Technical Summaries

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6141-01, Session 1

Image-based rendering method for mapping endoscopic video onto CT-based endoluminal views

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One of the indicators of early lung cancer is a color change in airway mucosa. Bronchoscopy of the major airways provides high-resolution color video of the airway tree's mucosal surfaces. In addition, 3D MDCT chest images provide 3D structural information of the airways. Unfortunately, the bronchoscopic video contains no explicit 3D structural and position information, and the 3D MDCT data captures no color or textural information of the mucosa. A fusion of the topographical information from the 3D CT data and the color information from the bronchoscopic video, however, enables realistic 3D visualization, navigation, localization and quantitative color-topographic analysis of the airways. This paper presents a method for topographic airway-mucosal surface mapping from bronchoscopic video onto 3D MDCT endoluminal views.

The method uses registered video images and CT-based virtual endoscopic renderings of the airways. The visibility and depth data are also generated by the renderings. Uniform sampling and over-scanning of the visible triangles is done before they are packed into a texture space. The texels are then re-projected onto video images and assigned color values based on depth and illumination data obtained from renderings. The texture map is loaded into the rendering engine to get the real-time navigation through the combined 3D CT surface and bronchoscopic video data. Tests were performed on pre-recorded bronchoscopy patient video and associated 3D MDCT scans. Results show that we can effectively accomplish mapping over a continuous sequence of airway images spanning several generations of airways.

6141-02, Session 1

Dual modality virtual colonoscopy workstation: design, implementation, and preliminary evaluation

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The aim of this study is to develop a single virtual colonoscopy (VC) workstation that supports not only CT, but also MR imaging procedures. The workflow should be optimized and be able to take advantage of both image modalities. The technological break through is at the real time volume rendering of spatial-intensity-inhomogeneous image data. VC aims at visualizing CT or MR tomography 3D images for detection of colon polyp and lesions. It is also called as CT/MR colonography based on the imaging modality that is employed. The published results of large scale clinical trial demonstrated more than 90% of sensitivity on polyp detection for certain CT colonography (CTC) workstation. The drawback of the CT colonoscopy is the radiation exposure. MR colonography (MRC) is free from the X-ray radiation. It achieved 100% specificity for polyp detection in published trials. The better tissue contrast in MR image allows the accurate diagnosis of inflammatory bowel disease, which is usually impossible in CT image. At present, most of the VC workstations are designed for CT procedure. They are not able to display multi-sequence MR series concurrently in a single application. The automatic correlation between 2D and 3D view is not available due to the difficulty of 3D model building for MR images. This study aims at enhancing a commercial VC product that was successfully used for CT procedure to equally support dark-lumen protocol MR procedure also.

6141-03, Session 1

Development of a navigation system for endoluminal brachytherapy in human lungs

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The endoluminal brachytherapy of peripherally located bronchial carcinoma is difficult because of the complexity to position an irradiation catheter led by a bronchoscope to a desired spot inside a human lung. Furthermore the size of the bronchoscope permits only rarely the insertion of a catheter into the fine segment bronchi. We are developing an image-guided navigation system which indicates a path for guidance to the desired bronchus. Thereby a thin catheter with an enclosed navigation probe can be led up directly to the target bronchus either by the use of the video of the bronchoscope or by the use of virtual bronchoscopy. Because of the thin bronchi and their moving soft tissue the navigation system has to be very precise. This accuracy is reached by a gradually registering navigation component which improves the accuracy in the course of the intervention through mapping the already covered path to the preoperatively generated graph based bronchial tree description. The system includes components for navigation, segmentation, preoperative planning, and intraoperative guidance. Furthermore the visualization of the path can be adapted to the specialist's habits (video of bronchoscope, 2D, 3D, virtual bronchoscopy etc.).

6141-04, Session 1

Augmented reality visualization for thoracoscopic spine surgery

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We are developing an augmented reality (AR) image guidance system in which information derived from medical images is overlaid onto a video view of the patient. The centerpiece of the system is a head-mounted display custom fitted with two miniature color video cameras that capture the stereo view of the scene. Medical graphics is overlaid onto the video view and appears firmly anchored in the scene, without perceivable time lag or jitter. We have been testing the system for different clinical applications. In this paper we discuss minimally invasive thoracoscopic spine surgery as a promising new orthopedic application. In the standard approach, the thoracoscope - a rigid endoscope - provides visual feedback for the minimally invasive procedure of removing a damaged disc and fusing the two neighboring vertebrae. The navigation challenges are twofold. From a global perspective, the correct vertebrae on the spine have to be located with the inserted instruments. From a local perspective, the actual spine procedure has to be performed precisely. Visual feedback from the thoracoscope provides only limited support for both of these tasks. In the augmented reality approach, we give the surgeon additional anatomical context for the navigation. Before the surgery, we derive a model of the patient's anatomy from a CT scan, and during surgery we track the location of the surgical instruments in relation to patient and model. With this information, we can help the surgeon in both the global and local navigation, providing a global map and 3D information beyond the local 2D view of the thoracoscope. Augmented reality visualization is a particularly intuitive method of displaying this information to the surgeon. To adapt our augmented reality system to this application, we had to add an external optical tracking system, which works now in combination with our head-mounted tracking camera. The surgeon's feedback to the initial phantom experiments is very positive, and we are now working in a joint team to get the system ready for clinical trials.

6141-05, Session 1

Simulation of guide-wire navigation in complex vascular structures

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The course and the success of an endovascular intervention can be influenced by the choice of the guide wire and primary by its ability to access to the lesion. The simulation of catheterism in complex vasculature is of main interest to aid the surgery planning. The overall objective of the simulation is to improve the choice of guide wire (with the simulation of its intrinsic features: torque, shape, rigidity, elasticity) as well as its navigation within patient specific vasculature. We propose a new approach for the simulation of guide wire navigation. It is based on: (i) the modeling of guide wire using "multi-body" approach and the representation of its internal characteristics, (ii) the modeling of artery as a surface mesh, (iii) the simulation of the interactions of the guide wire with its environment (artery and clinician). In this study, strength and elasticity of the guide wire are modeled. Only the "push" action performed by the clinician is considered. The global behavior of the guide wire is simulated by means of retraction and relaxation processes. Methods based on the graphics hardware have been developed (i) to detect the collisions between the guide wire and the artery walls (ii) to find the retraction direction which defines the local reaction of the guide wire. All these methods have been tested qualitatively on different patient vasculatures.

6141-06, Session 2

A novel visualization method for the ribs within chest volume data

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The ribs within computed tomography (CT) images form curved structures intersecting the axial plane at several oblique angles. Rib metastases and other pathologies of the rib are apparent in CT images. Analysis of the ribs using conventional 2D axial slice viewing involves manually tracking them through multiple slices. 3D visualization of the rib also has drawback due to occlusion. Examination of a single rib may require repositioning the viewpoint several times in order to avoid other ribs. We propose a novel visualization method that eliminates rib curvatures by straightening each rib along its centerline. This reduces both 2D and 3D viewing complexities. Our method is based upon first segmenting and extracting the centerlines of each rib. These steps are done through tracing based segmentation. Next, the centerlines are refined to a smoother contour. Each centerline is then used to resample and digitally straighten each rib. The result is a simplified volume containing only the straightened ribs, which can be quickly examined both in 3D and by scrolling through a series of about 40 slices. Additionally, a projection of the image can yield a single 2D image for examination. The method was tested on chest CT images obtained from patients both positive and negative for rib metastases. Preliminary results demonstrate the effectiveness of the visualization in detecting and delineating these metastases.

6141-07, Session 2

Visualizing the beating heart: interactive direct volume rendering of high-resolution CT time series using standard PC hardware

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Modern multi-slice CT (MSCT) scanners allow acquisitions of 3D data sets covering the complete heart at different phases of the cardiac cycle. This enables the physician to non-invasively study the dynamic behavior of the heart, such as wall motion artifacts. To this end an interactive 4D visualization of the heart in motion is desirable. However, the application of well-known volume rendering algorithms enforces considerable sacrifices in terms of image quality to ensure interactive frame rates. On one hand this is due to the amount of volume data to be processed, which goes well beyond the onboard memory provided by standard PC/workstation graphics hardware. On the other hand, achievable frame rates of most direct volume rendering algorithms are still very low for moderate volume sizes as they are limited by both computations and memory bandwidth.

In this paper we present a GPU-based shaded direct volume rendering algorithm that allows the interactive high-quality visualization of large medical time series data sets. In contrast to other work, our algorithm exploits the complete memory hierarchy for high cache and bandwidth efficiency. Additionally, several data-dependent techniques are employed to reduce the amount of volume data to be transferred and rendered. None of the proposed techniques sacrifices image quality in order to improve speed. By applying the method to a multi phase MSCT cardiac data set we show that we can achieve interactive frame rates on currently available standard PC hardware.

6141-08, Session 2

Fast maximum intensity projection with 3D nonlinear wavelets

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Despite the increasing interest in three-dimensional (3D) visualization, rendering algorithms still suffer from high numerical complexity and large memory requirements. With the continuously increasing volume of medial imaging data, fast visualization algorithms become crucial. Powerful mathematical techniques based on the wavelet transform promise to provide efficient multi-resolution visualization algorithms, optimizing hence 3D rendering.

Maximum Intensity Projection (MIP) is a 3D rendering algorithm that is used to visualize high-intensity structures within volumetric data. At each pixel the highest data value, which is encountered along a corresponding viewing ray, is depicted. In this paper, we propose a fast MIP 3D rendering that is based on a new hierarchical data representation. The proposed approach uses on a new morphological wavelet decomposition that allows for fast initial rendering and progressive subsequent refinements.

Our method includes a pre-processing step that is based on a non-linear wavelet representation in order to achieve efficient data compression and storage. It results in a very fast visualization algorithm. The rendering speed-up results from removing cells that do not contribute to any MIP projection and from an innovative storage scheme of the volume cells. The proposed algorithm gives very promising results. Very good MIP projections can be obtained with less than 20% of the volumetric data can be obtained. This makes our algorithm very competitive with the best MIP methods proposed so far in the literature.

6141-09, Session 2

Representation and visualization of variability in a 3D anatomical atlas using the kidney as an example

S. B. Hacker, H. Handels, Univ. Medical Ctr. Hamburg-Eppendorf (Germany)

Computer-based 3D atlases allow an interactive exploration of the human body. However, in most cases such 3D atlases are derived from one single individual, and therefore do not regard the variability of anatomical structures concerning their shape and size. Since the geometric variability across humans plays an important role in many medical applications, our goal is to develop a framework of an anatomical atlas for representation and visualization of the variability of selected anatomical structures. The basis of the presented project is the VOXEL-MAN atlas of the inner organs that was created from the Visible Human data set. For modelling anatomic shapes and their variability we utilize "m-reps" which allow a compact representation of anatomical objects on the basis of their skeletons. As an example we used a statistical model of the kidney that is based on 48 different variants. With the integration of a shape description

into the VOXEL-MAN atlas it is now possible to query and visualize different shape variations of an organ, e.g. by specifying a person's age or gender. In addition to the representation of individual shape variants, the average shape of a population can be displayed. Besides a surface representation, a volume based representation of the kidney's shape variants is also possible. It results from the deformation of the reference kidney of the volume based model according to the m-rep shape description. In this way a realistic visualization of the shape variants is made possible, as well as the visualization of the organ's internal structures.

6141-10, Session 2

Visualization of tumor-influenced 3D lung dynamics

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A framework for real-time visualization of a patient-specific tumor-influenced morphological lung dynamics is presented in this paper. This framework potentially allows clinical technicians to simulate the morphological changes of lung tissue under different breathing conditions. Consequently, this technique may provide a sensitive and accurate assessment tool for pre-operative and intra-operative clinical guidance. The proposed simulation method extends work previously developed for modeling and visualizing normal 3D lung dynamics. The model accounts for the local changes in lung elasticity (i.e. deformation) and the global motor response due to the presence of a tumor by utilizing properties of Green's functions. As a mathematical approach, the Green's function is a physically based approach that allows for higher level-of-detail modeling of the lung deformations by decreasing the computation processing time. This property allows an analytical estimation of the patient-specific tissue elastic parameters from the 4D lung phantoms at different level-of-detail of the lung model. The estimation of tissue elasticity can be validated by re-simulating the deformation and verifying its accuracy. Once estimated, the tissue elastic properties facilitates the simulation of tumor-influenced lung deformations subjected to any breathing condition modeled by a parametric Pressure-Volume (PV) relation. This PV relation is a second-order differential equation and accounts for the global muscle resistance influenced by the diaphragm and the ribcage, and the control of breathing caused by the motor drive. Thus the framework allows the clinical technicians to simulate and predict the effects of anatomical and behavioral changes in the lung dynamics thereby enabling better treatment procedures

6141-11, Session 2

Surface reconstruction from orthogonal contours

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Contouring of structures in medical images is often used for volume measurement. Contouring is usually performed using a single cross-sectional orientation. A potentially more efficient and accurate approach is to use two or more sets of orthogonal contours. In this case, a computational algorithm is needed for reconstructing the surface from the sets of orthogonal contours.

The following new method to reconstruct surface from two or more sets of orthogonal contours was developed.

The intersections of the orthogonal contours are detected and the contours are transformed into a set of polygons that cover the surface. The polygons are then triangulated in a combinatorical manner based on a minimum-area criterion with a constraint on inter-triangle bending. The set of possible triangulations for each polygon is determined using a look-up table. Volumes are then determined using the Green's theorem algorithm. Excellent results have been obtained for surface reconstruction of abdominal aortic aneurysms (AAA) from computed tomographic angiography (CTA). Surface reconstruction was applied in eight cases based on eight longitudinal and eight axial contours. All surfaces had a smooth and realistic appearance. Volumes measured using orthogonal contouring were highly consistent with clinical measurements of volume (R = 0.9938).

6141-12, Session 3

Robust surface registration using salient anatomical features in image-guided liver surgery

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A successful surface based image-to-physical space registration in image-guided liver surgery (IGLS) is critical to provide reliable guidance information and pertinent surface displacement data for use in deformation correction algorithms. The current protocol used to perform the image-to-physical space registration involves an initial pose estimation provided by a point based registration of anatomical landmarks identifiable in both the preoperative tomograms and the intra-operative presentation. The surface based registration is then performed via a traditional iterative closest point algorithm between the preoperative liver surface, segmented from the tomographic image set, and an intra-operatively acquired point cloud of the liver surface provided by a laser range scanner. Using the aforementioned method, the registration accuracy in IGLS can be compromised by poor initial pose estimation as well as tissue deformation due to the liver mobilization and packing procedure performed prior to tumor resection. In order to increase the robustness of the current surface-based registration method used in IGLS, we propose the incorporation of salient anatomical features, identifiable in both the preoperative image sets and intra-operative liver surface data, to aid in the initial pose estimation and to play a more significant role in the surface based registration via a novel weighting scheme. The proposed surface registration method will be compared with the traditional technique using both phantom and clinically acquired data. Additionally, robustness studies will be performed to demonstrate the ability of the proposed method to converge to reasonable solutions even under conditions of large deformation and poor initial alignment.

6141-13, Session 3

A realistic simulation framework for assessing deformable slice-to-volume (CT-fluoroscopy/CT) registration

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Lung cancer screening for early diagnosis is increasing in popularity. One screening method is to test tissue samples obtained from CT fluoroscopy (CTF) guided lung biopsy. CTF provides real time 3D feedback to the physician; however the view is limited to a single slice. Mentally reconstructing the direction of the needle when it is not in the imaging plane is a difficult task. We are currently developing 3D visualization software that will augment the physician's ability to perform this task. At the beginning of the procedure a CT scan is acquired at breath-hold. The physician then specifies an entry point and a target point on the CT. As the procedure advances, the physician acquires a CTF image, at breath-hold; the system then registers the current setup to the CT scan, enabling comparison between the plan and current situation. As the CT and CTF data are acquired at different breath-holds we need to deformably register them. To assess the performance of different registration algorithms for CTF/CT registration we propose to use a simulation framework. We simulate CTF images based on a single CT data set acquired at end expiration and positional information of implanted electromagnetically tracked fiducials, acquired throughout the respiratory cycle. This allows us to assess the performance of registration algorithms using CTF images that correspond

to different breath-holds. Finally, we evaluated Thirion's "demons" algorithm, as implemented in ITK, for the task of slice-to-volume registration. In all our experiments the registration failed, in the majority of cases the recovered displacements were less than 50% of the original ones.

6141-14, Session 3

Shape-based segmentation and visualization technique for evaluation of atherosclerotic plaque in coronary artery disease (CAD)

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The main goal of future developments in the field of diagnosis for cardiovascular disease is the reliable and non invasive detection of coronary artery disease (CAD). New generations of fast spiral CT using multislice techniques (MSCT) can show high-grade stenoses and also total occlusion with a spatial resolution comparable with more invasive techniques such as intravascular ultrasound (IVUS). Additionally to the visualization and measurement of high grade stenoses, the composition of the plaque tissue is an important factor for risk stratification and treatment decision. The risk of plaque rupture depends on plaque composition and the volumes of the different plaque compartments.

We present a novel, semiautomatic technique which allows for segmentation, visualization and evaluation of atherosclerotic plaque tissue in the coronary arteries. Our method uses a general tubular plaque model which needs only the location of the stenotic area inside the vessel and two healthy reference segments as input data. The system calculates automatically the centerline of the vessel and the contour of the contrast enhanced lumen. This information is used to initialize the tubular model, fit the model to the patient specific data and perform the rasterization of the volumetric data. At each step the user can interact with the data, especially the correct definition of the different plaque ranges (calcified, fatty, and fibrous) is up to the user. The system calculates all relevant parameter, such as: volume, mean density and relative percentage of all identified plaque compartments.

6141-15, Session 3

Image segmentation and registration for the analysis of joint motion from 3D MRI

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We report an image segmentation and registration method for studying joint morphology and kinematics from in vivo MRI scans and its application to the ankle joint motion. Using an MR-compatible loading device, a foot was scanned in a single neutral and seven dynamic positions including maximal flexion, rotation and inversion/eversion. A segmentation method combining graph cuts and level sets was developed which allows a user to interactively delineate 14 bones in the neutral position volume in less than 30 minutes total, including 10 minutes of user interaction. In the subsequent registration step, a separate rigid body transformation for each bone is obtained by registering the neutral position to each of the dynamic ones, which produced an accurate description of the motion between them. We have processed six datasets, including 3 normal and 3 pathological feet. For validation our results were compared with those obtained from 3DViewNix, a semi-automatic segmentation program, and achieved good agreement in volume overlap ratios (mean: 91.57%, standard deviation: 3.58%) for all bones. Our tool requires only 1/50 and 1/150 of the user interaction time required by 3DViewNix and NIH Image Plus, respectively, an improvement that has the potential to make joint motion analysis from MRI practical in research and clinical applications. We expect to process 30 feet by the time of SPIE 2006, and more results will be presented then.

6141-16, Session 3

Fast volume driven DRR rendering for 2D/3D registration

W. Birkfellner, R. Seemann, M. Figl, X. Yang, H. Bergmann, Medizinische Univ. Wien (Austria)

We present a simple and rapid method for generation of perspective digitally rendered radiographs (DRR) for 2D/3D registration based on splat rendering. Suppression of discretization artefacts by means of computation of Gaussian footprints - which is a considerable computational burden in classical splat rendering - is replaced by stochastic motion of either the voxels in the volume to be rendered, or by simulation of a X-ray tube focal spot of finite size. The result is a simple and fast perspective rendering algorithm using only a small subset of voxels. Our method generates slightly blurred DRRs suitable for registration purposes at framerates of approximately 10 Hz when rendering volume images with a size of 30 MB on a standard PC.

6141-17, Session 4

Accuracy protocols to access the influence of metallic objects on the performance of an electromagnetic tracking system

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Magnetic tracking systems are considered as an enabling technology for many image guided medical interventions, since they are not limited by line-of-sight requirements. The main draw back of those systems is their susceptibility to the presence of electrically conducting (mostly metallic) and ferromagnetic objects. Most research efforts in the past years were targeted at improving the robustness of electromagnetic tracking systems under the presence of distorting objects. Although impressive progress was achieved, current commercially available system are still affected by the presence of metallic objects, but to a much lesser extent than a few years ago.

Therefore it is important for an objective evaluation of a tracking system to develop protocols, which allow to access the magnitude of the distortion. At the same time the protocols should be also application relevant. The variety of distorting objects is huge and at the same time the main area of interest of this paper are medical tracking applications. Therefore protocols and distorting objects used in that paper focus on medical applications only.

Two protocols are discussed. One protocol accesses the influence of large metallic sheets in the environment of the tracking systems. This allows conclusions regarding the distortion of operating room tables instrument trays etc. The other protocol concentrates on distortions, which are caused by medical or surgical tools which can be found inside the operating volume of the tracking systems. As distorting objects rods of aprox. 150 mm length are used.

All used metals and alloys are representative for the operating room equipment or medical tools and instruments. The geometric shapes, dimensions and material specifications are given for all tested objects in order to allow to repeat those protocols.

The obtained results will guide users of electromagnetic tracking systems to optimize the setup of their systems to minimize possible distortions and to select favorable materials to design medical instruments and equipment used in conjunction with tracking systems.

6141-18, Session 4

Method for estimating dynamic EM tracking accuracy of surgical navigation tools

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Optical Tracking systems have been used for several years in Image Guided

medical procedures. Vendors often state static accuracies of a single retro-reflective sphere or LED. Expensive CMMs are used to validate the positional accuracy over the specified working volume. Users are interested in the dynamic accuracy of their tools. The configuration of individual sensors into a unique tool, the calibration of the tool tip, and the motion of the tool add additional errors.

Electro Magnetic (EM) tracking systems are considered an enabling technology for many image-guided procedures because they are not limited by line-of-sight restrictions and take minimum space in the Operating Room.

It is often difficult to quantify the accuracy of EM trackers because they can be affected by distortion from certain metal objects. Many high accuracy devices that would be used to validate the EM accuracy actually affect the measurements being taken. EM Tracker accuracy tends to vary over the working volume and orientation of the receiver.

We present a simple method for estimating the dynamic accuracy of EM tracked tools. We discuss the accuracy of the EM Tracker used in the GEHC family of surgical navigation systems. Results for other tracking technologies are included.

6141-19, Session 4

Fluoroscopy based accuracy assessment of electromagnetic tracking

Z. R. Yaniv, K. R. Cleary, Georgetown Univ.

Tracking organ motion due to respiration is important to enable precise interventions in the regions of the abdomen and thorax. Respiratory induced motion in these regions may limit the accuracy of interventions which do not employ some type of tracking. Existing methods use predictive models based on external tracking that is correlated to internal motion. This approach highly depends on the accuracy of the model used for correlating the two motions. Ideally, one would track the internal motion directly. We are investigating the use of electromagnetically tracked fiducials to enable real time tracking of internal organ motion. To validate the in-vivo accuracy of this approach we propose to use stereo-fluoroscopy. In this paper we show that stereo-fluoroscopy is accurate enough to serve as a validation method, displaying sub-millimetric accuracy (maximal error of 0.66mm). We study the effect of the bi-plane fluoroscopes on the electro-magnetic systems' accuracy, and show that placing the bi-plane fluoroscopes in a valid intra operative setup has a negligible effect on the tracking accuracy (maximal error of 1.4mm). Finally, we compare the results of stereo-fluoroscopy tracking and electromagnetic tracking of needles in an animal study, showing a mean (std) difference of 1.4 (1.5)mm between modalities. These results show that stereo-fluoroscopy can be used in conjunction with electro-magnetic tracking with minimal effect, and that the electromagnetic system is accurate enough for motion tracking of internal organs.

6141-20, Session 4

A system for rapid prototyping of hearts with congenital malformations based on the medical imaging interaction toolkit (MITK)

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Precise knowledge of the individual cardiac anatomy is essential for diagnosis and treatment of congenital heart disease. Complex malformations of the heart can best be comprehended not from images but from anatomic specimens. Physical models can be created from data using rapid prototyping techniques, e.g., lasersintering or 3D-printing. We have developed a system for obtaining data that show the relevant cardiac anatomy from high-resolution CT/MR images and are suitable for rapid prototyping. The challenge is to preserve all relevant details unaltered in the produced models.

The main anatomical structures of interest are the four heart cavities (atria, ventricle), the valves and the septum separating the cavities, and the great vessels. These can be shown either by reproducing the morphology itself or by producing a model of the blood-pool, thus creating a negative of the morphology. Algorithmically the key issue is segmentation. Practically, possibilities allowing the cardiologist or cardiac surgeon to interactively check and correct the segmentation are even more important due to the complex, irregular anatomy and imaging artefacts.

The paper presents the algorithmic and interactive processing steps implemented in the system, which is based on the open-source Medical Imaging Interaction Toolkit (MITK, www.mitk.org). It is shown how the principles used in MITK enable to assemble the system from modules (functionalities) developed independently from each other. The system allows to produce heart (and other anatomic) models of individual patients as well as to reproduce unique specimens from pathology collections for teaching purposes.

6141-21, Session 4

Comprehensive, powerful, efficient, intuitive: a new framework for clinical imaging applications

K. E. Augustine, D. R. Holmes III, D. P. Hanson, R. A. Robb, Mayo Clinic

One of the greatest challenges for a software engineer is to create a complex application that is comprehensive enough to be useful to a diverse set of users, yet focused enough for individual tasks to be carried out efficiently with minimal training. This "powerful yet simple" paradox is particularly prevalent in advanced medical imaging applications. Recent research in the Biomedical Imaging Resource (BIR) at Mayo Clinic has been directed toward development of an imaging application framework that provides powerful image visualization/analysis tools in an intuitive, easy-to-use interface. It is based on two concepts very familiar to physicians - Cases and Workflows. Each case is associated with a unique patient and a specific set of routine clinical tasks, or a workflow. Each workflow is comprised of an ordered set of general-purpose modules which can be re-used for each unique workflow. Clinicians help describe and design the workflows, and then are provided with an intuitive interface to both patient data and analysis tools. Since most of the individual steps are common to many different workflows, the use of general-purpose modules reduces development time and results in applications that are consistent, stable, and robust. While the development of individual modules may reflect years of research by imaging scientists, new customized workflows based on the new modules can be developed extremely fast. If a powerful, comprehensive application is difficult to learn and complicated to use, it will be unacceptable to most clinicians. Clinical image analysis tools must be intuitive and effective or they simply will not be used.

6141-22, Session 4

Creation of 4D imaging data using open source image registration software

K. H. Wong, Georgetown Univ.; L. Ibanez, Kitware Inc.; T. R. Popa, K. R. Cleary, Georgetown Univ.

4D images using CT or MRI will play a key role in radiation medicine as techniques for respiratory motion compensation become widely available. Knowledge of the motion of a tumor and surrounding anatomy will allow the creation of highly conformal dose distributions in organs such as the lung, liver, and pancreas. We propose a new method for 4D image acquisition that does not require any gating equipment and is based solely on open source image registration algorithms. Specifically, we use the Insight Toolkit (ITK) to compute the normalized mutual information (NMI) between images taken at different times and use that value as an index of respiratory phase. This method has the advantages of (1) being able to be implemented without any hardware modification to the scanner, and (2) basing the respiratory phase on changes in internal anatomy rather than external signal. We have demonstrated the capabilities of this method

with CT fluoroscopy data acquired from a swine model, and are now in the process of applying it to cross-sectional imaging data from human volunteers.

6141-23, Session 5

Percutaneous scaphoid pinning using ultrasound guidance

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We propose a novel surgical procedure for percutaneous pinning of fractured scaphoids. The procedure involves pre-operative planning of the screw position using a three-dimensional surface model of the scaphoid obtained from computed tomography images. Intra-operatively, the surface model is registered to ultrasound images captured by a transducer which is tracked by an optical camera. The screw drill used to insert the screw is also tracked by the camera. A novel graphical user interface that communicates with the optical camera, displays the surface model together with the planned screw position and the screw drill in real-time and guides the surgeon during screw insertion.

Laboratory tests on human scaphoid phantoms were performed to investigate the feasibility of the surgical procedure. The mean registration error (four landmarks for each phantom) was 2.5 mm (std: 1.1 mm, n = 12). The mean distance between the entry point of the planned and the actually realized screw position was 1.8 mm (std: 0.63 mm, n = 17). For the exit point the mean was 2.3 mm (std: 0.87 mm, n = 16). The mean of the angular error was 5.11° (std: 2.26°, n = 16).

The results show that the desired surgical accuracy (~2 mm) can be achieved with the proposed procedure. The advantages of the procedure are a reduced risk of infections and minimal soft tissue damage due to its percutaneous nature, and a reduction of ionizing radiation due to the employment of ultrasound imaging instead of fluoroscopy. Animal experiments are underway to investigate the influence of soft tissues.

6141-24, Session 5

A hybrid deformable model for virtual reality simulation of prostate brachytherapy

D. I. Levin, The Univ. of Western Ontario (Canada); A. Fenster, Robarts Research Institute (Canada); H. M. Ladak, The Univ. of Western Ontario (Canada)

Ultrasound (US) guided prostate brachytherapy is a minimally invasive form of cancer treatment during which a needle is used to insert radioactive seeds into the prostate at pre-planned positions. Interaction with the needle can cause the prostate to deform and this can lead to inaccuracy in seed placement. Virtual reality (VR) simulation could provide a way for surgical residents to practice compensating for these deformations. To facilitate such a tool, we have developed a hybrid deformable model that combines ChainMail distance constraints with Mass-Spring physics to provide realistic, yet customizable deformations. Displacements generated by the model were used to warp a baseline US image to simulate an acquired US sequence. The algorithm was evaluated using a gelatin phantom with a Young's modulus approximately equal to that of the prostate (60 kPa). A 2D US movie was acquired while the phantom underwent needle insertion and inter-frame displacements were calculated using normalized cross correlation. The hybrid model was used to simulate the same needle insertion and the two sets of displacements were compared on a frame-by-frame basis. The average per-pixel displacement error was 0.285 mm. A simulation rate of 100 frames per second was achieved using a 1000 element triangular mesh while warping a 300x400 pixel US image on an AMD Athlon 1.4 Ghz computer with 1 Gb of RAM and an ATI Radeon 9800 Pro graphics card. These results show that this new deformable model can provide an accurate solution to the problem of simulating real-time prostate brachytherapy.

6141-25, Session 5

A comparison study assessing the feasibility of ultrasound-initialized deformable bone models

H. Talib, K. T. Rajamani, J. Kowal, Univ. Bern (Switzerland); M. A. Styner, Univ. of North Carolina/Chapel Hill; M. A. Gonzalez Ballester, Univ. Bern (Switzerland)

This paper presents a feasibility and evaluation study for using 2D ultrasound in conjunction with our statistical deformable bone model in the scope of computer-assisted surgery (CAS). The final aim is to provide the surgeon with an enhanced 3D visualization for surgical navigation in orthopaedic surgery without the need for pre-operative CT or MRI scans. We unified our earlier work to combine several automatic methods for statistical bone shape prediction from a sparse set of surface points, and ultrasound segmentation and calibration to provide the intended rapid and accurate visualization. We compared the use of a tracked digitizing pointer to ultrasound to acquire landmarks and bone surface points for the estimation of two cast proximal femurs, where two users performed the experiments 5-6 times per scenario. The concept of CT-based error introduced in the paper is used to give an approximate quantitative value to the best hoped-for prediction error, or lower bound error, for a given anatomy. The conclusions of this work were that the pointer-based approach produced good results, and although the ultrasound-based approach performed considerably worse on average, there were several cases where the results were comparable to the pointer-based approach. It was determined that the primary factor for poor ultrasound performance was the inaccurate localization of the three initial landmarks, which are used for the statistical shape model.

6141-26, Session 5

3D segmentation of kidney tumors from freehand 2D ultrasound

A. Ahmad, Robarts Research Institute (Canada); T. M. Peters, Robarts Research Institute (Canada) and The Univ. of Western Ontario (Canada)

In order to completely remove a tumor from a diseased kidney, while minimizing the resection of healthy tissue, the surgeon must be able to accurately determine the location, size and shape of the tumor. Currently, the surgeon mentally estimates these parameters by examining pre-operative Computed Tomography (CT) images of the patient's anatomy. However, these images do not reflect the state of the abdomen during surgery. Furthermore, these images can be difficult to place in proper clinical context. We propose using Ultrasound (US), which is a fast, inexpensive imaging modality that can acquire real time images of the tumor and the surrounding tissues, then segmenting these US images in order to present the tumor as a three dimensional (3D) surface. Given the common use of laparoscopic procedures that inhibit the range of motion of the operator, we propose segmenting arbitrarily placed and oriented US slices individually using a tracked US probe. Given the known location and orientation of the US probe, we can assign 3D coordinates to the segmented slices and use them as input to a 3D surface reconstruction algorithm.

We have validated this approach on a virtual phantom of a sphere, 30 mm in diameter. 10 slices of the virtual phantom were generated using the Field II Ultrasound simulation program with 0.15 mm pixels. Using this approach we were able to rapidly (< 40 s) segment the images and found the average surface error to be 0.903 ± 0.489 mm.

6141-27, Session 5

3D ultrasound image guidance system used in RF uterine adenoma and uterine bleeding ablation system

M. Ding, X. Luo, C. Cai, C. Zhou, Huazhong Univ. of Science and Technology (China); A. Fenster, Robarts Research Institute (Canada)

Uterine adenoma and uterine bleeding are two of the most prevalent diseases in pregnant women in China. Many patients suffer these diseases in their life and some eventually lose their fertility. It is important to develop an appropriate and efficient surgical procedure to cure these diseases. In recent years, a minimally invasive ablation system using RF button electrode has been developed using the high temperature produced by the RF electrode to destroy tumor cells and stop uterine bleeding.

The current RF ablation system used in Chinese hospitals is guided by 2D ultrasound (US) imaging. The physician operates the RF electrode and the US probe with both hands, and the captured 2D US images are used to guide the insertion of the electrode. Because the electrode is needle-like, the physician can only observe the whole electrode if it is completely located in the US probe plane. The 2D US guidance is difficult to localize the electrode tip and often causes accidents, even death of the patient. In this paper, a 3D US guidance system is developed. First, a 3D US imaging system using rotational scanning of the abdominal probe is set up. A real-time 3D needle segmentation algorithm is used to find the electrode. Finally, the tip of electrode is determined along the segmented 3D needle and the whole electrode is displayed. Our preliminary experiment with bean phantom showed that a 600 by 512 by 512 image was reconstructed in 8s and a pin was displayed clearly.

6141-28, Session 6

Visualization and image-guided procedures in medicine: a retrospective and prospective view

R. A. Robb, Mayo Clinic

No abstract available.

6141-29, Session 6

Temporal response measurements of medical liquid crystal displays

H. Liang, A. Badano, U.S. Food and Drug Administration

Liquid crystal displays (LCDs) are fast gaining ground over the cathode ray tube (CRT) displays in the medical display market. High performing LCDs are considered to have comparable or better performance than CRTs in displaying static images. However, LCDs are inferior to CRTs in displaying moving scenes due to their slow response. The response time provided by display manufacturers is typically measured while switching the LCD from black to white and white to black. This is usually not the longest response time. In reality, the transition time between different gray scales can be many times longer. In this paper we report preliminary work on measuring the gray level response time of LCDs and simulating luminance errors caused by slow transition between some gray levels.

We first characterized the measuring system using a fast light-emitting diode (LED) to explore the accuracy and noise-filtering capability of the system. A 256x256 matrix of response time between different gray levels was then measured. Nearly half of the gray level transitions are much longer than the frame time (16.67~ms) of LCD displays. The longest response time was above 100~ms. When driving a display between these gray levels, the targeted gray level can't be achieved until many frame times. To understand how the slow response may affect the display's ability to render the desired image values, we calculated the achieved luminance based on the measured matrix. The results simulate the visual effect of displaying a moving object on the LCD monitors, and providing a reference for determining LCD performance.

6141-30, Session 6

Performance evaluation of a commercial system for quantitative measurement of display resolution and noise

E. W. Cleland, Smith College; E. Samei, Duke Univ.

Two key metrics that carry information about image quality of medical displays are resolution and noise. In the past, quantitative assessment of these properties has been done through laboratory measurements. For the first time, a device consisting of a CCD camera and analysis software has been made commercially available for measuring the resolution and noise of medical displays in a clinical setting. This study aims to evaluate this new product in terms of accuracy and precision. In particular, attention was paid to determine whether the device is appropriate for clinical use. This work involved the measurement of the Modulation Transfer Function (MTF) and the Signal to Noise Ratio (SNR) of two medical image displays, one Cathode Ray Tube (CRT) and one Liquid Crystal Display (LCD) using the software/camera system. To check for accuracy, the results were compared with published values of the MTF and NPS for the same displays. To assess the system's precision, measurements were made multiple times at the same setting. The performance of the system was also ascertained as a function of the focus setting of the camera. The results indicate that when the camera is focused within ± 0.64 mm of the optimum focus setting, the MTF value lies within 13.7 % of the best focus MTF at the Nyquist frequency and 11.92% in terms of total unsharpness. The device presents MTF figures with reasonable accuracy in the 10% to 20% range.

This work was supported in part by the NIH (R21CA095308) and by the Smith College Praxis Program.

6141-31, Session 6

Optimizing the image contrast on the softcopy liquid-crystal displays using error diffusion

J. Fan, H. Roehrig, M. K. Sundareshan, E. A. Krupinski, The Univ. of Arizona

Active-Matrix Liquid Crystal Displays (AM-LCD) are replacing the Cathode Ray Tube (CRT) as the dominant softcopy display in the radiology reading rooms. Results of some studies seem to confirm the superiority of LCDs. But they are still far from ideal. Like CRTs, LCDs generally possess a limited contrast resolution. On the other hand, they exhibit higher spatial noise than CRTs. During last year's meeting, we reported an error-diffusion-based method to tackle these two problems together. Only display properties were under consideration then. In this paper, we propose to include the image content into the error diffusion kernel to further increase the contrast of the image displayed on the LCD. First, the raw image will be filtered to get the information of the local derivatives, which will be used as the basis to determine the amount of the contrast enhancement. The areas in the image which have low contrast will be enhanced more than the areas with high contrast. Image noise will not be enhanced. The enhancement operation will modify the image and the changes will be treated as error and fed back to the error diffusion kernel. Note we will use a different set of diffusion weights for image contrast enhancement. But the two diffusion operations are done together. It is intended that the proposed display-based processing can not only produce a clinical image on an LCD with high fidelity, but also result in a physical image that has a good quality psychologically.

6141-32, Session 7

Image stabilisation of the beating heart by local linear interpolation

M. Groeger, G. Hirzinger, DLR (Germany)

The stabilisation of motion on the beating heart is investigated in the context of minimally invasive robotic surgery. Although reduced by mechanical stabilisers, residual tissue motion makes safe surgery still difficult and

time consuming. Compensation for this movement is therefore highly desirable. Motion can be captured by tracking natural landmarks on the heart surface viewed by a video endoscope.

Stabilisation is achieved by transforming the images using a motion field calculated from captured local motion.

Since the surface of the beating heart is distorted nonlinearly, compensating the occurring motion with a constant image correction factor is not sufficient. Therefore, heart motion is captured by several landmarks, the motion between which is interpolated such that locally appropriate motion correction values are obtained. To estimate the motion between the landmark positions, a triangulation is built and motion information in each triangle is approximated by linear interpolation. Results of motion compensation are evaluated by calculating the optical flow remaining in the stabilised images. The proposed linear interpolation model is able to reduce motion significantly and can also be implemented efficiently to stabilise images of the beating heart in realtime.

6141-33, Session 7

Exponential elastic model and its application in real-time simulation

H. Zhong, T. M. Peters, Robarts Research Institute (Canada)

In building a real-time realistic surgery simulator, material models and their computation methods are two fundamental components, and their accuracy reflected in visual and haptic feedbacks directly relates to the effect of surgery trainings, as well as its other applications. In this paper we employ an exponential elastic model to characterize the mechanical properties of pig liver at large strain (30%), and with a least-squares approach we obtain its two parameters Cs=0.678(Kpa), b=3.54 based on uniaxial test results.

With these parameters, the stress curves computed from a theoretical model are compared with the experimental data with a mean deviation of 4.8%, which demonstrates how accurate an exponential model can fit the experimental curves of pig liver. To validate that the calibration method works for the exponential model, we compare the results from the theoretical formula and those from a FEM computational model built in ABAQUS and their mean deviation is less than 0.9% (due to the truncation errors in the translation between Cauchy stress in ABAQUS and nominal stress used in experiments). Furthermore we compare this model under small strains with other linear or nonlinear material models and calculate a derived Young's modulus E=14.4Kpa which is comparable to results published in literature for pig liver.

This calibrated exponential model is then incorporated into our nonlinear finite element framework and through an interpolation approach, we simulated an interventional behavior on liver with the real-time speed.

6141-34, Session 7

Pre-operative simulation and post-operative validation of soft-tissue deformations for breast implantation planning

L. Roose, Katholieke Univ. Leuven (Belgium); W. De Maerteleire, 3D Medical BV (Netherlands); W. Mollemans, F. Maes, P. Suetens, Katholieke Univ. Leuven (Belgium)

Virtual surgery simulation plays an increasingly important role as a planning aid for the surgeon. A reliable simulation method to predict the surgical outcome of breast reconstruction and breast augmentation procedures does not yet exist, even though a method to pre-operatively assess the result of the procedure would be useful to ensure a symmetrical and naturally looking result, and could be a practical means of communication with the patient.

