping is used to align the set of beam-steered images and combine them. The improvement of the features makes detection of the epidural space easier.

6920-22, Session 5

Measuring shape complexity of breast tumors on ultrasound images

Y. Wei, Shanghai Jiao Tong Univ. (China)

The shapes of malignant breast tumors are more complex than the benign lesions due to their nature of infiltration into surrounding tissues. We investigated the efficacy of shape features and presented a method using polygon shape complexity to improve the discrimination of benign and malignant breast lesions on ultrasound. First, 63 lesions (32 benign and 31 malignant) were segmented by K-way normalized cut with the priori rules on the ultrasound images. Then, the shape measures were computed from the automatically extracted lesion contours. A polygon shape complexity measure (SCM) was introduced to characterize the complexity of breast lesion contour, which was calculated from the polygonal model of lesion contour. Three new statistical parameters were derived from the local integral invariant signatures to quantify the local property of the lesion contour. Receiver operating characteristic (ROC) analysis was carried on to evaluate the performance of each individual shape feature. SCM outperformed the other shape measures, the area under ROC curve (AUC) of SCM was 0.91, and the sensitivity of SCM could reach 0.97 with the specificity 0.66. The measures of shape feature and margin feature were combined in a linear discriminant classifier. The resubstitution and leave-one-out AUC of the linear discriminant classifier were 0.94 and 0.92, respectively. The distinguishing ability of SCM showed that it could be a useful index for the clinical diagnosis

and computer-aided diagnosis to reduce the number of unnecessary biopsies.

6920-23, Session 5

Image-based method for in-vivo freehand ultrasound calibration

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For freehand ultrasound systems, a calibration method is necessary to locate the position and orientation of a 2D B-mode ultrasound image plane with respect to a position sensor attached to the transducer. In addition, the acquisition time discrepancy between the position measurements and the image frames has to be computed. We developed a new method that addresses both of these problems, based on the fact that a freehand ultrasound system establishes approximately consistent 3D data of an arbitrary object. Two angulated sweeps of any object containing well visible structures are recorded, each at a different orientation. A non-linear optimization strategy maximizes the similarity of 2D ultrasound images from one sweep to reconstructions computed from the other sweep. No designated phantom is required for this calibration. The process can be performed in vivo on the patient - allowing for potentially more precise initial or refined calibration, since it is using the same tissue and tracking workspace that also will be used during the freehand ultrasound exam, or interventional navigation procedure. The underlying geometric formulation of our approach is presented to prove that all calibration parameters can be recovered. We evaluated the calibration method using freehand acquisitions on both a phantom and the human liver with a Siemens Sequoia ultrasound system. The accuracy was validated using a Siemens Antares 3D ultrasound probe as known reference (i.e. Ground Truth) geometry. We could resolve 5 calibration parameters with errors < 0.67mm in repeated execution of the method (the axial translation had a systematic bias of ~2mm). The overall mean relocation error of a point in the center of an ultrasound image at 7cm depth was 2.4mm.

6920-25, Session 5

Spatial compounding for rotating linear probe in the presence of parameter error using image registration

M. H. Choi, Kangwon National Univ. (South Korea); M. Bae, Hallym Univ. (South Korea)

Spatial compounding generally involves electronic steering of the ultrasonic beams. In this paper, we present the spatial compounding approach where the component image is acquired by mechanically rotating the probe element. A linear transducer array is rotated about an axis in the plane of the image. The goal is to avoid the problems associated with the electronic beam steering at a large angle such as grating lobe effect, decrease in the effective aperture size, and decrease in transducer sensitivity caused by obliquity factor.

In the computation of the ultrasound image, we need the exact values of coordinates of the axis of rotation and angular position of the transducer array. However, the construction of the rotation mechanism and the control system accompanies the inevitable uncertainties in these values. These parameter errors result in the target position error, and the consequence is the blurry compounded image. Correction for the parameter error is needed.

We present the spatial compounding for rotating linear probe in the presence of parameter error using image registration. The effect of the uncertainty in the mechanical parameters was compensated by registering the wire target images before spatial compounding. An efficient registration algorithm was developed to compute the transformation matrix required for the registration. The component images were registered by the transformation matrix before spatial compounding. The registration errors were reduced to less than a pixel. Spatial compounding results show that the blurring caused by the parameter uncertainty can be removed completely.