In this paper, we present a basic framework to simulate a subglandular breast implantation. Firstly, we propose a method to build a model of the patient's anatomy, based on a 3D picture of the skin surface in combination with thickness estimates of the soft tissue surrounding the breast. This approach is cheaper and faster than conventional methods based on CT or MR, and the image can be taken while the patient is standing upright. Secondly, a set of boundary conditions is defined to mimic the effect of the implant and the incision between muscle and breast tissue. Finally, we compute the new equilibrium geometry using the iterative FEM-based Mass Tensor Method, which is more computationally efficient than the traditional FEM approach when a limited amount of iterations is required for sufficient precision.

We illustrate our approach with a preliminary validation study on 4 patients, presenting promising results with a mean error between the simulated and the true post-operative breast geometry below 5 mm and maximal error below 10 mm, which was found to be useful for visual assessment in clinical practice.

6141-35, Session 7

Magnetic resonance elastography: an emerging imaging modality for visualizing the viscoelastic properties within soft tissues

M. M. Doyley, J. B. Weaver, F. E. Kennedy, Dartmouth Medical School and Dartmouth College; K. D. Paulsen, Dartmouth College

Magnetic resonance elastography (MRE) is an emerging imaging modality that derives intrinsic tissue mechanical property images from MR measured induced internal tissue displacements - images that are typically formed based on the premise that soft tissues exhibit linear isotropic elastic behavior. Although these assumptions are valid for some tissues, they may prove inappropriate for organs such as the breast that is known to exhibit significant viscoelastic tendencies. Consequently, we have developed a novel iterative inversion technique that computes the dominant mechanical parameters of a viscoelastic material (i.e. shear modulus, and the damping coefficient) from time-vary MR measured internal tissue displacements. Experiments were conducted on a breast cancer patient. The results revealed that taking proper account of viscoelastic effects in the breast provides diagnostically new information that could aid disease diagnosis. Therefore, it was concluded that the results were sufficiently encouraging to warrant in depth clinical evaluation.

6141-36, Session 7

An optimal three-stage method for anatomical shape reconstruction from sparse information using a dense surface point distribution model

G. Zheng, K. T. Rajamani, Univ. Bern (Switzerland)

Constructing anatomical shape from extremely sparse information is a challenging task. A priori information is often required to handle this otherwise ill-posed problem. In this paper, the problem is formulated as a three-stage optimal estimation process using an a priori dense surface point distribution model (DS-PDM). The dense surface point distribution model itself is constructed from an already-aligned training shape set using Loop subdivision. It provides a dense and smooth description of all a priori training shapes. Its application in anatomical shape reconstruction facilitates all three stages as follows. The first stage, registration, is to iteratively estimate the scale and the 6-dimensional (6D) rigid registration transformation between the mean shape of DS-PDM and the input points using the iterative closest point (ICP) algorithm. Due to the dense description of the mean shape, a simple point-to-point distance is used together with a k-D tree data structure to speed up the searching for closest point pairs. The second stage, morphing, optimally and robustly estimates a dense patient-specific template surface from DS-PDM using Mahalanobis distance based regularization. The estimated dense patient-specific template surface is then fed to the third stage, deformation, which uses a newly formularized kernel-based regularization to further reduce the reconstruction error. The proposed method is especially useful for accurate and stable surface reconstruction from sparse information when only a small number of a priori training shapes are available. It has been successfully tested on anatomical shape reconstruction of femoral heads using only dozens of sparse points, yielding very promising results.

6141-59, Poster Session

Physical study of the spatial noise of several medical LCDs

H. Roehrig, J. Fan, K. A. Gandhi, E. A. Krupinski, The Univ. of Arizona

Active-Matrix Liquid Crystal Displays (AM-LCD) are gradually replacing the CRTs in the radiology reading rooms. Results of some initial study seem to confirm the high hopes placed in LCDs and indeed, the few systems we have evaluated to date have image quality that in many aspects is superior to that of CRT displays. But they are still far from ideal. They possess some limitations and deficiencies, one of which is spatial noise. Spatial noise of CRTs is known to interfere with the diagnosis of microcalcifications in mammography and reduce the efficiency of diagnosis, especially when the abnormalities are subtle. Error diffusion technique has been used to reduce the spatial noise of an LCD by at least a factor of 2. The purpose of this paper was to investigate the magnitude of the spatial noise of several clinical monochrome LCD units and explore to what degree the spatial noise of these LCDs can be reduced. Of interest was also the question if the reduction in spatial noise affects the threshold contrast of human observers.

We used 5 monochrome LCD panels. They ranged in pixel matrix size from 1 M-Pixel through 3 M-Pixel to 5 M-Pixel. 3 LCDs used featured the common chevron-type pixel structure where the area of the three subpixels is the same. 2 LCDs featured the not so common cross-type pixel structure where the areas of the three sub-pixels are different by the ratio 100:50:25.

A high quality CCD camera was used for physical evaluation. The widely used coefficient of variance (CV) served as the measure of the spatial noise magnitude.

6141-60, Poster Session

A virtual image chain for perceived image quality of medical display

C. Marchessoux, J. Jung, Agfa-Gevaert NV (Belgium)

This paper describes a virtual image chain for medical display (project VICTOR: granted in the 5th framework program by European commission). The chain starts from raw data of an image digitizer (CR, DR) or synthetic patterns and covers image enhancement (MUSICA by Agfa) and both display possibilities, hardcopy and softcopy. The display chain consists of several modules. Raw images are either taken from scanners (CR-DR) or from a pattern generator, in which characteristics of DR-CR systems are introduced by their MTF and their dose-dependent Poisson noise. The image undergoes image enhancement and comes to display.

For soft display, color and monochrome monitors are used in the simulation. The image is down-sampled. The non-linear response of a color monitor is taken into account by the GOG or S-curve model, whereas the Standard Gray-Scale-Display-Function (DICOM) is used for monochrome display. The MTF of the monitor is applied on the image in intensity levels.

For hardcopy display, the combination of film, printer, light-box and viewing condition is modeled. The image is up-sampled and the DICOM-GSDF or a Kanamori Look-Up-Table is applied. An anisotropic model for the MTF of the printer is applied on the image in intensity levels. The density-dependent color (XYZ) is introduced by Look-Up-tables.

Finally a Human Visual System Model is applied to the intensity images in order to eliminate non-visible differences. Comparison leads to visible differences, which are quantified by image quality metrics. A specific image viewer is used for the visualization of the image and the visual difference maps.

6141-61, Poster Session

Measurement of MTFs for monochrome and color liquid crystal displays

A. Horii, M. Takamura, K. Ichikawa, Y. Kodera, M. Ikeda, T. Ishigaki, Nagoya Univ. (Japan)

We measured MTFs of liquid crystal displays (LCDs) by rectangular waveform analysis. This method is taking a picture of the bar pattern on the monitor surface with a digital camera, and analyzing the picture with a personal computer. The monitors used are the monochrome LCDs of 1M(about 1 million of the number of pixels), 2M, 3M, and 5M, and the color LCDs of 1M, 2M, 3M. The display of 2M used IPS system and VA system. 3M and 5M of the monochrome LCDs were examined when there was a protection filter or not. Two or three displays are used for each system.In both the monochrome and the color LCDs, MTFs became high as the matrix size increased. In the monochrome LCDs, MTF in horizontal direction was higher than MTF in vertical direction. And there was no difference when a protection filter was used or not. MTFs of the color LCDs had little difference in horizontal direction and the vertical direction. MTFs of the LCDs are influenced on the form and the fill factor of a pixel, and composition of sub pixels.

6141-63, Poster Session

Magnetic resonance imaging for image-guided implantology

G. Eggers, B. Kress, Ruprecht-Karls-Univ. Heidelberg (Germany); J. B. Fiebach, Univ. Duisburg-Essen (Germany); M. Rieker, D. Spitzenberg, R. Marmulla, H. Dickhaus, J. Mühling, Ruprecht-Karls-Univ. Heidelberg (Germany)

Introduction: Image guided implantology using navigation systems is more accurate than manual dental implant insertion. The underlying image data are usually derived from computer tomography. The suitability of MR imaging for dental implant planning is a marginal issue so far.

Materials and Methods: MRI data from cadaver heads were acquired using various MRI sequences. The data were assessed for the quality of anatomical imaging, geometric accuracy and susceptibility to dental metal artefacts. For dental implant planning, 3D models of the jaws were created. A software system for segmentation of the mandible and maxilla MRI data was implemented using c++, mitk, and qt.

Results: With the VIBE_15 sequence, image data with high geometric accuracy were acquired. Dental metal artefacts were lower than in CT data of the same heads. The manual segmentation of the jaws was simply, in comparison to segmentation of the dentition, since there is a lack of contrast to the intraoral soft tissue structures.

Discussion: MRI is a suitable method for imaging of the region of mouth and jaws. The geometric accuracy is excellent and the susceptibility to artefacts is low. However, there are yet two limitations: Firstly, the imaging of the dentition needs further improvement to allow accurate segmentation of these regions. Secondly, the sequence used in this study takes several minutes and hence is susceptible to motion artefacts.

6141-64, Poster Session

Electromagnetic tracker accuracy in CyberKnife suite

E. Wilson, H. J. Zhang, K. R. Cleary, Georgetown Univ.

Electromagnetic tracking has been available for over 10 years, but recent technological improvements in system accuracy, reliability and miniaturization of sensor coils have made possible new clinical applications. The nature of operation of EM systems however, makes them susceptible to field distortions due to ferromagnetic materials that are close to the measurement volume. Clinical Image-Guided Surgery (IGS) and Image-Guided Therapy (IGT) systems have successfully employed EM trackers in envi-

ronments that contain minimal electromagnetic interference. Less work has gone into integrating EM systems with larger medical devices such as the CyberKnife system [Accuray, California] used for stereotactic radiosurgery, in part due to the large immobile metal device components. Accurate EM tracking of internal fiducials in the CyberKnife suite could lead to more precise treatments. This study aims to investigate the accuracy limitations of the Aurora EM tracking system [NDI Inc, Waterloo] when used within the CyberKnife suite at Georgetown University Medical Centre [Washington, DC]. Preliminary tests indicate RMS errors under 1.029mm within an optimal subvolume of the measurement volume. This is comparable to an RMS error of 0.702mm obtained for a similar trial conducted in a ferromagnetically benign office environment, thereby indicating acceptable accuracy deviations within a sub-volume of the CyberKnife suite.

6141-65, Poster Session

Multimodal augmented reality system for surgical microscopy

J. Garcia Giraldez, H. Talib, M. Caversaccio, M. A. Gonzalez Ballester, Univ. Bern (Switzerland)

Image-guided, computer-assisted neurosurgery has emerged to improve localization and targeting, to provide a better anatomic definition of the surgical field, and to decrease invasiveness. Usually, in image-guided surgery, a computer displays the surgical field in a CT/MR environment, using axial, coronal or sagittal views, or even a 3D representation of the patient. Such a system forces the surgeon to look away from the surgical scene to the computer screen. Moreover, this kind of information, being pre-operative imaging, can not be modified during the operation, so it remains valid for guidance in the first stage of the surgical procedure, and mainly for rigid structures like bones.

In order to solve the two constraints mentioned before, we are developing an ultrasound-guided surgical microscope. Such a system takes the advantage that surgical microscopy and ultrasound systems are already used in neurosurgery, so it does not add more complexity to the surgical procedure. We have integrated an optical tracking device in the microscope and an augmented reality overlay system with which we avoid the need to look away from the scene, providing correctly aligned surgical images with sub-millimeter accuracy. In addition to the standard CT and 3D views, we are able to track an ultrasound probe, and using a previous calibration and registration of the imaging, the image obtained is correctly projected to the overlay system, so the surgeon can always localize the target and verify the effects of the intervention. Several tests of the system have been already performed to evaluate the accuracy, and clinical experiments are currently in progress in order to validate the clinical usefulness of the system.

6141-66, Poster Session

Near-infrared imaging and structured light ranging for automatic catheter insertion

V. C. Paquit, J. R. Price, Oak Ridge National Lab.; R. Seulin, F. Meriaudeau, Univ. de Bourgogne (France); K. W. Tobin, Jr., Oak Ridge National Lab.

Vein localization and catheter insertion constitute the first and perhaps most important phase of many medical procedures. Currently, catheterization is performed manually by trained personnel. This process can prove problematic, however, depending upon various physiological factors of the patient. We present in this paper initial work for localizing surface veins via near-infrared (NIR) imaging and structured light ranging. The eventual goal of the system is to serve as the guidance for a fully automatic (i.e., robotic) catheterization device. Our proposed system is based upon near-infrared (NIR) imaging, which has previously been shown effective in enhancing the visibility of surface veins. We locate the vein regions in the 2D NIR images using standard image processing techniques. We employ a NIR line-generating LED module to implement structured light ranging and construct a 3D topographic map of the arm surface. The located veins are mapped to the arm surface map to provide a camera-registered representation of the arm and veins. We will describe the techniques in detail and provide example imagery and 3D surface renderings.

6141-67, Poster Session

Feasibility study for image guided kidney surgery: assessment of required intraoperative surface for accurate image to physical registrations

A. B. Benincasa, L. W. Clements, S. D. Herrell, S. S. Chang, M. S. Cookson, R. L. Galloway, Jr., Vanderbilt Univ.

Currently, the removal of kidney tumor masses uses only direct or laparoscopic visualizations resulting in prolonged procedure and recovery times and reduced clear margin. Applying current image guided surgery (IGS) techniques, as those used in liver cases, to kidney resections (nephrectomies) presents a number of complications. Most notably is the limited field of view of the intraoperative kidney surface, which constrains the ability to obtain a surface delineation that is geometrically descriptive enough to drive a surface-based registration. Two different phantom orientations were used to model the laparoscopic and traditional partial nephrectomy views. For the laparoscopic view, fiducial point sets were compiled from a CT image volume using anatomical features such as the renal artery and vein. For the traditional view, markers attached to the phantom set-up were used for fiducials and targets. The fiducial points were used to perform a point-based registration, which then served as a guide for the surface-based registration. Laser range scanner (LRS) obtained surfaces were registered to each phantom surface using a rigid iterative closest point algorithm. Subsets of each phantom's LRS surface were used in a robustness test to determine the predictability of their registrations to transform the entire surface. Results from both orientations suggest that about half of the kidney's surface needs to be obtained intraoperatively for accurate registrations between the image surface and the LRS surface, suggesting the obtained kidney surfaces were geometrically descriptive enough to perform accurate registrations. This preliminary work paves the way for further development of kidney IGS systems.

6141-68, Poster Session

Computerized fluoroscopy with zero-dose image updates for minimally invasive femoral diaphyseal fracture reduction

G. Zheng, X. Dong, Univ. Bern (Switzerland)

In this paper, a computerized fluoroscopy with zero-dose image updates for femoral diaphyseal fracture reduction is proposed. It is achieved with a two-step procedure. Starting from a few (normally 2) calibrated fluoroscopic image, the first step, data preparation, automatically estimates the size and the pose of the diaphyseal fragments through three-dimensional morphable object fitting using a parametric cylinder model. The projection boundary of each estimated cylinder, a quadrilateral, is then fed to a region information based active contour model to extract the fragment contours from the input fluoroscopic images. After that, each point on the contour is interpolated relative to the four vertices of the corresponding quadrilateral, which resulted in four interpolation coefficients per point. The second step, image updates, repositions the fragment projection on each acquired image during bony manipulation using a computerized method. It starts with interpolation of the new position of each point on the fragment contour using the interpolation coefficients calculated in the first step and the new position of the corresponding quadrilateral. The position of the quadrilateral is updated in real time according to the positional changes of the associated bone fragments, as determined by the navigation system during fracture reduction. The newly calculated image coordinates of the fragment contour are then fed to a OpenGL(r) based texture warping pipeline to achieve a real-time image updates. The presented method provides a realistic augmented reality for the surgeon. Its application may result in great reduction of the X-ray radiation to the patient and to the surgical team.

6141-69, Poster Session

An effective technique for calibrating the intrinsic parameters of a vascular C-arm from a planar target

S. Gorges, K. Erwan, M. Berger, LORIA (France); Y. L. Trousset, J. Pescatore, GE Healthcare (France)

The real time recovery of the projection geometry is a fundamental issue in interventionnal navigation applications (e.g. guide wire reconstruction, medical augmented reality). In most works, the intrinsic parameters are supposed to be constant and the extrinsic parameters (C-arm motion) are deduced either from the orientation sensors of the C-arm or from additional sensors. However, due to the weight of the X-ray tube and the C-arm, the system is undergoing deformations which induce variations of the intrinsic parameters as a function of the C-arm orientations. In our approach, we proposed to measure the effects of the mechanical deformations onto the intrinsic parameters in a calibration procedure. Robust calibration methods exist (the gold standard is the multi-image calibration) but they are time consuming and too tedious to set up in a clinical context. For these reasons, we developed an original and easy to use method, based on a planar calibration target, which aims at measuring with a high level of accuracy the variation of the intrinsic parameters on a vascular C-arm.

The precision of the planar based method was evaluated with error propagation method and its appeared that the precision of intrinsic parameters are very good compared to the gold standard method. The method was also successfully used to assess to behavior of the C-arm with respect to the C-arm orientations. Results showed a clear variation of the principal point when the LAO/RAO orientation was changed. In contrast, the intrinsic parameters do not change during a cranio-caudal C-arm motion.

6141-70, Poster Session

Noninvasive CT to Iso-C3D registration for improved intraoperative visualization in computer assisted orthopedic surgery

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Supporting surgeons in performing minimally invasive surgeries can be considered as one of the major goals of computer assisted surgery.

Excellent intraoperative visualization is a prerequisite to achieve this aim.

The Siremobil Iso-C3D has become a widely used imaging device, which, in combination with a navigation system, enables the surgeon to directly navigate within the acquired 3D image volume without any extra registration steps. However, the image quality is rather low compared to a CT scan and the volume size (approx. 12cm_) limits its application.

A regularly used alternative in computer assisted orthopedic surgery is the use of a preoperatively acquired CT scan to visualize the operating field. But, the additional registration step, necessary in order to use CT stacks for navigation is quite invasive. Therefore the objective of this work is to develop a noninvasive registration technique.

We propose a solution that registers a preoperatively acquired CT scan to the intraoperatively acquired Iso-C3D volume, thereby registering the CT to the tracked anatomy. The procedure aligns both image volumes by maximizing the mutual information, an algorithm that has already been applied to similar registration problems and demonstrated good results.

Furthermore the accuracy of such a registration method has to be investigated in a clinical setup, integrating a navigated Iso-C3D in combination with an “Optotrak 3020” tracking system. We present early experience with the developed system and the achievable accuracy.

6141-71, Poster Session

IGSTK: framework and example applications using an open source toolkit for image-guided surgery applications

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Purpose: The field of image-guided surgery is rapidly expanding, as image-guided procedures are minimally invasive and involve less trauma for the patient. A typical image-guided system consists of a localizer for tracking instruments and the anatomy and a computer for processing the data and displaying the results. Another key component of an image-guided system is software, which usually requires the majority of the development effort. As new localizers and algorithms are developed, each research group must develop its own image-guided system, which can be a time-consuming undertaking. The purpose of the image-guided surgery toolkit is to enable robust image-guided applications to be easily created based on open-source software.

Methods: The software toolkit has been under development for about six months now and a beta release will be available by the time of the conference. Robustness and quality have been the highest priority in the design of the toolkit, which is based on the following existing opening source components: ITK for segmentation and registration, VTK for visualization, and FLTK for the user interface. The toolkit contains the basic software components to construct an image-guided system, including a localizer and a four-quadrant view incorporating image overlay.

Figure 1 presents a UML collaboration diagram of the major IGSTK components involved in a typical image-guided surgery application. The key components are from left to right:

1) View class for presenting results and displays to the physician
2) SpatialObjects class models physical objects including image data and simple geometrical shapes
3) SpatialObjectRepresentation class provides connection between SpatialObjects & View classes
4) Tracker class to store data from localizers (trackers)

Results: The major components of the toolkit have been completed and we are beginning to create example applications using the toolkit. The toolkit has been designed as a collaborative effort between several research groups. The main focus of the design has been on providing a robust toolkit that is thoroughly tested with an emphasis on safety in the clinical environment.

New or breakthrough work to be presented: This will be the first presentation of the IGSTK project.

Conclusions: Open source software has tremendous potential for improving the productivity of research labs and enabling the development of new medical applications. The image-guided software toolkit (IGSTK) should enable researchers to quickly build robust image-guided applications and enable the development of new image-guided techniques.

Note: This work has not been submitted for publication or presentation elsewhere. Related papers on the IGSTK project have been submitted to the upcoming MICCAI open source workshop.

6141-72, Poster Session

Comparison of three electromagnetic tracking systems using a standard protocol

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This paper uses an established protocol to evaluate and compare three popular miniature electromagnetic tracking systems (EMTS's): Aurora (A) (NDI, Burlington, CA), microBird (B) (Ascension, Burlington, VT) and Medtronic (C) (Minneapolis, MN). All EMTS's provide full 6 degrees of freedom (dof) and use different methods to avoid distortions caused by metallic objects.

For the protocol a machined base plate was used in which a 50 mm grid of holes was precisely drilled for position measurements. A circle of 32 equidistant holes in the center enables the accurate measurement of rotation. The sensors are clamped in a small mount which fits into pairs of grid holes on the base plate. Relative positional/orientational errors are found by subtracting the known distances/rotations between the machined locations from the differences of the mean observed position/rotation. To measure the influence of metallic objects we inserted rods made of steel (SST 303, SST 416), aluminum, and bronze into the sensitive volume between sensor and emitter.

Relative positional errors of 0.25 mm ± 0.22 mm (A), 1.14 mm ± 0.78 mm (B) and 0.38 mm ± 0.32 mm (C) were found for a distance of 50 mm and of 0.97 mm ± 1.01 mm, 3.17 mm ± 2.88 mm (B) and 1.25 mm ± 0.85 mm (C) for a distance of 300 mm. The biggest distortion caused by metallic objects results from SST 416. As example, the metallic distortion amounted to 0.53 mm (A), 41.5 mm (B) and 1.8 mm (C) when the rod is placed at a distance of 3 cm to the sensor.

6141-73, Poster Session

Volumetric CT measurement of the ischial tuberosities for designing analytical models of decubitus ulcers

D. R. Holmes III, R. A. Robb, Mayo Clinic

Decubitus ulcers can have a dramatic effect on the quality of life for some patients, particularly those prone to chronic development of skin ulcerations. The bones of the pelvis are particularly involved as nearly half of all ulcerations observed in the hospital are in the pelvic region. This work focuses on the development of methods to extract key parameters of the ischium from volumetric CT data of the pelvis which will be used for patient-specific modeling of high-pressure regions and the treatment of associated ulcers. Six volumetric CT scans were evaluated to determine the size and shape of the ischial tuberosities. Using oblique images computed from the CT data, cross-sectional measurements (approximately Superior-Inferior, Anterior-Posterior, and Left-Right) were made as descriptive parameters of the size and shape of ischial tuberosities. The mean length of the ischial tuberosities (S-I direction) is 12.35 cm. The mean dimension in the L-R and A-P directions are 2.97 cm and 3.78 cm, respectively. There is a significant difference between the L-R dimension and A-P dimension (measured $P<.001$ with paired t-test). Significant variation in the calcification of the hip bones was observed. Using these measurements, an investigator would be able model the ischial tuberosities for force and pressure calculations on the proximal skin, which could then be used to predict ulcerations in patients, or design new ulcer-inhibiting seating devices. Current efforts are focused on collecting a large cohort of data and making advanced measurements of the bony structures of the pelvis.

6141-74, Poster Session

Segmentation of the left and right cardiac ventricle using a combined bi-temporal statistical model

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The manual segmentation and analysis of high-resolution multislice cardiac CT datasets is both labor intensive and time consuming. Therefore it is necessary to supply the cardiologist with powerful software tools to segment the myocardium as well as the cardiac cavities and to compute the relevant diagnostic parameters. In this paper we present an automatic cardiac segmentation procedure with minimal user interaction. It is based on a combined bi-temporal statistical model of the left and right ventricle using the principal component analysis (PCA) as well as the independent component analysis (ICA) to model global and local shape variation.

To train the model we used manually drawn end-diastolic as well as end-systolic contours of the right epi- and of the left and right endocardium to create triangular surfaces of training datasets. These surfaces were used to build a mean triangular surface model of the left and right ventricle for the end-diastolic and end-systolic heart phase and to compute the PCA and ICA decorrelation matrices which are used in a point distribution model (PDM) to model the global and local shape variations.

In contrast to many previous attempts of model based cardiac segmentation we do not create separate models for the left and the right ventricle and for different heart phases, but instead create one single parameter vector containing the information of both ventricles and both heart phases. This enables us to use the correlation between the phases and between left and right side to create a model which is more robust and less sensitive e.g. to poor contrast at the right ventricle.

6141-75, Poster Session

Computational flow dynamics in patient specific model of cardiovascular system using CT and MRI

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After introduction on a new multislice computed tomography (MSCT) scanner, it has become possible to produce high-speed CT angiography (CTA) that selected preferred method for imaging in emergent vascular conditions. On the other hand, the imaging of blood vessels is often referred to as magnetic resonance angiography (MRA). Both of angiography offer the good quality of three-dimensional reconstruction.

In this study, patient specific model were reconstructed using multi-slice computed tomography (CT) and magnetic resonance imaging (MRI). The optimal transit time from intravenous injection to enhancement cardiovascular system was determined using a contrast bolus tracking technique and phase contrast magnetic resonance imaging (PC-MRI). The purpose of this study was to describe a novel visualization and technique of blood flow analysis in the human cardiovascular system in more detail by constructing realistic three-dimensional (3-D) vessel and cardiac model using CFD methods. CFD streamlines were displayed using a special illumination technique with blood pressure display, which gives a much better spatial understanding of the field´s structure than ordinary constant-colored lines. Real vector display using PC-MRI was also expressed to compare with the CFD simulation. On conclusion, Patient specific approach using CFD were effective to estimate blood flow state of the cardiovascular system.

6141-76, Poster Session

Subdivision-based parametric deformable model for surface extraction and creation of 3D statistical shape modeling of the knee cartilages

J. E. Fripp, Commonwealth Scientific & Industrial Research Organisation (Australia); S. Crozier, Univ. of Queensland (Australia); S. K. Warfield, Brigham and Women's Hospital; S. Ourselin, Commonwealth Scientific & Industrial Research Organisation (Australia)

Subdivision surfaces and parameterization are desirable for many algorithms that are commonly used in Medical Image Analysis. However, extracting an accurate surface and parameterization can be difficult for many medical objects of interest, due to noisy segmentations and the inherent variability of the object. The thin cartilages of the knee are an example of this, especially after damage is incurred from injuries or conditions like osteoarthritis. As a result, the cartilages can even have different topologies or exist in multiple pieces.

In this paper we present a topology preserving (genus 0) subdivision-based parametric deformable model that is used to extract the surfaces of the patella and meniscus cartilages in the knee. These surfaces have zero or very minimal thickness in areas without cartilage. The algorithm inherently incorporates several desirable properties, including: shape based interpolation, sub-division remeshing and parameterization. To illustrate the usefulness of this approach, the surfaces and parameterizations of the patella cartilage are used to generate a 3D statistical shape model.

6141-77, Poster Session

Optimizing needle placement in radiofrequency ablation treatment planning

C. R. Chen, M. I. Miga, R. L. Galloway, Jr., Vanderbilt Univ.

Radiofrequency ablation is a promising treatment modality for unresectable tumors in the liver. Treatment efficacy depends on accurate placement of the needle such that the resulting ablation covers the tumor and a specified margin. Furthermore, the ablation extents depend on the heterogeneity in the local tissue composition. To that end, a computational method is presented for optimizing needle placement for radiofrequency ablation treatment planning. The parameterized search is guided by an objective function that depends on transient, finite element solutions of coupled thermal and potential equations for each needle placement. A framework is introduced for solving the potential equation by using boundary elements to model the needle as discrete current sources embedded within a finite element mesh. This method allows finite element models to be solved for different needle locations without remeshing. We demonstrate that the method produces a search space amenable to gradient-based optimization techniques.

6141-78, Poster Session

Automatic surface correspondence methods for a deformed breast

D. R. Schuler III, J. J. Ou, S. L. Barnes, M. I. Miga, Vanderbilt Univ.

A significant amount of breast cancer research in recent years has been devoted to novel means of tumor detection, such as electrical impedance spectroscopy, microwave imaging, and elastography. Many of the detection methods, particularly elastography, involve deforming the breast and comparing the pre- and post-deformed images of the breast. This paper presents an automatic method for determining correspondence between images of a pendant breast and a partially-constrained, compressed breast. The algorithm is an extension to the symmetric closest point approach of Papademetris et al1. However, because of the unique deformation and shape change of a partially-constrained, compressed breast, the algorithm was modified through the use of iterative closest point (ICP) registration on easily identifiable sections of the breast images and weighted symmetric neighbor correspondence. The algorithm presented in this paper significantly improves correspondence determination between the pre- and post-deformed images for a simulation when compared to Papademetris et al's algorithm and a simple closest point algorithm.

6141-79, Poster Session

A pediatric brain structure atlas from T1-weighted MR images

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In this study, a pediatric brain atlas has been constructed from T1 weighted MR images. Twenty five brain structures, including cortical and subcortical structures, were manually delineated. The boundary surfaces of these twenty-five brain structures were extracted and then simplified based on the surface curvature. Surfaces with higher curvature are simplified with more reference points and lower curvature surfaces with less reference points. A 3D triangular mesh model for each brain structure was then constructed by triangulation of the reference points for each structure surface. To evaluate accuracy of the triangle mesh model, volumes of brain structures were defined based on their mesh models. Kappa index was calculated for each structure was calculated between the model-defined and original volume. The average kappa index of cortical and subcortical structures is 0.97 and 0.91, respectively. The brain atlas and structural mesh model could be used for therapy planning, knowledge and model driven segmentation, and structural shape analysis.

6141-80, Poster Session

Flow visualization for qualitative assessment of brainshift

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A methodology and software system have been developed to visualize motion in time-series MR or CT brain images acquired on the same patient. This software visualizes regions of brain that have moved during the time interval between scans. It is useful in detecting deformations and displacements that occur during brain surgery. Typically, intraoperative images are of lower resolution compared to presurgical images. Thus, it is possible to use intraoperative image data to correct presurgical (higher resolution) image data to account for brainshift during tumor resection. In addition, visualization of brainshift due to the growth of a tumor or aneurysm may provide additional insight into a patients' symptoms (paralysis or difficulty with speech). The method consists of three main steps.

In the first step, correspondence is established between a large number of point landmarks in two images through an automatic process. In the second step, the landmark correspondences are used to determine a transformation function that maps the pre-operative image to an intra-operative image point by point. The third step uses information in the obtained transformation to visualize local motion between the images. The registration process does not require the solution of a large system of equations, and therefore, the process is especially effective when a large number of correspondences are needed to account for local geometric differences between images.

6141-81, Poster Session

Improving image-guided neurosurgery using low-field intra-operative magnetic resonance imaging

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Intra-operative Magnetic Resonance Imaging (iMRI) provides the neurosurgeon with updated information accounting for structural modifications due to fluid leakage, brain shift, retraction, and tissue ablation that occur during surgery. The concept of a mobile low-field iMRI system coupled to a local radio-frequency shielding device has gained momentum in recent years as it is compatible with standard operating room (OR) and regular surgery instrumentation. The integration of a low-field iMRI system with image-guided neurosurgery systems is very promising as it enables to combine pre-operative high quality images from multiple modalities with updated information accounting for brain shift. The ultimate goal for the combination of neuronavigation with iMRI is to measure structural modifications, to build a biomechanical model of the alterations and to compute the 3D deformation field that will update our pre-operative information. In order to achieve this objective, the initial registration between pre-operative and intra-operative MRI before opening of the skull is of uttermost importance. We have already presented on patient data (SPIE MI 2005) a pre-processing scheme that can be applied to iMRI to enhance mutual information registration in a robust and accurate way. Since then, we have further improved the quality of this initial registration by correction of geometric distortions in iMRI based of phase maps measurements. All algorithms are implemented in ITK. This fully integrated platform of iMRI and navigation has been used on a series of patients in the OR. For each case, registration with optical tracking of the iMRI magnet combined with mutual registration algorithm has been quantitatively compared to standard registration method. Results demonstrate that the standard point and surface based registration using optically tracked tools is not as accurate as the iMRI based method which leads to superior navigation accuracy.

6141-82, Poster Session

Localization and labeling of rat brain in MRI based on Paxinos-Watson atlas

J. Cao, C. Cai, M. Ding, C. Zhou, Huazhong Univ. of Science and Technology (China)

Localization and labeling of function regions in brain is an important topic in experimental brain sciences because the huge amount of data collected by neuroscientists will become meaningless if we cannot give them a precise description of their locations. In this paper, we proposed a localization and labeling method of 3D MR image of rat brain based on atlas of Paxinos and Watson. Our objective is to use the specific atlas to accomplish localization and labeling of specified tissue of interest (TOI) to mimic a veteran expert such that the invisible or unclear anatomic function regions in the MR images of rat brain can be automatically identified and marked. We proposed a three-steps method to localize and label TOIs from MR image of rat brain. Firstly, 3D reconstruction. This aims at the extraction and 3D reconstruction of rat brain MRI, the digitization and 3D reconstruction of the atlas with the same spatial resolution. Secondly, two-steps registration. The global registration is to eliminate the big misalign and section angle offset between MRI and atlas. We can select different unambiguous and characteristic point pairs, and based on the correspondence a coarse registration is obtained. The local registration is to address individual variability of rat brain. We can acquire pairs of slice of MRI and atlas and align them respectively using snake model. Finally, localization and labeling. The goal is to localize and label TOIs in selected MR image of rat brain slice guided by well-registered atlas. The experiments demonstrated that our method is feasible.

6141-83, Poster Session

Subdural and depth electrode placement in the brain for validation of MEG in partial epilepsy

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Localization of ictal onset in nonlesional partial epilepsy continues to be a difficult undertaking particularly in the case of extratemporal epilepsy. This observation is supported by relatively poorer surgical outcomes in most series when compared with temporal lobe resections. Separate diagnostic innovations including magnetoencephalography (MEG), magnetic resonance spectroscopy (MRS) and positron emission tomography (PET) alone has not provided sufficiently consistent results to be reliably used in all circumstances. This paper fuses several modalities of data and visualizes objects of interests in a reference coordinates system to facilitate electrode implantation procedure from one level to the next (i.e., subdural to depth), and eventually, the localization of epileptogenetic zones.

We take the following steps to model objects of interest and to transfer multiple modalities of data into reference coordinates system: 1) Segmentation of subdural and depth electrodes, and cortical surface. 2) Registration of preoperative MRI and MEG, EEG, and post-implantation CT. Using the fused information, we determine candidate areas for electrode implantation. We eventually localize areas pertained to be epileptogenetic based on electrodes with highest activity during a typical seizure and time difference between clinical and EEG/MEG onsets.

The proposed method offers a relatively accurate appreciation of epileptogenicity zones, which is established through visualization and further quantitative analyses of fused data. Based on visual inspections in a perisylvian epileptic case, findings of subdural and depth electrodes match closely with the results of noninvasive MEG data analysis. Therefore, it provides a basis for validation of less expensive and noninvasive procedures such as MEG.

6141-84, Poster Session

A robust surface registration using a Gaussian-weighted distance map for brain PET-CT fusion

H. Lee, H. Hong, Seoul National Univ. (South Korea)

In this paper, we propose a robust surface registration using a Gaussian-weighted distance map (GWDM) for PET-CT brain fusion. Our method is composed of four steps. First, we segment the background of PET and CT brain images using 3D seeded region growing and apply inverse operation to the segmented images for getting head without holes. The sharpening filter is then applied to the segmented head in order to extract the feature points of the head from PET and CT images, respectively. At this time, non-head feature points extracted from noise or bed are removed in the extracted feature points by using shape quantification such as compactness and radial distance measures. Second, a GWDM is generated from feature points of CT images to lead the feature points extracted from PET images with large blurry and noisy conditions to robustly align at optimal location onto CT images. Third, similarity measure is evaluated repeatedly by weighted cross-correlation (WCC). Fourth, our optimization with adaptive space leaping is performed to rapidly converge on the optimal location. In our experiments, we evaluate our method using software phantom and clinical datasets with the aspect of visual inspection, accuracy, robustness, and computation time. In our method, RMSE for translations and rotations are less than 0.1mm and 0.2°, respectively in software phantom dataset and give better accuracy than the conventional ones. In addition, our method gives a robust registration at optimal location regardless of increasing noise level.

6141-85, Poster Session

Registration of laser range image of cortical surface to preoperative brain MR images for image-guided neurosurgery: preliminary results

B. Tsagaan, K. Abe, K. Iwami, Shizuoka Univ. (Japan); S. Yamamoto, S. Terakawa, Hamamatsu Univ. School of Medicine (Japan)

Neurosurgical navigation systems using preoperative images have a problem in their accuracy which is caused by brain deformation during surgery. To address this problem the use of laser range scanner in order to obtain intraoperative cortical surface, is under study in our currently developing navigation system. This paper presents preliminary results of registration of intraoperatively acquired range and color images to preoperative MR images, within the context of image-guided surgery. We register images by performing two procedures: mapping of color image on the range image; and registration between color-mapped range images and preoperative medical images. The color image is mapped on the range image using camera calibration. Point-based rigid registration of preoperative images to the intraoperative images is performed through calculation of common fiducials in the images.

Experimental results using intraoperatively acquired range images of cortical surface demonstrated the ability to perform registrations for MR images of the brain. In the future, we will focus on incorporating the above registration results into a biomechanical model of the brain to predict brain deformation during surgical procedures.

6141-86, Poster Session

Segmentation of brain volume based on 3D region growing by integrating intensity and edge for image-guided surgery

B. Tsagaan, K. Abe, M. Goto, Shizuoka Univ. (Japan); S. Yamamoto, S. Terakawa, Hamamatsu Univ. School of Medicine (Japan)

This paper presents a segmentation method of brain tissues from MR images, invented for our image-guided neurosurgery system under development. Our goal is to segment brain tissues for creating biomechanical model.

The proposed segmentation method is based on 3-D region growing and outperforms conventional approaches by stepwise usage of intensity similarities between voxels in conjunction with edge information. Since the intensity and the edge information are complementary to each other in the region-based segmentation, we use them twice by performing a coarse-to-fine extraction. First, the edge information in an appropriate neighborhood of the voxel being considered is examined to constrain the region growing. The expanded region of the first extraction result is then used as the domain for the next processing. The intensity and the edge information of the current voxel only are utilized in the final extraction. Before segmentation, the intensity parameters of the brain tissues as well as partial volume effect are estimated by using expectation-maximization (EM) algorithm in order to provide an accurate data interpretation into the extraction.

We tested the proposed method on T1-weighted MR images of brain and evaluated the segmentation effectiveness comparing the results with ground truths. Also, the generated meshes from the segmented brain volume by using commercial mesh generating software are shown in this paper.

6141-87, Poster Session

Knowledge modeling in image-guided neurosurgery: application in understanding intraoperative brain shift

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During an image-guided neurosurgery procedure, the neuronavigation system is subject to inaccuracy because of anatomical deformations which induce a gap between the preoperative images and their anatomical reality. Thus, the objective of many research teams is to succeed in quantifying these deformations in order to update preoperative images. Anatomical intraoperative deformations correspond to a complex spatio-temporal phenomenon. Our objective is to identify the parameters implicated in these deformations and to use these parameters as constrains for systems dedicated to update preoperative images. In order to identify these parameters of deformation we followed the iterative methodology used for cognitive system conception: identification, conceptualization, formalization, implementation and validation. First of all, a state of the art about cortical deformations has been established in order to identify relevant parameters probably involved in the deformations. As a first step, 30 parameters have been identified and described by an ontology. They were formalized into an Unified Modeling Language (UML) class diagram. We implemented that model into a web-based application in order to fill a database. Two surgical cases have been studied at this moment. After having entered enough surgical cases for data mining purposes, we expect to identify the most relevant and influent parameters and to gain a better ability to understand the deformations phenomenon. This original approach is part of a global system aiming at quantifying and correcting deformations.

6141-88, Poster Session

Assessment of radio frequency ablation treatment of hepatic tumors

P. F. Hemler, Hampden-Sydney College; E. S. McCreedy, R. Cheng, B. J. Wood, M. J. McAuliffe, National Institutes of Health

To insure that all cancerous cells are adequately destroyed during a Radio Frequency Ablation (RFA) procedure, probe manufacturers advise physicians to increase the treatment region by one centimeter (1cm) in all directions around the tumor. This enlarged treatment region provides a buffer to insure that cancer cells that migrated into surrounding tissue are also adequately treated and necrose. Even though RFA is a minimally invasive, image-guided procedure, it is difficult for physicians to confidently follow the specified treatment protocol. In this paper we assess an RFA treatment by comparing a registered image set containing the untreated tumor, including the 1 cm safety boundary, to that of an image set containing the treated region acquired one month after surgery. For this study, we used Computerized Tomography images as both the tumor and treated regions are visible. To align the image sets of the abdomen, we investigate three different registration techniques; an affine transform that minimizes the correlation ratio, a point (or landmark) based 3D thin-plate spline approach, and a non-linear B-spline elastic registration methodology. We found the affine registration technique simple and easy to use because it is fully automatic. Unfortunately, this method resulted in the largest visible discrepancy between the liver in the fused images. The thin-plate spline technique required the physician to identify corresponding landmarks in both image sets, but resulted in better visual accuracy in the fused images. Finally, the non-linear, B-spline, elastic registration technique used the registration results of the affine method as a starting point and then required a significant amount of computation to determine its transformation, but also provided the most visually accurate fused image set.