6920-26, Session 6**Temperature monitoring during tissue freezing using ultrasound speed measurements**

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A major limitation of thermal therapies is the lack of detailed thermal information needed to monitor the therapy. Temperatures are routinely measured invasively with thermocouples, but only sparse measurements can be made. Ultrasound tomography is an attractive modality for temperature monitoring because it is non-invasive, non-ionizing, convenient and inexpensive. It capitalizes on the fact that the changes in temperature cause the changes in sound speed. In this work, we investigate the possibility of monitoring large temperature changes, in the interval from body temperature to -40°C . The ability to estimate temperature in this interval is of a great importance in cryotherapy, where the cold temperature is used to destroy abnormal tissue. In our experiment, we freeze locally a tissue-mimicking phantom using one, two or three cryoprobes. The temperature changes are monitored using thermocouples and the changes in sound speed are computed using travel time tomography. Results show that above the freezing point the sound speed decreases as the temperature decreases. Once the samples begin to freeze there is a sudden and dramatic increase in sound speed and it continues to increase as the temperature decreases. Therefore, it is possible to monitor the freezing process and to detect malfunctioning of the cryo probes. Still, due to the strong speed gradient at the edge of the ice zone or equivalently the high spatial bandwidth, the classical tomographic sampling is limited by its maximum spatial sampling frequency. Novel reconstruction techniques based on parametric estimation of non-bandlimited signals are subject of current research

significant false negative rate for women with dense breasts. We report and discuss clinical breast imaging results obtained with operator independent ultrasound tomography.

A series of in-vivo experiments were carried out using a recently upgraded clinical prototype based on the principles of ultrasound tomography. The in-vivo performance of the prototype was assessed by imaging patients at the Karmanos Cancer Institute. Patients were recruited on the basis of having suspicious masses on mammography and were subsequently imaged with the prototype. Masses were identified by biopsy and their locations inferred from conventional mammography and ultrasound exams. These data were compared with the ultrasound tomograms in order to evaluate the in vivo detection capabilities of the prototype.

Our techniques successfully demonstrated in-vivo tomographic imaging of breast architecture in both reflection and transmission imaging modes. Masses as small as 6 mm in size were detected. These initial results indicate that operator-independent whole-breast imaging and the detection of cancerous breast masses are feasible using ultrasound tomography techniques. This approach has the potential to provide a low cost, non-invasive, and non-ionizing means of evaluating breast masses. Future work will concentrate on extending these results to larger trials.

6920-27, Session 6**Lamb waves detection in bovine cortical tibia using scanning laser vibrometry**

M. Hapsara, D. D. Illiescu, Univ. of Warwick (United Kingdom)

Most of the techniques for generating and detecting ultrasonic Lamb waves (e.g. angle-beam piezoelectric transducers, micro-electro mechanical systems (MEMS), comb and interdigital transducers, phased array transducers, and piezoceramic transducers) require physical contact with the measured objects. For objects with highly irregular surfaces such as bones, it will be very difficult to produce a good contact. Thus, a non-contact Lamb wave measurement technique, the scanning laser vibrometry, is proposed in this paper to examine a bovine cortical tibia in vitro. The ultrasonic Lamb waves used had the center frequency of 84KHz. The waves were generated using a planar transducer which was coupled with a cone-shaped resonant vibrator. Only the fundamental modes of a_0 and s_0 were expected to occur. 2-Dimensional images of the Lamb waves traveling in the bone were recorded. The scan results represent out-of-plane vibration of the surface of the bone. Lamb wave modes were verified with further post-processing analyses. In time-domain, time-history prediction of the modes is fitted onto the original signal as to confirm their common rising time for each mode. Frequency-domain methods, i.e. wavelet and space-wavenumber analyses, are also employed to define the traveling modes and their group velocity. The expected modes can be clearly defined at the center frequency. Additionally, a new mode, a_1 , was generated and detected at the higher frequency of the responses.

6920-29, Session 6**A novel software-based technique for quantifying placental calcifications and infarctions from ultrasound**

J. T. Ryan, Univ. College Dublin (Ireland); F. McAuliffe, M. Higgins, National Maternity Hospital (Ireland); M. Stanton, P. C. Brennan, Univ. College Dublin (Ireland)

In obstetrics, antenatal ultrasound assessment of placental morphology comprises an important part of the estimation of fetal health. Ultrasound analysis of the placenta may reveal abnormalities such as placental calcification and infarcts. Current methods of quantification of these abnormalities are subjective and involve a grading system of Grannum stages I-III. The aim of this project is to develop a software tool that quantifies semi-automatically placental ultrasound images and facilitates the assessment of placental morphology. We have developed a 2D ultrasound imaging software tool that allows the obstetrician or sonographer to define the placental region of interest. A secondary reference map is created for use in our quantification algorithm. Using a slider technique the user can easily define an upper threshold based on high intensity for calcification classification and a lower threshold to define infarction regions based on low intensity within the defined region of interest. The percentage of the placental area that is calcified and also the percentage of infarction is calculated and this is the basis of our new metric. Ultrasound images of abnormal and normal placentas have been acquired to aid our software development. A full clinical prospective evaluation is currently being performed and we are currently applying this technology to the three-dimensional ultrasound domain. We have developed a novel software-based technique for calculating the extent of placental calcification and infarction, providing a new metric in this field. Our new metric may provide a more accurate measurement of placental calcification and infarction than current techniques.

6920-28, Session 6**Detection and characterization of breast masses with ultrasound tomography: clinical results**

N. Duric, C. Li, P. Littrup, Karmanos Cancer Institute; L. Huang, Los Alamos National Lab.; C. Glide-Hurst, O. Rama, L. Bey-Knight, S. Schmidt, Y. Xu, J. Lupinacci, Karmanos Cancer Institute

Although mammography is the gold standard for breast imaging, its limitations result in a high rate of biopsies of benign lesions and a

6920-30, Session 6**A novel ultrasonic method for measuring breast density and breast cancer risk**

C. Glide-Hurst, N. Duric, P. Littrup, Karmanos Cancer Institute and Wayne State Univ.

Women with high mammographic breast density are at 4- to 6-fold increased risk of developing breast cancer compared to women with fatty breasts. However, current breast density estimations rely on mammography, which cannot provide accurate volumetric breast representation. Therefore, we explored two techniques of breast density evaluation via ultrasound tomography. A sample of ~ 100 patients was imaged with our clinical prototype; each dataset contained 45-75 tomograms ranging from near the chest wall through the nipple. Whole breast acoustic velocity was determined by creating image stacks and evaluating the sound speed frequency distribution. Ultrasound percent density (USPD) was determined by segmenting high sound speed areas

from each tomogram using a k-means clustering routine, integrating over the entire breast, and dividing by total breast area. Both techniques were independently evaluated using two mammographic density measures: (1) qualitative, as determined by a radiologist's visual assessment using BI-RADS Categories and (2) quantitative, via semi-automatic segmentation to calculate mammographic percent density (MPD) for craniocaudal and medio-lateral oblique mammograms. Approximately 140 m/s difference in acoustic velocity was observed between fatty and dense BI-RADS Categories. Increased sound speed was found with increased BI-RADS Category and quantitative MPD. Furthermore, strong positive associations between USPD, BI-RADS Category, and calculated MPD were observed. These results confirm that utilizing sound speed, both for whole-breast evaluation and segmenting locally, can be implemented to evaluate breast density. Having an operator-independent and non-ionizing means of evaluating breast density introduces interesting clinical applications, including assessing temporal changes, enabling more routine monitoring, and evaluating chemopreventative response.

6920-31, Session 7

Estimation of 3D cardiac deformation using spatio-temporal elastic registration of non-scanconverted ultrasound data

A. M. Elen, D. Loecx, H. Choi, H. Gao, P. Claus, F. Maes, P. Suetens, J. D'hooge, Katholieke Univ. Leuven (Belgium)

Spatio-temporal elastic registration of 3D cardiac ultrasound (US) data can be used to estimate the full 3D strain tensor. It is shown here that the registration may be performed on images in spherical coordinates, thus bypassing the scanconversion step which would redistribute the recorded data anisotropically over the image and introduce interpolation errors. This was done using simulated data in spherical and cartesian coordinates.

The motion and deformation of the left ventricle were approximated by a kinematic model based on a thick-walled deforming ellipsoid with randomly positioned point scatterers in the myocardium. 3D pyramidal US data sets were simulated using an adapted convolution model. A 3D data set in spherical coordinates was thus obtained. This data set was scanconverted, after which it was exported in a cartesian coordinate system to obtain the cartesian data set.

All 3D volumes in both spherical and cartesian coordinates were registered, using a B-spline based frame-to-frame elastic registration method. This yields an estimation of the 3D displacement field of each frame to the next. The accuracy of the cumulative displacement field (from end-diastole to end-systole) was quantified as the averaged percentage error on the estimated displacement in cartesian coordinates relative to the theoretical displacement. The mean accuracy of the estimated displacement was 10.78+/-4.46% for the data set in cartesian coordinates and 11.88+/-6.32% for the one in spherical coordinates. Since both accuracies are clinically acceptable and very alike, it is shown that 3D nonrigid registration to estimate the cardiac deformation from ultrasound images can be performed on non-scanconverted images.