6141-89, Poster Session

Fast 2D-3D marker-based registration of CT and X-ray fluoroscopy images for image-guided surgery

H. Hong, K. Kim, S. Park, Seoul National Univ. (South Korea)

In this paper, we propose a fast 2D-3D marker-based registration technique to fuse anatomical structure of 3D CT scans onto 2D X-ray fluoroscopy image. Our method is composed of three stages. First, DRRs (Digitally Reconstructed Radiography) are generated by maximum intensity projection based on hardware texture-based volume rendering. This technique is over 200 times faster than software-based one. Second, several confirmation markers are automatically segmented in DRRs and x-ray fluoroscopy images, respectively. Third, in/out-plane registration is proposed for real-time performance. In out-plane registration, we search for an optimal position of x-ray source in a 3D spherical coordinate system. Then, we calculate optimal translation and rotation vectors by using principal axes method in in-plane registration. Our method has been successfully six different CT and x-ray fluoroscopy pairs generated from cardiac phantom datasets. For accuracy evaluation, we calculate root-mean-square-error (RMSE) between confirmation markers of DRRs and x-ray fluoroscopy images. The average RMNS is less than 3mm in almost datasets. Experimental results show that our method is as accurate as conventional registration and much faster than the conventional one.

6141-90, Poster Session

Sequential intrinsic and extrinsic geometry calibration in fluoro CT imaging and navigation with a mobile C-arm

A. Cheryauka, S. Breham, W. D. Christensen, GE Healthcare

Design of C-arm equipment with 3D imaging and surgical navigation capabilities involves retrieval of repeatable gantry positioning information along the acquisition trajectory. Inaccurate retrieval or improper use of positioning information may cause degradation of the reconstruction results, appearance of image artifacts, or indicate false structures. The geometry misrepresentation can also lead to the navigation errors in relative pose and orientation assessments of anatomy-of-interest and interventional tools. Comprehensive C gantry calibration with an extended set of misalignment and motion parameters suffers from ambiguity caused by parameter cross-correlation and significant computational complexity. We propose the concept of a waterfall calibration that comprises sequential intrinsic and extrinsic geometry calibration delineation steps. Following the image-based framework, the first step in our method is intrinsic calibration that deals with delineation of geometry of the X-ray tube-Detector assembly. Extrinsic parameters define motion of the C-arm assembly in 3D space and relate the Camera and World coordinate systems. We formulate both intrinsic and extrinsic calibration problems in the vectorized form with total variation constraints. The proposed method has been verified by extensive numerical design and validated by experimental studies. Sequential delineation of intrinsic and extrinsic geometries has demonstrated very efficient performance. The method eliminates the cross-correlation between cone-beam projection parameters, provides significantly better accuracy and computational speed, simplifies the structures of calibration targets used, and avoids the unnecessary workflow and image processing steps. It appears to be adequate for quality and cost derivations in interventional surgery setting using a mobile C-arm.

6141-91, Poster Session

Spatio-temporal analysis tool for modeling pulmonary nodules in MR images

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To detect lung cancer at an earlier stage, a promising method is to apply perfusion magnetic resonance imaging (pMRI) modified to assess tumor angiogenesis. One key issue is to effectively characterize angiogenic patterns of pulmonary nodules. Based on our previous study addressing this issue, in this work, we develop STAT, a Spatio-Temporal Analysis Tool that implements not only our previously proposed pulmonary nodule modeling framework but also a user friendly interface and many extended functionalities. Our goal is to make STAT an easy-to-use tool that can be applied to more general cases. STAT employs the following overall strategy for modeling pulmonary nodules: (1) nodule identification using a correlation maximizatoin method, (2) nodule segmentation using edge detection, morphological operations and model-based strategy, and (3) nodule registration using landmark approach and thin-plate spline interporation. In nodule identification, STAT provides new schemes for selecting the template and refining results in difficult cases. In nodule segmentation, STAT provides additional flexibilities for creating the weighting mask, selecting morphological structure elements and individually fixing segmentation result. In nodule registration, our previous study uses principal component analysis for landmark extraction, which may not work in general. To overcome this limitation, STAT provides an enhanced approach that minimizes the bending energy of the thin plate spline interpolation between a landmark set and the template set. Our main application of STAT is to define blood arrival patterns in the lung to identify tumor angiogenesis as a means of early accurate diagnosis of cancer.

6141-92, Poster Session

ITK implementation of deformable registration methods for time-varying (4D) imaging data

T. R. Popa, Georgetown Univ.; L. Ibanez, Kitware Inc.; K. R. Cleary, K. H. Wong, Georgetown Univ.

Dynamic or 4D images (in which a section of the body is repeatedly imaged in order to capture physiological motion) are becoming increasingly important in medicine. These images are especially critical to the field of image-guided radiation therapy, because they enable treatment planning that reflects the realistic motion of the therapy target. Although it is possible to acquire static images and deform them based on generalized assumptions of normal motion, such an approach does not account for variability in the individual patient. To enable the most effective treatments, it is necessary to be able to image each patient and characterize their unique respiratory motion. Thus, we have developed an ITK-based software tool for the analysis of 4D imaging data. This interface can load DICOM images into memory, reorder/rebin them if necessary, and then apply one of three deformable registration methods in order to derive the respiratory motion. The interface allows output and display of the deformation field, display of images with the deformation field as an overlay, and tables and graphs of motion versus time. The registration is based on the open source Insight Toolkit (ITK) and the interface is constructed using the open source GUI tool FLTK, which will make it easy to distribute and extend this software in the future.

6141-93, Poster Session

A novel 2D-3D registration algorithm for aligning fluoro images with 3D pre-op CT/MR images

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We propose a novel and fast way to perform 2D-3D registration between available intra-operative 2D images with pre-operative 3D images in order to provide better image-guidance. The current work is a feature based registration algorithm that allows the similarity to be evaluated is a very efficient manner and is much lower than that of intensity based approaches. The current approach is focused on solving the problem for neuro-interventional applications and therefore we use blood vessels, and specifically their centerlines as the features used for registration. The blood vessels are segmented from the 3D datasets and their centerline is extracted using a sequential topological thinning algorithm. Segmentation of the 3D datasets is straightforward because of the injection of contrast agents. For the 2D image, segmentation of the blood vessel is performed by subtracting the image with no contrast (native) from the one with a contrast injection (fill). Following this we compute a modified version of the 2D distance transform. The modified distance transform is computed such that distance is zero on the centerline and increases as we move away from the centerline. This allows us a smooth metric that is minimal at the centerline and large as we move away from the vessel. This is a one time computation, and need not be reevaluated during the iterations. Also we simply sum over all the points rather than evaluating distances over all point pairs as would be done for similar Iterative Closest Point (ICP) Algorithm based approaches. We estimate the three rotational and three translational parameters by minimizing this cost over all points in the 3D centerline

6141-94, Poster Session

A novel ultrasound-guided shoulder arthroscopic surgery

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This paper presents a novel volumetric ultrasound-guided system for shoulder arthroscopic surgery. The system tracks and displays sensorized surgical instruments relative to the anatomy of the patient. The purpose of the system is to improve the surgeon's perception of the three-dimensional space within the anatomy of the patient in which the arthroscope is manipulated and to provide guidance towards the targeted anatomy. Preoperatively, sequential computed tomography images of the patient are acquired from which a three-dimensional model is built. Intra-operatively, live ultrasound images from the shoulder of the patient are captured to register the three-dimensional model to the actual anatomy of the patient. An initial registration is obtained by matching at least three points manually selected on the model to their corresponding points identified on the ultrasound images of the patient. Then the final registration is obtained with an iterative closest point, or a sequential least squares estimation technique, or an intensity-based algorithm. In the present study the registration results of these techniques were compared. After final registration of the three-dimensional model to the ultrasound images, the surgical instruments can be displayed relative to the three-dimensional anatomy model of the patient. Our proposed system does not increase invasiveness of the shoulder arthroscopy. In addition it is easy to use and sufficiently fast to be applicable in the operating room.

6141-95, Poster Session

3D freehand ultrasound calibration using an electromagnetic tracked needle

H. J. Zhang, F. Banovac, K. R. Cleary, Georgetown Univ.

3D freehand ultrasound makes it possible to image a whole volume of interest intra-operatively in a fast, cost-effective, and flexible way. However, the device must be calibrated before it can be registered with other image modalities. We present an electromagnetically needle-based approach for calibrating 3D freehand ultrasound as a prerequisite for the intra-operative navigation system. Although most existing calibration methods require a complex and tedious experiment with a customized calibration phantom, our method does not. It requires only several frames ¨C three to nine in our experiment ¨C to detect the tracked needle's tip in the 2D ultrasound image. The whole experimental setup needs only a water container. The tracked needle is dipped into the water and moved freehand to locate the tip in the ultrasound imaging plane. The images that show the needle tip are recorded and the tip¡¯s points are manually or automatically identified. For each frame, the pixel indices, as well as the positions of the tracker and the needle, are used as the inputs, and the calibration matrix is reconstructed. Three group positions, each with nine frames, are recorded for calibration and validation. Despite the lower accuracy of the electromagnetic tracking device compared to optical tracking device, the maximum RMS error for calibration is 1.22mm with six or more frames, which shows that our proposed approach is accurate and feasible.

6141-96, Poster Session

Ultrasound self-calibration

E. M. Boctor, I. Iordachita, G. Fichtinger, G. D. Hager, Johns Hopkins Univ.

This paper describes a new robust method for 2D and 3D ultrasound probe calibration using a closed-form solution. Prior to calibration, a position sensor is attached to the probe and is used to tag each image/volume with its position and orientation in space. At the same time, image information used to determine target location in probe coordinates. The calibration procedure uses these two pieces of information to determine the transformation (translation, rotation, and scaling) of the scan plane with respect to the position sensor. We introduce a novel methodology for real-time in-vivo quality control of tracked US systems, in order to capture registration failures during the clinical procedure. In effect, we dynamically recalibrate the tracked US system for rotation, scale factor, and in-plane position offset up to a scale factor. We detect any unexpected change in these parameters through capturing discrepancies in the resulting calibration matrix, thereby assuring quality (accuracy and consistency) of the tracked system. No phantom is used for the recalibration. We perform the task of quality control in the background, transparently to the clinical user while the subject is being scanned. We present the concept, mathematical formulation, and experimental evaluation in-vitro. This new method can play an important role in guaranteeing accurate, consistent, and reliable performance of tracked ultrasound.

6141-97, Poster Session

Embedding VTK and ITK into a visual programming and rapid prototyping platform

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Visualization and image processing of medical datasets has become an essential task for clinical diagnosis support as well as for treatment planning. In order to enable a physician to use and evaluate algorithms within a clinical setting, easily applicable software prototypes with a dedicated user interface are essential. However, substantial programming knowledge is still required today when using powerful open source libraries

such as the Visualization Toolkit (VTK) or the Insight Toolkit (ITK). Moreover, these toolkits provide limited graphical user interface functionality. In this paper, we present the visual programming and rapid prototyping platform MeVisLab which provides flexible and simple handling of visualization and image processing algorithms of VTK/ITK, Open Inventor and the MeVis Image Library by modular visual programming. No programming knowledge is required to set up image processing and visualization pipelines. Complete applications including user interfaces can be easily built within a general framework. In addition to the VTK/ITK features, MeVisLab provides a full integration of the Open Inventor library and offers a state-of-the-art integrated volume renderer. The integration of VTK/ITK algorithms is performed automatically: an XML structure is created from the toolkits' source code followed by an automatic module generation from this XML description. Thus, MeVisLab offers a one stop solution integrating VTK/ITK as modules and is suited for rapid prototyping as well as for teaching medical visualization and image analysis. The VTK/ITK integration is available as package of the free version of MeVisLab.

6141-98, Poster Session

Interactive dual-volume rendering visualization with real-time fusion and transfer function enhancement

H. Macready, J. Kim, D. D. Feng, W. Cai, The Univ. of Sydney (Australia)

Dual-modality imaging scanners combining functional PET and anatomical CT constitute a challenge in volumetric visualization that can be limited by the high computational demand and expense. This study aims at providing physicians with multi-dimensional visualization tools, in order to navigate and manipulate the data running on a consumer PC. We have maximized the utilization of pixel-shader architecture of the low-cost graphic hardware and the texture-based volume rendering to provide visualization tools with high degree of interactivity. All the software was developed using OpenGL and Silicon Graphics Inc. Volumizer, tested on a Pentium mobile CPU on a PC notebook with 64M graphic memory. We render the individual modalities separately, and performing real-time pervoxel fusion. We designed a novel "alpha-spike" transfer function to interactively identify structure of interest from volume rendering of PET-CT. This works by assigning a non-linear opacity to the voxels, thus, allowing the physician to selectively eliminate or reveal information from the PET-CT volumes. As the PET and CT are rendered independently, manipulations can be applied to individual volumes, for instance, the application of transfer function to CT to reveal the lung boundary while adjusting the fusion ration between the CT and PET to enhance the contrast of a tumour region, with the resultant manipulated data sets fused together in real-time as the adjustments are made. In addition to conventional navigation and manipulation tools, such as scaling, LUT, volume slicing, and others, our strategy permits efficient visualization of PET-CT volume rendering which can potentially aid in interpretation and diagnosis.

6141-99, Poster Session

Volume rendering segmented data using 3D textures: a practical approach for intraoperative visualization

N. Subramanian, R. Mullick, V. Vaidya, GE Global Research (India)

Volume rendering has high utility in visualization of segmented datasets. However, volume rendering of the segmented labels along with the original data causes aliasing artifacts due to the sharp discontinuity at the boundaries. This issue is further amplified in 3D textures based volume rendering due to the uncontrollability of the interpolation stage.

We describe an approach which helps minimize aliasing artifacts while maintaining the high performance of 3D texture based volume rendering-both of which are critical for intra-operative visualization. Our approach embeds label information in the channel dedicated for gradient information. Subsequently, during the render stage 2D texture lookups are employed to map voxel colors and opacities based on gradient and original volume intensities. In contrast to previously reported algorithms, our algorithm does not require multiple passes for rendering and supports greater than 4 masks. It also allows for real-time modification of the color/opacities of the segmented structures along with the original data. Additionally, these capabilities are available with minimal texture memory requirements among comparable algorithms. Results are presented on clinical and phantom data.

6141-100, Poster Session

Slice cutting and partial exposing techniques for 3D texture-based volume rendering

L. Wu, V. R. Amin, Iowa State Univ.

Three-dimensional texture-based volume rendering is a technique that treats a 3D volume as a 3D texture, renders multiple 2D object-oriented slices and blends all of them together. This technique is thoroughly developed in computer graphics and medical visualization, and widely accepted for interactive visualization due to continuing advancement of computer hardware. This research aims at developing both fast slice cutting and partial exposing algorithms used in real-time 3D-texture-based volume rendering for image-guided surgery and therapy planning. Inspired by lossless image compression algorithms which compress images by removing the redundant information, the slice cutting algorithms developed in this paper reduce the calculation cost by using the information from previous calculations that avoids unnecessary or redundant calculations. The new slice cutting algorithms integrate the intersection point calculation and the winding procedure for 3D texture-based volume rendering. They also introduce some other additionally useful features, such as section view and slice view without modifying the original 3D texture. The partial exposing techniques developed in this research use computer graphics techniques including stencil buffer, depth buffer and frame buffer manipulations to cutout the undesired area from volume data set instead of physically modifying the original volume data. These two techniques are successfully applied in real-time MRI/CT brain visualization. The new slice cutting algorithms dramatically reduce the computation time compared to traditional slice cutting algorithms. The partial exposing techniques can be applied to achieve arbitrary shape of cutaway with any orientation rather than regular axis-aligned shapes, such as cube, without sacrificing rendering performance.

6141-101, Poster Session

A 3D summary display for reporting of organ tumors (lung nodules)

H. Shen, Siemens Corporate Research; M. M. Shao, Philips Medical Systems

We describe a visualization tool for the reporting of organ tumors such as lung nodules. It provides a 3D visual summary of all the detected and segmented tumors and allows the user to navigate through the display. The detected and segmented nodules are displayed, using surface rendering to show their shapes and relative sizes. Anatomic features are used as references. In this implementation, the two lung surfaces are rendered semi-transparent as the visual reference. However, other references could be used, such as the thoracic cage, airways, or vessel trees. The display is of 3D nature, meaning that user can rotate the objects as a whole, view the display at different angles. The user can also zoom the display at will to see an enlarged view of a nodule. The 3D display is spatially synchronized with the main window that displays the volume data. A click on a nodule in the 3D display will update the main display to the corresponding slice where the nodule is located, and the nodule location will be outlined in the slice that is shown in the main widow. This is a general reporting tool that can be applied to all oncology applications using all modalities, whenever the segmentation and detection of tumors are essential.

6141-102, Poster Session

Graphics hardware-based volumetric medical dataset visualization and classification

Q. Zhang, Robarts Research Institute (Canada); R. A. Eagleson, The Univ. of Western Ontario (Canada) and Robarts Research Institute (Canada); T. M. Peters, Robarts Research Institute (Canada) and The Univ. of Western Ontario (Canada)

Direct volumetric visualization of medical dataset has important application in areas such as minimally-invasive therapies and surgical simulation. We have developed a commodity graphics hardware accelerated 3D medical image visualization system, in which a viewing-direction based dynamic texture slice resampling scheme is proposed and implemented on an Nvidia graphics processing unit (GPU). In popular fixed-slice-distance hardware-based volume rendering algorithms, such as 2D and 3D texture mapping, the non-isotropic nature of the volumetric medical images and the constantly changed viewing rays make it difficult to render medical datasets uniformly during volume rotation, generating noticeable artifacts at some viewing angles. In our algorithm, we utilize graphics hardware to dynamically slice the volume texture according to the viewing directions during the rendering process, in which the slice number can be dynamically increased without additional video memory consumption. Near-uniform slice spacing can be achieved in real-time and updated as the viewing angles change, so improved uniform visual quality is achieved with high rendering performance. To further improve rendering efficiency, we have implemented a multi-resolution scheme within our rendering system, which offers the user the option to highlight the volume of interest (VOI) and render it with higher resolution than the surrounding structures. This system also incorporates a fragment-level interactive post-classification algorithm that modifies the texture directly within the texture unit on graphics card, making it possible to interactively change transfer function parameters and navigate medical datasets in real-time during the 3D medical image visualization process.

6141-103, Poster Session

High quality GPU rendering with displaced pixel shading

H. J. Zhang, J. J. Choi, Georgetown Univ.

Direct volume rendering via hardware accelerated volume texture has positioned itself as an efficient tool for volume visualization. Especially, the traditional ray tracing algorithm is alternatively implemented by the shading language integrated with graphical processing units (GPU). Compared with the traditional CPU-based ray tracer, a high sample rate is needed to achieve the similar high image quality through slice-based volume rendering technique. We proposed a method to use the displaced pixel shading to generate the high quality image with relatively few slices and get the satisfied results. The actual surface position point is reconstructed by the linear interpolation between the outer and inner point, and this surface point is used as the displaced pixel for the iso-surface illumination. To speed up the pixel shader calculation, multi-pass and early Z-culling techniques are used to improve the rendering speed. The first pass simply locates and stores the exact surface Z value of each ray beam using a few pixel instructions, and then the second pass uses relative more instructions to shade the surface at the previous position. A new 3D edge detector from our previous experiment is integrated to provide the more realistic rendering result compared with the widely used gradient normal estimator. A program named DirectView is made based on DirectX 9.0c and HLSL language for volume rendering. Several data sets are tested and the result shows that our algorithm can provide a smoother and more accurate shading image with relative few intermediate slices.

6141-37, Session 8

Integration of real-time X-ray fluoroscopy, rotational X-ray imaging and real-time catheter tracking for improved navigation in interventional cardiac electrophysiology procedures

R. M. Manzke, R. Chan, Philips Research Labs.; G. Shechter, Philips Medical Systems Technologies Ltd. (Israel); S. Sokka, Philips Research Labs.; D. Stanton, Philips Electronics North America; Z. J. Malchano, Massachusetts General Hospital; V. Rasche, Philips Medical Systems; V. Reddy, Massachusetts General Hospital

A novel approach for improved guidance in interventional electrophysiology (EP) procedures is presented which combines rotational X-ray imaging, real-time fluoroscopic X-ray imaging, and real-time catheter tracking. Rotational X-ray data and real-time fluoroscopy data are obtained from a Philips FD10 flat detector X-ray system and are registered with real-time localization data from catheter tracking devices. The visualization and registration of rotational X-ray data with catheter location data enables the physician to better appreciate the underlying anatomy of interest in three dimensions and to navigate the interventional or mapping device more effectively. Furthermore, the fused information streams from rotational X-ray, real-time X-ray fluoroscopy and real-time, three-dimensional catheter locations offer direct imaging feedback during interventions, facilitating navigation and potentially improving clinical outcomes. With this technique one is able to reduce the time required for fluoroscopy during the procedure, since the registered catheter can be visualized with rotational projection views obtained at the start of the intervention.

We present a demonstrator application, which integrates, registers, and visualizes the various data streams. It can be implemented in the clinical work-flow with reasonable effort. Results are presented from imaging experiments and the robustness and the accuracy of this technique are determined based on phantom studies.

6141-38, Session 8

Targeted endo-myocardial injections of stem cells using fused MRI and X-ray guidance

L. F. Gutiérrez, R. DeSilva, E. R. McVeigh, C. R. Ozturk, R. J. Lederman, NHLBI/National Institutes of Health

We have previously described a method to register MR images with live X-ray Fluoroscopy (XF) using fiducial markers and validated this approach in phantom experiments. Here we present the use of this technique to guide a catheter-based procedure in vivo. Using a porcine model of myocardial infarction, direct injections of stem cells were targeted at regions around the infarcted tissue by fusing the MRI-determined infarct location with live XF. Myocardial thickness as measured from the MR images was also displayed to prevent injecting into tissue that was thinner than the injection needle length. The stem cells were mixed with tissue dye for ex vivo examination after sacrifice. 10 ± 3 injections per animal were safely performed in 10 out of 11 Yucatan mini swine. In one animal, operator inexperience resulted in non-hemodynamically significant perforation of the myocardium. Injections could be targeted to the borderzone of even very small infarcts. Injections were classified as intra-infarct, peri-infarct, or remote according to expected location from MR—XF fusion and ex vivo examination. The classifications were (23.7%, 44.7%, 31.6%) and (20.5%, 45.5%, 34.1%) from fusion and tissue dye, respectively. Fiducial-based fusion of MRI and live XF enabled successful targeted endo-myocardial injections of stem cells.

6141-39, Session 8

Endoscopic navigation system using 2D/3D registration

J. B. Hummel, M. Figl, W. Birkfellner, H. Bergmann, Medizinische Univ. Wien (Austria)

The paper describes an interventional computer-aided navigation system aimed at supporting endoscopic navigation and a more accurate collection of biopsy specimen by means of image fusion. In particular, an endoscope which provides the physician with real time ultrasound (US) and a video image, is equipped with a electromagnetic tracking system. A view that corresponds to the actual image of the US scan head is derived from a preoperative computed tomography (CT) slice by means of oblique reformatting. Both views are to be displayed side by side on the computer display. The position of the image acquired by the US scanhead is determined by the miniatured EMTS after applying a calibration of the endoscope's scanhead. The relative orientation between the patient coordinate system and a preoperative dataset (such CT or MR image) is derived from a 2D/3D registration. This was achieved by calibrating an interventional CT data set by means of an optical tracking system using the same algorithm as for the US calibration. Then the correct slice from the interventional CT is used for a 2D/3D registration to the preoperative 3D dataset yieling a high quality image at the correct position. The fiducial registration error (FRE) for the US calibration amounted to 3.6 mm ± 2.0 mm for the optical calibration. For the interventional CT we found a FRE of 0.36 ± 0.12 mm. The error for the 2D/3D registration was 4.2 ± 1.6 mm.

6141-40, Session 8

Minimization of optical tool tracking error using fulcrum correction in minimally invasive interventions with application to prostate biopsy procedure

D. W. Cool, The Univ. of Western Ontario (Canada) and Robarts Research Institute (Canada); S. Shi, D. B. Downey, Robarts Research Institute (Canada); J. Izawa, London Health Sciences Ctr. (Canada); T. M. Peters, A. Fenster, Robarts Research Institute (Canada)

Real-time 3D optical tracking of free-hand imaging devices or surgical tools has been studied and employed for object localization in many minimally invasive interventions. However, the surgical workspace for many interventional procedures is often sub-dermal with tool access through ports from surgical incisions or anatomical orifices. To maintain the optical line-of-sight criterion, external extensions of inserted imaging devices and rigid surgical tools must be tracked to localize the internal tool tips. Unfortunately, tracking by correspondence is very susceptible to noise as orientation errors on the external tracking end compound into both rotational and translational errors on the internal, workspace position. These translational errors are proportional to the length of the probe and the sine of the angulation error. Therefore small angulation tracking errors can quickly compromise the accuracy of the tool tip localization.

We propose a real-time tracking correction technique that uses the rotational fulcrum created by the device entry port to minimize translational and rotational noise errors for tool tip localization. This could apply to many forms of interventions, but we focus on the application to the prostate biopsy procedure for tracking a transrectal ultrasound (TRUS) probe. In vitro studies were performed using the Claron Technology(r) Micron Tracker(c) to track a TRUS probe in a fixed rotational phantom. We were able to accurately calculate the fulcrum position within a ± 5° rotation window and our experimental results showed > 4-fold improvement in RMS localization of the internal TRUS location using fulcrum correction over the raw tracking information.

6141-42, Session 9

Rapid registration of multimodal images using a reduced number of voxels

X. Huang, N. A. Hill, Robarts Research Institute (Canada); J. Ren, The Univ. of Western Ontario (Canada); T. M. Peters, Robarts Research Institute (Canada)

Rapid registration of multimodal cardiac images can improve image-guided cardiac surgeries and cardiac disease diagnosis. While mutual information (MI) is arguably the most suitable registration technique, this method is too slow to converge for real time cardiac image registration; moreover, correct registration may not coincide with a global or even local maximum of MI. These limitations become quite evident when registering real time 3D ultrasound (US) images and dynamic 3D magnetic resonance (MR) images of the beating heart. To overcome these problems, we propose a registration method that uses a reduced number of voxels of the US images, while retaining adequate registration accuracy. Prior to registration we preprocess the images such that only the most representative anatomical features are depicted. By selecting samples from preprocessed images, our method can dramatically speed up the registration process as well as ensure correct registration. We have validated this method for registering US and computed tomography (CT) images of a rib cage phantom and for registering dynamic US and MR images of the beating heart of a volunteer. Experimental results on the rib cage phantom show that our method can achieve adequate registration accuracy (1.46 ± 0.53 mm) in 10 % the computation time of conventional registration methods. Experimental results on in vivo cardiac images demonstrate significant improvements in registration speed without compromising registration accuracy. We believe this method has the potential to facilitate intra-operative image fusion for minimally invasive cardio-thoracic surgical navigation and permit easier and more accurate cardiac disease diagnosis.

6141-43, Session 9

A piecewise function-to-structural registration algorithm for image-guided cardiac catheter ablation

Y. Su, D. R. Holmes III, M. E. Rettmann, R. A. Robb, Mayo Clinic

An extensive simulation study was performed to examine different point-to-surface registration techniques for intra-operative registration of preoperative patient data to points collected with electrophysiologic anatomy mapping systems. Three point-to-surface registration methods were evaluated using simulated points sampled from a preoperative heart model. Downhill Simplex (DS) based method outperformed the Iterative Closest Point (ICP) method and a chamfer transform based method. One hundred simulations were performed under a variety of noise and sampling conditions. Less than four pixels root mean squared distance (RMSD) error was observed when there was a 2-pixel standard deviation Gaussian noise in the point cloud coordinates. This registration error was mainly due to the added noise in the sampled points. A near optimal registration can be achieved when 50 or more points randomly sampled on the surface are used as point samples. Reasonable registration can be achieved when 25 points are used. A motion-compensating approach to registration was evaluated in order to account for the different transformation that each anatomical structure may undergo during the procedure due to respiratory motion and other factors. A piecewise registration method, which registers different anatomical structure independently, was evaluated, and favorable results were obtained as compared to a global registration approach. Further validation is in progress to evaluate the piecewise registration using realistic dynamic phantoms and in vivo animal studies.

6141-44, Session 9

3D soft tissue prediction with a tetrahedral mass tensor model for a maxillofacial planning system: a quantitative validation study

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In this paper we present an extensive quantitative validation study on 3D facial soft tissue simulation for maxillofacial surgery planning. The study group contained 10 patients. In previous work we presented a new Mass Tensor Model to simulate the new facial appearance after maxillofacial surgery in a fast way. 10 patients were preoperatively CT-scanned and the surgical intervention was planned. 4 months after surgery, a post-operative control CT was acquired. In this study, the simulated facial outlook is compared with post-operative image data. Distances between predicted and actual post-operative facial surfaces are quantified and visualized in 3D. As shown, the average median distance measures only 0.46mm and the average 90% percentile stays below 1.6mm. We can conclude that our model clearly provides an accurate prediction of the real post-operative outcome and is therefore suitable for use in clinical practice.

6141-45, Session 9

A Laplace equation approach for shape comparison

E. Pichon, D. Nain, M. Niethammer, Georgia Institute of Technology

In this paper we propose a principled approach for shape comparison. Given two surfaces, one to one correspondences are determined using the Laplace equation. The distance between corresponding points is then used to define both global and local issimilarity statistics between the surfaces. For improved accuracy, we propose a Boundary Element Method. Our approach is applicable to datasets of any dimension and offers subpixel resolution. We illustrate the usefulness of the technique for validation of segmentation, by defining global dissimilarity statistics and visualizing errors locally on color-coded surfaces. We also show how our technique can be applied to multiple shapes comparison.

6141-46, Session 9

Automatic anatomical segmentation of the liver by separation planes

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The conventional Couinaud's classification separates the liver into eight functionally independent anatomical segments, corresponding to the dispersion of the portal vein branches. Surgical oncological liver planning is based on the location of these segments and tumors inside them. Then the detection of the boundaries between these segments constitutes the first step of liver preoperative planning.

The method proposed in this paper, devoted to processing of liver binary images preliminary segmented from CT-scans, has been designed to delineate Couinaud's segments by automatically positioning separation planes between them. It detects a set of landmarks using a priori anatomical knowledge about the liver structures and differential geometrical criteria concerning its shape.

These landmarks are then used to finally determine the position of these separation planes. In order to evaluate the relevance of the method, it has been applied on a database composed of 7 clinical cases. The automatically obtained segment delineations have been compared with manual results provided by two human experts.

The validations proves the method's accuracy for most of the region delineation planes, allowing to automate a significant part of liver preoperative planning.

6141-47, Session 9

Tumor volume measurement and volume comparison plug-ins for ITK

T. R. Popa, Georgetown Univ.; L. Ibanez, Kitware Inc.; E. Levy, K. R. Cleary, Georgetown Univ.

Volume measurement plays an important role in many medical applications in which physicians need to quantify tumor growth over time. For example, tumor volume estimation can help care providers diagnose patients, and can also help them observe the effects of therapy, such as temporary remission. Moreover, tumor volume comparison has important applications. These measurements can help physicians assess surgical outcomes, and can help researchers compare segmentation methods and conduct validation and reliability studies of volume measurements.

For users to quickly check the results of volume data processing, they need a user interface with volume visualization features. Volview, a software application designed by Kitware, provides such an interface, and its "plug-ins" architecture makes it possible to use it as a delivery platform for advanced image processing technology.

In this study, we have developed a new way to evaluate segmentation methods, and we have focused especially on liver tumor segmentation with level sets.

We present a set of algorithms - two volume computing algorithms and three volume comparison algorithms - for segmented tumor data sets. These developments use the Insight Segmentation and Registration Toolkit (ITK) from the National Library of Medicine. These implementations are also available as plug-ins for the VolView package. Semi-automated segmentation plug-ins for VolView are already available.

For volume comparison, we have implemented three methods that we consider vital for a basic segmentation evaluation: maximum surface distance measure, mean absolute surface distance, and volumetric overlap measure.

We have implemented two measures for volume measurement, one that involves voxel counting and another that provides finer volume measurement by anti-aliasing the tumor volume.

6141-48, Session 10

XFEM-based modeling of successive resections for preoperative image updating

L. M. Vigneron, P. A. Robe, Univ. de Liège (Belgium); S. K. Warfield, Brigham and Women's Hospital; J. G. Verly, Univ. de Liège (Belgium)

While an image-guided surgery procedure progresses, preoperative images become increasingly irrelevant as a result of the organ of interest (e.g., the brain) being subjected to various deformations due, e.g., to brain shift, cuts, retractions, and resections. Even if intraoperative images are acquired, preoperative images cannot be discarded, since they are of better quality and some modalities are not available intraoperatively. It is thus critical to update preoperative images in real-time during surgery.

Our approach to updating is based on (1) estimating the displacements of local surfaces (e.g., of cortex, ventricles, and tumor) that are extracted and tracked using successive intraoperative MRI images, (2) estimating displacements throughout the organ volume using a biomechanical model and the Finite Element Method (FEM), and (3) warping preoperative images accordingly.

Conventional FEM has serious limitations for modeling tissue discontinuities associated with cuts, retractions, and resections. Indeed for every intraoperative image showing a new discontinuity, a remeshing must be done, which entails a high computational cost. We propose a new method based on the eXtended Finite Element Method (XFEM) that allows the organ to be modeled by finite elements without explicitly meshing cut surfaces. Discontinuities can then be arbitrarily located with respect to the underlying finite element mesh. In addition, no remeshing is required when the discontinuity changes shape. We have developed and

tested a preliminary end-to-end 2D system for updating preoperative imagery using intraoperative images in the presence of deformations due to brain shift followed by successive resections.

6141-49, Session 10

Comparative study of brain deformation estimation methods

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The shift of brain tissues during surgical procedures affects the precision of Image-Guided Neurosurgery (IGNS). Finite element model-based methods for non-rigidly maintaining registration improve the accuracy of the alignment between the patient and the image volume throughout surgery. A predictive model, also termed the best prior estimate (BPE), the weighted basis solutions (WBS) method, and the adjoint equations method (AEM) have been developed for this purpose. In this paper, we present a quantitative validation study in a series of patient procedures. In addition, we have continued to investigate the sensitivity of the AEM solution to inverse parameter selections in clinical cases. Surface and subsurface displacement data are acquired from intraoperative ultrasound and stereopsis images and are used as "ground truth" in a quantitative study to evaluate the accuracy of model estimates. Several types of clinical deformation are considered, including gravitational sagging, cortical distension, and combinations of collapse and expansion of the exposed parenchyma. The AEM method shows the best overall results. The study of the inversion parameters suggest that the size of the variance in the measurement error, the correlation length and the estimated boundary conditions are important to the results, which is consistent with the findings from previous porcine experiments.

6141-50, Session 10

Integration of patient specific modeling and advanced image processing techniques for image-guided neurosurgery

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A major challenge in neurosurgery oncology is to achieve maximal tumor removal while avoiding postoperative neurological deficits. Therefore, estimation of the brain deformation during the image guided tumor resection process is necessary.

While anatomic MRI is highly sensitive for intracranial pathology, its specificity is limited. Different pathologies may have a very similar appearance on anatomic MRI. Moreover, since fMRI and diffusion tensor imaging are not currently available during the surgery, non-rigid registration of preoperative MR with intra-operative MR is necessary.

This article presents a translational research effort that aims to integrate a number of state-of-the-art technologies for MRI-guided neurosurgery at the Brigham and Women's Hospital (BWH). Our ultimate goal is to routinely provide the neurosurgeons with accurate information about brain deformation during the surgery.

The current system is tested during the weekly neurosurgeries in the open magnet at the BWH. The pre-operative data is processed, prior to the surgery, while both rigid and non-rigid registration algorithms are run in the vicinity of the operating room.

The system is tested on 9 image datasets. A method based on edge detection is used to quantitatively validate the results. 95% Hausdorff distance between points of the edges is used to estimate the accuracy of the registration.

Overall, the minimum error is 1.4 mm, the mean error 2.23 mm, and the maximum error 3.1 mm. The mean ratio between brain deformation estimation and rigid alignment is 2.07. It demonstrates that our results can be 2.07 times more precise then the current technology.

6141-51, Session 10

Automated brain shift correction using a pre-computed deformation atlas

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Compensating for intraoperative brain shift using computational models has shown promising results. Since computational time is an important factor during neurosurgery, a priori knowledge of the possible sources of deformation can facilitate rapid updates in model-updated image-guided systems (MUIGS). In this paper, we use sparse intraoperative data acquired with the help of a laser-range scanner and introduce a strategy for integrating this information with the computational model. The model solutions are computed preoperatively and are combined with the help of a statistical model to predict the intraoperative brain shift. Validation of this approach is performed with measured intraoperative data. The results indicate our ability to predict intraoperative brain shift to an accuracy of 1.3mm ± 0.7mm. This method appears to be a promising technique for increasing the speed and accuracy of MUIGS.

6141-52, Session 10

Replacing the surgical microscope

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The surgical microscope is an indispensable tool in modern neurosurgery. Not only does it provide magnification and proper illumination, but due to the close positioning of its optics allows 3D vision down narrow operation tunnels otherwise unavailable to normal vision. On the other hand its large size and weight accompanying by the massive microscope stands necessary for stability and freedom of movement are a clear drawback. Additionally with the introduction of optically coupled neuronavigation system, the microscope often shadows the required line of sight between navigational tools and the infrared cameras of the system. This results in time consuming repositioning of the microscope when the navigation system is in use. We have evaluated a 3D high definition television system as a substitute for the neurosurgical microscope in a variety of neurosurgical procedures. The system consists of a miniature 3D TV camera with an integrated fiber optic co-axial light source mounted on a lockable flexible arm. The display consists of 2 high definition miniature color TV screens, with accompanying optics, mounted on a frame suspended from a lightweight stand. The TV camera is positioned close to the surgical field and can be easily repositioned as required for an optimal viewing angle. The display once positioned remains stationary in front of the surgeon's eyes enabling the surgery to be carried out in a comfortable position. The system has proven satisfactory in all of the procedures where it has been used.

6141-53, Session 11

Incorporating seed orientation in brachytherapy implant reconstruction

Y. Zhou, A. K. Jain, G. S. Chirikjian, G. Fichtinger, Johns Hopkins Univ.

Intra-operative quality assurance and dosimetry optimization in prostate brachytherapy critically depends on the ability of discerning the locations of implanted seeds. Various methods exist for seed matching and reconstruction from multiple segmented C-arm images. Unfortunately, using three or more images makes the problem NP-hard, i.e. no polynomial-time algorithm can provably compute the complete matching. Typically, a statistical analysis of performance is considered sufficient. Hence it is of utmost importance to exploit all the available information in order to mini-

mize the matching and reconstruction errors. Contemporary algorithms use only the information about the seed center, disregarding useful information about the orientation and length of seeds. While this has little dosimetric impact, it can positively contribute towards seed matching and 3D implant reconstruction accuracy. This can be decisive information when hidden and spuriously segmented seeds need to be matched, where reliable and generic methods are not yet available. We expect orientation information to be particularly useful in reconstructing large and dense implants. To this end, we have developed a method that incorporates information about seed orientation into our previously proposed reconstruction algorithm (MARSHAL), using a closed-form mathematical formulation. Experiments on 85 and 100-seed phantom implants and three images gave an average matching rate of 98.6%. The average reconstruction errors for matched and mismatched seeds were 0.7mm and 1mm for position; 1.10 and 3.30 for orientation, respectively. Thus seed orientation appears to be a powerful additive in fluoroscopy based brachytherapy implant reconstruction.

6141-54, Session 11

A perspective matrix-based seed reconstruction algorithm with applications to C-arm based intra-operative dosimetry

S. Narayanan, P. S. Cho, Univ. of Washington

Most of the currently published seed reconstruction algorithms are based on a simulator based setting where accurate information about the geometry is known. Most physicians performing prostate brachytherapy however use C-arms in the operating room. Information such as source to axis distance, the image acquisition angles, the central axis of the image are not accurately known when C-arms are used. We propose a perspective matrix based reconstruction algorithm that requires no such knowledge of geometry and can be easily derived from known points. The perspective matrix calculates the transformation of a point in 3D space to the imaging coordinate system. An accurate representation of the imaging geometry can be derived from the eleven degrees of freedom (DOF) generalized projection matrix (GPM). In this paper we show how GPM can be derived given the theoretical minimum number of points. We propose an algorithm to compute the seed to X-ray source line given the GPM. The algorithm can be extended to any of the current ray-tracing based seed reconstruction algorithms. Reconstruction using the GPM does not require calibration of C-arms and the images can be acquired at arbitrary angles. The reconstruction is performed in near real-time. Our simulations show that reconstruction using GPM is robust and accuracy is independent of the source to film distance and location of fiducials with respect to points of interest. Seed reconstruction from C-arm images acquired at unknown geometry provides a useful tool for intra-operative dosimetry in prostate brachytherapy.

6141-55, Session 11

Rapid prototype modeling in a multimodality world

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Introduction: Rapid prototype modeling (RPM) has been applied in medicine principally for bones (that are easily extracted from CT data sets) for the planning of orthopaedic or maxillo-facial interventions, and/or custom prostheses and implants. Based on newly available technology, multimodality approaches - that have been making great strides in many medical applications - can now be applied to RPM, particularly for complex musculo-skeletal (MSK) tumors where multimodality often transcends CT alone.