6920-32, Session 7

Real-time visualization of pulsatile tissue-motion in B-mode ultrasonogram for assistance in bedside diagnosis of ischemic diseases of neonatal cranium

M. Fukuzawa, M. Yamada, N. Nakamori, Kyoto Institute of Technology (Japan); Y. Kitsunezuka, Saiseikai Hyogo-ken Hospital (Japan)

Pulsatile tissue-motion caused by artery pulsation of blood flow has been visualized as a video stream in real time from B-mode ultrasonogram with a newly-developed PC-based visualization system which can concurrently execute the three processes: (1) capturing an input B-mode video-stream (640x480 pixels/frame, 30 fps) into the system memory, (2) detecting the strength and the phase of pulsatile tissue-motion at each pixel from a heartbeat-frequency component in Fourier transform of a series of pixel value as a function of time, and (3) generating an output video-stream of pulsatile-phase image, in which the motion phase is superimposed as color gradation on an input B-mode stream when the motion strength exceeds a proper threshold. By optimizing

the visualization software with the streaming SIMD extensions (SSE), the output video-stream of pulsatile-phase image has been continuously generated at more than 10 fps. As the result that the visualization technique proposed here is applied to a B-mode stream of neonatal cranium, the output video-stream reveals characteristic shape of motion region and local fluctuation of motion phase due to obstruction and disturbance of blood flow, which may strongly assist pediatricians in bedside diagnosis of ischemic diseases. Although the sway of the ultrasonic probe and/or neonate's head is appeared as unwanted motion-artifacts, it may be easily reduced by feedback to probe handling. It may be recognized from the experimental results that the real-time visualization proposed here has advantages over the retrospective one in exhibiting the artery pulsation of blood flow.

6920-33, Session 7

Quantitative Shear Modulus Imaging Using Spatially Modulated Acoustic Radiation Force

S. A. McLeavey, M. G. Menon, E. Elegbe, Univ. of Rochester

We present a new method for imaging the shear modulus of tissue using impulsively applied acoustic radiation force. In this method, a shear wave of known wavelength is induced by using the radiation force of interfering or sequentially fired beams. The frequency of this shear wave will be proportional to the square root of the shear modulus of the excited region. RF cross correlation of tracking pulses is used to measure the tissue velocity in response to the applied radiation force and to estimate the frequency of the shear wave. By stepping the spatially modulated "push" beam across a region of interest, we can generate images of shear modulus. This method was implemented on a Siemens Antares scanner and images of cylindrical lesions in gelatin phantoms formed. The estimated modulus from our technique is compared with modulus values obtained by standard methods and found to be in good agreement. In addition to the phantom results we will show images of lesions in beef liver.

6920-34, Session 7

Image-based speckle tracking for tissue motion characterization in a deformable cardiovascular phantom

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We present an image-based speckle-tracking algorithm for quantification of tissue deformation (TD) and rotation (ROT) in dynamic cardiovascular phantom models. Infinitesimal Lagrangian strain was computed from the change in distance between two calipers positioned within the wall of a pulsatile phantom and compared with reference measurements derived from cardiac CT imaging. In a torsion phantom, rotational tissue excursion in a 2D plane was estimated and compared with reference values from CT-scan data. Tissue deformation and rotation measurements correlated strongly with their respective reference measurements. Our algorithm is capable of estimating strain and rotation from distinct tissue regions without requiring explicit cardiac border detection, a step which can be especially challenging in patients with poor acoustic windows.

6920-35, Session 7

Improving diagnostic quality of IVUS palpography By incorporating catheter motion compensation

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Intravascular Ultrasound (IVUS) strain imaging of the luminal layer in coronary arteries, coined as IVUS palpography, utilizes conventional radiofrequency (RF) signals acquired at two different levels of intraluminal pressure. The signals are cross-correlated to obtain the microscopic tissue displacements, which can be directly translated into local strain of the vessel wall. However, tissue motion caused by catheter translation results in signal decorrelation and invalid strain estimates. A method based on the scale-space optical flow (OF) algorithm is

proposed to account for the catheter motion. The computed OF vector field quantifies the amount of local tissue misalignment in consecutive frames. Subsequently, the extracted motion information is used to realign the signals prior to the cross-correlation analysis, reduce the RF signal decorrelation, and increase the number of valid strain estimates. The advantage of applying the motion compensation algorithm in IVUS palpography was demonstrated on a mid-scale validation study on 14 in-vivo IVUS pullbacks.

6920-36, Session 7

Strain index: a new visualizing parameter for ultrasound elastography

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Elastography, an ultrasound modality based on the estimation of the mechanical properties of tissues, has a strong potential in the diagnosis and prognosis of tumors. For instance, tissue affected by breast and prostate cancer undergoes a change in its elastic properties. These changes can be measured using ultrasound signals.

The standard way to visualize elastography is the representation of the axial strain. Other approaches investigate the information contained in shear strain elastograms, vorticity or the representation of the full strain tensor. In this work, we propose to represent the elastic behaviour of tissues through the visualization of the trace of the strain tensor. Based on the mathematical interpretation of the strain tensor, this novel parameter is equivalent to the sum of the absolute values of the eigenvalues of the strain tensor, and constitutes a measure of the total amount of strain of the soft tissue.

In order to show the potential of this visualization approach, a tissue-mimicking phantom was modeled as a 10x10x5 cm region containing a centered 10 mm cylindrical inclusion three times stiffer than the surrounding material, and its elastic behavior was simulated using finite element analysis software. Synthetic pre- and post-compression (1.25%) B-mode images were computer-generated with ultrasound simulator software. The results show that the visualization of the strain index significantly improves the representation and detection of inclusions, and may add insight in the detection of different types of tumors.

6920-37, Session 7

A new approach to elastography using a modified demons registration algorithm

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The standard way to estimate the displacement field from which researchers obtain the strain in elastography is the time-domain cross-correlation estimator (TDE). Optical flow (OF) methods have been also characterized and their use keeps increasing.

We introduce in this paper the use of a modified Demons Algorithm (MDA) to estimate the displacement field and we compare it with OF. A least-squares strain estimator (LSE) is applied to estimate the strain from the displacement. The input for the algorithm comes from the ultrasound scanner standard video output; therefore, its clinical implementation is immediate.

To test the algorithm, a tissue-mimicking phantom was modeled as a 10x10x5 cm region containing a centered 10mm cylindrical inclusion three times stiffer than the surrounding material, and its elastic behavior was simulated using COMSOL Multiphysics 3.2 software. Synthetic pre- and post-compression (1.25%) B-mode images were computer generated using FIELD II ultrasound simulator. Afterward, the algorithm was tested with a commercial CIRS breast elastography phantom, applying a 2% freehand compression.

Axial displacement fields' and strain figures are presented and in the

case of the synthetic one compared to the ground truth given by the FE software. Although other researchers have used registration methods for elastography, as far as we know, they have not been used as stand-alone methods but together with elastic modulus reconstruction or FE which iteratively varies material properties to improve registration.

Ongoing research includes characterization of the performance of the method comparing it with other displacement estimation methods in elastography and clinical validation.

6920-39, Poster Session

Development of whole breast ultrasound scanner and viewer for mass screening

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Ultrasonography is one of most important methods for breast cancer screening in Japan. However, the ultrasonography using conventional handheld probe is operator-dependent. Therefore, the quality of imaging depends on the operator technique, and the ultrasound images have less objectivity. Moreover, it is difficult for radiologists to interpret using comparison of left and right breast ultrasound images, comparison of previous ultrasound images, and double reading because ultrasound images are poor reproducibility and it is difficult to record entire breast images. In order to improve such problems, we developed whole breast ultrasound scanner and viewer. An entire breast could be automatically scanned with an area 16 cm x 16 cm in three overlapping runs within approximately 30 seconds. A whole breast slice image was generated from three original images. These three original images was automatically registered and integrated by our developed viewer. A whole breast image comprised of 84 - 1344 slice images. In addition to axial (B-mode) slice images, sagittal slice images and coronal slice images could be generated from the whole breast image. As a result, objective and reproducible ultrasound images were obtained by using the scanner. Radiologists could interpret using comparison of left and right breast ultrasound images, comparison of previous ultrasound images, and double reading. The screening time was also reduced. The problems of ultrasonography using the conventional handheld probe were improved by using our proposed systems. The performance of mass breast cancer screening using ultrasonography might be improved by using our proposed systems.

6920-40, Poster Session

Software implementation of ultrasound beamforming using ADSP-TS201 DSPs

H. Sohn, S. Seo, J. Kim, T. Song, Sogang Univ. (South Korea)

We present a software-based ultrasound beamformer to build a fully software-based ultrasound scanner which performs real-time delay-sum beamforming using fractional delay filters using ADSP-TS201 DSPs (Analog Device Inc.). Receive dynamic focusing generally requires fast transfer of a large amount of data for inter-channel summation and for delay control. The DSPs are connected in pipelined network architecture without a glue logic using the DSP's parallel ports, which allows the connection of unlimited DSPs. Each DSP has a small input FIFO which takes as input the data samples from each ADC and can take delay values either from a memory (to use pre-calculated delay values) or an external FPGA (for real-time delay calculation) via its LVDS channel. Two fractional delay beamformer (FDBF) schemes are implemented on the DSP system. Each scheme is programmed in assembly code optimized for speed; instruction level parallelism is secured to maximally utilize the four execution units of each DSP, pipeline scheduling is employed to avoid pipeline stall, and instruction reordering techniques are used to prevent memory contention while preserving the program semantics. It is found that dynamic focusing is carried out faster when delay filtering is performed prior to inter-channel summation, whereas hardware implementation of the FDBF favors performing delay filtering after inter-channel summation. The frame rate achievable with 16 DSPs is up to 28Hz when the sampling rate is 40MHz, the view depth is 20cm, the number of scanline is 128, and the number of channel is 64.