Material and Methods: CT data sets are acquired for primary evaluation of MSK tumors in parallel with other modalities (e.g., MR, PET, SPECT). In our approach, CT is segmented to provide bony anatomy for RPM and all other data sets are registered to the CT reference. Parametric information relevant to the tumor's characterization is then extracted from the multimodality space and merged with the CT anatomy to produce an hybrid RPM-ready model. This model - that can readily accommodate multimodality visualization - is then produced on the latest generation of 3D printers that permits both shapes and colors.

Results: Multimodality models of complex MSK tumors have been physically produced on modern RPM equipment. The new approach has been found to be a clear improvement over the previously disconnected physical RPM and digital multimodality visualization.

Conclusion: New technical developments keep opening doors to sophisticated medical applications that can directly impact the quality of patient care. Although this early work still deals with bones as base models for RPM, its use to encompass soft tissues is already envisioned for future approaches.

6141-56, Session 11

3D ultrasound-based patient positioning for radiotherapy

M. H. Wang, R. N. Rohling, The Univ. of British Columbia (Canada); N. Archip, Harvard Medical School; B. Clark, British Columbia Cancer Agency (Canada)

A new ultrasound-based system for the verification of patient positioning during radiotherapy treatment is described. Our system incorporates the use of a tracked 3D ultrasound scan of the target anatomy during the simulation session. This ultrasound scan is registered to the simulation CT to allow the transfer of planned dose information. Immediately prior to treatment, another 3D ultrasound scan is acquired and automatically registered to the simulation ultrasound, enabling the patient position to be determined inside the LINAC.

Ultrasound-based patient positioning is becoming increasingly popular as a method for accurately localizing the target and reducing dose margins during radiotherapy treatment. Compared to other ultrasound patient positioning systems in use, our system has a number of significant advantages. These include using dedicated 3D probes to acquire data, performing ultrasound image registration automatically, and the potential for reducing the effect of errors such as organ displacement due to ultrasound probe pressure. Another novelty is the direct use of infra-red LEDs from the OPTOTRAK tracking system as fiducial markers in CT.

Experiments carried out on a phantom show that our proposed method of registering simulation CT and 3D ultrasound using infra-red LEDs can achieve a RMS target registration error of 1.67 mm. To investigate the practical feasibility of performing intensity-based automatic registration of 3D ultrasound, a volunteer immobilised in a thermoplastic mask was scanned in the neck region with tracked 3D ultrasound. 44 out of 45 registrations were successful. This indicates that our proposed methods are suitable for neck-based radiation therapy treatment applications.

6141-57, Session 11

CT fluoroscopy-guided robotically assisted lung biopsy

S. Xu, G. Fichtinger, R. H. Taylor, Johns Hopkins Univ.; F. Banovac, K. R. Cleary, Georgetown Univ.

Lung biopsy is a common interventional radiology procedure. One of the difficulties in performing the lung biopsy is that lesions move with respiration. This paper presents a new robotically assisted lung biopsy system for CT fluoroscopy that can automatically compensate for the respiratory motion during the intervention. The system consists of a needle placement robot to hold the needle on the CT scan plane, a radiolucent stereotactic adapter (Z-frame) for registration of the CT and robot coordinate systems, and a frame grabber to obtain the CT fluoroscopy image in real-time. Real-time CT fluoroscopy images are used to noninvasively track out-of-plane motion of a pulmonary lesion. The 3D position of the lesion is automatically determined by real-time image processing and the motion of the robot is controlled to compensate for the lesion motion. The system was validated under CT fluoroscopy using a respiratory motion simulator. A swine study was also done to show the feasibility of the technique in a respiring animal.

6141-58, Session 11

Stochastic modeling, virtual refinement and deterministic fabrication of tissue engineering scaffolds

S. Rajagopalan, R. A. Robb, Mayo Clinic

Tissue engineering attempts to address the ever widening gap between the demand and supply of organ and tissue transplants using natural and biomimetic scaffolds. The current scaffold fabrication techniques can be broadly classified into (a) conventional, irreproducible, stochastic techniques producing biomorphic “secundam naturam” but sub optimal scaffold architecture and (b) rapidly emerging, repeatable, computer-controlled Solid Freeform Fabrication (SFF) producing, “contra naturam” scaffold architecture. This paper presents an image-based scaffold optimization strategy based on microCT images of the conventional scaffolds. This approach, attempted and realized for the first time, synergistically exploits the orthogonal techniques to create repeatable, biomorphic scaffolds with optimal scaffold geometry. The ramifications of this image based computer assisted intervention to improve the status quo of scaffold fabrication might contribute to the previously elusive deployment of promising benchside tissue analogs to the clinical bedside.

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6142-01, Session 1

Imaging in medicine: X-ray computed tomography

E. L. Siegel, Veterans Affairs Medical Ctr.

No abstract available.

6142-02, Session 1

Imaging in medicine: radiography

J. T. Dobbins III, Duke Univ.

No abstract available.

6142-03, Session 1

Low-cost digital radiographic imaging systems: the x-ray light valve

J. A. Rowlands, I. Koprinarov, C. A. Webster, K. Schad, P. Oakham, S. Germann, Sunnybrook and Women's Health Sciences Ctr. (Canada)

In recent years new x-ray radiographic systems based on large area flat panel technology have revolutionized our capability to produce digital x-ray radiographic images. However, AMFPIs are extraordinarily expensive compared to the systems they are replacing. There is a clear need for a low cost imaging system which will replace AMFPIs for completely general applications in radiology.

We examine different approaches that are being considered to make lower cost x-ray imaging devices for digital radiography, including reducing the cost of existing flat panel systems, scanned projection x-ray, computed radiography and optically demagnified x-ray screen/camera systems. All of these approaches are quite expensive and none has the image quality of AMFPIs.

We have identified a revolutionary new approach, the X ray Light Valve (XLV). We propose to combine three well-established technologies: 1. a-Se as an x-ray to image charge transducer, 2. liquid crystal (LC) display technology and 3. digital scanner readout, to achieve our goal of immediate readout with image quality comparable to an AMFPI, while keeping costs low. The XLV system has been shown theoretically to have all the properties required and most of these properties have been demonstrated experimentally. X-ray images created with a high quantum efficiency XLV system have been demonstrated for first time. The resolution has been shown to exceed 10 lp/mm.

6142-04, Session 1

A multi-beam x-ray imaging system based on carbon nanotube field emitters

J. Zhang, G. Yang, Y. Lee, The Univ. of North Carolina at Chapel Hill; Y. Cheng, B. Gao, Q. Qiu, Xintek, Inc.; J. Lu, O. Zhou, The Univ. of North Carolina at Chapel Hill

In most of the current tomographic imaging systems, a single x-ray tube is mechanically rotated around an object to collect the multiple projection images required for tomographic reconstruction. Difficulty in mechanically and precisely rotating a large x-ray tube limits the data acquisition rate and complicates the system design. Carbon nanotube (CNT) based field emission x-ray tube has shown several intrinsic advantages over the thermionic x-ray tubes, including the ability to generate pulsed x-ray in arbitrary waveforms and the potential for miniaturization. Here we report a multi-beam field emission x-ray (MBFEX) source that can generate a scanning x-ray beam to image an object from multiple projection angles without mechanical motion. It includes a gated carbon nanotube field emission cathode with an array of electron emitting pixels, which can be triggered individually to generate a scanning x-ray beam to produce multiple x-ray images from different viewing angles. The performance of this x-ray source was fully characterized. Multilayer images of different imaging phantoms were reconstructed to demonstrate its potential applications in tomographic imaging. The acquisition time of this MBFEX source is only limited by the required x-ray exposure time since no mechanical motion is needed and the electronic switching time is negligible. This can lead to a fast data acquisition for tomographic imaging as well as a simplified experimental setup.

6142-06, Session 2

Comparison of software and human observers in reading images of the CDMAM test object to assess digital mammography systems

K. C. Young, J. J. Cook, J. M. Oduko, The Royal Surrey County Hospital NHS Trust (United Kingdom); H. T. Bosmans, Univ. Ziekenhuizen Leuven (Belgium)

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-observer error. To overcome these problems a software program (CDCOM) is available to automatically read CDMAM images, but the optimal method of interpreting the output is not defined. This study evaluates methods of determining threshold contrast from the program, and compares these to human readings for a variety of mammography systems. Three methods considered are (a) simple thresholding (b) psychometric curve fitting, and (c) smoothing and interpolation. Each method leads to similar threshold contrasts but with different reproducibility, evaluated by a bootstrap method. Method (a) had relatively poor reproducibility with a standard error in threshold contrast of 17.7%. This was reduced to 7.6% when a curve fitting procedure was added. Method (c) had the best reproducibility with an error of 6.7%, reducing to 4.9% with curve fitting. A panel of three human observers had an error of 5.3% reduced to 3.2% by curve fitting. However this does not include inter-observer error. All automatic methods led to threshold contrasts that were lower than for humans. The ratio of human to program threshold contrasts varied with detail diameter and was 1.58±.08 (sem) at 0.1mm and 1.83±.07 at 0.25mm. There was a good correlation between the threshold contrast determined by humans and method (c) (R=0.89 for 0.25mm diameter).

6142-07, Session 2

Anatomically adaptable automatic exposure control (AEC) for amorphous selenium (a-Se) full field digital mammography (FFDM) system

M. J. Varjonen, P. Strommer, Planmed Oy (Finland)

Purpose: This paper will present new anatomically adaptable automatic exposure control (AEC) for amorphous selenium (a-Se) full field digital mammography (FFDM) system.

Method and materials: The AEC operation is based on a principle where the imaging chain components are all modeled into the system software. Once the imaging parameters are all known it enables the system to exactly define the tissue composition imaged and utilize exposure parameters optimal for it. Based on the detected object composition together with the other imaging parameters the amount of signal produced by the amorphous selenium flat panel is exactly calculated and the desired dose of the exposure on the detector is thereby reached accurately. The AEC consists of 48 individual detectors that cover a selenium flat panel area of 100 cm2. It is therefore able to measure a well representative sample of

the tissue to be exposed and adjust the exposure parameters optimal for the tissue composition.

Results: Clinical benefits of AEC are found because of fully understanding the behavior of the x-ray beam together with the calculation models of the AEC. This gives better understanding of breast anatomy in all mammography screening and diagnostic cases, and responses to various tissue compositions by optimizing the image quality and dose.

Conclusion: The spectrum of the x-ray radiation changes remarkably when passing through the various materials on its path. Optimal image quality and dose requires anatomically adjusted imaging parameters present the true breast tissue composition taking account in all different glandular tissue in the breast. Based on the detected object composition together with the other imaging parameters the amount of signal produced by the selenium flat panel is exactly calculated, and the desired image quality and dose is reached accurately.

6142-08, Session 2

Investigation of minimum dose requirements for a dedicated mammotomography system with unique arbitrary orbit capability and quasi-monochromatic beam

R. L. McKinley, M. P. Tornai, Duke Univ.

We use a previously reported optimized quasi-monochromatic beam technique together with unique complex orbits made possible with a novel dedicated cone-beam transmission computed mammotomography (CmT) system to investigate low dose limitations for pendant, uncompressed breasts. Several investigators have used a guideline of dose for CmT at that used for dual-view mammography (4-6 mGy for average breast size). This dose is somewhat arbitrary and it may be possible that we can reduce this significantly without sacrificing image quality using our quasi-monochromatic beam, complex acquisition orbits, offset geometry, and iterative reconstruction techniques. High scatter and low scatter resolution phantoms (acrylic) and a breast phantom with sponge are used to evaluate the effect of dose on resolution and image artifacts. Complex saddle acquisition reconstructions (necessary to overcome cone-beam distortion) are carried out for a total dose at approximately 0.33, 0.17, and 0.08X that of dual-view mammography. Initial reconstructions are also carried out for a cadaver breast from a 48 year-old woman at 0.53X that of dual-view. Iterative reconstruction uses an OSTR algorithm with 0.5x0.5x0.5mm^3 voxels. We evaluate the reconstructions initially for resolution and image artifacts. Resolution was unaffected down to the minimum dose levels tested (i.e. 8% of dual-view). Image artifacts increased as dose was reduced but did not appear to greatly degrade image quality. Preliminary breast tissue results illustrate excellent subjective image quality at approximately half that of dual-view dose levels. Results indicate that our quasi-monochromatic beam together with complex orbit capability, and iterative reconstruction can be used to provide sufficient image quality for practical mammotomography of uncompressed breasts at significantly lower dose than dual view; potentially at least a 2-fold improvement over other approaches using circular orbits and broad beams.

6142-09, Session 2

Comparison of polychromatic and monochromatic x-rays for imaging

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Monochromatic X-rays have been proposed for medical imaging, especially in the mammographic energy range. Our previous investigations have shown that the contrast of objects such as lesions or contrast media can be enhanced considerably by using monochromatic X-rays compared to the common polychromatic spectra. Admittedly, only one specific polychromatic spectrum and one monochromatic energy had been compared.

In this work, we investigated the contrast yielded by a series of different X-ray spectra obtained by varying tube voltage and beam filtering. This resulted in spectra of different mean energies and spectral widths. The objects under examination were aqueous solutions containing different chemical elements such as I, Gd, Dy, Yb, and Bi.

A monoenergetic spectrum at 17.5 keV was obtained using a mammographic X-ray tube with a Mo anode and a monochromator equipped with a HOPG crystal. Moreover, we simulated quasi-monoenergetic spectra at different energies and with different widths.

As a result, we demonstrated that in many cases spectra with an energetic width of some keV yield an equivalent contrast to monoenergetic radiation at the same energy. Therefore, the advantage in image contrast of monochromatic X-rays at 17.5 keV over narrow-band polychromatic X-ray spectra obtained by appropriate filtering is only small. Thus, the additional expenditure for a mammography system with HOPG monochromator that can deliver only a small X-ray dose and the unfavorable slot-scan geometry can be avoided. Monochromatic X-rays will only be justified for diagnostic imaging in a limited number of specific cases.

6142-10, Session 2

Optimization of operating conditions in photon-counting multi-slit mammography based on Si-strip detectors

M. C. Åslund, Kungliga Tekniska Högskolan (Sweden) and Sectra Mamea AB (Sweden); B. Cederström, Kungliga Tekniska Högskolan (Sweden); M. Lundqvist, Sectra Mamea AB (Sweden); M. E. Danielsson, Sectra Mamea AB (Sweden) and Kungliga Tekniska Högskolan (Sweden)

Contrast-to-noise ratio (CNR) and average glandular dose (AGD) measurements have been performed on a photon-counting full-field digital mammography system to determine the optimal operating conditions for different breast thickness (simulated by BR12). Several beam qualities were experimentally evaluated by using different combinations of tube voltage and added filters with a tungsten target. The CNR and AGD were also calculated theoretically for an extended number of operating conditions.

As figure-of-merit for each operating condition, a dose-efficiency was calculated as the CNR squared divided by the AGD. The relative performance of the theoretical model agrees well with the relative measured values. The improved weighing of information achieved with photon-counting compared to energy integrating detectors results in slightly higher optimal tube voltage. The dose efficiency decrease was found to be small if the tube voltage was increased from optimal, extending the range of clinically feasible tube voltages. All filter materials achieved approximately the same CNR for a fixed AGD, if the filter thickness was determined from an image acquisition time constraint. The exceptions were when the energy of the K-edge of the filter material coincided with that of the incident spectrum.

6142-108, Session 2

Applying the European protocol for the quality control of the physical and technical aspects of mammography screening to digital systems

R. VanMetter, M. D. Heath, L. M. Fletcher-Heath, Eastman Kodak Co.

Assuring the image quality of digital systems for mammography screening applications is now widely recognized. It has become imperative that both vendors and buyers understand the application of proposed guidelines to such systems. One example, Part B or the European Protocol for the Quality Control of the Physical and Technical Aspects of Mammography Screening (EPQCM) prescribes criteria for several interconnected image quality metrics. The focus of this study is on the EPQCM “threshold-contrast visibility” test. The goal of this study is to quantify the effects of several experimental variables, including the choice of CDMAM phantom and several methodological choices that are currently unspecified by the EPQCM.

Threshold-contrast visibility requires human observers to score images of a CDMAM or similar 4-AFC targets. The viewing environment and presentation context of individual targets have been varied. In particular, we have studied a recently reported automated display protocol that isolates individual 4-AFC targets, automatically optimizes window/level, and automatically records visual scores. Full-field digital mammography and CR images were scored in our laboratory by trained observers on a diagnostic quality 5-megapixel flat panel monitor. These, as well as synthetic scores, were used to investigate the role of analysis methodology on the resulting threshold-contrast visibility. Both near-neighbor correction (described in the literature supplied with the CDMAM 3.4 phantom) and maximum-likelihood-estimation (MLE) analysis were used. Bootstrap sampling was used to estimate the variance for the MLE method.

Contrast sensitivity has been shown to depend on the viewing environment and presentation context. Optimized presentation software improves the visual scores of small diameter targets by as much as 26%, while reducing the time needed for scoring. However, as in our previous studies, substantial inter- and intra-observer variability remains an important limitation. Strictly following the 4-AFC paradigm generally results in lower threshold-contrast visibility, while reducing the subjectivity of the test. These results for human visual scoring were supported by studies with synthetic data. Finally, preliminary studies revealed systematic differences between two CDMAM phantoms, with one phantom showing 20% lower threshold-contrast visibility, when averaged over all target diameters from 0.1 to 2.0 mm.

In conclusion, the threshold-contrast visibility test recommended by the EPQCM guidelines omits critical experimental details and thereby suffers several substantial sources of variability that can be mitigated by following optimized techniques. As previously reported, other important sources of variability cannot be readily reduced. A set of recommendations, which supplement the EPQCM guidelines are provided that can reduce the variability of test results.

6142-11, Session 3

Evaluation of a photon-counting breast tomosynthesis imaging system

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Digital breast tomosynthesis promises solutions to many of the problems currently associated with projection mammography, including elimination of artifactual densities from the superposition of normal tissues and increasing the conspicuity of true lesions that would otherwise be masked by superimposed normal tissue. We have investigated a novel tomosynthesis system, in which 48 photon counting, orientation sensitive, linear detectors are precisely aligned with the focal spot of the x ray source. The x ray source and the digital detectors are scanned in a continuous motion across the patient; each linear detector collecting an image at a distinct angle. The 48 simultaneously collected images are of very high image quality due to several special characteristics of this detector technology, including essentially complete insensitivity to scattered radiation, a complete lack of additive electronic detector noise, and no residual image, ghosting or blooming artifacts. Data appropriate for tomosynthesis of a volume of height 8 cm can be acquired over a region 24x30 cm2 within 10 seconds. The system is typically operated at 30 to 40 kVp W/Al and yields a mean glandular dose less than or equal to a normal film/screen mammogram. Technique optimization will be discussed. Theoretical and experimental measurements of system modulation transfer function (MTF), noise power spectra (NPS), and detective quantum efficiency (DQE) will be reported. The MTF is determined by the sampling aperture of the detector elements, and the scanning motion; the NPS is white. A Phase I clinical trial involving 30 patients in ongoing. Examples drawn from initial clinical experience will be discussed.

6142-12, Session 3

High-speed large-angle mammography tomosynthesis system

J. W. Eberhard, P. Staudinger, J. Smolenski, J. Ding, A. Schmitz, J. McCoy, A. Al-Khalidy, M. A. Rumsey, W. Ross, C. E. Landberg, B. E. Claus, GE Global Research; P. L. Carson, M. M. Goodsitt, H. Chan, M. A. Roubidoux, Univ. of Michigan Medical Ctr.; J. Thomas, J. Osland, Via Christi Regional Medical Ctr.

A new mammography tomosynthesis prototype system that acquires 21 projection images over a 60 degree angular range in approximately 8 seconds has been developed and characterized. Fast imaging sequences are enabled by a high power tube and generator for faster delivery of the x-ray exposure and a high speed detector read-out. An enhanced a-Si/CsI flat panel digital detector provides greater DQE at low exposure, enabling tomo image sequence acquisitions at total patient dose levels between 150% and 200% of the dose of a standard mammographic view. For clinical scenarios where a single MLO tomographic acquisition per breast may replace the standard CC and MLO views, total tomosynthesis breast dose is comparable to or below the dose in standard mammography. The system supports co-registered acquisition of x-ray tomosynthesis and ultrasound data sets by incorporating an ultrasound transducer scanning system that rotates into position above the compression paddle for the ultrasound exam. Initial images acquired with the system are presented.

6142-13, Session 3

Quantification for contrast-enhanced digital breast tomosynthesis

A. G. Carton, J. Li, M. Albert, S. Chen, A. D. Maidment, Univ. of Pennsylvania

We have investigated the technical requirements necessary to quantitatively analyze contrast-enhanced digital breast tomosynthesis (CE-DBT) exams. Using a simplified physiological model, a maximum concentration of approximately 3mg iodine/cm2 in a 0.5cm thick breast lesion is expected when administering 70ml of 320mg iodine/ml Visipaque(r). This corresponds to only small changes in x-ray transmission; up to 5% for a 4cm thick compressed breast. A set of parameters that may influence accurate measurement of such small concentrations of iodine uptake were investigated. These include exposure reproducibility, linearity of the detector as a function of position, temporal response of the detector, and scatter. Breast tissue equivalent phantoms were imaged with gelatin disks containing iodinated contrast agent solutions of various concentrations and non-iodinated controls. Images were acquired with a GE 2000D (Milwaukee, WI) FFDM system modified to allow CE-DBT, using a Rh target, a 0.25mm Cu filter, 49kVp, 100mAs, and without a grid. Exposure variations account for a 0.3% variation in the total transmitted x ray intensity. We found that the system is non-linear and that the response varies across the detector. The temporal response of the detector is not reproducible; systematic variations in the relative signal intensity were observed when a series of exposures was repeated with exactly the same time-intervals between the individual exposures. As the system lacks a grid, scattered radiation significantly affected response; scatter can account for more than 50% of the recorded signal. Methods for correcting these technical issues will be presented.

6142-14, Session 3

Gaussian frequency blending algorithm with matrix inversion tomosynthesis (MITS) and filtered back projection (FBP) for better digital breast tomosynthesis reconstruction

Y. Chen, Duke Univ. and Duke Univ. Medical Ctr.; J. Y. Lo, Duke Univ. and Duke Univ. Medical Ctr. and Duke Univ.; J. T. Dobbins III, Duke Univ. and Duke Univ. Medical Ctr.

Breast cancer is a major problem and the most common cancer among women. The nature of the two-dimensional mammography makes it very difficult to distinguish a cancer from overlying breast tissues. Digital Tomosynthesis refers to a three-dimensional imaging technique that allows reconstruction of an arbitrary set of planes in the breast from limited-angle series of projection images as the x-ray source moves. Several tomosynthesis algorithms have been proposed including Matrix Inversion Tomosynthesis (MITS) and Filtered Back Projection (FBP) that have been investigated in our lab. MITS shows better high frequency response in removing out-of-plane blur, while FBP shows better low frequency contents. This paper presents an effort to combine MITS and FBP for better breast tomosynthesis reconstruction. A high pass Gaussian filter was designed and applied to three-slice slabbing MITS reconstructions. A low pass Gaussian filter was designed and applied to the FBP reconstructions. A frequency weight parameter was studied to blend the high passed MITS with low passed FBP frequency components. Four different reconstruction methods were investigated and compared with human subject images: 1) MITS blended with Shift-And-Add (SAA), 2) FBP alone, 3) FBP with applied Hamming and Gaussian Filters, and 4) Gaussian Frequency Blending (GFB) of MITS and FBP. Results showed that, compared with FBP, Gaussian Frequency Blending (GFB) has better performance for high frequency contents such as better reconstruction of micro-calcifications and removal of high frequency noise. Compared with MITS, GFB showed more low frequency breast tissue contents.

6142-15, Session 3

Optimizing filtered backprojection reconstruction for a breast tomosynthesis prototype device

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Breast tomosynthesis is being discussed as a method to reduce tissue overlap by imaging and to obtain 3-D information. It is expected that both sensitivity and specificity may be increased compared to conventional mammography. Here, we formulate a filtered backprojection (FBP) reconstruction method for tomosynthesis with linear scanning. The goal is to investigate this procedure and to assess its impact on image quality.

Linear systems theory and the analysis of the sampling scheme in Fourier space lead to a general approach for a FBP procedure. The reconstruction filter consists of the inversion of the projection-backprojection geometry, of a spectral filter to regularize noise and a so called slice thickness filter that controls the width of the reconstructed slices. In addition, the reconstruction pipeline comprises a preprocessing step, a postprocessing module and the visualization. We analyze the influence of the ingredients of this reconstruction scheme on the reconstructed image quality of phantoms and of human subjects from data acquired with a prototype device*) based on an amorphous selenium detector.

We present results for various preprocessing steps such as intensity correction of the projections. We show that by employing the slice thickness filter incomplete sampling artifacts occurring around high contrast objects such as microcalcifications can be reduced. The spectral filter is used to balance noise and spatial resolution. We compare these results with image postprocessing like averaging over several slices.

In conclusion, by the versatile filter design, image quality of FBP reconstruction can be adjusted to the user's needs and to the diagnostic task in a wide range. Our reconstruction pipeline may prove to be an effective tool to optimize the acquisition, the image processing, and the reconstruction parameters.

*) Work in progress. Not commercially available in the U.S.

6142-16, Session 4

Motion artifacts from an inverse-geometry CT system with multiple detector arrays

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Inverse-geometry CT (IGCT) is a promising new scanning geometry. Employing a scanned-anode x-ray source array the system is expected to provide sub-second volumetric imaging with isotropic resolution and no cone-beam effects. Three detector arrays spaced apart laterally can achieve a 50 cm in-plane FOV with a 31 cm source. However, when three separate detector arrays are used, motion artifacts are expected to be different than in conventional CT and need to be assessed. Simulations were performed for two objects representing slow and fast motion as well as periodic and non-periodic motion. The simulations were repeated at different points in the FOV to study motion effects in three regions: 1) the inner 15 cm region which is sampled only by the central detector array, 2) the transition between the inner and outer regions, and 3) the outer region which is sampled by all three detector arrays. 2D simulations assumed 125 "views" acquired in step-and-shoot mode over 360 degrees. A gridding algorithm was used to resample the data into parallel ray data which were then filtered and backprojected. Artifacts from the inner region are exactly like those that arise in a traditional CT system. The most significant artifacts caused by the multi-detector nature of the system are in the outer region, at the angles where the object sampling transitions between detector arrays. These streaking artifacts are comparable to motion artifacts in conventional CT and can be reduced by increasing the overlap region at the expense of FOV size and SNR uniformity.

6142-17, Session 4

Design considerations in cardiac CT

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In cardiac CT temporal resolution is directly related to the gantry rotation time of 3rd generation CT scanners, which cannot be substantially reduced below current standards of 0.33 s - 0.35 s due to mechanical limitations.

Basically Electron Beam Tomography (EBT) provides temporal resolution of 100 ms and below, but suffers from limited spatial resolution and cannot easily be equipped with multi-slice detectors. An alternative to EBT is a dual-source-detector 3rd generation CT scanner. The tube-detector pairs are mounted on the gantry with an angular offset of 900. Due to the mechanical configuration data are acquired at the same temporal position in cardiac cycle. The benefit of the dual source-detector device is threefold: 1. Exposure time for a cardiac image is reduced by a factor of 2 due to the parallel data acquisition. 2. Consequently, the temporal resolution is increased by the same factor 3. Faster volume coverage in cardiac spiral imaging is achieved, because multi-segment reconstruction techniques often applied in single source cardiac CT, that limit the table feed, are not needed any more. In contrast to single source cardiac CT the temporal resolution does not depend on the heart rate. An immediate consequence of 1. and 3. is a significant reduction of patient dose.

For a dual source scanner with 330 ms rotation time a robust temporal resolution of 83 ms is established.

First clinical images demonstrate that excellent image quality is achieved in routine coronary CT angiography examinations independent of the patient's heart rate at pitch values of typically 0.25-0.5.

6142-18, Session 4

Effect of heart rate on CT angiography using the enhanced cardiac model of the 4D NCAT

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We investigate the effect of heart rate on the quality and artifact generation in coronary artery images obtained using helical multi-slice computed tomography (MSCT) with the purpose of finding the optimal time resolution for data acquisition. To perform the study, we used the 4D NCAT phantom, a computer model of the normal human anatomy and cardiac and respiratory motions developed in our laboratory. Although capable of being far more realistic, the 4D NCAT cardiac model was originally designed for low-resolution imaging research, and lacked the anatomical detail to be applicable to high-resolution CT. In this work, we updated the cardiac model to include a more detailed anatomy and physiology based on high-resolution clinical gated MSCT data. The enhanced 4D NCAT was then used to simulate patients with varying anatomies and different heart rates (50-150 beats/minute) and with various cardiac plaques of known size and location within the coronary arteries. For each simulated patient, helical MSCT projection data was generated with data acquisition windows ranging from 100 to 250 ms centered within the quiet phase (mid-diastole) of the heart using an analytical CT projection algorithm. The projection data were reconstructed into CT images, and the contrast to noise ratio of the plaques was then measured to assess the effect of heart rate and to determine the optimal time resolution required for each case. Our results indicate the importance of optimizing the time resolution with regard to heart rate and plaque location for improved CT images at a reduced patient dose.

6142-19, Session 4

Toward time resolved 4D cardiac CT imaging with patient dose reduction: estimating the global heart motion

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Coronary artery imaging with multi-slice helical computed tomography is a promising noninvasive imaging technique. The current major issues include the insufficient temporal resolution and large patient dose. We propose an image reconstruction method which provides a solution to both of the problems. The method uses an iterative approach repeating the following four steps until the difference between the two projection data sets falls below a certain criteria in step-4: 1) estimating or updating the cardiac motion vectors, 2) reconstructing the time-resolved 4D dynamic volume images using the motion vectors, 3) calculating the projection data from the current 4D images, 4) comparing them with the measured ones. In this study, we obtain the first estimate of the motion vector. We use the 4D NCAT phantom, a realistic computer model for the human anatomy and cardiac motions, to generate the dynamic cone-beam projection data sets as well to provide a known truth for the motion vectors. Then, the electrocardiogram-gated helical reconstruction is applied to generate volumetric 4D cine images: f(t,r). Here, we use one heart beat for each position r so that the time information is retained. Next, the magnitude of the first derivative of f(t,r) with respect to time, i.e., |df/dt|, is calculated and summed over a volume-of-interest, which is called the global heart motion index (GHMI). The two end-points of the initial motion estimates are determined by the GHMI. We demonstrate the agreement between the motion vectors estimated from the GHMI and that defined by the 4D NCAT phantom.

6142-20, Session 4

Optimized time window for cardiac CT reconstruction based on Doppler tissue imaging (DTI) data

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Optimal time windowing in cardiac CT reconstruction would permit a reduction of motion artifacts. We used Doppler tissue Imaging (DTI) in order to acquire the speed and displacement of region of interest in one direction with a high temporal resolution. Applied on different segments of coronary arteries, 3D information is recovered in three quasi orthogonal acquisitions (abdominal, parasternal and apical views). Their reproducibility was carried on five healthy subjects. This experiment will allow finding the best time window for reconstruction. A window of half the rotation time (250ms for our CT) was estimated based on minimization of the motion variation in 3D. Since we obtained a high reproducibility between the two sessions (generally <2mm), DTI could be an interesting approach to evaluate motion in 3D. This yields more information as compared to 2D data. Future work will require additional acquisitions and experiments in order to analyze more in depth the variability and the influence of the heart rate. The collected data will be used also as input for our motion platform and CT simulation.

6142-21, Session 4

ECG gated continuous circular cone-beam multicycle reconstruction for in-stent coronary artery imaging: a phantom study

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A retrospectively gated cardiac cone-beam reconstruction for continuous circular acquisition with parallel ECG recording is introduced. It is applied to visualize in-stent restenoses of a moving stent phantom. The 3D back-projection is performed for object points illuminated by the source over an angular range of 360°. The projection data as an input for the reconstruction algorithm are selected on the basis of the ECG in order to reduce multiple rotations to one complete rotation. This is done by calculating a constant window width around phase points in a way that all view angles are covered. This approach guarantees a smooth transition between angular segments selected from different heart cycles. An in-vitro stent phantom consisting of two plastic rods simulating the contrast-medium-filled coronary vessel is investigated. Three degrees of stenoses are implemented. One vessel is covered with a stainless steel stent of 3.0 mm in diameter and 30 mm in length. The phantom is placed within a contrast solution with a density difference to the coronary lumen equivalent to an in-vivo difference. The stent phantom is attached to a dynamic cardiac phantom in order to simulate the heart motion. Projection data of the stent phantom are acquired with a 40-line CT scanner. The temporal resolution of the reconstructed data sets is calculated from the time sensitivity profile, and the image quality is assessed in different motion states. The method delivers images of stents in-vitro at an excellent visibility and is able to rule out in-stent occlusions.

6142-22, Session 5

Impact of noise-on-image reconstruction for diffuse optical tomography

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Diffuse optical tomography (DOT) uses the transmission of near-infrared light through tissue to image absorption and scattering. Especially for mammography applications DOT might become of clinical use.

In this work we present simulation results on the influence of noise on the detectability of lesions for the Philips mammoscope system.

Noise can have a significant impact on the image quality. It can prevent the detection of even high contrast lesions. The influence of noise can be reduced by a proper treatment in the reconstruction algorithm.

But it changes also the effective sampling pattern of the imaging system if noisy data are not used (or used with a lower weight).

In the case of this optical tomography system this means that lesions are only detectable up to a certain depth. This depth depends on where the signal power gets close to the constant noise floor, and on the volume and contrast of the lesion.

Our simulation results show that the detection of lesions with 10 mm diameter and 100% absorption contrast should be possible with the mammoscope system, even in the worst case where the lesion is located in the center of the breast.

6142-23, Session 5

High-resolution multiphoton optical tomography of tissues: an in vitro and in vivo study

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Multiphoton optical tomography based on NIR (near-infrared) femtosecond laser pulses provides non-invasive optical sectioning of skin with high spatial and intracellular resolution and high tissue penetration. The imaging system DermaInspect was used to perform this technology in clinical studies in vivo on patients with suspected melanoma. Pigmented cell clusters based on non-linear luminescence were clearly distinguished from non-pigmented cells in the epidermis using the autofluorescence of endogenous fluorophores like NAD(P)H, flavins, keratin, elastin, collagen and melanin. Some of the investigated tissues showed differences in the structure of the epidermal layers and the presence of dendritic cells compared to normal skin.

Multiphoton laser microscopy was used to visualize extracellular matrix (ECM) structures of native and tissue engineered heart valves. The quality of the resulting 3-D images allowed an exact differentiation between collagenous and elastic fibers. The analysis of heart valve tissues of patients with cardiomyopathy revealed a dramatic loss of its capability to generate SH (second harmonic), indicating a structural deformation of the collagenous fibers, which was virtually impossible to obtain by routine histological or immunohistological staining

These results indicate that NIR femtosecond laser scanning systems can be employed as novel non-invasive optical technology for 3-D resolved ECM component imaging and in vitro and in vivo tissue diagnosis.

6142-24, Session 5

Generalized auto-calibrating technique for image reconstruction from sensitivity encoded MRI data

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MRI with multiple receiver coils (parallel MRI) has been extensively used to achieve higher spatial and temporal resolution, suppress imaging artifacts, and reduced scan time. A number of techniques has been proposed to reconstruct images from reduced (undersampled) k-space datasets acquired by multiple coils. All the techniques require some type of calibration information to describe image encoding by spatially varying coil sensitivities. This information can be derived from supplementary calibration scans. However, this approach increases scan time and can be erroneous due to patient motion between calibration and imaging scans. Auto-calibrating techniques such as the commonly used GRAPPA, do not require calibration scans and estimate reconstruction coefficients directly from acquired k-space data. GRAPPA typically gives good quality results for low undersampling rates. However, strong noise amplification and non-resolved aliasing artifacts makes the technique less applicable in cases of high undersampling. In this work, we have proposed a novel auto-calibrating technique for image reconstruction from sensitivity encoded MRI data that overcomes limitations of the existing auto-calibrating techniques. In the proposed technique (GARSE), specifics of coil sensitivity representation in the image and k-space domains are utilized in the reconstruction in such a way that more trustworthy reconstruction coefficients can be identified resulting in improved image quality. GARSE reconstruction coefficients are spatially variable and adjusted according to local coil sensitivities characteristics, whereas GRAPPA reconstruction coefficients are spatially invariant and, therefore, sub-optimal. Results from MRI studies of phantoms and humans demonstrate substantial advantages of GARSE in comparison with GRAPPA, especially for high undersampling rates.

6142-25, Session 5

Reducing temporal fluctuations in MRI with the multichannel method SENSE

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The use of multi-channel acquisitions is used in MRI to decrease acquisition time. The difference in sensitivity of neighboring channels is used to ensure artifact free images. For studies such as fMRI the temporal stability of the signal is more important than artifacts, since only the signal changes are studied. To ensure artifact free noise representation a new type of weight is used. By effectively selecting and eliminating low SNR pixels, increased temporal stability is achieved. A one-parameter family of masks is defined to ensure that the non-contiguous region can be selected with limited user interaction. Using the parallel imaging method SENSE the proposed method is tested with in-vivo data from 4 subjects, to ensure noise suppression and demonstrate correct assignment of fMRI activation.

6142-26, Session 5

Description of statistical theory of magnetic resonance imaging

T. Lei, Univ. of Pennsylvania

The underlying phenomena in Magnetic Resonance imaging (MRI) physics, reconstruction, and analysis can be described by their statistics.

This paper reports some new developments and focuses on two aspects:

(1) new insights into statistical theory of MRI beyond its conclusions, and

(2) three new applications of this theory spanned from image analysis to imaging physics.

Why MR signals as well as k-space samples are statistically independent?

When k-space samples are independent, why pixels in the reconstructed images are correlated? How does this correlation arise? Are spatially asymptotic independence and exponential correlation coefficient consistent?

Why the homogeneity and scales can be characterized by stationarity and ergodicity? This paper provides answers to these questions.

The first application of statistical theory of MRI is a stochastic model-based image analysis approach. The second application is a sensor array processing approach for detecting distinctive object regions. The third application shows impact of statistical findings of MR image to MRI system designs.

Statistical investigation into MRI not only provides a better understanding the intrinsic features of MRI (analysis), but also leads to an improved design of MRI (synthesis).

6142-27, Session 6

Performance evaluation of a dual-crystal APD-based detector module for positron emission tomography

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Positron Emission Tomography (PET) scanners dedicated to small animal studies have seen a swift development in recent years. Higher spatial resolution, greater sensitivity and faster scanning procedures are the leading factors driving further improvements. We are developing a second-generation animal PET scanner, the LabPET, that combines avalanche photodiode (APD) technology with a highly integrated, fully digital, parallel electronic architecture. This work reports on the performance characteristics of the LabPET quad detector module, which consists of LYSO/LGSO phoswich assemblies individually coupled to reach-through APDs. Individual crystals 2x2x ~10 mm3 in size are optically coupled in pair along one long side to form the phoswich detectors. Although the LYSO and LGSO photopeaks partially overlap, the good energy resolution and decay time difference allow for efficient crystal identification by pulse-shape discrimination. Conventional analog discrimination techniques result in significant misidentification, but advanced digital signal processing methods make it possible to circumvent this limitation, achieving virtually error-free decoding. Preliminary timing resolution results of 3.4 ns and 4.5 ns FWHM have been obtained for LYSO and LGSO, respectively, using analog CFD techniques in reference to a fast plastic detector. However, measurements implementing digital techniques to identify crystals and perform the time discrimination have shown that intrinsic timing resolutions in the range of 2 to 4 ns FWHM can be achieved.

6142-28, Session 6

High voltage protection in active matrix flat-panel imagers

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Various direct and indirect active matrix flat-panel imagers (AMFPI) are being investigated for x-ray imaging. In both direct AMFPI and indirect AMFPI with avalanche gain, a bias potential of several hundred or thousand volts is required to operate the photoconductor. Under the condition of a large amount of radiation exposure between subsequent readout, a potential of > 60 V could appear across the amorphous silicon (a-Si) thin film transistor (TFT) and cause permanent damage. The purpose of this paper is to investigate a simple pixel design for high voltage protection. It uses the pixel electrode as an additional gate for the top channel of an a-Si TFT to drain excess image charge from the pixel electrode until an equilibrium is reached (where the TFT channel current equals the detector signal current) and the pixel potential reaches a predetermined safe maximum value Vpmax. This “dual-gate” TFT structure without additional protective device simplifies the TFT array design and improves yield. However special care is required to understand the characteristics of both top and bottom gate to ensure sufficient detector dynamic range and reliable high voltage protection. A physical model for dual-gate a-Si TFTs was developed and the device parameters were determined by fitting the model to experimentally measured TFT characteristics from a dual-gate a-Si array. Our results showed that the top channel has significantly higher density of interface trap states than the bottom channel. Nevertheless it provides adequate protection of the TFT with Vpmax of ~40 V for typical radiographic exposures.

6142-29, Session 6

Low-noise pixel architecture for advanced diagnostic medical x-ray imaging applications

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The most widely used architecture in large-area amorphous silicon (a-Si) flat panel imagers is a passive pixel sensor (PPS), which consists of a detector and a readout switch. While the PPS has the advantage of being compact and amenable toward high-resolution imaging, reading small PPS output signals requires external column charge amplifiers that produce additional noise and reduce the minimum readable sensor input signal.

In contrast to PPS circuits, on-pixel amplifiers in a-Si technology reduce readout noise by decoupling off-pixel noise sources, such as external charge amplifier and data line noise, from the sensor input. The off-pixel noise is reduced by the charge gain of the pixel amplifier, allowing for low-noise performance. Theoretical calculations and simulation results for gain, linearity, pixel area requirements and noise indicate the applicability of the amplified a-Si pixel architectures for low-exposure, real-time fluoroscopy. In addition, the detailed noise results allow for the computation of noise performance as a function of transistor dimensions for both amorphous silicon and polysilicon technologies, allowing the designer to choose appropriate device dimensions when designing flat-panel imaging circuits.

6142-30, Session 6

A new 2D-tiled detector for multislice CT

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The tremendous increase in speed with which the body can now be scanned using multislice CT has improved the diagnostic ability of the modality, especially in time critical applications involving contrast injection. Advances in photodiode and front-end electronics technology now allow a CT detector module to be made that can be tiled in two dimensions. An array of such modules can be used to easily make a CT scanner with hundreds of slices with the promise of scanning whole organs with a single revolution and further improving diagnostic ability. Recently, the back-illuminated CT photodiode has been developed which has its electrical connections on the underside. With all four sides of the silicon chip free, the photodiodes can be tiled in two dimensions. In addition, improvements in front-end electronics now allow the A/D converters for all photodiode elements to be placed completely behind the photodiode. A prototype detector module has been constructed and tested. Measurements of DQE, MTF, dynamic range and temporal response are presented showing that the module has the same high performance as detectors found in current diagnostic CT scanners. A dynamic range of 250,000:1 at a frame rate of 10,000 fps has been achieved. Alternatively a dynamic range of 1,000,000:1 can be achieved at 2,500 fps. This new compact 2D tiled detector with digital data output can be used as a basic building block for future multislice detection systems enabling larger coverage and the promise of improved diagnostic ability.

6142-31, Session 6

Novel CT detector based on an inorganic scintillator working in photon-counting mode

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Detectors working in photon counting mode offer an interesting alternative to the common charge integrating detectors for computed tomography (CT), because they can potentially measure the energy of every detected X-ray photons and achieve better image contrast sensitivity for a

given dose. Unfortunately, most current X-ray detectors suffer from limited count rate capability, due to a long charge migration time in semiconductor and gas detectors, or a slow decay time in ceramic scintillators. To overcome these difficulties, we propose to use pixel detectors based on fast light emitting inorganic scintillators individually coupled to avalanche photodiodes with parallel, low-noise, fast digital processing electronics to provide real time single event detection and recording. The proposed detector was investigated with 2 x 2 x 10 mm3 Lu1.9Y0.1SiO5 (LYSO), a fast decay time (40 ns), heavy (7.19 g/cc) scintillator that is also suitable for coincidence detection of annihilation radiation (511 keV) in positron emission tomography (PET). Therefore, the detector characteristics make it a good candidate for implementation in a combined PET/CT dual-modality scanner. Although only coarse spectral analysis is possible in the X-ray energy range, it is demonstrated that appropriate CT images for anatomical localization can be obtained at very low dose in counting mode using a PET/CT simulator set up for small animal imaging. Data will be reported on CT image resolution, noise, contrast and dose.

6142-32, Session 6

Three-dimensional columnar CsI model for x-ray imaging system simulations using MANTIS: validating for noise, blur, and light output

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In previous work, we and others have focused the validation of detector models for computational simulations of imaging system performance on matching, to a small difference, specific aspects of the detector's performance, i.e., modulation transfer function or light output. In this work, instead, we selected three parameters that, together, represent a more complete description of the imaging properties of the phosphor screen to be modeled. The performance parameters are the information factor determined from pulse-height spectra, the light output (either in absolute or relative scale), and the point-response function. Using this methodology, we obtained model screens that exhibit good agreement with recent experimental measurements available in the literature, over a wide x-ray energy range. The models are being used in conjunction with MANTIS, a Monte Carlo code for simulating imaging systems that tracks x rays, electrons, and optical photons in the same geometric model with x-ray and electron physics models from the PENELOPE package, and optical physics models from DETECT-II. Examples of the simulation outputs with respect to pulse-height spectra and point-response functions at different x-ray incidence angles will be presented. This study allows us to incorporate realistic detector models into a detailed and complete Monte Carlo simulation of the entire imaging system including the object and its absorbed dose map.

6142-33, Session 7

Evaluation of noise and resolution properties of a penalized-likelihood CT sinogram restoration algorithm

P. J. La Rivière, P. Vargas, The Univ. of Chicago

In this work we perform a detailed study of the resolution and noise properties of a penalized-likelihood sinogram restoration algorithm that we have been developing for preprocessing of computed tomography (CT) data. We have formulated CT sinogram preprocessing as a statistical restoration problem in which the goal is to obtain the best estimate of the line integrals needed for reconstruction from the set of noisy, degraded measurements. The degradations that afflict raw CT data include beam hardening, off-focal radiation, detector afterglow, and electronic crosstalk, among others. We estimate the line integrals by maximizing a roughness-penalized Poisson likelihood-based objective function. The maximization algorithm is based on the separable paraboloidal surrogates strategy and image reconstruction can then proceed by use of existing, non-iterative approaches. We demonstrate that the approach can correct for sinogram degradations, eliminating the image artifacts caused by beam hardening and off-focal radiation. We also evaluate the local modulation transfer function, local noise power spectrum, and local noise equivalent quanta in a numerical test phantom and find that the proposed approach outperforms standard approaches based on deconvolution and shift-invariant filtration.

6142-34, Session 7

Comparison of three sinogram restoration methods

P. Forthmann, T. Köhler, Philips GmbH (Germany); M. Defrise, Vrije Univ. Brussel (Belgium); P. J. La Rivière, The Univ. of Chicago

The raw data acquired during a computed tomography (CT) scan carry the unwanted traces of a number of adverse effects connected with the measurement setup and process. To name a few, these effects include systematic errors like detector crosstalk and afterglow, as well as fluctuations in tube power during the scan, but also statistical effects like photon noise.

The systematic errors can be corrected analytically by inverting the corresponding matrix, but this will be at the cost of increased noise. Successive application of a noise reduction filter, on the other hand, will reduce resolution again. Even if it were possible to find the ideal balance in this tradeoff, it is a fundamental deficiency that the approaches based on direct matrix inversion correspond to a gaussian model and hence do not take properly into account the non-uniform variance of the measurement noise.

An alternative to analytic deconvolution is penalized maximum-likelihood (PL) restoration of the sinogram data with a Poisson model, which better corresponds to the actual statistical distribution of the measurement, and therefore allows to improve the tradeoff between noise and spatial resolution in the deconvolved data.

The objective of this contribution is to confirm the aforesaid by applying the PL method and two exemplary analytical methods to a 3D helical thorax phantom data set, and to quantify the resulting performance differences in terms of noise and resolution.

6142-35, Session 7

Investigation of image lag in a newly built high-speed flat-panel detector-based cone-beam CT imaging system

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A cone-beam CT imaging system has been developed based on a high-speed flat-panel detector specially designed for cone beam CT. This system has shown great potential for early breast cancer detection with high contrast and spatial resolution, and the potential for high-speed dynamic studies. Image lag plays an important role in this newly built system by affecting the image quality. This also determines the tolerable range of the detector frame rate, which is the key factor in the dynamic studies. This paper investigated the relationship of the image lag with various parameters of this new system, including the frame rate, detector modes, kVp, effective dynamic range of the detector, projection data with high contrast objects, image noise level, and spatial resolution. A method to correct the artifacts caused by image lag has been demonstrated. Tradeoff between image noise level and spatial resolution has been made during the correction. Specially designed phantoms for breast imaging were used for phantom studies. Iodinated contrast media was injected into the phantom for the study of image lag caused by high contrast objects. This paper demonstrates strategies to achieve the best possible image quality for the performance of high-speed dynamic studies utilizing cone-beam imaging in the future.

6142-36, Session 7

Design and development of C-arm based cone-beam CT for image-guided interventions

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The objective of image-guided intervention is to improve the efficacy of minimally invasive procedures and reduce morbidity by providing the physician with image-based anatomical and physiological information in real time. In a typical interventional suite, digitally subtracted X-ray projection images (DSA images) provide the image guidance. However, the vessels in DSA images overlap with each other limiting diagnostic power. With the advances in modern large-area flat-panel detectors, C-arm based cone-beam CT has attracted attention as an image-guided intervention platform. In this paper, we will present how to design and develop flat-panel detector based cone-beam CT on a C-arm gantry (GE INNOVA 4100 system, Waukesha, Wisconsin). Both the well-known single circular scanning geometry (C-geometry) and a novel CC-geometry (a scanning geometry that allows us to acquire a complete cone-beam projection data set for exact image reconstruction) were experimentally implemented to acquire cone-beam projection data. Novel cone-beam image reconstruction algorithms (a new approximate image reconstruction algorithm for the circular scanning geometry and a new mathematically exact image reconstruction algorithm for the complete CC-geometry) were developed to reconstruct images. A helical BB-phantom and the P-matrix method were used to calibrate the scanning geometries. A physical phantom was constructed to quantitatively measure the high-contrast spatial resolution, low-contrast soft tissue detectability, and cone-beam artifacts for both scanning geometries. Image corrections were conducted to correct beam-hardening artifacts. Newly euthanized rats were scanned and reconstructed to compare the image quality of single circular scanning geometry and the novel CC-geometry.

6142-37, Session 7

A novel cone beam CT breast-imaging scanner: preliminary system evaluation

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The purpose of the study is to characterize the imaging performance of the newly built prototype system. This CBCTBI scanner system has one x-ray source and one flat panel detector (Varian's PaxScan 4030CB FPD) mounted on a rotating assembly. A patient table is mounted above the rotating tube/detector assembly. The table has a hole through it that allows a woman's breast to hang pendant in the imaging volume at the rotation axis. The tube/detector assembly rotates around the rotation axis and acquires multiple 2D projection images of the uncompressed breast located at the rotation axis in ~10 seconds. The gantry's rotating x-ray tube/detector assembly has two degrees of freedom. Slip ring technology allows continuous rotation of the x-ray tube/detector assembly concentric to the opening in the table to achieve the Circle scan. Also, it has a controlled vertical motion during the rotation to perform spiral scan over 20 cm of travel. The continuous 360° rotation is designed to have speeds up to 1 rev/sec. This system was used for a series of breast-imaging phantom studies, breast specimen studies, and finally for patient studies. The results show that all simulated carcinomas and calcifications can be detected faithfully using the cone beam CT imaging technique with a glandular dose level less than or equal to that of a single two-view mammography exam. The results indicate that the FPD-based cone beam CT imaging system has much better detectability of small breast tumors compared to the conventional mammography imaging system.

6142-38, Session 7

Z-scan cone-beam CT

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In this paper, a novel scanning principle to generate cardiac images with 10~15 ms temporal resolution and 0.5 mm spatial resolution will be presented. Three new features distinguish Z-scan CT from conventional helical cone-beam CT. (1) Multiple x-ray sources will be arranged along the anterior/posterior direction (Z-direction). (2) View sampling is highly sparse. The total number of view angles will be about 300 to cover the entire imaging target (heart). (3) The rotational speed of gantry rotation is very slow, i.e. 20 seconds/rotation compared with 0.3 second/rotation for the state-of-the-art helical 64-slice CT scanner. Numerical simulations were conducted to demonstrate the feasibility of Z-scan CT principle. Using a single x-ray source and a flat-panel imager, static phantom experiments were conducted to test the feasibility of Z-scan principle on an optical bench top. We present the rationale behind Z-scan CT. The system parameters such as tube and detector requirements were also calculated for imaging an iodine filled vessel. The results from both numerical simulations and phantom experiments to test the Z-scan CT scanning principle will be presented.

6142-39, Session 8

Application of x-ray computed tomography based on the refraction contrast to biomedicine

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Immediately after discovery of x-rays, ever since then the contrast in conventional x-ray absorption images is formed by the difference of x-ray absorption coefficient between internal tissues of biological and/or medical substances. Therefore x-ray pictures depicted reflect internally localized distribution of x-ray absorption in object. There comes up one problem: for materials consisting of low-Z elements, such as biological soft tissues conventional absorption based x-ray imaging can hardly reveal their internal structure. In order to solve this problem one may find a very good solution: phase-interference can make soft tissue visible with x-rays by adopting an x-ray interferometer.

A first application of X-ray refraction based CT to a biomedical object has been successfully achieved. This system comprises a double-crystal arrangement of highly perfect silicon crystals with reflection of 220 at 17.5 keV. Each data set of x-ray image involving refraction contrast and absorption contrast consists of two, one was taken on the left flank of the rocking curve while the other at the right flank. The whole data set comprising 900 frames with angle interval of 0.2O has been acquired by a CCD detector. Refraction component of images can be extracted by a mathematical procedure during the data processing. In this study this novel system has been applied to biological sample as object. The experiment was carried out at the 5T vertical wiggler beamline, BL-14B, at the Photon Factory that is in operation of 2.5 GeV, 400 mA.

6142-40, Session 8

3D cryo-section/imaging of blood vessel lesions for validation of MRI data

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Vascular disease is a leading cause of death and disability in the western world. Diagnosis and staging of atherosclerosis is a challenge, especially with regards to the identification of plaque vulnerability. We are developing imaging methods based upon MRI and intravascular microcoils. In order to rigorously validate our algorithms and imaging methods, we have developed a new imaging system that allows one to obtain 3D histology of vessel segments, excised from cadaver and to characterize the tissues

of atheroma using autofluorescense (excitation: 475 nm, emission: >525 nm) and episcopic microscopy bright field images. After embedding the vessel, the block is frozen, and block face microscopic images are taken every 0.2 mm with a resolution of 0.03 mm x 0.03 mm. The series of images is then corrected for uneven illumination, serially registered to one another, and the 3D vessel segment is reconstructed. Some sections are recovered and processed with histological staining for validation. Seven tissue types can be identified from the episcopic images: necrotic core, calcification, lipid pool, media, advantitia, fibrosis, thrombus, and normal intima. Since the whole vessel segment is available, we can accurately register data to images from MR, or other modalities, for validation. In addition, visualization tools such multi-planar reformatting 3D rendering can be used to study plaque morphology.

6142-41, Session 8

Performances of different reflectance and diffuse optical tomographic approaches in fluorescence molecular imaging of small animals

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Optical imaging of fluorescent probes is an essential tool for investigation of molecular events in small animals for drug developments. In order to get high level localization and quantification information of fluorescent labels, CEA-LETI has developed efficient approaches in classical reflectance imaging as well as in diffuse optical tomographic imaging with continuous and temporal signals. This paper presents an overview of the different approaches investigated and their performances.

High quality fluorescence reflectance imaging is obtained thanks to the development of an original “multiple wavelengths” system. The uniformity of the excitation light surface area is better than 15%. Combined with the use of adapted fluorescent probes, this system enables an accurate detection of pathological tissues, such as nodules, beneath the animal’s observed area. Performances for the detection of ovarian nodules on a nude mouse will be shown.

In order to investigate deeper inside animals and get 3D localization, diffuse optical tomography systems are being developed for both slab and cylindrical geometries. For these two geometries, our reconstruction algorithms are based on analytical expressions of light diffusion. Thanks to an accurate introduction of light/matter interaction process in the algorithms, high quality reconstructions of tumors in mice have been obtained. Respective advantages of these two geometries will be discussed, and reconstruction of ovarian and lung tumors on mice will be presented.

By the use of temporal diffuse optical imaging, localization and quantification performances can be improved at the price of a more sophisticated acquisition system. Such a system based on a pulsed laser diode and a time correlated single photon counting device has been set up. Performances of this system for localization and quantification of fluorescent probes are presented.

6142-42, Session 8

Image quality assessment of a pre-clinical flat-panel volumetric micro-CT scanner

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Small animal imaging has recently become an area of increased interest because more human diseases can be modeled in transgenic and knockout rodents. Current micro-CT systems are capable of achieving spatial resolution on the order of 10 μm, giving highly detailed anatomical information. However, the speed of data acquisition of these systems is relatively slow, when compared with clinical CT systems. Dynamic CT perfusion imaging has proven to be a powerful tool clinically in detecting and diagnosing cancer, stroke, pulmonary and ischemic heart diseases. In order to perform this technique in mice and rats, quantitative CT images must be acquired at a rate of at least 1 Hz. Recently, a research preclinical CT scanner (eXplore Ultra, GE Healthcare) has been designed specifically for dynamic perfusion imaging in small animals. Using an amorphous silicon flat-panel detector and a clinical slip-ring gantry, this system is capable of acquiring volumetric image data at a rate of 1 Hz, with in-plane resolution of 150 μm, while covering the entire thoracic region of a mouse or whole organs of a rat. The purpose of this study was to evaluate the principal imaging performance of the micro-CT system, in terms of spatial resolution, image uniformity, linearity, dose and voxel noise for the feasibility of imaging mice and rats. Our investigations show that 3D images can be obtained with a limiting spatial resolution of 2.7 line pairs per mm and noise of ± 50 HU, using an acquisition interval of 8 seconds at an entrance dose of 6.4 cGy.

6142-43, Session 8

Rotating slat collimator design for high-energy near-field imaging

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Certain elements are vital to the body and an imbalance of elements can either be a symptom or cause of certain pathologies. Neutron Stimulated Emission Computed Tomography (NSECT) is a spectroscopic imaging technique whereby the body is illuminated via a beam of neutrons causing elemental nuclei to become excited and emit characteristic gamma radiation. Acquiring the gamma energy spectra in a tomographic geometry allows reconstruction of elemental concentration images. Previously we have demonstrated the feasibility of NSECT using first generation CT approaches; while successful, the approach does not scale well and has limited resolution. Current gamma cameras operate in an energy range too low for NSECT imaging. The orbiting Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI) captures and images gamma rays over the high-energy range equivalent to NSECT’s (3 keV to 17 MeV) by utilizing Collimator-based Fourier transform imaging. A High Purity Germanium (HPGe) detector counts the number of energy events per unit of time, providing spectroscopic data. While a pair of rotating collimators placed in front of the detector modulates the number of gamma events, providing spatial information. Knowledge of the number of energy events at each discrete collimator angle allows for 2D image reconstruction. This method has proven successful at a focus of infinity in the RHESSI application. Our goal is to achieve the same results at a reasonable near-field focus. A gamma-ray, rotating-collimator-detector setup was programmed in the GEANT4 simulation environment and various collimator designs were evaluated in order to achieve enough modulation for 2D image reconstruction. Successful reconstruction in a near-field (50 cm source-to-detector) 3cm x 3cm field of view (FOV) has been achieved with a resolution of 2mm. This is an encouraging first step in achieving 3D tomographic images of small animals.

6142-44, Session 9

Spatial x-ray gating: a tool for automated regional x-ray exposure management

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Regional x-ray exposure management is a class of techniques for x-ray dose reduction and image quality improvement in both radiography and fluoroscopy. The x-ray beam is modulated spatially prior to its interaction with the imaged objects according to their morphology, local dose sensitivities and regions of interest. We present a new class of automated feedback-controlled methods for real-time spatial modulation of an x-ray beam and outline their applications in interventional imaging. The method employs spatial x-ray gating, a technique in which various beam regions are blocked for controlled portions of the frame integration period while the beam intensity is modulated in time. Several configurations are considered that employ oscillating shutter arrays, shutter element rotation, and inter-element interferences. More so than many previously considered

adaptive beam modulators, this method can provide predictable smooth attenuation fields with precise and sensitive controls operating, if desired, automatically in a feedback loop. The proposed methods include image processing algorithms to drive the feedback control mechanism and to remove the effects of beam modulation from the residual images.

6142-45, Session 9

Applying a proposed definition for receptor dose to digital projection images

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Digital radiographs are currently characterized in terms of a variety of incompatible, vendor-specific speed metrics, which make it difficult for users to monitor detector dose. AAPM Task Group 116 was formed to "Standardize an Image Receptor Dose Index for Digital Radiography," prompting the publication of a proposed definition for receptor dose (Proc. SPIE 5745, 442-457, 2005), which can be readily implemented on any system that acquires a projection x-ray image and produces a display-ready image. This paper carries that work forward by demonstrating the applicability of the proposal to a range of digital detector types and to clinical, anthropomorphic-phantom and geometric-phantom images.

Digital receptor dose can be usefully defined for the four ISO beam qualities in terms of the exposure needed to produce a specified display response in a displayed image, analogous to the ISO speed for screen-film images. It requires that the system produce an original image (calibrated in terms of the relationship between system response and exposure for the standard set of x-ray beam qualities defined by ISO-9236-1) and a display-ready image. The receptor dose is computed in terms of the median pixel value in the original image, which corresponds to a reference pixel value in the display-ready image.

The exposure response of CsI, a-Se, and BaFBrI-based digital radiography acquisition systems, as well as commonly used screen-film combinations, have been measured for the four ISO beam qualities. Anthropomorphic phantoms have been used to demonstrate cross-technology receptor-dose agreement when common exposures are used to produce matched renderings. The proposed receptor-dose metric was computed for a sample of 620 clinical images for which body-part thickness technique factors (kV, mAs, and SID) were known. Analysis of this data demonstrates that receptor dose can be a useful predictor of exposure adequacy over a wide range of body parts and thicknesses.

In conclusion, the proposed vendor-independent receptor-dose metric has been shown to produce consistent results across a representative range of digital-receptor technologies for both phantom and clinical images. It has also been shown to produce results that are consistent with existing standards for screen-film technology and thereby provides a consistent measurement bridging the transition to digital imaging.

6142-46, Session 9

The impact of angular separation on the performance of biplane correlation imaging for lung nodule detection

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In this paper, we evaluate the performance of Biplane Correlation Imaging (BCI) using a set of off-angle projections acquiring with an anthropomorphic chest phantom. BCI reduces the effect of anatomical noise, which would otherwise impact the detection subtle lesions in planar imaging. BCI also minimizes the number of False Positives (FPs) when used in conjunction with Computer Aided Detection (CAD) applied to a set of coronal chest x-ray projections by eliminating non-correlated nodule candidates in the images.

In this method, two digital images of the chest are acquired within a short time interval from two slightly different posterior projections. The image data are then incorporated into the CAD algorithm in which nodules are detected by examining the geometrical correlation of the detected signals in the two views, thus largely "canceling" the impact of anatomical noise.

Seventy-one low exposure posterior projections were acquired of an anthropomorphic chest phantom containing tissue equivalent lesions with small angular separations (0.32 degree) over a range of 20 degrees, [-10°, +10°], along the vertical axis. The data were analyzed to determine the accuracy of the technique as a function of angular separation.

The results indicated that the best performance was obtained when the angular separation of the projection pair was greater than 6 degrees. Within the range of optimum angular separation, the number of FPs per image, FPpI, was ~1.1 with average sensitivity around 75%.

6142-47, Session 9

Evaluation of a physical based approach of correction of scatter radiation in thorax cone beam CT

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Cone beam CT (CBCT) enables three-dimensional imaging with isotropic resolution. X-ray scatter management is a challenging task for quantitative CBCT imaging of thorax: scatter radiation level is significantly higher on cone beam systems compared to collimated fan beam systems. The effects of this scattered radiation are cupping artifacts, streaks, and quantification inaccuracies. The beam stops conventional scatter estimation approach can be used for CBCT but leads to a significant increase in terms of dose and acquisition time. At CEA-LETI, an original scatter management process without supplementary on-line acquisition has been developed, the API (Analytical transformation Plus Indexation based) method. This method of

scatter correction is based on two steps: scatter calibration through off-line acquisitions in order to evaluate the level of scatter radiation on tomographic projections and analytical transformation issued from physical equations in order to estimate the shape of scatter radiation projections. This approach has been applied with success in bone densitometry and mammography. This paper presents in detail the API method and evaluates it in CBCT for thorax phantoms. To compare different scatter correction approaches, tomographic reconstructions were performed on rough data corrected from scatter by API and by classical beam stops approach. The API method provides results in good agreement with the beam stops array approach, suppressing cupping artifact. The results indicate that the API method is effective for quantitative CBCT imaging of thorax. Compared to a beam stops array method it needs a lower x-ray dose and shortens acquisition time.

6142-48, Session 9

Scatter correction for cone-beam computed tomography using simulated object models

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Scattered radiation is a major source of artifacts in cone-beam computed tomography. In this paper, a novel software-based method for retrospective scatter correction is described and evaluated. The method is based on estimating a simple geometric model (e.g., a homogeneous water-like

ellipsoid) of the imaged object from the set of acquired projections. This is achieved by utilizing a mathematical optimization procedure to determine the model parameters for which there is maximum correspondence between the measured projections and the projections of the model. Subsequently, Monte-Carlo simulations of this model are used for calculation of scatter estimates for the acquired projections. Finally, using the scatter-corrected projections, tomographic reconstruction is conducted by means of cone-beam filtered back-projection. The correction method is evaluated using different simulated and experimentally acquired projection data sets, as well as using clinical data from neuro interventions.

6142-49, Session 9

Development of next generation digital flat panel catheterization system: design principles and validation methodology

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Purpose: With the introduction of the first cardiac digital flat panel angiography (DFP) system in 2000 (GE- Innova 2000), it became evident that conventional design principles and metrics of image capture and clinical performance had to be amended in light of performance improvements and digital detector technology attributes. The design of the next-generation DFP system today requires pushing further the limits of metrics such as fluoroscopic detective-quantum-efficiency (DQE), focusing on increased visualization of rapidly moving vessels surrounded by air filled lungs, the spine and diaphragm over the entire dynamic range and validation of the improvements in performance through a combination of standardized methods and new tests simulating critical clinical tasks. This abstract discusses design improvements of the next generation DFP system (Innova 2100IQ) and validation techniques to benchmark clinical performance wrt the Innova 2000 system as well as other state of the art DFP systems collectively representing the industry performance standard.

Methods: Specific design improvements in the Innova 2100IQ system include a new detector with significant improvement in DQE at fluoroscopic (73% at 1μR) and record (79%) doses, intelligent xray exposure management, a high power tube coupled with enhanced spectral filtration and sophisticated dynamic range management algorithms. Validation was conducted using both the standard SCAI-NEMA benchmarking methodology (including dose and six independent image quality parameters) and a blinded-reviewer study using a newly developed moving-stent anthropomorphic chest (CRMSAC) phantom. The CRMSAC phantom consisted of five fully deployed coronary stents placed along the expected paths of the left and right coronary arteries and driven by a computerized motor-controlled stage simulating coronary artery motion profiles. A stationary chest phantom was placed over the moving stage. SCAI-NEMA data was acquired for simulated patient sizes (20 and 30cm thickness) at 15 fps fluoro-low mode, and results averaged across all fields of view on the new GE Innova 2100IQ system and the GE Innova 2000 and for the equivalent 17 cm side / 25 cm diagonal FOV set up for the 2 non-GE DFP systems at 20 cm thickness. Fluoroscopic image sequences were acquired of the CRMSAC phantom on all systems and sequenced in random order. Four blinded reviewers ranked the visibility of each stent in an image sequence for a subset of images on a likert scale. Results were averaged over all viewers.

Results: The Innova 2100IQ system demonstrated improved static and moving guidewire visibility and iodine target visibility performance compared to the Innova 2000 at reduced dose (refer table 1 in supplemental doc). The CRMSAC phantom study in parallel revealed a significant difference ($p<=0.05$) in stent visibility (Table 2). The Innova 2100IQ also demonstrated higher dynamic range and improved stationary and moving wire visibility at equivalent/ lower doses wrt the non-GE systems (Table 3). The blinded CRMSAC phantom review wrt the other DFP systems is currently underway.

Conclusions: Both the SCAI-NEMA and CRMSAC phantom measurements confirm the Innova 2100IQ design goal of providing improvements in device and vessel visibility aspects in a cardiac environment marked by anatomical motion against a wide range of tissue densities wrt the Innova 2000 system. Images and measurement data across other DFP systems will also be shared. In addition to the individual SCAI_NEMA image quality parameters, the CRMSAC phantom test methodology may help provide a single figure of merit by integrating many system behaviors into one clinically relevant observer test.

6142-50, Session 10

High-performance dual-energy imaging with a flat-panel detector: imaging physics from blackboard to benchtop to bedside

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The application of high-performance flat-panel detectors (FPDs) to dual-energy (DE) imaging offers the potential for dramatically improved detection and characterization of subtle lesions through reduction of "anatomical noise," with applications ranging from thoracic imaging to image-guided interventions. In this work, we investigate DE imaging performance from first principles of image science to preclinical implementation, including: 1.) generalized task-based formulation of NEQ and detectability as a guide to system optimization; 2.) measurements on a DE imaging benchtop; and 3.) a preclinical system developed in our laboratory for cardiac-gated DE chest imaging in a research cohort of 100 patients. Theoretical and benchtop studies directly guide clinical implementation, including detector selection, optimal kVp, filtration, dose allocation, and DE image decomposition. The advantages associated with double-shot versus single-shot DE imaging are quantified in terms of the dual-energy NEQ and detectability. Optimal kVp are found to depend strongly on dose, ranging from [60/120] kVp at low-dose to [90/150] kVp at high-dose. Filters are investigated that not only harden the high-kVp beam (e.g., Cu or Ag) but also soften the low-kVp beam (e.g., Ce or Gd). Optimal dose allocation between low- and high-kVp images is found to depend on dose and body habitus, ranging from ~0.55 at high-dose to ~0.25 at low dose. Fourier-based selection of tissue decomposition provides a guide to optimal DE reconstruction. Preclinical DE images afford valuable testing and verification of optimal deployment, facilitating the development of DE CAD and comparison of DE imaging performance to low-dose CT and radiography.

6142-51, Session 10

The impact of cardiac gating on the detection of coronary calcifications in dual-energy chest radiography: a phantom study

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The detection of coronary calcifications with CT is generally accepted as a useful method for predicting coronary artery disease. Film-screen X-ray and fluoroscopy have also been shown to yield high predictive value for coronary disease diagnosis, but have minimal sensitivity. Recently, flat-panel detectors capable of dual-energy (DE) techniques have enabled the separation of soft-tissue and bone from images. Clinical studies report substantially improved sensitivity for the detection of coronary calcifications using these techniques. However, heart motion causes minor artefacts from mis-registration of calcified structures and soft-tissue structures, resulting in inconsistent detection. This research examines whether gating improves the reliability of calcification detection. Single-energy, and gated, and non-gated DE imaging techniques are examined in a dynamic phantom model.

An anthropomorphic phantom was developed to simulate both cardiac and soft-tissue motion, and generate ECG-like output signals. A gating system was developed to synchronize two DE exposures to a repeated phase of the cardiac cycle. The phantom and motion artefact accuracy was verified by comparison with clinical images of patients with calcifications. The detection of calcifications in non-gated, and gated techniques was compared to standard techniques.

Gating reduces the effect of motion artifacts in the DE images. Without

gating, motion artefacts cause greater variability in calcification detection. With gating, the detection rate is more consistent.

The effects of motion on DE cardiac calcification detection have been demonstrated and characterized in a phantom model that mimics the clinical scenario for dual-energy examinations. Potential exists for reliable cardiac calcification detection with gated dual-energy radiography.

6142-52, Session 10

Accuracy and precision of dual energy CT imaging for the quantification of tissue fat content

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We present the analysis of the accuracy and precision of dual energy material basis decomposition for the quantification of tissue fat content in computed tomography. We compare the benefits of a pre-reconstruction dual energy imaging technique versus image based dual energy decomposition technique using a numerical simulation. A phantom containing plastics of known composition is measured to validate the technique. The accuracy of the image based dual energy decomposition technique is contingent on the amount of beam hardening encountered in the phantom. The accuracy of the pre-reconstruction dual energy technique depends on how accurately the system spectral response can be modeled. In both cases the precision of the dual energy imaging is determined by the photon flux.

6142-53, Session 10

Dual-energy imaging using a photon counting detector with electronical spectrum-splitting

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This paper presents a dual-energy imaging technique optimized for contrast-enhanced mammography using a photon counting detector. Each photon pulse is processed separately in the detector and the addition of an electronic threshold near the middle of the energy range of the x-ray spectrum allows discrimination of high and low energy photons. This effectively makes the detector energy sensitive, and allows the acquisition of high- and low-energy images simultaneously. These high- and low-energy images can be combined to dual-energy images where the anatomical clutter has been suppressed. By setting the electronic threshold close to 33.2~keV (the k-edge of iodine) the system is optimized for dual-energy contrast-enhanced imaging of breast tumors. Compared to other approaches, this method not only eliminates the need for separate exposures that might lead to motion artifacts, it also eliminates the otherwise deteriorating overlap between high- and low-energy spectra.

We present phantom dual-energy images acquired on a prototype system to illustrate that the technique is already operational, albeit in its infancy. We also present a theoretical estimation of the potential gain in tumor signal-difference-to-noise ratio when using this electronic spectrum-splitting method as opposed to acquiring the high- and low-energy images separately with double exposures with separate x-ray spectra. Assuming ideal energy sensitive photon counting detectors, we arrive at the conclusion that the signal-difference-to-noise ratio could be increased by 145% at constant dose. We also illustrate our results on synthetic images.

6142-54, Session 10

Multispectral single-scan lung imaging system: part I-initial feasibility

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This paper describes a system for multi-spectral single-scan lung imaging. The proposed approach relies on a low noise detector sampled at a high rate. The proposed method overcomes limitations of CCD time-and-delay integration slot-scanning systems. The system design and preliminary specifications are described. The results of initial spectral and system simulations in support of system feasibility per the outlined specifications are described. Initial investigations support the potential of the proposed approach to alleviate four shortcomings of the current digital flat-panel approach to chest radiography: (i) by enabling dynamic multi-spectral imaging in a single scan, the approach reduces the time delay between exposures, thus reducing sensitivity to motion; (ii) the approach enables dynamic technique feedback and technique adaptation, eliminating the need for a pre-exposures and reducing the likelihood of poor x-ray techniques in local image areas; (iii) by enabling direct measurement of the scatter field, the proposed method allows further scatter correction resulting in image quality improvements; (iv) finally, full-frame sampling of a digital detector allows imaging of the beam penumbra, thereby reclaiming the detection quantum efficiency loss due to over-collimation in current TDI slot-scanning approach; the resulting DQE potentially exceeds that of flat-panel detectors by a factor up to two.

6142-55, Session 11

Simulated and experimental technique optimization of dual-energy radiography: abdominal imaging applications

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With growing clinical acceptance of dual-energy chest radiography, there is increased interest in the application of dual-energy techniques to other clinical areas. This paper describes the creation and experimental validation of a poly-energetic signal-propagation model for technique optimization of new dual-energy clinical applications. The utility of this model is verified using phantom experiments simulating typical abdominal radiographic applications such as intravenous urography (IVU) and the detection of pelvic and sacral bone lesions in the presence of bowel gas.

The model is composed of a spectral signal propagation component and an image-processing component. The spectral propagation component accepts detector specifications, x-ray spectra, phantom and imaging geometry as inputs, and outputs the detected signal and estimated noise. The image-processing module performs dual-energy logarithmic subtraction and returns figures-of-merit such as contrast and CNR, which are evaluated in conjunction with Monte Carlo calculations of dose.

Phantoms assembled from acrylic, aluminum, and iodinated contrast-agent filled tubes were imaged using a range of kVp's and dose levels. Simulated and experimental results were compared by dose, clinical suitability, and system limitations in order to yield technique recommendations that optimize one or more figures of merit.

The model accurately describes phantom images obtained in a low scatter environment. For the visualization of iodinated vessels in the abdomen and the detection of pelvic bone lesions, both simulated and experimental results indicate that dual-energy techniques recommended by the model yield significant improvements in CNR without significant increases in patient dose as compared to conventional techniques.

6142-56, Session 11

Light transport in trabecular bone: Monte Carlo simulation based on 3D triangle meshes

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Light transport in trabecular bone is not well understood despite its clinical interest. Recent experimental studies on optical bone biopsies lack models that relate their measurements to the underlying morphology and thus to tissue condition. Laser surgery can also benefit from a better understanding of energy distribution in cancellous bone. A novel Monte Carlo (MC) simulation environment, able to efficiently compute complex geometries and account for refraction and reflection on tissue boundaries has been developed to provide the missing insight. The geometry description is based on a 3D triangle mesh organised in a bounding-volume hierarchy. This efficient structure allows a fast photon-surface intersection test,

ensuring a sufficient number of photon paths and thus a good signal-to-noise ratio. The simulation program has been validated against well-known problems of refractive optics and turbid media. The new tool has been applied to high-resolution models of trabecular bone based on microCT scans, indicating that a number of significant effects have been, up to now, disregarded. More specifically, light guiding by diffuse reflectance and specular reflectance on the trabeculae seems to have a fundamental impact on long-range light transport. The structure related anisotropy that this light guiding should produce is certainly remarkable.

Calculation of time resolved signals in transmission and reflectance geometries has been demonstrated, paving the way to numerical evaluation of new minimally invasive diagnostic techniques, and offering a link to evaluation of Optical Coherence Tomography (OCT) in complex heterogeneous geometries. Preliminary experimental results on the environment and the observed effects are presented.

6142-57, Session 11

Optimal spectra for indirect detector breast tomosynthesis

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The detection of lesions in conventional mammography is a difficult task, predominantly due to the masking effect of superimposed parenchymal breast patterns. Breast tomosynthesis is a technique that has been proposed to reduce this masking effect, by providing the radiologist with tomographic image slices through the breast. The goal of this research was to investigate the impact of varying x-ray spectra on image quality of breast tomosynthesis using an indirect CsI based detector. The ideal observer SNR was used as a figure-of-merit, under the assumption that the imaging system is linear and shift-invariant. Computation of the ideal observer SNR used a serial cascade model to predict signal and noise propagation through the detector, as well as a realistic model of the lesion detection task in breast imaging. A commercial, indirect detector breast tomosynthesis prototype system was modeled which acquires 11 projection views by rotating the x-ray tube over a 50 degree angular range, with the breast and detector remaining stationary. Specific attention was focused on the impact of electronic noise for indirect detector breast tomosynthesis. Three different target/filters were studied including Mo/Mo, Mo/Rh, and W/Rh. Spectra were scaled to give a total of 2.4 mGy average glandular dose to the breast. It was observed that the W/Rh target/filter exhibited the best performance. In addition, electronic noise was observed to have a moderate effect on the SNR with more impact for thinner breasts and lower kVp settings. In general, electronic noise increased the optimal kVp setting slightly.

6142-58, Session 11

Development of a computer-generated model for the coronary arterial tree based on multislice CT and morphometric data

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Accurate modeling of coronary circulation provides a better understanding of cardiovascular diseases and their underlying causes. To study the coronary circulation, a computer generated 3D model for the coronary arterial tree was developed based on the knowledge from two datasets: (1) gated multi-slice computed tomography (MSCT) angiographic data obtained from a normal human subject and (2) statistical morphometric data obtained from several porcine hearts. The main coronary arteries and heart structures were segmented from the MSCT data to define the initial segments of the vasculature and geometrical details of the boundaries. An iterative rule-based computer generation algorithm was then developed to extend the coronary artery tree beyond the initial segmented branches. The algorithm was governed by the following factors: (1) the statistical morphometric measurements of the connectivities, lengths, and diameters of the arterial segments, (2) repelling forces from other segments and boundaries, and (3) optimality principles to minimize the drag force at each bifurcation in the generated tree. Using this algorithm, the segmented coronary artery tree from the MSCT data was optimally extended to create, a 3D computational model of the largest six orders of the coronary arterial tree. The new method for generating the 3D model is effective in imposing the constraints of anatomical and physiological characteristics of coronary vasculature. When combined with the 4D NCAT phantom, a computer model for the human anatomy and cardiac and respiratory motions, the new model provides a unique tool to study cardiovascular characteristics and diseases through direct and medical imaging simulation studies.

6142-59, Session 11

Monte Carlo simulation of x-ray scatter based on patient model from digital breast tomosynthesis

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We are developing a patient-specific scatter assessment method using digital breast tomosynthesis (DBT) reconstructions. A Monte Carlo (MC) package was used to simulate the x-ray photon transport in breast volume. The x-ray spectrum was taken from published data. The acquisition geometry, the x-ray tube target/filter, kVp and HVL were identical to those in a prototype DBT system. The volumetric breast composition model was generated from actual DBT reconstruction, which is a 3D attenuation coefficient map of a breast volume. The DBT reconstruction was obtained using a maximum likelihood algorithm from eleven projections. At each DBT projection angle, primary and scattered x-ray distributions on the detector plane were generated by MC simulation. Effects of x-ray spectrum, breast shape, voxel size, and attenuation-to-composition mapping methods were investigated. For a 4.6 cm compressed patient breast and a 26 kVp Rh/Rh x-ray beam, the scatter to primary ratio (SPR) ranges from 0.1 to 0.6 depending on pixel location, projection angle, and breast composition mapping. The distribution of scattered x-rays is strongly dependent on the shape of the breast volume, indicating that accurate scatter correction should be breast specific. When the breast composition is changed from 30% adipose 70% fibroglandular to 55% adipose 45% fibroglandular, the SPR changes less than 5%, but scatter itself increases more than 20%. For the same skin entrance exposure, the shape and the magnitude of the scatter profile is sensitive to the beam energy in a monoenegetic beam simulation. The method developed may be used for scatter correction in DBT.