6920-41, Poster Session

High throughput SAFT for an experimental USCT system as MatLab implementation with use of SIMD CPU instructions

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At Forschungszentrum Karlsruhe an Ultrasound Computer Tomography (USCT) system is under development for early breast cancer detection. The current 3D demonstrator system consists of approx. 2000 transducers, which are arranged in layers on a cylinder of 18cm diameter and 15cm height. The approach for visualization is based on SAFT. With 3.5 million of acquired raw data sets (A-Scans) and several billion voxels a reconstruction with non optimized code will take up to several weeks on one computer. The aim of this work was the development and analysis of a performance optimized algorithm for the SAFT reconstruction for a software environment based on Mathwork's MATLAB. Three implementations were developed and compared: a plain MATLAB code, an optimized MATLAB code and a MATLAB code using a newly developed, optimized assembler library based on SSE SIMD instructions. An additional optimization was applied by reduction of the function call overhead. The performance gain was factor 2 for the optimization of the MATLAB code. When using the assembler library an acceleration of factor 42 was reached and additional 10% speedup was gained using the blocked function calls.

The developed MATLAB code using an optimized assembler library for SAFT reconstruction resulted in a significant gain in reconstruction performance and still offers the comfortable development of additional signal processing in MATLAB.

6920-42, Poster Session

A method to design an optimum pair of transmit and receive periodic sparse arrays

G. Kim, T. Song, Sogang Univ. (South Korea)

The periodic sparse array (PSA), consisting of sub-arrays of L elements distributed in P -element intervals ($L < P$), are used to increase the effective aperture size in imaging with 2D array or hand-held scanners. A method has been proposed to design an optimum transmit and receive PSAs, denoted $U(P_1, L_1)$ and $U(P_2, L_2)$, where P_1 , P_2 , L_1 , and L_2 are determined to eliminate the dominant grating lobes (DGL) in the overall beam pattern. We present a method to design a nonuniform-amplitude PSA pair with improved beam pattern or higher sparseness. First, an optimum PSA pair is designed based on the previous method. The transmit PSA, $U(P_1, L_1)$, can be represented as the convolution of an L_1 -element dense array $U(L_1)$ and $U(P_1, 1)$ which is identical to an array obtained by upsampling a dense reference array by a factor of P_1 . In the new design method, the reference array is modified by convolving with a uniform-amplitude array $U(K_1)$ of length K_1 and then upsampled by P_1 , yielding a nonuniform-amplitude sparse array $A(P_1, 1)$. Finally, the amplitude shaded transmit PSA is obtained by convolving $A(P_1, 1)$ with $U(L_1)$. The shaded receive PSA is obtained similarly. Since the downsampled versions of $A(P_1, 1)$ and $A(P_2, 1)$ are both dense arrays producing no extra grating lobes, the DGL elimination property is maintained. Moreover, by setting K_1 and K_2 equal to P_2 and P_1 , respectively, additional null points can be placed at all other grating lobe positions. The simulation results show that the new method reduces the grating lobe levels by more than 10dB in all cases.

6920-43, Poster Session

Image quality improvement and computational cost reduction in ultrasonic imaging system

J. Lee, T. Song, Sogang Univ. (South Korea)

Display pixel based focusing (DPBF) technique suggested to get rid of digital scan conversion (DSC) by focusing the ultrasound waves directly on each display pixels was proven to provide much finer ultrasound image than the conventional DSC-based image. However, DPBF increases the computational cost because it should construct dummy imaging points centered around each display pixel to perform quadrature demodulation

for envelope detection. In this work, a modified DPBF method based on multi-order sampling to reduce the computation amount for use in software-based ultrasound imaging is presented. In the proposed DPBF method, receive focusing is performed on each display pixel and $M-1$ neighboring dummy imaging points to perform M th order sampling for envelope detection. Since it suffices to use $M = 5$ to obtain the envelope error of about -55dB and the overall computational cost depends mainly on the number of focal points, the computational complexity of the proposed DPBF method is reduced by more than 300% compared to the original DPBF technique using 16-tap filters for quadrature demodulation. The proposed method also outperforms the conventional ultrasound imaging method in computational complexity. The proposed method is verified through experiments using the real data acquired from a 7.5MHz linear array connected to a commercial scanner. Not to mention the advantage in computation cost, the proposed method provides a much finer image of the carotid area than the conventional imaging method. The speckle patterns also appear to have clear boundaries with the proposed method.

6920-45, Poster Session

Photoacoustic 3D visualization of tumor angiogenesis

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Photoacoustic imaging is used to obtain a range of three-dimensional images representing tumor neovascularization over a 10-day period after subcutaneous inoculation of pancreatic tumor cells in a rat.

The images are reconstructed from data measured with a double-ring photoacoustic detector. The ultrasound data originates from the optical absorption by hemoglobin of 14 ns laser pulses at a wavelength of 1064 nm. Three-dimensional data is obtained by using two dimensional linear scanning. Scanning and motion artifacts are reduced using a correction algorithm. The data is used to visualize the development of the individual blood vessels around the growing tumor, blood concentration changes inside the tumor and growth in depth of the neovascularized region. The three-dimensional vasculature reconstruction is created using the Visualization Toolkit. A composition of the vasculature on day three, seven, eight and ten qualitatively shows the tumor growth.

6920-46, Poster Session

Imaging of acoustic attenuation and speed of sound maps using photoacoustic measurements

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Photoacoustic imaging is an upcoming medical imaging modality with the potential of imaging both optical and acoustic properties of objects. We present a measurement system and outline reconstruction methods to image both speed of sound and acoustic attenuation maps of an object using only photoacoustic excitation. These acoustic properties can be used in a subsequent step to improve the image quality of the optical absorption distribution by incorporating the speed of sound and acoustic attenuation maps in the reconstruction. By proper placement of a passive element we obtain isolated measurements of the object's acoustic properties, independent on the optical absorption inside the object. This passive element acts as a photoacoustic source and measurements are obtained by allowing the generated acoustic signal to propagate through the object. In our approach we reconstruct the acoustic attenuation and speed of sound maps from their projections. The inversion of projections of the speed of sound map and the acoustic attenuation map from these measurements are closely related. Projection measurements are obtained from the received acoustic signal generated by the passive element. For acoustic attenuation the projections of attenuation are extracted from the signal via a maximum likelihood approach that operates on the data in the frequency domain. By making use of the Kramers-Kronig relations the projected attenuation can subsequently be used to extract the speed of sound projections by using the phase delay at different frequencies of the received signal. Finally maps of acoustic attenuation and speed of sound are reconstructed by inversion of the projections.

6920-48, Poster Session**A study of 3-way image fusion for characterizing acoustic properties of breast tissue**

Y. Xu, N. Duric, C. Li, J. Lupinacci, S. Schmidt, C. Glide-Hurst, Karmanos Cancer Institute

Unlike conventional ultrasound (US) imaging systems, our CURE (Computed Ultrasound Risk Evaluation) prototype employs a detector ring, formed by 256 individual transducers, each of which is able to send and receive US signals. Scanning from the chest wall to the nipple of the patient, with the patient's breast suspended inside the ring, a series of 2D raw data sets are collected. Three types of images, reflection, sound speed and attenuation, are generated from the raw data using tomographic reconstruction algorithms. Each type of image, usually presented as a gray scale image, maps different characteristics of the breast tissue. This study is focused on fusing all three types of images to create true color (RGB) images by assigning a different primary color to each type of image. The resulting fused images display multiple tissue characteristics that can be viewed simultaneously. Preliminary results indicate that it may be possible to characterize breast masses on the basis of viewing the superimposed information. Such a methodology has the potential to dramatically reduce the time required to view all the acquired data and to make a clinical assessment. Since the color scale can be quantified, it may also be possible to segment such images in order to isolate the regions of interest and to ultimately allow automated methods for mass detection and characterization

6920-49, Poster Session**Comparison of ultrasound attenuation tomography techniques for breast cancer diagnosis**