6142-60, Session 11

Breast cancer diagnosis using neutron simulated emission computed tomography: dose and count requirements

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Neutron Stimulated Emission Computed Tomography (NSECT) was evaluated as a potential technique for breast cancer diagnosis. NSECT can form a 3D tomographic image with an elemental (isotopic) spectrum provided at each reconstructed voxel. The target is illuminated (in vivo) by a neutron beam that scatters in-elastically producing characteristic gamma emission that is acquired tomographically with a spectrograph. Images are reconstructed of each element in the acquired spectrum. NSECT imaging was simulated for benign and malignant breast masses. A range of the number of incident neutrons was simulated from 19 million to 500k neutrons. Characteristic spectra were analyzed for statistically significant differences between benign and malignant. For 1 million incident neutrons, there were 61 differences in the spectra that were statistically significant ($p < 0.05$). Of these, 23 matched known characteristic emission from 6 elements that have been found in the breast (Br, Cs, K, Mn, Rb, Zn). The dose to two breasts was less than 3% of the dose of a 4 view screening mammogram. Increasing the dose to 52% of the mammogram (19 million neutrons) provided 89 significant spectral differences that

matched 30 known emissions from 7 elements that have been found in the breast (Br, Co, Cs, K, Mn, Rb, Zn). Decreasing the dose to 1.4% (500K neutrons) eliminated all statistically significant matches to known elements. This study suggests that NSECT may be a viable technique for detecting human breast cancer in vivo at a reduced dose compared to 4 view screening mammography.

6142-61, Session 12

Theoretical investigation of very high quantum efficiency, segmented, crystalline detectors for low-contrast visualization in megavoltage cone-beam CT

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Megavoltage cone-beam computed tomography using active matrix flat-panel imagers (AMFPIs) is a promising candidate for providing important image guidance for radiation therapy. Unfortunately, the practical clinical implementation of this technique is limited by the relatively low detective quantum efficiency (DQE) of conventional megavoltage AMFPIs, which is approximately 1% at 6 MV. However, a recently developed engineering prototype AMFPI, based on a 40 mm thick segmented CsI:Tl converter, has exhibited DQE values considerably higher than those observed for conventional megavoltage AMFPIs. This allows the prototype to produce high quality projection images at doses significantly lower than those required for conventional megavoltage AMFPIs. It is therefore interesting to examine upper limits on performance when such devices are used to form cone beam tomographic images. In this study, Monte Carlo-based techniques were used to estimate the contrast-to-noise ratio (CNR) from tomographic images of a cylindrical phantom. The phantom consists of soft tissue-equivalent materials corresponding to liver, brain, and breast, embedded in water. CNR was estimated for 10 and 40 mm thick segmented detector configurations based on two scintillator materials (CsI:Tl and BGO) and incorporating septal walls with different densities. The results obtained from these early studies suggest that such converters can provide visualization of soft tissue contrast (e.g., electron density differences of 2%) in tomographic images at doses comparable to those encountered in kilovoltage cone-beam CT.

6142-62, Session 12

CMOS cassette for digital upgrade of film-based mammography systems

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While full-field digital mammography (FFDM) technology is gaining clinical acceptance, the overwhelming majority (96%) of the installed base of mammography systems are conventional film-screen (FSM) systems. A high performance, and economical digital cassette-based product to conveniently upgrade FSM systems to FFDM would accelerate the adoption of FFDM, and make the clinical and technical advantages of FFDM available to a larger population of women. The planned FFDM cassette is based on our commercial Digital Radiography (DR) cassette for 10cm x 10cm field-of-view spot imaging and specimen radiography, utilizing 150μm columnar CsI(Tl) scintillator and 48μm active-pixel CMOS sensor modules. Unlike a Computed Radiography (CR) cassette, which requires an external digitizer, our DR cassette transfers acquired images to a display workstation within approximately 5 seconds of exposure, greatly enhancing the patient flow. We will present the physical performance of our prototype system against other FFDM systems in clinical use today, using established objective criteria such as the Modulation Transfer Function (MTF), Detective Quantum Efficiency (DQE), and subjective criteria, such as a contrast-detail (CD-MAM) observer performance study. Driven by the strong demand from the computer industry, CMOS technology is one of the lowest cost, and the most readily accessible technologies available for FFDM today. Recent popular use of CMOS imagers in high-end consumer cameras have also resulted in significant advances in the imaging performance of CMOS sensors against rivaling CCD sensors. This study promises to take advantage of these unique features to develop the first CMOS based FFDM upgrade cassette.

6142-63, Session 12

New light-amplifier-based detector designs for high spatial resolution and high sensitivity CBCT mammography

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New cone-beam computed tomographic (CBCT) mammography system designs are presented where the detectors provide high spatial resolution, high sensitivity, low noise, wide dynamic range, negligible lag and high frame rates similar to features required for high performance fluoroscopy detectors. The x-ray detectors consist of a phosphor coupled by a fiber-optic taper to either a high gain image light amplifier (LA) then CCD camera or to an electron multiplier CCD. When a square-array of such detectors is used, a field-of-view (FOV) to 20 x 20 cm can be obtained where the images have pixel-resolution of 100 μm or better. To achieve practical CBCT mammography scan-times, 30 fps may be acquired with quantum limited (noise free) performance below 0.2 μR detector exposure per frame. Because of the flexible voltage controlled gain of the LA's and EMCCDs, large detector dynamic range is also achievable. Features of such detector systems with arrays of either Gen2 or Gen3 LAs optically coupled to CCD cameras or arrays of EMCCDs coupled directly are compared. Quantum accounting analysis is done for a variety of such designs where either the lowest number of information carriers off the LA photo-cathode or electrons released in the EMCCDs per x-ray absorbed in the phosphor are large enough to imply no quantum sink for the design. These new LA or EMCCD based systems could lead to vastly improved CBCT mammography, ROI-CT, or fluoroscopy performance compared to systems using flat panels.

6142-64, Session 12

Effect of ghosting on the modulation transfer function of a-Se based flat panel imagers

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The purpose of this project is to identify all the mechanisms contributing to resolution loss in direct conversion flat panel imaging systems. The approach is to measure the Modulation Transfer function of an amorphous selenium (a-Se) based flat panel imaging system under different conditions of prior uniform exposure (ghosting).

It is found that ghosting causes a very noticeable change in the modulation transfer function of a rested a-Se based flat panel detector. Against all prior expectations the MTF was improved (increased) by ghosting. This effect was modeled and shown to arise from an equilibrium occurring between trapping of electrons and recombination of geminate holes with trapped electrons. The net result is that the MTF of an a-Se flat panel imager is unaffected by bulk trapping of carriers provided the panel is not permitted to become completely rested between exposures.

The breakthrough work is that the loss of MTF due to trapping of electrons in a rested a-Se flat panel imager has been clearly identified for the first time. The complete disappearance of this MTF degradation due to an equilibrium being established between fresh trapping and recombination of previously trapped electrons with mobile holes has also been identified for the first time. The understanding of the role of all the mechanisms involved with MTF loss in a-Se detectors is finally established.

6142-65, Session 12

Single-photon spatial resolution enhancement of columnar CsI(Tl) using centroid estimation and event discrimination

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We have examined the spatial resolution of a columnar CsI(Tl), single-photon imaging system using an approach that estimates the interaction position to better than the spread of the light distribution. A columnar scintillator is directly coupled to a 512x512 internal-gain CCD camera (16 um pixels) binned at 2x2 to sample at 32 um pixels. In the gamma-ray/scintillator interaction, optical photons are generated and sampled over multiple pixels. The resultant image shows clusters of signal at the original interaction site, clusters from Cs & I K x-rays up to several hundred microns away, and clusters from collimator K x-rays. The signal spread across pixels and K x-ray interactions result in a degradation of system spatial resolution. Cluster pixel data can be processed to better estimate the interaction position within the initial interaction cluster and to discriminate between and eliminate distant K x-rays resulting in a substantial improvement in spatial resolution. Spatial resolutions better than 100 μm were obtained; a result previously achievable only with pixellated semiconductor detector arrays.

6142-66, Session 13

A practical method for measuring the H matrix of digital x-ray and cone beam CT imaging systems

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Digital clinical systems designed for radiography or cone-beam computed-tomography are highly shift-variant. The x-ray cone-angle of such systems can be as large as 15o, resulting in large variations of the focal spot projection across the image field. Additionally, the oblique x-ray beam incidence on the detector creates a location-dependent asymmetric point-response function. Knowledge of the system's eigenvectors and eigenvalues is therefore essential for a full description of the system's deterministic properties. Furthermore, the H matrix can be used for the determination of the null-space of a system, or in the implementation of iterative reconstruction algorithms. The H matrix interrogates an imaging system by finely moving a point-source throughout the space occupied by the object. This procedure can be impractical for such high dimensional systems. We propose a practical method for measuring the H matrix of a radiographic system by separately measuring the system's individual components. The measurement procedure involves standard tools such as a focal-spot/pinhole camera, and an edge. The focal spot image is measured and re-projected through the object location. Finely-sampled point-response functions on the horizontal and vertical directions are measured for varying x-ray incidence angles on the detector, using the edge method. Using the measured data and a model derived from Monte Carlo simulations we obtain the location-dependent detector point-response function. The resulting system point-response is the location-dependent convolution of the projection of the focal spot with the detector point-response function. The system H matrix can then be calculated at a given location on the detector. The eigenvalues and eigenvectors are generated and interpreted.

6142-67, Session 13

Experimental spectral measurements of heavy K-edge filtered beams for x-ray computed mammotomography

D. J. Crotty, R. L. McKinley, M. P. Tornai, Duke Univ.

A compact, CmT-SPECT system for dedicated 3D breast imaging (mammotomography) is in development. The CmT component utilizes novel, heavy K-edge filtration to practically narrow the spectrum of the cone-shaped x-ray beam incident on the patient's pendant, uncompressed breast. This quasi-monochromatic beam in CmT is expected to improve discrimination of tissue with very similar attenuation coefficients while restraining exposure levels to below that of existing dual view mammography. Our previous extensive simulation studies showed the optimal energy range that provides maximum dose efficiency for a 50/50 adipose/glandular breast is in the 35-40keV range. This current study aims to experimentally validate previous simulation results. Here, experimental pre-breast and post-breast collimated x-ray beam spectral measurements are made under tube operating voltages between 40-100kVp using filter materials from Z=13-74, with K-edge values spanning that of Ce (K=40.4keV), and using different attenuating thicknesses of filter material, approximately equivalent to the 200th and 500th attenuating value layer (VL) thickness (at 60kVp). Ce-filtered post breast spectra for 8cm and 12cm breasts are measured for a range of breast adipose/glandular compositions for 200th VL and 500th VL filters. Evaluated figures of merit include mean beam energy, spectral full-width at tenth-maximum, and beam hardening, Measurements are shown to corroborate the simulations, suggesting that 200th VL Ce filtration may have the most optimal performance in the dedicated mammotomography paradigm.

6142-68, Session 13

Preliminary validation of a new methodology for estimating dose reduction protocols in neonatal chest computed radiographs

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The risk of radiation exposure is greatest for pediatric patients and thus there is great incentive to reduce the radiation dose used in diagnostic procedures for children to "as low as reasonably achievable" (ALARA). Testing of low-dose protocols presents a dilemma however, as it is unethical to expose patients with possibly suboptimal techniques to determine optimum protocols. To overcome this problem for computed radiography (CR), we developed a dose reduction simulation tool that takes existing clinical images and adds synthetic noise to create realistic images that correspond to images generated with lower doses. This tool can be used to study the effects of noise on diagnostic performance in observer studies. We tested the accuracy of the simulator, both quantitatively and qualitatively. Using the simulation tool to add stochastic noise, a novel observer-consistency study was developed to determine optimum dose reduction strategies. The results indicate that the use of this tool is promising for achieving the ALARA goal for dose in pediatric CR.

6142-69, Session 13

A method to measure the temporal MTF to determine the DQE of fluoroscopy systems

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Fluoroscopy is generally acknowledged to be a high dose procedure. To maximize the patient benefit-to-risk ratio, systems must be designed to produce the highest possible image quality for a given patient exposure, and quality assurance programs must be designed to ensure these standards are maintained. While the detective quantum efficiency (DQE) is often used in radiography to quantify "dose efficiency," attempts to measure the DQE of fluoroscopic systems have produced nonsensical results due to system lag reducing measured noise power spectrum (NPS) values. Methods involving the use of the system temporal modulation transfer function (MTF) have been proposed to remove this effect. However, these methods are not easily implemented in a clinical setting and as a result, the DQE of fluoroscopic systems is rarely measured.

We have developed a novel method to measure system temporal MTF using a modified slanted-edge method and acquiring image data while the slanted-edge is translated across the detector with known velocity. Each pixel from a video frame is mapped to a spatiotemporal coordinate based on the distance and time from passage of the edge at that pixel. Using data acquired with both stationary and moving (approximately 30 mm/s) edges, we calculate both the spatial and temporal MTF.

The method has been demonstrated using a bench-top fluoroscopic system using a three-year old Dunlee intensifier and detector exposures characteristic of clinical procedures. Image data was acquired using a CCD camera and laboratory frame-capture system. The temporal MTF has a 10% value at approximately 50 Hz. Results are validated by direct laboratory measurement of the temporal decay curve.

6142-70, Session 13

A novel method to characterize the MTF in 3D for computed mammotomography

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A novel phantom has been developed to measure the MTF in 3D for dedicated computed mammotomography (CmT) system. The phantom consists of three tungsten wires, positioned nearly orthogonal to each other. Simultaneous measurements of the MTF are taken at the center and various locations of the three orthogonal reconstructed planes. Our CmT system uses a Varian Paxscan 2520 digital x-ray detector which can be positioned anywhere in ~2pi steradian band with arbitrary trajectories. Using a half-cone beam acquisition and positioning the phantom near the center of rotation, projection images are acquired over 360 degrees. To date, several 3D orbits are evaluated including vertical axis of rotation, circle plus two arcs, and saddle. The phantom was imaged using our standard Ce K-edge filtration yielding a quasi-monochromatic x-ray beam, on a short 55cm SID. Reconstructions were performed using an iterative ordered-subsets transmission algorithm on rebinned projection images, using various numbers of subsets and iterations. Rotation of reconstructed slices isolated each wire onto its own plane. Along the length of each wire, corresponding MTFs were calculated from 1D line spread functions. Through simulation and measurement, accuracy of wire method was verified by comparison of the projection MTFs computed from a wire and an standard edge device. Results indicated minor variations in MTF among the three orthogonal planes, which imply a high degree of uniform sampling in the imaged volume. The findings indicate that the phantom can be used to assess the resolution in 3D as well as potential degradative effects of reconstruction algorithms.

6142-71, Session 13

Measurement of the spatial resolution of a clinical volumetric computed tomography scanner using a sphere phantom

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The rapid development of modern multi-slice computed tomography (MSCT) scanners has provided imaging systems with cone-beam geometry, sub-millimetre slice thickness, and gantry rotation speeds approaching 0.3 seconds per revolution. Clinical MSCT scanners routinely generate volume data sets yet the methods used to quantify spatial resolution remain relatively unchanged from those used to evaluate single slice scanners. Standard methods of assessing spatial resolution include line-pair phantoms or thin wires. These two-dimensional phantoms are typically evaluated through visual inspection of the phantom image data where the smallest structure that can be discriminated indicates the limiting spatial resolution. A thin wire may be used to approximate a delta function in order to calculate the modulation transfer function (MTF). The MTF of a clinical CT scanner may be measured more accurately by imaging a slanted edge (1). The evolution of clinical MSCT scanners, which routinely produce volumetric data sets with isotropic resolution, has made the slanted edge method impractical. The idea of imaging an edge may be extended to three dimensions by imaging a phantom consisting of a sphere embedded in a uniform media, in order to calculate the MTF of a volume CT scanner (2), (3). A cylindrical phantom consisting of a Teflon (or Delrin) sphere embedded in a uniform media of silicone is imaged with a clinical MSCT scanner. Using a sphere phantom, the point spread function (PSF) and MTF are independently measured for each of the three axes (left-right, anterior-posterior, and axial) of a clinical MSCT scanner. Furthermore, the sphere phantom is imaged at the centre and periphery of the trans-axial field of view in order to quantify the azimuthal blur associated with high-speed gantry rotation. The sphere method of assessing resolution is well suited to evaluating spatial resolution in modern volume CT scanners where gantry speed, table speed, pitch, and slice thickness are the parameters of most interest in scanning protocols.

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6142-83, Poster Session

Data pre-processing for quantification in tomography and radiography with a digital flat panel detector

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In order to obtain accurate quantitative results, flat panel detectors require specific calibration and correction of acquisitions. Main artifacts are due to bad pixels, variations of photodiodes characteristics and inhomogeneity of X-ray sensitivity of the scintillator layer. Other limitations for quantification are the non-linearity of the detector due to charge trapping in the transistors and the scattering generated inside the detector, called detector scattering. Based on physical models of artifacts generation, this paper presents an unified framework for the calibration and correction of these artifacts. The following specific algorithms have been developed to correct them. A new method for correction of deviation to linearity is based on the comparison between experimental and simulated data. Method of detector scattering correction is performed on two steps: off-line characterization of detector scattering by considering its spatial distribution through a convolution model and on-line correction based on a deconvolution approach. Radiographic results on a thorax phantom imaged with a flat panel detector with amorphous silicon scintillator demonstrate that differences between expected and experimental values are significantly reduced by applying non-linearity correction and detector scattering correction. Results obtained on tomographic reconstructions of phantoms are in very good agreement with expected attenuation coefficient values. Thus, this paper shows clearly the great efficiency of the new image processing models for application of flat panels to quantitative radiography or tomography.

6142-84, Poster Session

Flat panel detector-based cone beam CT for dynamic imaging: system evaluation

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The purpose of this study is to characterize a newly built FPD-based CBCT prototype for dynamic imaging. A CBCT prototype has been designed and constructed by heavily modifying a GE HiSpeed Advantage (HSA) CT gantry, incorporating a newly acquired large size real-time flat panel detector (Varian PaxScan 4030CB), a new x-ray generator and a dual focal spot angiography x-ray tube that allows the full coverage of the detector.

During data acquisition, the x-ray tube and the FPD can be rotated on the gantry over Nx360 degrees due to integrated slip ring technology with the rotation speed of one second/revolution. With a single scan time of up to 40 seconds , multiple sets of reconstructions can be performed for dynamic studies. This system was used for a series of phantom studies: a low contrast CT phantom, a high contrast spatial resolution CT phantom, a specially designed 3D spatial resolution phantom, and a humanoid chest phantom with kVp values ranging from 80 kVp - 120 kVp. Through the phantom studies, the optimal kVp operational range was determined. A newly developed dynamic reconstruction algorithm and antiscatter technique, as well as a dynamic flow phantom, were also evaluated. Finally, 3D and 4D animal (dog) studies were performed with contrast injection Direct 3D reconstructions were obtained to evaluate the system for cone beam CT for lung and angiography imaging applications. For comparison, all the phantoms were scanned using a GE multi-slice CT (four slice) spiral CT based on the same exposure level. The imaging system's high contrast spatial resolution, uniformity, and low contrast resolution were measured. The results indicate that the spatial resolution of the FPD-based CBCT prototype is isotropic and better than that of MSCT, and its low contrast resolution is approximately equivalent to that of MSCT with equivalent total exposure level. This research work demonstrates through phantom studies that FPD-based cone beam CT imaging potentially may become a useful imaging tool for lung cancer detection, diagnosis and management.

6142-85, Poster Session

Experimental comparison of cone beam CT (CBCT) reconstruction and multiview reconstruction (MVR) for microangiography (MA) detector system

V. Patel, A. Kuhls, P. Noel, A. Walczak, C. Ionita, R. Chityala, K. Hoffmann, R. Tranquebar, S. Rudin, Univ. at Buffalo

The new Multi-View Reconstruction (MVR) method for generating 3D vascular images was evaluated experimentally. The MVR method requires only a few digital subtraction angiographic (DSA) projections to reconstruct the 3D model of the vessel object compared to 180 or more projections for standard CBCT. A full micro-CBCT dataset of a contrast filled carotid vessel phantom was obtained using a Microangiography (MA) detector. From this dataset a few projections were selected for use in the MVR technique. Similar projection views were also obtained using a standard x-ray image intensifier (II) system. A comparison of the 2D views of the MVRs (MA and II derived) with reference micro-CT data demonstrated best agreement with the MA MVRs especially at the curved part of the phantom. Additionally the full 3D MVRs were compared with the full micro-CBCT 3D reconstruction resulting in mean centerline deviation from the micro-CBCT derived reconstructions of 86 micron for the MA MVR and 141 micron for the II MVR. The comparison implies that an MVR may be substituted for a full micro-CBCT scan for evaluating vessel segments with consequent substantial savings in patient exposure and contrast media injection yet without substantial loss in 3D image content. If a high resolution system with MA detector is used, the improved resolution could be well suited for endovascular image guided interventions where visualization of only a small field of view (FOV) is required.

6142-86, Poster Session

Geometry calibration phantom design for 3D imaging

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Most approaches to 3D x-ray imaging geometry calibration use some well-defined calibration phantom containing markers. The calibration aims at minimizing the so-called re-projection error, i.e., the error between projected marker locations based on the current estimate of the imaging geometry, and the detected true marker locations in the acquired projection image. Phantoms that are being employed consist usually of spherical markers arranged in some spatial pattern. One widely used phantom consists of spherical markers in a helical arrangement.

The presented framework establishes a good intuitive understanding of the calibration problem, and allows to evaluate the performance of different phantom designs. It is based on a linear approximation of the error propagation between parameters of the imaging geometry, the re-projection error, and the "backprojection misalignment", which ultimately dictates 3D image quality. This methodology enables us to characterize the statistics of the parameters describing the imaging geometry, based on simple assumptions on "measurement noise", i.e., phantom and pre-processing accuracy. We also characterize the 3D misalignment in the backprojection used in 3D reconstruction, which directly impacts 3D image quality. In a comparison of different phantom designs -using backprojection misalignment as a metric- a "candy cane" phantom was found to give superior performance.

The presented approach gives many useful intuitive insights into the calibration problem and its key properties. It can also be leveraged, e.g., for an easy implementation of a fast and robust calibration algorithm.

6142-87, Poster Session

Impact of CT detector pixel-to-pixel crosstalk on image quality

K. J. Engel, L. Spies, G. Vogtmeier, Philips Research Labs. (Germany); R. P. Luhta, Philips Medical Systems

In Computed Tomography (CT), the image quality sensitively depends on the accuracy of the X-ray projection signal, which is acquired by a two-dimensional array of pixel cells in the detector. If the signal of X-ray photons is spread out to neighboring pixels (crosstalk), a decrease of spatial resolution may result. Moreover, streak and ring artifacts may emerge.

Deploying system simulations for state-of-the-art CT detector configurations, we characterize origin and appearance of these artifacts in the reconstructed CT images for different scenarios. A uniform pixel-to-pixel crosstalk results in a loss of spatial resolution only. The Modulation Transfer Function (MTF) is attenuated, without affecting the limiting resolution, which is defined as the first zero of the MTF.

Additional streak and ring artifacts appear, if the pixel-to-pixel crosstalk is non-uniform. Parallel to the system simulations we developed an analytical model. The model explains resolution loss and artifact level using the first and second derivative of the X-ray profile acquired by the detector. Simulations and analytical model are in agreement to each other. We discuss the perceptibility of ring and streak artifacts within noisy images if no crosstalk correction is applied.

6142-88, Poster Session

The effect of reducing radiation dose with combination x-ray modulation and Boost3D

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Multislice CT with a larger number of detector rows has recently become mainstream. As a result, there is more opportunity to perform scanning with a thin slice thickness. A large number of obvious raster type artifacts occur when X-ray absorption in the lateral direction is extremely high (such as for the shoulder and the pelvis). There are two methods to solve this problem. One is that X-ray modulation is carried out during rotation so that the exposure dose can be increased for the region with high X-ray absorption and reduced for the region with low X-ray absorption. The other method is that the region which leads to an artifact is filter-processed using image processing so that the amount of artifacts can be reduced.

From the viewpoint of image quality and exposure dose, we have evaluated the method we have developed, which combines X-ray modulation technology (X-ray Modulation) and artifact elimination processing (Boost3D).

For evaluation, acrylic elliptical phantoms were used. Assuming image SD to be at a constant level, it was found that exposure dose can be reduced by approximately 25 % from the combined use of X-ray Modulation and Boost3D.

6142-89, Poster Session

Windmill artifacts analysis in MSCT

O. Amir, I. Sabo-Napadensky, Philips Medical Systems Technologies Ltd. (Israel)

One of the most important advantages of the novel MSCT with increased number of slices is the ability to reduce the scan time. However, does the increased number of slices in the MSCT enforce us to reduce the pitch, in order to avoid windmill artifacts, hence preventing us from decreasing the scan time?

In this work we address this issue along with other aspects of the windmill artifacts. We study the dependence of the splay artifacts, their strength and frequency, on the number of slices and on the pitch.

The study demonstrates, that when retaining constant bed speed while increasing the number of slices, the intensity of the windmill artifacts is reduced significantly.

Images of scans performed with the same pitch, yet with various number of slices are compared. It is observed, that the intensity of the splay artifacts is similar, independent of the number of slices. The frequency of the artifacts however, increases with the number of slices.

The study concludes that the same pitch can be used for a various number of slices in MSCT without changing the level of windmill artifacts. Scanning with the same pitch using wider coverage enables an advantageous shorter scan time in novel MSCT.

6142-90, Poster Session

Amplitude correlated four-dimensional cone beam CT

J. Lu, X. R. Zhu, The Univ. of Texas M.D. Anderson Cancer Ctr.; P. Munro, Varian Medical Systems, Inc.; T. Pan, The Univ. of Texas M.D. Anderson Cancer Ctr.

We have developed an amplitude correlated (AC) 4-dimensional cone beam CT (4D-CBCT) imaging technique on the Varian cone beam CT system. We use the Varian Real-time Positioning Monitoring (RPM) system to synchronize the recording of the respiratory motion and the 4D-CBCT imaging. The projection data of the same amplitude in respiratory motion are used to reconstruct an image of the corresponding amplitude in RPM. In the absence of hysteresis of respiratory motion, we can utilize the two CBCT projections in the same breathing cycle: one in the inspiration to expiration and one in the expiration to inspiration to improve the signal to noise ratio, reduce the aliasing due to insufficient sampling in the angular direction. And alternatively, it can reduce the scan time by half as compared with a previously published 4D-CBCT with the same image quality.

6142-91, Poster Session

Combination of CT scanning and fluoroscopy imaging on a flat-panel CT-scanner

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We developed and evaluated a prototype flat-panel detector based Volume CT (VCT) scanner. Additional to the standard scanning modes we implemented a Fluoroscopy scan mode as well as continuous rotation scanning. The novel functionality combines the advantages of a high resolution Volume CT scanner with the ability to acquire projection images with a reasonable field of view also in z direction.

We mounted a Varian 4030CB a-Si flat-panel detector in a multi slice CT-gantry (Siemens Medical Solutions) which provides a 25 cm field of view with 18 cm z-coverage at isocenter. Scanning without rotation is equivalent to a conventional fluoroscopic examination. Additional to the projection data a volume CT scan provides tomographic images with 3D isotropic resolution of the same section.

Furthermore we implemented a continuous rotation mode. Up to 80 sec scanning at a rotation time ranging from 3 to 20 sec allows perfusion studies and temporal resolved investigations of the distribution of contrast agents.

Up to now the scanner was used for phantom and specimen studies. At the current level of image quality, several clinical applications are in reach. The integration of a flat panel detector in a CT gantry opens the possibility to combine conventional fluoroscopy and CT functionality with a large field of view and very high spatial resolution.

6142-92, Poster Session

Comparison measurements of DQE for two flat panel detectors: fluoroscopic detector vs. Cone beam CT detector

R. Betancourt Benitez, R. Ning, D. L. Conover, Y. Yu, Univ. of Rochester

The physical performance of two flat panel detectors have been evaluated using standard x-ray beam qualities set by IEC 62220-1, namely RQA3, RQA5, RQA7 and RQA9. The flat panel detectors evaluated in these studies are based on an amorphous silicon photodiode array that is coupled to a thallium-doped Cesium Iodide scintillator and to a thin film transistor (TFT) array. One detector is the Paxscan 2520 that is designed for fluro imaging, and has small dynamic range and large image lag. The other detector is the Paxscan 4030CB that is designed for cone beam CT, and has a large dynamic range (>16-bit), smaller image lag and many different imaging modes. Both detectors are produced by Varian Medical Systems. The linearity of the FPDs was investigated by using an ionization chamber and Al filtration to obtain the beam qualities previously mentioned. Since the FPDs are used in the fluoroscopic mode, image lag of the FPDs was measured in order to investigate its effect on these studies. The spatial resolution of the FPDs was determined by obtaining the pre-sampling modulation transfer functions for each detector. A sharp edge was used in accordance to IEC 62220-1. Next, the NNPS was calculated for various exposure levels at each of the aforementioned radiation qualities. Finally, the DQEs of the FPDs were obtained with a slightly modified version of the international standard set by IEC 62220-1. Through these studies, it was possible to determine if the measured quantitites, especially the DQEs, from these two detectors differ and if so, and how they differ.

6142-93, Poster Session

A possible method for dose reduction in the CT practice

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It is known that the amount of the x-ray radiation applied presently in CT practice is not used optimally. A large fraction of radiation traversing the patient either is not detected at all or is used ineffectively. The reason lies partly in the reconstruction algorithms used for recovering the absorption coefficient from the collected data. The widely used reconstruction method in CT, Filtered Back Projection (FBP), is intended to invert the data which correspond to parallel geometry. However, the direct collection of parallel data is either not possible, or absolutely impractical. For practical use of FBP, fan beam geometry is used to reduce the scanning time. Collection of data with the fan beam geometry, however, is more expensive in terms of the dose consumption. One can show that the amount of x-rays in the set of fan beams is approximately two times bigger than the amount of x-rays in the parallel rays with the same number of views. By collecting parallel data in an effective way one could expect a dose reduction approximately by a factor of two. We have found out that a special mask, applied to x-ray fans allows us to generate the rays that, with high accuracy, correspond to parallel geometry. With the help of a new algorithm,

OPED, that we discovered recently, the data collected in this manner can be used effectively for reconstruction. Additionally this geometry can be optimally applied to flat panel detector geometry with constant detector pixel size.

6142-94, Poster Session

Image quality in adult and pediatric phantoms when scanned at different x-ray tube voltages (kV)

W. Huda, K. M. Ogden, E. M. Scalzetti, R. L. Lavallee, Upstate Medical Univ./SUNY; E. Samei, Duke Univ.

We investigated how contrast to noise ratios (CNR) varied with x-ray tube voltage in different sized patients. Anthropomorphic phantoms (newborn, 10 year old, adult) were scanned a GE LightSpeed scanner. Measurements were made of the tissue attenuation (HU) in the head, chest and abdomen regions, as well as the corresponding noise values. Scans were performed at a constant mAs and four x-ray tube voltages. The CT attenuation coefficient showed little variation with x-ray tube voltage or with patient size and body location. At 120 kV, the highest CNR was in the newborn abdomen, with the corresponding adult abdomen being a factor of 3.5 lower. CNR for tissue lesions values were similar in all body regions (i.e., head, chest, abdomen) for newborns and 10 year olds, but varied by about a factor of two in adults. Increasing the x-ray tube voltage from 80 to 140 kV improved tissue CNR by approximately a factor of two in all patient sizes, and all body regions examined. Patient size and x-ray tube voltages affect lesion CNR value by modifying the amount of image noise. Our data quantify how technique factors, patient size, and scanned body region will affect soft tissue detection in a uniform background.

6142-95, Poster Session

Dual-energy contrast-enhanced digital mammography (DE-CEDM): optimization on digital subtraction with practical x-ray low / high-energy spectra

B. Chen, Z. Jing, A. Smith, S. Parikh, Hologic, Inc.; Y. Parisky, Univ. of Southern California

Dual-energy contrast enhanced digital mammography (DE-CEDM), which is based upon the digital subtraction of low/high-energy image pairs acquired before / after the administration of contrast agents, may provide physicians physiologic and morphologic information of breast lesions and help characterize their probability of malignancy. This paper proposes to use only one pair of post-contrast low / high-energy images to obtain digitally subtracted dual-energy contrast-enhanced images with an optimal weighting factor deduced from simulated characteristics of the imaging chain. Based upon our previous CEDM work, quantitative characteristics of the materials and imaging components in the x-ray imaging chain, including x-ray tube (tungsten) spectrum, filters, breast tissues / lesions, contrast agents (non-ionized iodine solution), and selenium detector, were systemically modeled. Using the base-material (polyethylene-PMMA) decomposition method based on entrance low / high-energy x-ray spectra and breast thickness, the optimal weighting factor was calculated to cancel the contrast between fatty and glandular tissues while enhancing the contrast of iodized lesions. By contrast, previous work determined the optimal weighting factor through either a calibration step or through acquisition of a pre-contrast low/high-energy image pair. Computer simulations were conducted to determine weighting factors, lesions' contrast-to-noise values, and dose levels as functions of x-ray techniques and breast thicknesses. Phantom and clinical feasibility studies were performed on a modified Selenia full field digital mammography system to verify the proposed method and computer-simulated results. The resultant conclusions from the computer simulations and phantom/clinical feasibility studies will be used in the upcoming clinical study.

6142-96, Poster Session

Dual-energy imaging using a digital scanned multi-slit system for mammography: evaluation of a differential beam filtering technique

H. Bornefalk, Kungliga Tekniska Högskolan (Sweden); M. Hemmendorf, T. Hjärn, Sectra Mamea AB (Sweden)

This paper describes a method for single exposure contrast enhanced dual-energy imaging of tumors utilizing a scanned multi-slit system for digital mammography. In the multi-slit setup, the detector arrays and pre-collimator slits are aligned in several lines orthogonal to the scan direction. This geometry is advantageous to dual-energy imaging, since it allows differential filtering of the x-ray beam in the pre-collimator slits. A high-energy image can be constructed from those lines where the filter material has been chosen to harden the x-ray beam and the low-energy image from the lines with a filter producing softer beams. Both images are obtained in the same scan, eliminating the need to change tube voltages and anode materials and minimizing the risk of motion artifacts.

To maximize separation of the high- and low-energy spectra around the k-edge of the iodinated contrast agent (33 keV), this prototype evaluation utilizes a liquid filter of Iodine dissolved in a low-atomic number solute (Xylene) for the low-energy lines and a thick (6 mm) Aluminum filter for the high energy lines. The relatively thick Aluminum filter needed to harden the beam significantly reduces the x-ray flux to the detector with reduced image statistics as a consequence. However, even with the tube loading restrictions set by a standard mammography x-ray tube (50 kVp, 150 mA and a scan time of 10 s) this generates enough flux to satisfactorily image an average sized breast. Logarithmic subtraction of the images produces essentially anatomical clutter-free images with the contrast-enhanced lesions clearly visible. The method is illustrated on a purpose-built phantom.

6142-97, Poster Session

Nonlinear dual-spectral image fusion for improving cone-beam-CT-based breast cancer detectability

Z. Chen, R. Ning, D. L. Conover, Y. Yu, Univ. of Rochester

Cone-beam computed tomographic breast imaging (CBCTBI) can easily detect micro-calcification and distinguish fat and glandular tissues. However, it is a challenging task for CBCTBI to distinguish benign and malignant tumors, due to the subtle difference in x-ray attenuation coefficient. Since breast tissue exhibits energy-dependent attenuation behavior (which is not used by CBCTBI due to energy-integration detection) due to the adoption of polyenergetic x-ray source, we will exploit this nature by equipping the CBCTBI with dual-spectra imaging. By cone-beam scanning a breast object with two polyenergetic spectra, we obtain two spectral image datasets. The conventional dual-energy CT processing schemes include 1) pre-reconstruction spectral image subtraction, 2) post-reconstruction volume subtraction, and 3) basis material decomposition. In this paper, we propose a nonlinear dual-spectral imaging fusion scheme. In implementation, we co-register the projection images of two spectral images, and combine two paired dual-spectral images into a single image by a two-variable polynomial. The polynomial is established by a reference material, and its mapping is interpreted as a reference-material equivalence. For the purpose of benign and malignant tumor discrimination, we select the reference material such that the mapped equivalence difference between benign and malignant tumors are deliberately increased (or exaggerated). In this manner, we will improve the benign and malignant tumor detectability. The nonlinear fusion scheme possesses these properties: 1) no subtraction; 2) no increase in feature dimension; and 3) nonlinear discrimination enhancement in feature space. Its disadvantage lies in the interpretation of nonlinear mapping.

6142-98, Poster Session

Removal of calcium to improve vascular stenosis diagnosis using dual-energy CT: a feasibility study

J. Zhang, A. Primak, J. G. Fletcher, C. H. McCollough, Mayo Clinic

The presence of calcium plaque within a vessel produces partial volume, beam hardening and blurring artifacts, resulting in poor visualization of the vessel lumen. This impairs the detection of the underlying lumen and can cause overestimation of stenosis severity. The goal of this study is to test the feasibility of using dual-energy CT to remove calcium artifacts for vascular applications, especially the detection of significant stenosis in cerebrovascular, coronary and peripheral artery disease. To achieve this goal, dual-kV material decomposition was implemented using CT projection raw data. A phantom simulating the presence of calcified plaques adjacent to iodinated vessels with various stenosis severities was developed. The phantom was scanned using 80 kVp and 140 kVp spectra. Percent area stenosis was measured for the dual-spectra images and compared to those using single spectra CT (120kVp). Dual-energy CT images were formed using a linear combination of the low and high-energy CT projection data. This combination suppresses calcium signal. Dual-energy CT angiography improves the accuracy in the detection of the underlying lumen stenosis in the presence of calcium plaque, especially for small arteries with high grade stenosis. The results demonstrated that the use of dual-energy CTA can suppress calcium signal and its related artifacts. The detection of percent area stenosis is more accurate using dual-spectra CTA with calcium suppression techniques than using single energy CTA. Clinical trials investigating the utility of this technique are warranted.

6142-99, Poster Session

An iteration algorithm in dual-energy x-ray imaging based on polychromatic physics model

S. Tang, X. Mou, T. Luo, Xi'an Jiaotong Univ. (China)

ABSTRACT In this paper, we aim at a polychromatic physics model of dual-energy medical x-ray imaging and present a corresponding computation method, which includes two steps: first, bd(s, theta), i.e. the parameter used for expressing the component of Compton scatter, and bp(s, theta), i.e. the parameter used for expressing the component of Photoemission Effect, are decided by solving a nonlinear equation system; then a FBP (Filtered Back Projection) algorithm is used to reconstruct the decomposition images from the sinograms of bp(s, theta) and bp(s, theta). It is noticed that the first step is the most time-consuming, so it is very important to find out a high-speed and effective iteration computation method. In this paper, we propose a Newton iteration method with an effective estimation strategy of initial value for quickly solving the nonlinear equation system. A CT simulation experiment was implemented to validate the effectiveness of the whole procedure.

6142-100, Poster Session

A computation method of dual-energy x-ray imaging

X. Mou, S. Tang, W. Hong, Xi'an Jiaotong Univ. (China)

Dual-energy X-ray imaging is an important method of medical imaging, capable of not only obtaining spatial information of imaging object but also disclosing its chemical components, and has many applications in clinic. The current computation methods of dual-energy imaging are still based on the model of mono-energy spectrum imaging with some linear calibration, while they are incapable to reflect correctly the physical characteristics of dual-energy imaging and obstruct deeper research in this field. The article presents a new medical X-ray imaging model in accordance with physics of imaging and its corresponding computational method. The computation process includes two steps: first, to compute two attenuation parameters that have clear physical meaning: equivalent electron density and attenuation parameter of photoemission; then to compute the components of high- and low-density mass through a group of simple equation with two variables. Experiments showed that such method has quite a satisfactory precision in theory, that is, the solutions of parameters under different exposure voltages and thickness of tissue for several main tissues of human body are much low in deviations, whose quotient of standard deviation divided by mean are mostly under 0.1%, and at most 0.32%. The method provides not only a new computational way for dual-energy X-ray imaging, but also a feasible analysis for its nature. In addition, the method can be used to linearly rectify data of dual-energy CT and analyze the chemical component of reconstructed object by means of parameters clear in physics.

6142-101, Poster Session

The line-noise-reduction for low dose x-ray fluoroscopy with the flat panel detector

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According to the clinical study, the line noise present in the fluoroscopy images is a significant barrier for performing a lower dose study. Reduction in line noise, which implies reduction in fluoroscopic dose will greatly benefit the patients. The purpose of this study is to detect and reduce this line-noise from the fluoroscopic images making it possible to perform a lower dose fluoroscopy imaging. We detect line noise by acquiring a dark image (image with no exposure) and then comparing the average of the line data along the gate line to the neighborhood lines. The line whose average is above the statistics of the ROI (standard deviation and the mean of ROI) is selected for noise-removal processing. We have applied this method to the collimated dark images of phantom. The lines detected with noise are interpolated with neighborhood lines to remove the line noise. The FPD system has few detecting sizes and clinicians have a choice to select a smaller detecting size to decrease the skin dose to the patient. Outside of the imaging area, the FPD is covered with the collimator. We applied this method to a dark image (1024 x1024) with 54 lines with line noise. The SD improved up to 10%. For a chest phantom, most of the line noise disappeared. Our new line-noise-reduction algorithm is successful in reducing the line noise in the fluoroscopy images. Our line-noise-reduction algorithm will help to lower the fluoroscopy dose in the FPD, which is most desirable in fluoroscopic imaging.

6142-102, Poster Session

Light induced degradation in amorphous silicon photodiodes and implications for diagnostic medical imaging applications

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Amorphous silicon photodiodes are increasingly being used as fundamental components in digital diagnostic medical imaging system including large area chest radiography, mammography and real time fluoroscopy. The intrinsic a-Si:H material (i-a-Si:H), commonly deposited by Plasma Enhanced Chemical Vapor Deposition (PECVD), is well known to suffer from both light and bias stress induced instabilities over time that can result in an increase in dark current and a decrease in photoconductivity. In contrast, research in Hot-Wire Chemical Vapor Deposition (HWCVD) indicates that a-Si:H films grown by HWCVD can have superior physical and electronic properties to those grown by PECVD.