C. Li, N. Duric, Karmanos Cancer Institute; L. Huang, Los Alamos National Lab.

Ultrasound attenuation parameters of breast masses are closely related to their types and pathological states. Therefore, estimated attenuation parameters can be used as a feature in quantitative breast tissue characterization. In this study, attenuation coefficients are obtained using three different attenuation tomography techniques, namely, amplitude decay, spectral ratio, and complex signal energy ratio. In the first method, the amplitude decay of the transmitted signal through the breast relative to the water shot signal is used to calculate attenuation coefficients. In the second method, the spectral ratio between transmitted pulses through the breast and water is used to obtain attenuation coefficients. In the third method, the complex energy ratio is estimated by calculating the signal energy ratio using the amplitude envelopes of the breast and water ultrasound signals. These three methods are tested using breast phantom data and then applied to in vivo data acquired using a clinical ultrasound breast imaging system with a ring transducer array, termed Computed Ultrasound Risk Evaluation (CURE). Our attenuation tomography results show that the amplitude decay method yields attenuation coefficients with more artifacts than the other two methods. There is bias and variability in the estimated attenuation using the spectral ratio method due to its sensitivity to different band-widths and signal-to-noise ratios of the data. Compared with amplitude decay and spectral ratio methods, the complex signal energy ratio method is more robust and yields images with fewer artifacts.

6920-51, Poster Session**Simulation of microbubble response to ambient pressure changes**

K. S. Andersen, J. A. Jensen, Danmarks Tekniske Univ. (Denmark)

Blood pressure measurement is a daily routine, which is used to diagnose severe heart, lung, and kidney diseases. To measure the pressure in arteries and organs locally, a pressure catheter is used. As this is an invasive technique it alters the flow and is inconvenient to the patient. Therefore, many attempts to find a non-invasive procedure have been made. The theory on microbubbles clearly indicates a relation between the ambient pressure and the acoustic behaviour of the bubble.

The purpose of this study was to optimize the sensitivity of pressure

measurements through bubble response simulations. The behaviour of two different contrast agents was investigated as a function of the driving pulse and ambient pressure.

Simulations of Levovist using a rectangular driving pulse show an almost linear reduction in the subharmonic component as Pov is increased. For a 12 cycle driving pulse, a reduction of 2.8 dB is observed when changing Pov from 0 to 25 kPa. Increasing the pulse duration makes the reduction even more clear. For a pulse with 64 cycles, the reduction is 9.9 dB. This simulation is in good correspondence with measurement results presented by Shi et al. 1998, who found a linear reduction of 9.6 dB. Further simulations of Levovist show that also the shape and the acoustic pressure of the driving pulse are very important factors. The best pressure sensitivity of Levovist was found to be 0.40 dB/kPa. For Sonazoid, a reduction of 11.4 dB has been found giving a pressure sensitivity of 0.45 dB/kPa.

6920-52, Poster Session**Harmonic quadrature demodulation for extracting the envelope of the 2nd harmonic component**

S. Kim, J. Song, T. Song, Sogang Univ. (South Korea)

An efficient method for separating the harmonic component ($2f_0$) from the fundamental component (f_0) using harmonic quadrature demodulation is presented. In the proposed method, the focused ultrasound signal is mixed with cosine and sine signal waveforms of harmonic frequency $2f_0$ to produce the inphase and quadrature components, respectively. The quadrature component is Hilbert-transformed and then added to the inphase component.

This process cancels out both the high and low frequency components of the mixed fundamental signal and the high frequency component of the mixed harmonic signal, leaving only the envelope of the harmonic signal at the base band. This signal is then fed to a low-pass filter to remove out of band noise. In summary, this method can extract the harmonic signal after a single transmit-receive event even when there exists frequency overlap between the f_0 and $2f_0$ components. Hence, the proposed method is superior to the pulse inversion method which requires twice as many transmit-receive cycles as well as the conventional filtering method which has a bandwidth limitation. Therefore, one can find the proposed method useful not only for tissue harmonic imaging but also for contrast agent imaging in applications where high frame rate or low motion artifact is important. The proposed method is verified by both the analytic and computer simulation studies.

For a stationary target, the difference between the estimated harmonic signals by the proposed and the pulse inversion methods is within 0.1%.

6920-53, Poster Session**Measurement of thermally-ablated lesions in sonoelastographic images using level set methods**

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In the last two decades the capability of sonoelastography to detect lesions based on elasticity contrast has been tested and verified. Currently, segmentation of lesions depicted in sonoelastographic images is performed manually which can be a time consuming process prone to intra- and inter-observer variability. This work proposes a semi-automated segmentation algorithm for sonoelastographic data. The user starts by planting a seed in the perceived center of the lesion. Fast marching methods are used to create an initial estimate of the lesion. Subsequently, level set methods refine its final shape by attaching the segmented contour to edges defined in the image while maintaining smoothness. The algorithm was applied to in-vivo sonoelastographic images from twenty five thermal ablated lesions created in porcine liver. The estimated area was compared to results from manual segmentation and from gross pathology images. Initial results of the algorithm are comparable to manual segmentation while the inter- and intra-observer variability is significantly reduced.