In this research, we report on the material properties and stability of i-a-Si:H material by comparing the photoconductivity degradation of the HWCVD and PECVD films over time. Then, we discuss the p-i-n diode fabrication process and examine the leakage and photo-current degradation in the HWCVD and PECVD photodiode structures over time via bias and time stress measurements. Also, we investigate the quantum efficiency degradation over time in a-Si:H p-i-n detectors grown by PECVD.

6142-103, Poster Session

Temperature coefficients and noise performance studies for the back-illuminated arrays for medical imaging applications

A. O. Goushcha, B. Tabbert, I. Goushcha, Semicoa

Noise characteristics of the backlit, pin photodiode arrays having different vertical structures were studied. We showed that in many cases, the non-optical crosstalk between adjacent elements determines the noise performance and detectivity of the array pixels. For the arrays with the structure described in our recent works, the crosstalk always remained well below 0.01%, which allowed to reach the minimum noise level of ~ 1.0E-15 A/sq_rt_Hz determined by the thermal noise. In contrast, for the arrays built applying conventional structures the crosstalk was two orders of magnitude higher, which noticeably decreased the sensitivity of the pixels increasing their noise and switching their operation towards background-limited performance. The background signal originated from the non-optical crosstalk and produced a noise level significantly higher that the thermal noise. We also compared the temperature coefficients for different arrays. For the structures described in the cited above reference, the measured value of the shunt resistance temperature coefficient was typically below 8%/C and the responsivity temperature coefficient value did not exceed +0.02%/C within the spectral range from 450 through 800 nm. The advantages and drawbacks of application of the reported in this work photodiode arrays in high quality imaging systems are discussed.

6142-104, Poster Session

Novel x-ray image sensor using CsBr:Eu phosphor for computed radiography

H. Nanto, Kanazawa Institute of Technology (Japan)

Photostimulated luminescence (PSL) characteristics of CsBr phosphor doped with different luminescence center such as In2O3, Eu2O3, EuCl3, SmCl3, TbCl3, GdCl3 or NdCl3 as a candidate of a new photostimulable phosphor for medical x-ray imaging sensor are estimated. It is found that x-ray irradiated Eu-doped CsBr (CsBr:Eu) exhibites intense PSL. Each peak wavelength of the PSL emission and stimulation spectra of CsBr:Eu phosphor is 450 nm and 690 nm , respectively. The dependence of PSL properties on preparing conditions of CsBr phosphor such as Eu concentration, sintering temperature and sintering time, is studied and optimum preparing condition is also studied. It is found that PSL intensity of CsBr:Eu phosphor prepared under an optimum condition is higher than that of commercially available imaging plate (IP) using BaFBr:Eu. Modulation transfer function and Winner spectrum of IP using CsBr:Eu phosphor film are also estimated.

6142-105, Poster Session

Transparent BaCl2:Eu2+ glass-ceramic scintillator

G. Chen, J. A. Johnson, F. De Carlo, Argonne National Lab.; R. Weber, Containerless Research, Inc.; S. Schweizer, Argonne National Lab. and Univ. Paderborn (Germany); P. J. Newman, D. R. MacFarlane, Monash Univ. (Australia)

X-ray scintillators are widely used for indirect x-ray detection. Most scintillators are based on single crystals or structured crystals that are expensive to fabricate and/or difficult to scale up. As an alternative, we have developed a transparent, efficient, and inexpensive glass-ceramic scintillator. This glass-ceramic is based on a Eu2+-doped fluorozirconate glass formula. Subsequent heat treatment of the glass causes formation of BaCl2 crystals (10 - 20 nm in size) that are embedded in the glass matrix. The x-ray image resolution of the scintillator is just slightly worse than that of a single-crystal CdWO4 scintillator. However, the former has a higher normalized scintillation efficiency. The effects of Eu2+ dopant concentration and thermal processing condition on the scintillator properties will also be discussed. The feasibility of using this glass-ceramic scintillator for mammography and computed tomography will be demonstrated. Our study suggests that the glass-ceramic scintillator has high potency for applications in such fields as medical x-ray imaging and radiation detection for homeland security.

6142-106, Poster Session

Energy-dependent scintillation efficiency of fluorozirconate-based glass-ceramic x-ray detectors

S. L. Schweizer, S. Köneke, Univ. Paderborn (Germany); G. Chen, J. A. Johnson, F. De Carlo, Argonne National Lab.; R. Weber, Containerless Research Inc.

We investigated the energy-dependent scintillation efficiency of Eu-doped fluorozirconate glass-ceramic x-ray detectors in the energy range from 4-20 keV. The experiments were per-formed at the Advanced Photon Source (Argonne National Laboratory, Argonne, IL, USA). The glass ceramics are based on Eu-doped fluorozirconate glasses which were additionally doped with bromine or chlorine to initiate the nucleation of BaX2 (X = Br, Cl) nano-crystals therein. The x-ray excited scintillation is due to the 5d-4f transition of Eu embedded in the BaX2 nano-crystals whereas Eu in the glass does not luminesce. Upon appropriate annealing the nano-crystals grow and undergo a phase transition from a hexagonal to an orthorhombic phase of BaX2. The scintillation efficiency is investigated as a function of the x-ray energy as well as of the particle size and structure of the embedded nano-particles. The scintillation effi-ciency versus x-ray energy dependence shows that the efficiency is inversely proportional to the photo-absorption of the material, i.e. the more photo-absorption the less scintillation.

6142-107, Poster Session

Quantitative evaluation of mercuric iodide thick film for x-ray imaging device

K. J. Kim, S. S. Kwang, J. K. Park, S. H. Cho, B. Y. Cha, J. W. Shin, S. H. Nam, J. H. Kim, Inje Univ. (South Korea)

In this paper, we investigated electrical characteristics of the X-ray detector of mercuric iodide (HgI2) film fabricated by PIB(Particle-In-Binder) Method with thicknesses ranging from approximately 200* to 240*. In the present study, using I-V measurements, their electrical properties such as leakage current, X-ray sensitivity, and signal-to-noise ratio (SNR),were investigated. The results of our study can be useful in the future design and optimization of direct active-matrix flat-panel detectors (AMFPD) for various digital X-ray imaging modalities.

6142-05, Poster Session

CR mammography offers preferred image quality while maintaining the diagnostic quality of film

L. M. Fletcher-Heath, Eastman Kodak Co.; A. Richards, Eastman Kodak Co. (Canada); S. Ryan-Kron, Eastman Kodak Co.

Though X-ray mammography remains the leading method of early breast cancer detection, the market requires that digital modalities advance into an arena where analog has long been the gold standard. There are two major problems associated with this market need: 1) the expense of direct digital systems, and 2) the cost-effective alternative-computed radiography (CR) mammography-though accepted in many regions, remains unproven worldwide. This pilot study responds to the growing desire to acquire and display cost-effective digital mammographic images by exploring the acceptability of CR mammography. Images were collected, with informed consent, from 49 subjects representing a range of breast tissue types. Comparison views were collected on the same breast, same compression, using AEC on state-of-the-art film systems (Kodak MIN-R L, MIN-R 2000, or MIN-R EV) followed by CR. Digital images were processed using the Kodak DirectView EVP software and printed for hard

copy feature comparison. Twelve experienced mammographers scored a subset of cases for a total of 64 readings. A rating scale from 1 to 5 was used (strong preference for film=1, strong preference for CR=5; 3 indicates equivalence). Results demonstrated that CR was equivalent or preferred to conventional screen/film for overall image quality (33% scored 3 and 51% scored >3), image contrast (19% scored 3 and 68% scored >3) and sharpness (27% scored 3 and 51% scored >3). Noise assessment was statistically equivalent. This study also indicated that diagnostic quality was maintained in assessing abnormalities for attributes necessary to evaluate masses and microcalcifications as compared to screen/film.

6142-109, Poster Session

Comparison of a-Se direct conversion and CsI indirect conversion flat-panel digital detectors: a clinical assessment of image quality for general radiography applications

L. L. Barski, X. Wang, Eastman Kodak Co.; J. Wandtke, D. Waldman, Univ. of Rochester; D. H. Foos, J. Yorkston, Eastman Kodak Co.

An observer study was conducted to compare the diagnostic quality of human-subject images obtained using a-Se (amorphous selenium) and CsI (Cesium Iodide) flat-panel detectors. Each detector was attached to an x-ray source and gantry equipment of similar configuration and installed in a university hospital radiology department. One hundred image pairs representing a stratified sampling of exam types were acquired. Image pairs were captured of the same body part and projection for a particular subject, using each of the two detectors and were acquired within a few minutes of each other. Manual exposure methods were used and the images were captured with technique factors corresponding to average exposure levels equivalent to approximately a 400-speed screen-film system. Offset and gain corrected, but otherwise unprocessed, image data from both digital radiography systems were stored to a research workstation. The same image-processing package was used to process the images from both systems to achieve images having similar tonal properties, although different parameters were used in the frequency processing to account for the different MTF and noise properties of the CsI and a-Se detectors. The processed images were evaluated by radiologists using a research workstation that was equipped with a 3MP (MegaPixel), flat-panel monitor, and software to facilitate the image comparisons. Four radiologists (three board certified, one fifth year resident) used subjective rank-order criteria to evaluate overall diagnostic quality and preference. Standard statistical analysis techniques applied to the ratings (399 total observations) indicate that a-Se and CsI detectors produce images having comparable diagnostic quality to those images that were captured using exposure technique factors that correspond to a 400-speed screen-film system.

6142-110, Poster Session

Novel features of the x-ray scatter profile that are not modeled by convolution of the primary

J. E. Tkaczyk, GE Global Research; Y. L. Trousset, GE Heathcare; D. J. Walter, Y. Du, GE Global Research

Measurements are used to quantify the level of x-ray scatter and scatter-to-primary ratio resulting from the wide-field x-ray illumination of phantoms with uniform and non-uniform thickness and composition. The flat panel detector provides a precise means to measure the profile of scatter and the primary signals. Both the magnitude and spatial kernel shape of scatter can be ascertained by analysis of the detector signal. A convolution model of scatter that is adaptable to rapid simulation and correction algorithms is tested against the measured profiles. For uniform acrylic phantoms the agreement is generally within 10%. In the uniform acrylic case, the main discrepancy occurs at the edges of the FOV where the curvature of the modeled curve tends to be too large. For phantoms of non-uniform thickness or non-uniform composition, some dramatic qualitative differences with the convolution model are observed. For example, cusp-like features associated with the edge of an illuminated object are entirely missed by the convolution model but can be duplicated within a 3D point kernel model. This work presents results under some typically encountered phantom and system conditions, but resulting in some unusual scatter profile characteristics. These results are of interest to evaluate the sufficiency of correction algorithms and quantitative applications in medical x-ray and VCT.

6142-111, Poster Session

Effects of radiation dose level on calcification visibility in cone beam breast CT: a preliminary study

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To investigate how the radiation dose level affects the detection of microcalcifications in cone beam breast CT, simulated calcifications were embedded in simulated breast tissue and imaged with an experimental cone beam CT system. The system employs a 30×40 cm^2 a-Si/CsI based flat panel detector with a pixel size of 194 microns. Eight clusters of simulated calcifications, each of a different size range, were embedded in a stack of 10.5 cm diameter lunch meat slices and positioned along a 6.4 cm diameter circle centered with the phantom. 300 projection images (over 360 degrees) were acquired in the non-binning mode at various dose levels (0.3, 0.6, 1.2, 1.8, 2.4, and 3.6 mGy at the isocenter), and were reconstructed with the Feldkamp algorithm. 850×850×250 volume data were extracted from the reconstructed images and displayed on a review workstation with two 1600 by 1200 CRT monitors. Three readers reviewed the images independently and counted the number of calcifications for each size group. The mean ratio of visible calcifications, averaged over all readers, was computed as a function of the calcification size for various dose levels. The isocenter dose required was also estimated and plotted as a function of the calcification size for various threshold visibility ratios. Two-tailed t-test was used to compute the p values to quantify the statistical significance for performance differences between dose levels. (This work was supported in part by a research grant CA104759 from the NCI and a research grant EB-00117 from the NIBIB).

6142-112, Poster Session

A point-by-point scatter correction technique for cone beam breast CT using the scanning sampled measurement (SSM) technique

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We have developed and investigated a scanning sampled measurement (SSM) technique for scatter measurement and correction in cone beam breast CT imaging. A breast tissue equivalent phantom was mounted on a rotating table between the x-ray source and detector to simulate cone beam breast CT imaging. A 2-D array of lead beads, with the beads 1-cm apart from each other and slightly tilted vertically, were placed between the object and x-ray source. A series of lead bars were also added across the phantom edges to obtain better scatter estimation. A series of projection images were acquired as the phantom is rotated and the lead beads/bars shifted vertically from one projection view to the next. Image signals in the lead beads/bar shadows were used to obtain sampled scatter measurements which were then interpolated to form an estimated scatter distribution for each projection image. The image data behind the lead bead/bar shadows were restored by interpolating image data from two adjacent projection views to form shadow free projection images. The estimated scatter distribution was then subtracted from the corresponding restored projection image to obtain the scatter corrected projection image.

Our preliminary experiment has demonstrated that it is feasible to implement the SSM technique for scatter estimation and correction in cone beam breast CT imaging. The scatter corrected projection images resulted in more accurate reconstructed CT image data and largely removed the cupping effects.

This work was supported in part by a research grant CA104759 by NIH-NCI and a research grant EB00117 by NIH-NIBIB.

6142-113, Poster Session

Scattered radiation in flat-detector based cone-beam CT: analysis of voxelized patient simulations

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This paper presents a systematic assessment of scattered radiation in flat-detector based cone-beam CT. The analysis is based on simulated scatter projections of voxelized CT images of different body regions allowing to accurately quantify scattered radiation of realistic and clinically relevant patient geometries. Using analytically computed primary projection data of high spatial resolution in combination with Monte-Carlo simulated scattered radiation, practically noise-free reference data sets are computed with and without inclusion of scatter. The impact of scatter is studied both in the projection data and in the reconstructed volume for the head, thorax, and pelvis regions. Currently available anti-scatter grid geometries do not sufficiently compensate scatter induced cupping and streak artifacts, requiring additional software-based scatter correction. The required accuracy of scatter compensation approaches increases with increasing patient size.

6142-114, Poster Session

Effects of scattered radiation and beam quality on low contrast performance in cone beam breast CT

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We are developing a cone beam CT system for breast imaging. Based on our experience with specimen images, detection of tumors is determined by the morphology of tissues rather than density differences between glandular tissue and tumor. Hence, the visualization of tissues is based on the contrast between adipose tissue and denser tissues. In this work, we investigated the effects of scattered radiation and beam quality on the low contrast performance relevant to cone beam breast CT imaging. For experiments, we constructed phantoms consisting of simulated fat and soft tissues. X-ray scatter fraction was altered by varying the cone beam angle. Beam quality was altered by varying the tube voltage from 50 to 100 kV. We computed the contrast-to-noise ratio (CNR) squared from reconstructed images and normalized it to the air kerma measured at the center of the phantom. The results were used as the figure of merit (FOM). For a given cone beam angle, the FOM increased by about 50 % as the kVp was varied from 50 to 80 and stayed relatively flat from 80 to 100. When the cone angle was reduced by half, the FOM increased by about 80 % for all kVp's tested. In conclusion, the CNR is dominated by x-ray scatter and tube voltage should be kept above 80 kVp to maximize visualization of soft tissue contrast in cone beam breast CT. This work was supported in part by a research grant CA104759 by the NIH-NCI and a research grant EB00117 from the NIH-NIBIB.

6142-115, Poster Session

Emission contamination of the transmission image in a dual modality computed mammotomography system

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A dual modality SPECT/CT computed mammotomography (CmT) system for dedicated functional/structural breast imaging is under development. In simultaneous, dual-modality imaging, contamination of the transmission (x-ray) image by emission photons from the uncompressed, pendant breast and torso is an important consideration in the design of hybrid imaging hardware. The lack of detector collimation implies increased absorption of lower energy scattered emission photons from the breast and neighboring torso region that potentially increases transmission image noise. This study investigates the nature and extent of this cross contamination. The x-ray detector is a Varian Paxscan 2520 with a 20x25cm^2 field of view (FOV) and 600μm thick CsI(Tl) scintillation layer. The center of the breast is placed nominally 20cm from the detector surface. The radionuclide used in the SPECT protocol is ^{99m}Tc, with a 140.6keV photopeak; x-ray detection efficiency at 140.6keV is approximately 19%. Three water-filled breast phantoms representing different breast sizes from 325 to 1500mL are filled with 0.5mCi of ^{99m}Tc and placed near the x-ray detector FOV with the SPECT camera placed in several polar and azimuthal locations about the pendant breast. A 475ml plastic container with 2mCi of ^{99m}Tc is placed above the breast phantom, simulating torso activity. Projection images are taken with and without x-ray illumination and the images are then examined for emission-source contamination. Initial results indicate emission contamination has little effect on the mean transmission image pixel value. Additional studies involving realistic anthropomorphic torso phantoms with varying breast and torso activity concentrations may further illuminate expected contamination levels.

6142-116, Poster Session

Comparison of scatter correction methods for CBCT

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In contrast to the narrow fan of clinical Computed Tomography (CT) scanners, Cone Beam scanners irradiate a much larger proportion of the object, which causes several times more X-rays scattering. If this scatter is not corrected, the reconstructed images exhibit artifacts: The middle area of the object becomes darker than the outer area, as the density in the middle of the object is underestimated. We compared three methods of correcting for scatter artifacts. 1) A heuristically-estimated constant was subtracted from each projection image (Uniform Scatter Fraction). 2) A beam-hardening-type correction followed by comparing with a cylindrical norm. 3) A combination of both. 4) Using the projections, the object dimensions were estimated in order to compute the scatter with a physical model. In our preliminary results, the first method significantly reduced scatter artefacts. Method two and method three lead to similar image quality and effectively reduced scatter artifacts.

6142-117, Poster Session

Calculation of x-ray images of an anthropomorphic chest phantom with Monte Carlo methods for clinical and physical image quality evaluation

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Monte Carlo (MC) computer simulation of chest x-ray imaging systems has hitherto been performed using anthropomorphic phantoms with large (~3mm) voxel sizes. The aim for this work was to develop and use a Monte Carlo computer program to compute projection x-ray images of a high-resolution anthropomorphic voxel phantom for visual clinical image quality evaluation and dose-optimization. An Alderson anthropomorphic chest phantom was imaged in a CT-scanner and reconstructed with isotropic voxels of 0.7mm. The phantom was included in a Monte Carlo simulation program using the collision density estimator to derive the energy imparted per unit area to each pixel in the image for primary and scattered photons by allowing for the attenuation and scatter of x-rays in the phantom, grid and image detector. Imaging conditions (tube voltage, filtration, grid and image detector) are varied and images compared to real computed radiography (CR) images of the chest phantom. Two example simulated (computed) PA chest images are presented: one image where no scattered photons and one where all scattered photons contributed to

the image. In the former, the thoracic vertebrae are more clearly visualized against the heart and lung than in the real digital radiograph (141 kV, Fuji CR) where scattered photons reduce the contrast. The simplicity in changing the imaging conditions allows us not only to produce images of existing imaging systems, but also of hypothetical, future imaging systems. We conclude that the calculated images of the high-resolution voxel phantom are suitable for human detection experiments of large low-contrast lesions.

6142-118, Poster Session

A Monte Carlo investigation on the impact of scattered radiation on image resolution and noise

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Scattered radiation plays a significant role in mammographic imaging, with scatter fractions over 50% for larger, denser breasts. For screen-film systems, scatter primarily affects the image contrast, reducing the conspicuity of subtle lesions. While digital systems can overcome these contrast effects, they remain susceptible to scatter's impact on the image resolution and noise. To better understand these effects, we have created a Monte Carlo model of a mammographic imaging system adaptable for different imaging situations. This model was capable of producing pairs of images -one each for the primary and scattered photons. Resolution was assessed by interrogating a phantom with a pencil beam of radiation and evaluating the point spread function of the resultant images. The point spread function from a 4.5 cm breast dropped to 5% at 0.62 mm. Noise was calculated by exposing a phantom with a uniform beam of radiation and computing the noise power spectrum. The scatter NNPS showed a low-frequency peak that extended until 0.625 mm^{-1}. Further results will be presented at the meeting. This work was supported in part by USAMRMC W81XWH-04-1-0323.

6142-119, Poster Session

A comparison of the performance of new screen-film and digital mammography systems

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This work compares the detector performances of the recent Kodak Min-R EV 190/Min-R EV and current Kodak Min-R 2190/Min-R 2000 mammography screen-film combinations with the Kodak CR 850M system using the new EHR-M and standard HR plates. Basic image quality parameters (MTF, NNPS and DQE) were evaluated according to ISO 9236-3 (i.e. 28 kV; Mo/Mo; HVL = 0.64 mm eq. Al) at an entrance air kerma level of 60 *Gy. Compared with the Min-R 2000, the Kodak Min-R EV screen-film system has a higher contrast and an intrinsically lower noise level, leading to a better DQE. Due to a lower noise level, the new EHR-M plate improves the DQE of the CR system, in comparison with the use of the standard HR plate (30% improvement) in a mammography cassette. Compared with the CR plates, screen-film systems still permit to resolve finer details and have a significantly higher DQE for all spatial frequencies.

6142-120, Poster Session

Dynamic platform for moving organ imaging

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In order to move phantoms (maximum weight: 70kg), a multimodality platform (CT, PET, Radiotherapy) has been developed. This allows the study of the influence of motion on image quality. The translation system (160 mm in the z axis, maximal speed of 50 $mm{\cdot}s^{-1}$) is controlled by a computer via a NI Motion Controller PCI 7344 (National Instrument, TX, USA). As an initial experiment, an anthropomorphic cardiac CT phantom (QRM, Möhrendorf, Germany) was moved linearly with speeds of 5, 10 and 20 $mm{\cdot}s^{-1}$. Acquisitions were done on a Siemens Somatom Volume Zoom CT Scanner. To compare dynamic and static images; mutual information, correlation coefficient, standard deviation, volume computation and radiologist scoring were conducted. The mean position error of the platform is 0.1mm ± 0.04. Automatic evaluation of the image quality and/or the blurring is not easy. However, we found an increase in artifacts with the speed of the phantom. The platform allows us to simulate physiological motions (respiratory and cardiac) in order to study their real influence on image quality and to correct them. We can already produce z axis physiological motion with the platform. More degrees of freedom (y and z rotations, x and y translations) will be added to improve the simulation of physiological motions.

6142-121, Poster Session

The use of the anode heel affect in thoracic radiology: a visual grading analysis

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For decades, the antero-posterior (AP) projection of the thoracic spine has represented a substantial challenge. Patient thickness varies substantially along the cranio-caudal axis resulting in images that are too dark for the upper vertebrae and too light, or with excessive quantum mottle, towards the 9th to 12th thoracic vertebra. The anode heel affect is a well known phenomenon, however there is a paucity of reports demonstrating its exploitation in clinical departments for optimising images. The current work, using an adult, tissue-equivalent anthropomorphic phantom, explores if appropriate positioning of the anode can improve image quality for thoracic spine radiology. At each of 5 kVps (70, 81, 90, 102, 109) thirty AP thoracic spine images were produced, 15 with the anode end of the tube towards the cranial part of the phantom and 15 with the anode end of the tube facing caudally. Visual grading analysis of the resultant images demonstrated significant improvements in overall image quality and visualisation of specific anatomical features for the cranially facing anode compared with the alternative position,, which were most pronounced for the 1st to 4th and 9th to 12th vertebrae. These improvements were evident at 70, 81 and 90 kVp, but not for the higher beam energies. The results demonstrate that correct positioning of the X-ray tube can improve image quality for thoracic radiology at specific tube potentials. Further work is ongoing to investigate whether this easy to implement and cost-free technique can be employed for other examinations.

6142-122, Poster Session

Scatter correction using beam stop array algorithm for cone-beam CT breast imaging

W. Cai, R. Ning, D. L. Conover, Univ. of Rochester

In flat-panel detector-based cone-beam CT breast imaging (CBCTBI), scatter is a major factor that degrades image quality. It has been shown that despite the use of a compensation filter and a large air gap, scatter still causes problems when imaging a large breast phantom with our CBCTBI prototype. For a size D breast phantom (21.5cm x 17cm x10cm), the SPR could be as high as 0.6 at the center part near the chest wall. A cupping artifact was obvious in the corresponding reconstructed axial slices. We propose to conquer the residual scatter by using a beam-stop array (BSA) algorithm, which was presented in previous papers by our group. In the current prototype, the Varian 2520 detector is an indirect flat-panel detector, which causes veiling glare problem. This is to be corrected together with the error due to the finite x-ray focal spot size, in order to get more accurate estimation for the scatter image. Since the breast is nearly axially symmetric, only one or two more projections for scatter images are required for the BSA algorithm. Therefore, the angular interpolation part in the algorithm could be simplified. The results show that the scatter artifact in CBCT breast imaging could be corrected by the BSA algorithm with the dose to patient increased by only less than 1%.

6142-123, Poster Session

Response of a CsI/amorphous-Si flat panel detector as a function of incident x-ray angle and its implications for tomographic mammography

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Mammographic x-ray tomography offers separation of overlying anatomic structure by virtue of the 3-dimensional data set. In this application, the breast is compressed against the detector and the x-ray source traverses a limited angle arc about this stationary target. The angle of incidence of x-ray photons to the detector plane changes with the angle of the source along the arc. Because of the finite thickness of the scintillator and projection across the pixel area, one expects that the response of the detector will be a function of the angle of incidence. This study presents measurement results of the gain, modulation transfer function (MTF), noise power spectra (NPS) as a function of the x-ray incident angle and explains the measured response with a model of the scintillator characteristics. The change in response with angle trades off against the wide angular coverage needed to insure tomographic separation of superimposed structures. Two mechanisms for MTF dependence on angle are demonstrated. The dominant effect is that travel of x-ray photons through the scintillator at non-normal incidence involves an in-plane component. This mechanism leads to a significant but deterministic blurring of the incident image, but has no effect on the noise transfer characteristics of the detector. A secondary effect is that at high angles, x-ray-to-optical conversion occurs at positions in the scintillator further away from the photodiode surface. This leads to a small net decrease in MTF and NPS at angles above 60degrees. The deterministic character of the angular dependence of gain, MTF and NPS leads to the conclusion that sufficient angular range can be supported by this detector construction in order to yield excellent functionality in the context of tomography.

6142-124, Poster Session

Dosimetric and image quality assessment of different acquisition protocols of a novel 64 slices CT scanner

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Dose and image quality assessment in computed tomography (CT) are almost affected by the vast variety of CT scanners (axial CT, spiral CT, low-multislice CT (2-16), high-multislice CT (32-64)) and imaging protocols in use.

Very poor information is at the moment available on 64 slices CT scanners. Aim of the work is to assess image quality related to patient dose indexes for a commercially available 64 slices CT scanner.

CT dose indexes (weighted computed tomography dose index, CTDIw and Dose Length Product, DLP) were measured with a standard CT phantom for the main protocols in use (head, chest, abdomen and pelvis) and compared with the values displayed by the scanner itself. The differences were always below 7%. All the indexes were below the Diagnostic Reference Levels defined by the European Council Directive 97/42. Effective doses were measured for each protocol with thermoluminescent dosimeters inserted in an anthropomorphic Alderson Rando phantom and compared with the same values computed by the ImPaCT CT Patient Dosimetry Calculator software code and corrected by a factor taking in account the number of slices (16 to 64). The differences were always below 20%. The effective doses range from 1.5 mSv (head) to 12.4 mSv (abdomen). The dose reduction algorithm of the scanner was assessed comparing the effective dose measured in a phantom (a standard man cylinder, no dose reduction) to the dose computed on 46 patients. The reduction factors range from 5% to 32%, depending on the protocol used and patient size. The possibility of a further dose reduction was investigated measuring image quality (spatial resolution, contrast and noise) as a function of CTDIw. This curve shows a quite flat trend decreasing the dose approximately to 80% and a sharp fall below that value. All the information allowed to optimize the protocols so obtaining an overall mean dose reduction up to 35% compared to a standard 64 slices scan.

6142-125, Poster Session

Novel NPS measurement method for medical liquid crystal display using periodic components subtraction technique

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A novel noise power spectrum (NPS) measurement method for medical liquid crystal display (LCD) was developed. A uniform image displayed on an LCD was imaged with a high resolution single-lens reflex type digital camera (D70, Nikon) equipped with a close-up lens. In order to avoid significant errors (frequency leakages) caused by strong periodic components of the pixel structures, noise profile data was processed by periodic components subtraction, and NPS was calculated from the processed profile with Fast Fourie transformation (FFT). Horizontal and vertical NPSs at the center of display area were measured up to the 10 Nyquist frequency. Actual measurements were performed with various models of monochrome 2M and 3M pixel LCDs to investigate difference of conventional method and our proposed method. Resultant NPSs obtained from the conventional method with simple FFT included significant errors over the whole frequency ranges, but our proposed method could compensate most of those errors. Resultant NPSs of our method indicated clearly the difference of noise property between the displays we measured, which corresponded to the visual evaluation for them.

6142-126, Poster Session

A method of accuracy evaluation of line spread function (LSF) and point spread function (PSF) measured in the computed tomography

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To characterize spatial resolution of computed tomography (CT), point spread function (PSF) or line spread function (LSF) in the scan-plane is frequently employed. The aim of this study is to propose a simple method for evaluating the accuracy of PSF or LSF on the image. We calculate the image by using the PSF or LSF based on the previous model to understand of spatial resolution in CT image systems. By comparing the calculated image with scanned image of a simple phantom, the validity of PSF or LSF is confirmed. When the PSF or LSF is precise, calculated image is resulted in good agreement with scanned image. As one example, we measured the LSF in our multi-slice scanner (Sensation-16, SIEMENS) by the conventional method, and the phantom was scanned with the same conditions. The CT-value profile on the image calculated by using the LSF was almost similar to it on scanned image, in which mean-square difference between those profiles was 245 (HU). However, when we obtained LSF by an inappropriate manner, the CT-value profile on the calculated image showed the difference with it on scanned image, in which mean-square difference between those profiles was 1512 (HU). We could evaluate the accuracy of the LSF by investigating the difference between the calculated image and scanned image. This technique is applicable to validate slice sensitivity profile (SSP) in z-direction perpendicular to the scan-plane. When the measurement of PSF, LSF or SSP is performed, proposed method is effective for verification of them.

6142-127, Poster Session

Substrate effect on indirect digital radiography system performance

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In a typical indirect flat panel digital radiography detector, a phosphor screen is coupled to an a-Si:H imaging array, whose pixels comprise an a-Si:H photodiode and an a-Si:H TFT switch. This two-dimensional array is fabricated on a thin glass substrate that usually contains a rather high concentration of heavy elements such as barium. The phosphor screen converts the incident X-rays into optical photons that are detected and converted into electric charges by the photodiodes. The charges collected at each photodiode are then converted into a digital value by using the underlying readout electronics. The imaging performance of the detector in terms of presampling modulation transfer function (MTF), noise power spectrum (NPS), and detective quantum efficiency (DQE) has been studied by using the parallel-cascaded linear systems analysis for various systems (e.g., Cunningham and Zhao et al.). In these analyses, only the effect of K-fluorescence reabsorption in the phosphor screen has been included. However, the effect of K-fluorescence from heavy elements in the glass substrate of the array was not taken into account. This K-fluorescence may be excited directly by primary X-rays that penetrate the overlying phosphor and interact in the glass, or by K-fluorescence X-rays that escape from the phosphor into the glass. In this paper, we extend the parallel-cascaded linear systems model to include the effect of K-fluorescence from heavy elements in the glass substrate. As an example, the MTF, NPS, and DQE of an indirect flat panel imager using a Gd2O2S:Tb phosphor screen, an a-Si:H photodiode/TFT array, and a glass substrate are calculated. Degradations in MTF and DQE as a result of the K-fluorescence from the substrate are presented and discussed.

6142-129, Poster Session

A robust x-ray tube spectra measuring method by attenuation data

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X-ray tube spectra measuring method is presented in this paper. The measurement is accomplished by reconstruction from attenuation data based on a nine-parameter tungsten anode X-ray spectral model. The proposed model is derived from physical basis and composed of three parts: bremsstrahlung spectra, photoemission attenuation by X-ray tube inherent and added filter, characteristic radiations denoted by four Dirac delta functions. Firstly, for simplicity, the four characteristic radiations of the spectra model are merged into two according to a reasonable hypothesis. Secondly, the spectra reconstruction based on the modified model is carried out by calculating the model parameters from measured attenuation data. To further improve the stability, two kinds of materials are used as the attenuators. Experiments show that this method can reach high precision and is insensitive to the noise in measured attenuation data. From the 10 measured attenuation data (7 from Al, and 3 from Copper) with 5% Poisson noise added, the precision of the reconstructed spectra can reach 98.56% for 70kVp X-ray tube with tiny characteristic radiation, and 97.94% for 120kVp X-ray tube with characteristic radiation. Spectrum is the characteristic of X-ray tube and widely used for many purposes. In engineering, the spectrum is mostly reconstructed from attenuation data, but it is an ill-posed problem in mathematics. The method we presented with the features of including characteristic radiation, insensitive to noise and fewer attenuation data demand will help to solve this problem perfectly.

6142-130, Poster Session

Choosing the right resolution for vessel visualization in MR angiography

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In magnetic resonance imaging (MRI), theoretically attainable spatial resolution is characterized by the extent of k-space used for image reconstruction, which is inversely related to the pixel size. Whereas the visible resolution is characterized by the object size at which the object of interest is visually separable from the background. In MRI, the visibility of the object can be decreased by increasing the spatial resolution. Hence, it becomes very important to choose the right spatial resolution to view the object of interest. In this paper, we have analyzed the visibility of vessel detail in magnetic resonance angiography (MRA) and the probability of projection of vessels in the minimum intensity projection (MinIP) and maximum intensity projection (MIP) images as a function of spatial resolution. This analysis is a foundation for determining the extent of k-space that should be used for image reconstruction to visually identify a particular vessel/anatomic detail of interest and thus help in maximizing the amount of vessel information displayed in MRA as well as projection images.

6142-131, Poster Session

New microangiography system development providing improved small vessel imaging, increased contrast-to-noise ratios, and multiview 3D reconstructions

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A new microangiographic (MA) system integrated into a c-arm gantry has been developed allowing for precise placement of a MA detector at the exact same angle as the standard x-ray image intensifier (II) with unchanged source and object position. The MA detector can also be arbitrarily moved about the object and easily moved into the field of view (FOV) in front of the lower resolution II when higher resolution angiographic sequences are needed. The benefits of this new system are illustrated in a neurovascular study, where a rabbit is injected with contrast media for varying oblique angles. Digital subtraction angiographic (DSA) images were obtained and compared using both the MA and II detectors for the same projection view. Vessels imaged with the MA detector appear sharper and smaller vessels can be visualized in the MA images. Visualization of ~100 μm vessels was possible in the MA whereas not in the II images. Further, the MA could resolve vessel overlap where the II could not. Contrast to noise ratios (CNR) were calculated for vessels of varying sizes for the MA versus the II and were found to be similar for large vessels, approximately double for medium vessels, and infinitely better for the smallest vessels. In addition, a 3-D reconstruction of selected vessel segments was performed, using multiple (three) projections at oblique angles, for each detector. This new MA/II integrated system should lead to improved diagnosis and image guidance of neurovascular interventions by enabling initial guidance with the low resolution large FOV II combined with use of the high resolution MA during critical parts of diagnostic and interventional procedures.

6142-132, Poster Session

Matrix addressable x-ray source for medical imaging

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A new x-ray source is being developed for medical research and diagnostic applications. This source could radically change the use of x-rays in areas ranging from digital tomosynthesis to computed tomography. The proposed source is a high-bandwidth, matrix-addressable array of individual cold-cathode x-ray point sources that can be made to cover

areas of roughly one square millimeter to several square meters. This flat panel x-ray source could be used to construct, for example, compact, flat-panel-based tomography systems for use in the field, laboratory, and rural clinic.

Experiments directed toward demonstrating the feasibility of using microfabricated cold cathode field electron emission sources for tomographic imaging have been initiated. Electron beam currents of 25 mA at voltages of 25 kV have been used to produce x-ray source spot diameters of 250 m. Analysis of both filtered and unfiltered x-ray spectra from molybdenum anodes show clear characteristic x-ray lines. These x-ray source characteristics are consistent with the requirements for human breast imaging.

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6142-133, Poster Session

Novel SNR determination method in parallel MRI

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We devised two kinds of new methods for accurate measurement of the image signal-to-noise ratio (SNR) in parallel magnetic resonance imaging (MRI) because image noise of the parallel MRI was not spatially constant. The first method (Consecutive method), more than fifty consecutive scans of the uniform phantom were obtained with identical scan parameters. Then the SNRs in each pixel were calculated from the ratio of mean signal intensity to standard deviation of the time domain on a pixel-by-pixel. For the second method (Remove method), the phantom was removed after the first scan, and the second scan was done with identical parameters and with the RF coil loading devise. The SNRs in each pixel were then obtained from the ratio of the signal intensity of the first scan multiplied by the square root of pi/2 to the second scan (w/o phantom) image filtered by the running mean (7 by 7 pixels). Moreover actual geometry factors were calculated from image SNRs of parallel and no parallel MRI. The image SNR and actual geometry factor of parallel MRI with the Consecutive method agreed with that of the Remove method. The SNRs of no parallel MRI with above two methods conformed with that of conventional SNR method such as NEMA standard or AAPM report. Both new methods make it possible to obtain a more detailed determination of SNR in parallel MRI, and to calculate the actual geometry factor.

6142-134, Poster Session

Fast parallel MRI reconstruction using B-spline approximation (PROBER)

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Parallel MRI is a way to use data obtained simultaneously from several coils to increase the speed of MRI acquisition. The receiver coils have distinct spatial sensitivities over the imaged area. Therefore, the measured data contains more information about the position of the signal than data obtained by a single coil. The idea is to speed up the acquisition by sampling k-space more sparsely and compensate the data loss with the use of the additional information obtained from more receiver coils.

The key contribution of our work is design of a reconstruction algorithm working in image domain. We emphasize on the speed of the reconstruction and minimization of the reconstruction error.

Most of the methods that work in image domain estimate the reconstruction transformation independently in each point. This makes the reconstruction time to increase significantly with image size. We propose an algorithm that uses the fact that coil sensitivities are smooth in space. Therefore we assume that the reconstruction coefficients are also smooth in space.

We use B-spline functions to approximate these coefficients. The B-spline coefficients are estimated by solving a linear system which size depends on the number of splines and coils and does not depend on the resolution. This reduces the number of estimated variables and thus speeds up the estimation.

We tested our method on phantom and in-vivo data. We compared our method with Siemens implementation of GRAPPA and mSENSE in terms of theoretical time complexity and quality of the reconstructed images.

6142-135, Poster Session

First attempt of the medical application of the refraction-based computed tomography

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In recent years, the X-ray refraction contrast was widely developed and applied in different fields of science which deal with the nondestructive observation methods. As it follows from the name, the refraction contrast is the distribution of the X-ray intensity dependent on the deflection angle of the X-ray beam. This property of the contrast provides certain advantages over other contrasts such as absorption and phase-shift. The refraction contrast can show tiny details of the inner structure which are invisible in other types of the X-ray imaging techniques. Another advantage of the X-ray refraction contrast is the sensitivity to the low Z materials. The absorption coefficient of these materials may be two o three orders lower than the refraction index and therefore they may be almost invisible in the absorption contrast while the refraction contrast provides very beautiful images with very high intensity modulation. This property of the refraction contrast may be of great importance in the medical applications of the X-ray. The advantages provided by the refraction contrast allow one to expect the same advantages of the computed tomography (CT) from the refraction contrast. Therefore this report is dedicated to the realization of the refraction-based CT. It describes the theoretical background of the problem, experimental realization of the method and actual results of the reconstruction of the breast cancer sample. The data experimental data were acquired using X-ray synchrotron source at Photon Factory (KEK, Japan). The energy of used in the experiment was 11.7kev. The spacial resolution of the reconstructed images is about 20 microns.

6142-136, Poster Session

MRI-relaxometry BMD-measurements using conventional phase symmetrized rapid increased flip spin echo (PRISE) and standard gradient echo (GE)

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The aim of this study was to use conventional MRI protocols for BMD measurements using MRI-Relaxometry. Cortical and trabecular bone separation cannot be performed in DEXA, so the results might lead to erroneous interpretation of BMD values. One of the new special protocols is Gradient-Echo Sampling of Free-Induction-Decay and Echo (GESFIDE) used on General-Electric systems for deriving R2(=1/T2), R2*(=1/T2*) and R2'(=R2*-R2) in several application. GESFIDE give 8-16 echoes (images) in single scan. It can be used only in system with high slew rate (22 mT/m.s or greater) due to several high slew rate gradients with high amplitudes in small periods.

This study was performed by 1.5T MRI system (Picker Vista-Q800) with slew rate of 13 mT/m.s, SNR phantom (1.25gr/l CuSO4, with T2=200ms for calibration), a body RF-Coil, 7 normal, 7 osteopenia, 7 osteoporosis volunteers and Lunar DEXA system (DPX-MD). To determine R2* and R2, several Gradient-Echo(GE) and Spin-Echo(SE) protocols with different TE/

TR were analyzed and compared with GESFIDE protocol's gradients. Also calculated R2 and R2* using SNR phantom were compared with desired amounts. Then in coronal section of femoral-neck, relaxation rates were compared with BMD.

Therefore, for R2* measurement standard-GE protocol with TE=13.42/18/26.8ms, TR=800ms and ST=8mm [CV(R2*)=2.96%] and for R2 measurement PRISE protocol with TE=36/54/63/72ms, TR=800ms and ST=8mm [CV(R2)=3%] were selected. R2* and R2' showed a significant positive correlation with BMD($r=0.62$, $p<0.05$).

Finally, in accordance with DEXA values, the results showed that PRISE and standard GE are proper protocols for BMD-measurements in femoral-neck in spite of GESFIDE.

6142-137, Poster Session

Photo-bleaching compensation for autofocus algorithms in fluorescence microscope applications

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Efficient autofocus algorithms play an important role in automatic image acquisition in microscope applications. Focus algorithms are based on a criterion function applied to images acquired at different z-axis positions. The function maximum corresponds to the focus position. Hence, a robust autofocus function should show a sharp peak at the focus position. Many functions with these characteristics have been proposed in the literature, most of them assuming that the image roughly maintains some basic properties during the autofocus process. In some fluorescence microscope applications, however, the photo-bleaching effect may change these properties reducing the effectiveness of autofocus functions.

In this paper, we report our experience in looking for effective autofocus functions for automatic image acquisition in ImmunoFluorescence Assay (IFA). We propose to use two functions that greatly improve the performance with respect to functions commonly proposed in the literature. The first function is based on the image histogram and it is suited to in the coarse phase of autofocus, when the z-axis steps are larger to speedup the identification of the interval where lies the focus position. The second function is a popular autofocus function properly modified to compensate the effects of photo-bleaching. It is best suited to be used in the other phases of the autofocus process when smaller steps are taken to precisely identify the focus position. Effectiveness of the proposed functions has been assessed on real images, confirming that they allow obtaining a focus function where a sharp peak is simply identifiable.

6142-138, Poster Session

MR image reconstruction using the GPU

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Magnetic resonance (MR) image reconstruction has reached a bottleneck where further speed improvement from the algorithmic perspective is difficult. However, some clinical practices such as real-time surgery monitoring demand faster reconstruction than what is currently available. For such dynamic imaging applications, measurement data sampled along radial trajectories in k-space recently revived due to fast image acquisition, relatively good signal-to-noise ratio and better resistance to motion artifact compared to the conventional rectilinear raster scan. Concurrently, using the graphic processing unit (GPU) to improve algorithm performance has become increasingly popular. In this paper, we evaluate the speeds and image quality for the GPU implementation of three reconstruction algorithms that are suited for radial trajectories. Since the fast Fourier transform (FFT) is an important part of most MR image reconstruction algorithms, an efficient GPU implementation of the FFT will also be described in detail. Among the three algorithms, two are based on the interpolation scheme in k-space - one is data-driven (this is known as the gridding algorithm) and the other grid-driven. The third one is filtered backprojection which is widely used in computed tomography. Additionally, to remove the streaking artifacts outside the imaged object in the context of filtered backprojection, we create a foreground/background mask which is automatically estimated from the projection data. Our results show that the GPU implementation is 5 to 10 times faster than a conventional CPU implementation with comparable image quality.

6142-139, Poster Session

New extraction method of phase information for x-ray diffraction enhanced imaging

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The X-ray diffraction enhanced imaging (DEI) is one of X-ray phase-contrast imaging methods, which are applied to inspect internal structures of weakly absorbing low-Z samples, such as soft issue in the medical field or fibres in the material field. These samples have weak absorption of X-rays but change phase-shifts of X-rays well. So the differential edges of samples are distinct in phase-contrast images. The key problem of DEI is how to extract phase information (the refractive-angle image) from a series of original images in the different positions of the rocking curve of the analyzer crystal. There are two main extraction methods for DEI: the geometric-optics approximation method and the statistical method of multiple images. But they are not accurate and have respective shortcomings. Thus, this paper presents a new extraction method, named 'statistical-geometric-optics approximation method', which takes advantage of the above two methods. Firstly a computer simulation of DEI was carried out. Then the three methods were tested by simulated data and a comparison was given in theory. Finally, A DEI experiment at Beijing Synchrotron Radiation Facility (BSRF) proved that the new method could improve the exactness of geometric-optics approximation solutions and the Signal to Noise Ratio (SNR) of refractive-angle images.

6142-140, Poster Session

Spectral imaging of skin: experimental observations and analyses

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The emergence of compact optical spectral imaging technologies has motivated the study of their use in a variety of applications, including medical diagnosis and monitoring. In particular, large format CCD focal planes in conjunction with spectrally tunable devices offer enhanced spatial information together with visible and near infrared (NIR) spectroscopic data for the passive, noninvasive, measurement of human skin and near surface tissue characteristics.

One such spectral imaging system was recently developed by mating a Liquid Crystal Tunable Filter (LCTF) together with a 2048x2048 silicon CCD focal plane. This system is capable of collecting more than 30 co-registered spectral images spaced every 10 nanometers and spanning 400 to 720 nanometers. This system combines the potential of near infrared diffuse reflectance spectroscopy with the high spatial resolution of traditional optical imaging techniques.

Spectral images were acquired of portions of the hands and arms of several test subjects with a variety of features observable. The observations were collected in a "light box" under controlled illumination conditions. Images of a diffuse reflectance standard and instrument dark frames were collected to allow conversion of the raw images to spectral reflectance.

Example images and reflectance spectra from normal skin, as well as from moles, wounds, and scars will be shown. Preliminary assessments of achieved signal-to-noise level, spectral image registration, and focal plane uniformity will be presented. Results will also be shown for a new algorithm extracting the saturated oxygen hemoglobin fraction from these data.

6142-141, Poster Session

Anatomically constrained conductivity estimation of the human head

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A surgical treatment of epilepsy or studying the brain functional activity requires localizing the neural activity centers with great deal of accuracy. Until recently, most practical source localization methods in the field of electro- and magnetoencephalography (EEG/MEG) neuroimaging modalities have relied upon analytical multi-shell spherical models for a human head in the forward calculations. The conductivity values of the modeled head tissues are usually taken from the scattered published data on non-specific measurements in vitro. In this paper, we describe an experimental and computational procedure for accurately and non-invasively characterizing the electrical conductivity of the constituent tissues of the human head. We then report the preliminary results of the first experiments performed on a human subject. Data (potentials recordings and sensor positions) were collected using 128 channel Geodesic Sensor Net/Photogrammetry System during external small current injection and along with a high resolution (1 mm x 1 mm x 1mm) segmented 3D MRI/CT digital image of subject's head fed into the computational finite difference based model. The multi-component alternative direction implicit (ADI) algorithm, parallelized with OpenMP, was used to solve the forward volume conduction problem. The inverse search was implemented using the MPI protocol and the simplex algorithm. The computational environment was designed on a heterogeneous multicluster platform. The conductivity extraction of three type tissue conductivities of the subject (scalp, skull and brain) has been successfully demonstrated and shown to be consistent with their physiological ranges reported in the related biomedical literature.

6142-142, Poster Session

Fat/water separation in a single MRI image with arbitrary phase shift

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A variety of techniques have been proposed to remove the lipid signal from MRI images. Generally, these can be grouped into lipid-separation techniques that distinguish water from lipid signal after the data has been received, and lipid-suppression techniques that prevent the lipid signal from being received. Field inhomogeneity is a primary concern in the design of both techniques. In lipid separation the most common approaches to dealing with inhomogeneity are variations on Dixon imaging. In general, Dixon imaging consists of taking multiple images at different TEs and then using the differences in phase between water and lipids at each TE to separate the two components of each pixel.

The primary downside to Dixon imaging is the requirement for multiple images with stationary anatomy, often with specific TEs. An alternate approach is to take only one image, estimate phase errors to correct for inhomogeneity or other effects, and then separate the water and lipid using the known phase shift. This has shown promise in previously published work, but the water and lipid signals were always perpendicular. This fixes the TE, which may be undesirable in some contexts.

We consider the possibility of separation from a single, phase-corrected image with an arbitrary angle between water and lipid signals. A simple change of basis is presented to separate water and lipid signals into two images with additive zero-mean Gaussian noise. However, we show that as the angle between water and lipid nears pi or 0, the noise power in the separated images increases rapidly. We discuss techniques for reducing this noise magnification.

6142-143, Poster Session

Spectral imaging of near-surface oxygen saturation

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A number of non invasive methods have been developed to characterize parameters in near-surface skin tissue; however, the work has usually been concerned with using either spectral or spatial information. This motivated our study in which both spatial and spectral data are used to extract features for characterizing the spatial distribution of near-surface oxygen saturation. This paper addresses combined physical and statistic models to retrieve the ratio of oxy- and deoxy-hemoglobin in tissues from data collected by an imaging spectrometer. To retrieve the oxygen saturation fraction from the data, algorithms from the literature using two or three wavelengths were compared to our new algorithm using the many more wavelengths (25 to 60) available in imaging spectrometer data, and noise reduction achieved through principal component transformations.

In addition to the analysis of experimental spectral imagery, an oxygen saturation phantom of size 128x128 pixels was simulated. In the forward process, reflectance image is constructed from an assumed oxygen saturation map and the absorption coefficients of Oxy-Hemoglobin, Deoxy-Hemoglobin, Melanin and other chromophores. The reflectance data have 60 bands spanning 400nm to 990nm with 10nm interval in the spectral dimension. White Gaussian noise is added to the reflectance to simulate losses in the actual experiment. In the backward process, oxygen saturation image is reconstructed by applying different algorithms using 2 wavelengths (1), 3 wavelengths (2), 25 and 60 wavelengths. The resultant images are evaluated by their mean squared error.

6142-144, Poster Session

Effects of collimator dependency and correction methods on I-123 SPECT images using x-ray-based attenuation map

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Low energy (LE) collimator is generally used in I-123 SPECT imaging. However, the septal penetration and scattering of photons emitted with energy above 159 keV will affect the image contrast and quantitative accuracy of images. To reduce this effect, medium energy (ME) collimator has been used with the cost of lower counting statistics and spatial resolution. The effects of collimator dependency on the quantitative accuracy of attenuation corrected (AC) I-123 SPECT images using X-ray-based attenuation map is investigated. Both brain and heart/thorax phantoms are used to evaluate different degree of attenuation effect between brain and thorax. Experiments were performed at different target-to-background ratios to simulate different object contrast. Both photopeak and scatter projections were collected for dual-energy window scatter correction (SC). Images were reconstructed and compared using different methods, which included FBP, and OSEM without corrections, with AC, with SC, and with AC and SC. In both phantom studies, the image contrast and quantitative accuracy were both improved with the use of CT-based transmission map for AC. The image contrast provided by ME collimator is better than that of LE collimator, especially in the region with void activity of thorax phantom. From the results of phantom studies, medium energy collimator with CT-based transmission map shows improvement in image contrast and quantitative accuracy of I-123 SPECT images.

6142-145, Poster Session

Discrete tomography from micro-CT data: application to the mouse trabecular bone structure

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Discrete Tomography (DT) deals with the reconstruction of an image from a number of projections when this image is known to have only a small number of gray values. The knowledge of the discrete set of gray values can significantly reduce the number of projections required for a high-quality reconstruction.

In this paper, a feasibility study is presented of the application of discrete tomography to micro-CT data from a mouse leg as to study the structural properties of the trabecular bone. The set of gray values in the reconstructed image is restricted to only three values, for the air background, the soft tissue background, and trabecular bone structure. It is shown that, using discrete tomography, scanning time and X-ray dose can be reduced by at least a factor of three if morphometry instead of the actual gray levels are of interest in medical CT images.

6142-146, Poster Session

Development of a K-edge micro CT for the study of tumor angiogenesis in small animals

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A new linear and tomographic scanner for small animals, based on a couple of parallel quasi-monochromatic X-rays beams with different centroid energy, is under development at the Dept. of Physics of the University of Bologna. The aim of the project consists in the study - by the in vivo imaging - of the growth and metastasis formation of various tumour typologies on mice.

The earlier dignosis of tumor depends on the knowledge of precancerous and first-stage changes of tissue. As a cancer develops, the cancer cells may produce chemicals that cause new blood vessels to form nearby. These new blood vessels nourish the cancer cells, which can continue to grow and form a tumor large enough to see on X-rays. As demonstrated in previous works, the imaging system based on the dual energy quasi-monochromatic beams allows greater sensitivity to the low concentrations of the iodinated contrast medium than traditional X-ray apparatus. Moreover the dual energy technique allows to distinguish difference between linear absorption coefficients of healthy and pathological tissues.

The work will be performed on new human and murine cell lines: 1) human tumors in immunodepressed mice, 2) mouse tumors in inbred mice, 3) autochthonous tumors of transgenic/knockout mice.

In this paper, the TC apparatus, its characterization and first images will be presented.

6142-147, Poster Session

Illumination correction of colour retinal images

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Non-uniform illumination is a common problem in many practical imaging scenarios. It is a critical problem in the field of medical imaging where it can affect the diagnosis performed by a human expert or by an automatic analysis system. It gets worse in the case of retinal imaging where many independent factors lead to this problem, affecting a large number of images. Few attempts have been made to address this problem and those existing suffer from many drawbacks. In this paper, we propose a novel image adaptive technique to remove the effect of non-uniform illumination from colour retinal images, addressing many of these drawbacks. This technique was tested on 100

images and it was found to perform quite well. Images which were not affected by non-uniform illumination as well as parts of affected images under good illumination were not over-corrected. Opthalmologists who examined the results of correction concurred on the quality improvement of the corrected images and their utility in facilitating better diagnosis.

6142-148, Poster Session

Imaging of the skin crater caused by laser ablation during liver cancer treatment

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In treating cancers, either chemotherapy or major surgical removal process of the cancerous cell are the traditional treatment of the cancers. Laser ablation on the other hand was used in small scale to localize or control the area over to treatment of the surface skin cancer. This study, will introduce a new techniques in treating the deep cancers cells, by using a reversed indo-laser ablation technique to target the volumetric center of the tumor or the origin of the epidemic activity of the cancer. By using a high pulsed laser and under a controlled insertion of the laser guide to target the center of the tumor and work out the ablation process to ablate the volumetric activity from the center to the outer cells. Imaging of the ablation process will be introduced by using IR CCD camera and an enhancement computerized images, the threshold of the elasticity of the border between the healthy and the sick cell will be determined. In addition, the feasibility of reconstructing the crater at the liver surface due to the carbon dioxide laser ablation technique will be discussed and presented.

6142-149, Poster Session

Improved diagnostics using polarization imaging and artificial neural networks

U. M. Klimach, The Catholic Univ. of America; Y. K. Zou, H. Zhao, Boston Applied Technologies Inc.; J. Xuan, The Catholic Univ. of America

In recent years there has been an increasing interest in the propagation of polarized light in randomly scattering media. This paper presents a novel approach for cell and tissue imaging and diagnostics by using full Stokes imaging and Artificial Neural Networks (ANNs). Phantom experiments were conducted using a Stokes polarization imaging apparatus. Two types of phantoms, consisting of polystyrene latex spheres 42μm and 99μm in diameter, respectively, were prepared to simulate different conditions of epidermal layer of skin. A set of four images which contains not only the intensity, but also the polarization information were taken and converted to Stokes components. Wavelet transforms are applied to polarized images in Stokes components for initial feature analysis and extraction. Artificial neural networks (ANNs) were used to extract diagnostic features (i.e., classification features based on Fisher criterion) for improved classification and prediction. The ANN was trained according to LOO (Leave One Out). The results show that the classification performance using Stokes images was significantly improved over the intensity only images.

6142-150, Poster Session

Comparison of two detector systems for cone beam CT small animal imaging: a preliminary study

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Purpose: To compare two detector systems- one based on the CCD and Image Amplifier, the other based on a-Si/CsI flat panel, for cone beam CT imaging of small animals.

We are developing a high resolution, high framing rate detector system for cone beam CT imaging of small animals. The system consists of a 2048_3076_12 bit CCD optically coupled to an image amplifier and a thin x-ray phosphor screen. The CCD has an intrinsic pixel size of 12 μm but the effective pixel size can be adjusted through magnification adjustment of the optical coupling systems. The system is used in conjunction with an X-ray source and a rotating stage for holding and rotating the scanned object in cone beam CT imaging experiments. The advantages of the system include but are not limited to the ability to adjust the effective pixel size and to achieve extremely high spatial resolution. However, the need to use optical coupling compromise the DQE of the system. In this paper, we will describe and discuss the design considerations of this detector system. Imaging characteristics of the system will be presented and compared with those of an a-Si/CsI flat panel detector system. Cone beam CT images of phantoms and mice obtained with the two systems will be presented and compared.

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6142-151, Poster Session

Maximum likelihood reconstruction of circular cone-beam CT data

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The behavior of a Maximum Likelihood reconstruction algorithm applied to circular cone-beam CT data is examined. In a simulation study, it is shown that unacceptable artifacts appear, if a constant initial image is used. These artifacts are removed, if the initial image is generated from a low-dose helical pre-scan.

6142-152, Poster Session

Penalized weighted least-squares approach to sinogram noise reduction and image reconstruction for low-dose x-ray computed tomography

J. Wang, Stony Brook Univ.; T. Li, Stanford Univ.; H. Lu, Fourth Military Medical Univ.; Z. Liang, Stony Brook Univ.

The noise of low-dose computed tomography (CT) sinogram follows approximately a Gaussian distribution with nonlinear dependence between the sample mean and variance. The noise is statistically uncorrelated among detector bins. However the correlation coefficient matrix of the sinogram among views indicates a strong signal correlation among neighboring views. By the use of the Karhunen-Loève (KL) transform to decorrelate the signal among neighboring views, a penalized weighted least-squares (PWLS) objective function, which accurately models the noise property, can be formulated and an optimal sinogram can be estimated by minimizing the objective function, followed by filtered backprojection (FBP) for rapid image reconstruction. In this work, we compared the KL-PWLS method with an iterative image reconstruction, which uses the Gauss-Seidel algorithm to minimize the PWLS objective function in image domain. We also compared the KL-PWLS with an iterative sinogram smoothing method, which uses the iterated conditional mode algorithm to minimize the PWLS objective function in sinogram space, followed by FBP. Phantom experiments show a comparable performance of the three PWLS methods in suppressing the noise-induced artifacts and preserving resolution in CT images. Computer simulation concurs with the phantom experiments in terms of noise-resolution tradeoff and detectability in low contrast environment. The KL-PWLS noise reduction has the advantage in computing time for low-dose CT imaging.

6142-153, Poster Session

An extended half-scan Feldkamp-type CT reconstruction

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In this paper, a Feldkamp-type (FDK) approximate algorithm for helical multislice Computed Tomography (CT) is proposed for reconstructing transaxial image slices. An extended half-scan scheme is proposed to ensure that all points on the transaxial slice satisfy the Tuy's condition and, therefore, have potential to be exactly reconstructed. We derive a formula for obtaining the minimum length of the extended half-scan helix, and apply it in the proposed approximate reconstruction algorithm. Computer simulations are conducted to evaluate the algorithm, in comparison with the existing FDK-type reconstruction algorithms. It is shown that the proposed algorithm can reduce artifacts which exist in conventional FDK-type algorithms. Especially, compared with a recent algorithm on using short-scan data for reconstructing nutating curved surfaces which satisfy Tuy's condition, our proposed algorithm uses less scanning data and directly reconstructs the whole transaxial slice. Furthermore, since the length of extended half-scan helix is independent from the axial position, the proposed algorithm is more computationally efficient in axial multislice imaging in field.

6142-154, Poster Session

Tomosynthesis reconstruction with simultaneous algebraic reconstruction technique (SART) on breast phantom data

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

Digital tomosynthesis mammography (DTM) is a promising approach to breast cancer detection. DTM can provide 3D structural information of the breast tissue by reconstructing the imaged volume from 2D projections acquired at different angles in a limited angular range. In this work, we investigate the application of the Simultaneous Algebraic Reconstruction Technique (SART) to this limited-angle cone-beam tomographic problem. Projection-view images of a breast phantom were acquired from 11 angles by manually moving the x-ray tube of a GE Senographe 2000D FFDM system in 3° increments over a 30° angular range. During image acquisition, the phantom and the digital detector (X-Y plane) are stationary. We used an ACR phantom and two additional phantoms that were designed to evaluate the phantom image quality and reconstruction artifacts. We subdivided the 3D image volume into a set of voxels of sidelengths 0.1mm x 0.1mm x 1mm in the X-Y-Z directions, respectively, and developed an algorithm to track the path-lengths of the x-rays intersecting the grid of voxels. The Back-Projection (BP) method was also implemented as a comparison to SART. The contrast-to-noise ratio (CNR), line profile of features and an artifact spread function (ASF) were used to quantitatively evaluate the reconstruction results. Preliminary results show that both BP and SART can separate superimposed phantom structures along the Z direction but SART is relatively more effective in improving the conspicuity of tissue-mimicking details and suppressing the interplane blurring, and thus leading to an improved ASF. For the phantoms with homogeneous background, the BP method resulted in less noisy reconstruction and higher CNR values for masses than SART, but SART provided greater enhancement in the contrast of calcification clusters and the edge sharpness of masses and fibrils. The image noise was increasingly amplified by SART as the number of iterations increased. It was shown that acceptable reconstruction can be achieved by SART after only one or two iterations.

6142-155, Poster Session

An inversion method for the exponential radon transform based on the harmonic analysis of the Euclidean motion group

C. E. Yarman, B. Yazici, Rensselaer Polytechnic Institute

This paper presents a new method for the exponential Radon transform inversion based on the harmonic analysis of the Euclidean motion group of the plane. The proposed inversion method is based on the observation that the exponential Radon transform can be modified to obtain a new transform, defined as the modified exponential Radon transform, that can be expressed as a convolution on the Euclidean motion group. The convolution representation of the modified exponential Radon transform is block diagonalized in the Euclidean motion group Fourier domain. Further analysis of the block diagonal representation provides a new class of relationships between the spherical harmonic decompositions of the Fourier transforms of the function and its exponential Radon transform. The block diagonal representation provides a method to simultaneously compute all these relationships. The proposed algorithm is implemented using the fast implementation of the Euclidean motion group Fourier transform and its performances is demonstrated in numerical simulations.

6142-156, Poster Session

Elliptical extrapolation of truncated 2D CT projections using Helgason-Ludwig consistency conditions

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Image reconstruction from truncated tomographic data is an important practical problem in CT in order to reduce the X-ray dose and to improve the resolution. The main problem with the Radon Transform is that in 2D the inversion formula globally depends upon line integrals of the object function. The standard Filtered Backprojection algorithm (FBP) does not allow any type of truncation. A typical strategy is to extrapolate the truncated projections with a smooth 1D function in order to reduce the discontinuity artefacts. The low-frequency artifact reduction however, severely depends upon the width of the extrapolation, which is unknown in practice.

In this paper we develop an extrapolation method for truncated 2D CT-data, when only a local area (ROI) is to be imaged. The first step is to complete the truncated sinogram with Radon data of a uniform ellipse. The parameters of this ellipse are then optimized using Helgason-Ludwig consistency conditions. The innovative aspect is that the shape and structure of the region surrounding the ROI is described by a specific object with only few parameters, in this case a uniform ellipse.

Two types of truncation are simulated: the 'interior' problem, for which no exact reconstruction is possible, and the 'truncated arms' problem, for which exact reconstruction algorithms are available. Simulations for the interior problem show that our method achieves an error which is very close to the error obtainable with the optimal (but unknown in practice) width of a cos_ extrapolation. The accurate results of the elliptic extrapolation for the `truncated arms' problem, nicely illustrate the efficiency of this approach. Remark finally that the algorithm can also be used for other mathematical shapes. A similar method has earlier been used successfully for attenuation correction in SPECT

6142-157, Poster Session

An alternative inversion formula for the cone-beam transform

C. E. Yarman, B. Yazici, Rensselaer Polytechnic Institute

This paper presents an alternative formulation for the cone-beam projections given an arbitrary source trajectory and detector orientation. This formulation leads to a weighted back projection type inversion formula. Conditions required to achieve an exact reconstruction, which relate the source trajectory and the domain of reconstruction, are presented.

6142-158, Poster Session

A new approach of 3D SPECT reconstruction for near-field coded aperture imaging

B. Hong, Z. Mu, Y. Liu, Yale Univ.

Near-field coded aperture imaging is known to have superior image resolution and count sensitivity over conventional parallel-hole collimated nuclear imaging. There have been several studies in reconstruction of two dimensional planar objects using coded aperture imaging technologies. Nevertheless, image reconstruction for three dimensional (3D) objects has not been extensively investigated. In this paper, a 3D reconstruction method for near-field coded aperture imaging is presented. We first introduce a depth-dependent correction factor in the generic expectation maximization (EM) algorithm by considering a scale factor for each slice decoding. As the out-of-focus information of each slice is removed from the other slices in a 3D object constituted by a stack of slices at different depths, each slice decoding no longer contains other slices' information. The decoded slices for each angle are subsequently summed to generate a "clean" in-focus projection. The ordered subset expectation maximization (OSEM) method is used to reconstruct the full 3D object from the decoded projections of the different acquisition angles. To evaluate the performance of our method, a 3D micro tubing phantom filled with 99mTc radioactive solution was used. A dual-head SPECT system equipped one head with a parallel-hole collimator and the other with a coded aperture module was used for image acquisitions. Our method using the EM with the depth-dependent correction from coded aperture projections demonstrates significant improvement in image resolution as compared to parallel-hole collimated images. Our preliminary experimental results showed this method has potential of reconstructing 3D near-field coded aperture images and improving SPECT image resolution.

6142-159, Poster Session

Noise reduction of low-dose helical CT by 3D penalized weighted least-squares sinogram smoothing

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

Helical computed tomography (HCT) has several advantages over conventional step-and-shoot CT for imaging a relatively large object, especially for dynamic studies. However, HCT may increase X-ray exposure significantly to the patient. This work aims to reduce the radiation by lowering the X-ray tube current (mA) and filtering the low-mA (or dose) sinogram noise. Based on the noise properties of HCT sinogram, a three-demensional (3D) penalized weighted least-squares (PWLS) objective function was constructed and an optimal sinogram was estimated by minimizing the objective function. To consider the difference of signal correlation among different direction of the HCT sinogram, an anisotropic Markov random filed (MRF) Gibbs function was designed as the penalty. The minimization of the objection function was performed by iterative Gauss-Seidel updating strategy. The effectiveness of the 3D PWLS sinogram smoothing for low-dose HCT was demonstrated by a 3D Shepp-Logan head phantom study.

6142-160, Poster Session

Quarantine MAP reconstruction of PET/CT data using dual priors

J. C. Chan, S. Meikle, R. R. Fulton, W. T. Cai, D. D. Feng, The Univ. of Sydney (Australia)

Maximum a posteriori (MAP) reconstruction makes use of an anatomical prior from CT or MRI imaging to enforce smoothness of reconstructed PET images while preserving anatomical edges. The tendency of this technique to smooth parts of the image between anatomical boundaries may reduce the detectability of functional lesions if, as is commonly the case, the edges of these lesions do not conform to anatomical boundaries. We have investigated the use of a functional prior in addition to an anatomical prior to improve the detection and quantification of lesions in PET imaging. We introduce a new parameter, Q, which controls the weight, β, of the edge-preserving smoothing prior on a spatially-variant basis, to enable a reduction of the smoothing effect in regions containing lesions. Such regions constitute the functional prior. They can be defined, for example, by applying a threshold to a previously reconstructed PET image. They are subjected to a lesser degree of smoothing, as determined by the combined effects of Q and β. We call this dual-prior technique quarantine MAP reconstruction (QMAP). Thus, the method alters the degree of smoothing in specific parts of the image with the aim of enhancing lesion detectability. We have compared the QMAP algorithm in computer simulations with standard One-Step-Late (OSL) reconstruction and OSL with CT prior information. QMAP provided better lesion contrast than the other algorithms, without altering the properties of other parts of the image. In future work, we will assess its performance in comparison with other dual prior approaches in clinical and phantom studies.

6142-161, Poster Session

Computer simulation of FDK reconstruction with the in-line holographic projection data

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

Phase contrast imaging uses the phase coefficient rather than the attenuation coefficient to image objects. Consequently, it may resolve some structures that have similar attenuation coefficients but different phase coefficients as their surroundings. Phase contrast imaging is also an edge-enhanced imaging technique. With this method, the boundary of lesions could be easily determined for clinical evaluation of margins. In this paper, the possibility of using an in-line method in CT reconstruction was explored. Starting from the interference formula of in-line holography, a weak attenuation assumption was made. With this assumption, the terms in the interference formula could be approximately expressed as linear integrals, which is the requirement for all CT algorithms. Thus, the FDK algorithm could be applied for this in-line method, with some mathematical imperfection. The reconstructions for both fan-beam CT and cone-beam CT were studied. The results showed that all the lesions in the numerical phantom could be observed with an enhanced edge. However, the reconstructed images have some streak artifacts, due to the edge-enhancement nature of phase contrast imaging in acquiring the projection data. Cone beam phase contrast reconstruction images have many more artifacts and errors than that in the fan beam case. Also, a very small x-ray focal spot size and a high-resolution detector are required for the implementation.

6142-162, Poster Session

Reconstruction implementation based on a flat panel detector cone-beam breast imaging CT (CBCTBI)

D. Yang, R. Ning, D. L. Conover, Y. Yu, Univ. of Rochester

Flat panel detector-based cone-beam CT breast imaging (CBCTBI) may be a substitute for current mammography for breast tumor diagnostics. The Modified FDK (MFDK) algorithm is used for circular reconstruction. Based on the system geometrical configuration, it turns out that when the HCN (height from chest wall to nipple) of the breast is less than 10 cm, MFDK is sufficient to achieve satisfactory reconstruction. However, when HCN is greater than 10 cm, an obvious attenuation coefficient drop along the rotation axis and geometrical distortion around the nipple area will be noticed for a low contrast object like the breast. A sparse helical line scan algorithm is proposed to be incorporated in the MFDK to correct the above flaws when the HCN is greater than 10 cm and less than the one that the x-ray can maximally cover in one circular scan. The proposed scheme is applied to a computer simulated low contrast breast phantom . The prototype CBCTBI system consists of an x-ray tube, a new designed CT gantry, a 40´30 cm Varian Paxscan 4030CB real time FPD.For computer simulation, all scanning and detector parameters are set up according to the actual CBCTBI prototype system. The computer simulated phantom study shows that the MFDK plus sparse helical line scanning scheme improves the image quality in terms of uniformity, low contrast detectability, and geometric correctness.

6142-163, Poster Session

Interpolations methods for Mojette transform

M. C. Servières, N. C. Normand, J. V. Guédon, Univ. de Nantes (France)

The Mojette transform is an exact discrete version of the Radon transform. It allows to reconstruct object in a discrete special geometry. In this paper, there are two goals. The first one is to show how the Mojette projections can be interpolated to get a larger set of projections from a small set of known projections, then the second one is to rebin classic projections to the special Mojette sampling.

In the first part, we recall the sampling geometry adapted to the discrete geometry of the reconstructed image then we present an exact backprojection filtering Mojette reconstruction scheme with a definite number of projections. We assess the quality of the image reconstruction in the case of an insufficient number of projections, using phantoms.

In the second part, an angular interpolation method is presented to interpolate more projections, from a set of known projections, then an interpolation on the projections is described to show how to rebin projections in the Mojette geometry.

6142-164, Poster Session

Cone-beam image reconstruction with spherical detectors using BPF algorithm

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Both flat-panel detector and cylindrical detector have been used in CT systems for data acquisition. The cylindrical detector generally offers a sampling of a transverse image plane more uniformly and admits fan angles larger than does a flat-panel detector. However, in the longitudinal dimension, the cylindrical and flat-panel detectors offer identical sampling of the image space. In this work, we investigate a detector of spherical shape. Such a spherical detector may have some advantages over the flat-panel and cylindrical detectors. For example, it can yield uniform sampling of the 3D image space because the solid angle subtended by each individual detector bin remains identical, thus reducing the detector size when the cone-beam angle is large. We have extended the algorithms that we have developed previously for cone-beam CT, including the backprojection-filtration (BPF) algorithm, to reconstruct images from data acquired with a spherical detector. Furthermore, we have conducted computer-simulation studies, in which a 3D HEAD phantom and other phantoms were used to generate cone-beam data for the spherical detector. The quantitative results in these studies demonstrate that accurate images can be obtained from data acquired with a spherical detector by use of our extended cone-beam algorithms.

6142-165, Poster Session

Effect of random coincidences for quantitative cardiac PET studies using 3D oxygen-15 water scans

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Purpose. We investigated the effect of random coincidence estimation methods on the quantitative accuracy of iterative and analytic reconstruction methods to determine myocardial blood flow (MBF) in PET studies using H215O. Methods. Dynamic scans were acquired on the EXACT3D PET scanner on pigs after H215O injection (resting and dipyridamole-induced stress). Radioactive microspheres (MS) were used to provide a "gold standard" of MBF values. The online subtraction (OS) and maximum likelihood (ML) random estimation methods were combined with (i) 3D-RP, (ii) FORE + attenuation-weighted OSEM, (iii) FORE-FBP and (iv) 3D-OSEM. Factor images were generated by means of linear dimension reduction and resliced to short axis images; 16 ROIs were defined in the left myocardium and 2 ROIs in the left and right cavities. ROIs were projected onto the dynamic images to extract time-activity-curves, which were then fitted to a single compartment model to estimate regional and global absolute MBF. Microsphere measurements were obtained in a similar way and 64 pairs of measurements were made.

Results. The ML method improved SNR of 3D-RP, FORE-FBP, FORE-OSEM, and 3D-OSEM by 8%, 8%, 7% and 3% respectively. Compared to the OS method, the ML method improved the accuracy of CFR values of 3D-OSEM, 3D-RP, FORE-OSEM and FORE-FBP by 9%, 7%, 1% and 3% respectively. Regression analysis provided better correlation with 3D-OSEM and FORE-OSEM when combined with the ML method. Conclusion. ML random estimation method combined with 3D-OSEM and FORE-OSEM delivered the best performance for absolute quantification of MBF using O-15 water compared with the microsphere

6142-166, Poster Session

Acceleration of fluoro-CT reconstruction for a mobile C-Arm on GPU and FPGA hardware: a simulation study

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Fluoro CT imaging in interventional and minimally-invasive surgery requires high-performance computing solutions that meet operational room demands, healthcare business requirements, and the constraints of a mobile C-arm system. The computational requirements of clinical procedures using CT-like data are increasing rapidly, mainly due to the need for rapid access to medical imagery during critical surgical procedures. The highly parallel nature of Radon transform and CT algorithms enables embedded computing solutions utilizing a parallel processing architecture to realize a significant gain of computational intensity with comparable hardware and program coding/testing expenses. In this paper, using a sample 2D and 3D CT problems, we explore the programming challenges and the potential benefits of embedded computing using commodity hardware components. The accuracy and performance results obtained on three computational platforms: a single CPU, a single GPU, and a solution based on FPGA technology have been analyzed. We have shown that hardware-accelerated CT image reconstruction can be achieved with similar levels of noise and clarity of feature when compared to program execution on a CPU, but gaining a performance increase at one or more orders of magnitude faster. Practical 3D reconstruction and a variety of volumetric image processing applications will benefit from similar accelerations. Overall, in the interventional surgery setting, acceptable image quality appears to be a compromise between clinical usefulness of image information, degree of image degradation due to processing, and image chain throughput.

6142-167, Poster Session

Application of the half-scan technique to cone beam breast CT imaging: a preliminary study

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Purpose: To investigate the feasibility of applying the half-scan technique to cone beam breast CT imaging.

Methods and Materials: We have constructed a rotating phantom, stationary gantry bench top system to conduct imaging experiments for cone beam breast CT. Full-scan data (360 projection views over 360 degrees) were acquired with a pixel size of 0.194mm and reconstructed with FDK algorithm. Half-scan data (207 views) were extracted from the full-scan data and reconstructed with Yang's algorithm. Two size groups, 0.355~0.425 and 0.425~0.5mm , of calcifications embedded in a 10.5 cm diameter salami phantom were imaged at 80kVp and two different tube currents, 1.6 and 0.8 mA. Half-scan images are compared to full-scan images reconstructed from the 1.6 mA and 0.8 mA data sets. A breast specimen from mastectomy was also imaged at 50 kVp and 10 ma. Both full-scan and half-scan images were reconstructed and compared.

Results and Discussion: Images obtained with the half-scan technique at 1.6 mA are found to be slightly noisier than those obtained with the full-scan technique at 1.6 mA. This may be due to the fact that the total exposure with the half-scan technique amounts to only 58% of that with the full-scan technique. The image quality of the half-scan images obtained at 1.6 mA is comparable to that of the full-scan images obtained at 0.8 mA, reflecting the fact that the total exposures in both cases are about the same. Similarly, breast specimen images obtained with the half-scan technique depict comparable anatomical details except a slightly higher noise.

Conclusion: Our study showed that the half-scan technique may be used to obtain cone beam CT images with a quality approaching that obtained with the full-scan technique at the same dose level.

6142-168, Poster Session

A backprojection filtered image reconstruction algorithm for circular cone-beam CT

L. Li, Z. Chen, L. Zhang, Y. Xing, K. Kang, Tsinghua Univ. (China)

In this paper we present a backprojection filtered type (BPF type) reconstruction algorithm for cone-beam circular scans based on Zou and Pan's work. The algorithm could use all the projection data passing through PI-line segments in scanning range. Because all the projection data in is used, the algorithm has a good quality for practical projection data. The algorithm is implemented using numerical and practical experiments. The practical experiments were done on our 450 keV X-ray CT system with a flat-panel detector. We also compare the results with FDK reconstructions. From the experimental results, we get the spatial resolution and density resolution of our CT system. In the end, the conclusions are achieved.

6142-169, Poster Session

Implementation of strip-area system model for fan-beam collimator SPECT reconstruction

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We have implemented a more accurate physical system representation - a strip-area system model (SASM) for improved fan-beam collimator (FBC) SPECT reconstruction. This approach required implementation of modified ray tracing and attenuation compensation in comparison to a line-length system model (LLSM). We have compared performance of SASM with LLSM using a Monte Carlo and analytical simulations of FBC SPECT (40 cm focal length, 120 views with a circular orbit with 17 cm radius of

rotation) from a thorax phantom containing Tc-99m activity of 1.775 μCi/ml in the hot myocardium and 0.1775 μCi/ml in the reminder of the thorax. The focal length of FBC was 40 cm and 4.92x108-gamma photon histories were simulated with a NaI detector and energy window set at 18%. OSEM reconstruction was performed with OS=3 in a 64x64 matrix with attenuation compensation (assuming uniform attenuation of 0.13 cm-1). Scatter correction and smoothing were not applied. We observe overall improvement in SPECT image bias, visual image quality and an improved hot myocardium contrast for SASM vs. LLSM. In contrast to LLSM, the sensitivity pattern artifacts are not present in the SASM reconstruction. In both reconstruction methods cross-talk image artifacts (e.g. inverse images of the lungs) can be observed due to uniform attenuation map used. SASM applied to fan-beam collimator SPECT results in better image quality and improved hot target contrast, as compared to LLSM, but at the expense of 3-fold increase in reconstruction time.

6142-170, Poster Session

Accelerating 3D cone beam T-FDK algorithm on commodity PC graphics hardware

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

T-FDK algorithm is an FDK-type cone beam CT reconstruction algorithm. Like other 3D reconstruction algorithms, T-FDK is time consuming because of the large amount of data processing involved. One solution to this problem is utilizing PC graphics boards (GPU) for acceleration. The recent dramatic evolution of GPU makes this method come to the practical track. In this paper, we use a new floating point GPU to speedup the 3D T-FDK algorithm that is different from original FDK method in structure. Because floating point pipelines are slower than hardwired 8-bit texture mapping facilities but are more precise numerically, we balance the reconstruction speed and quality by using both of them. Using nVIDIA GeForce 6800 GT, Our GPU accelerated T-FDK method gives a speed 27.612 times faster than a software implementation.

6142-171, Poster Session

Image reconstruction from projections using ridgelet transform

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Image reconstruction is inversion of the Radon transform in two dimensions. In Computerized Tomography (CT) an image is reconstructed from a finite subset of its projections (taken at distinct angles) in the form of Radon transform. Ridgelet transform is the application of one dimensional wavelet transform to the slices of Radon transform. In the present work an algorithm for image reconstruction from finite number of projections (inverse Radon transform) using inverse Ridgelet transform for image reconstruction is presented. The problem is considered within the framework of parallel beam geometry for Computerized Tomography. Existing theory for Ridgelets suggests that this new approach can outperform Wavelet methods in image reconstruction. Discrete version of Ridgelet transform is developed to obtain reconstruction from parallel beam projection data. The algorithm is tested on standard Shepp-Logan head phantom. We demonstrate the effectiveness of our algorithm by comparison with already established algorithms is presented. The quality of the reconstructed image in comparison comes out to be as good as or better than other methods. The present problem finds application in large number of scientific, medical and technical fields.

6142-172, Poster Session

Radial intensity projection for lumen: application to CT angiographic imaging

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H. Hayashi, Nippon Medical School (Japan)

It is important for diagnosis of lumen, such as a calcified plaque of a coronary and a colon polyp to reconstruct the cross sectional image of tubular organ (i. e. Curved Planar Reconstruction: CPR). However, it may overlook the object of diagnosis with some angle, because each CPR image has the only limited angle.

Therefore we have developed a method to reconstruct an image including all directional information based on luminal centerline: Radial Intensity Projection for lumen (RIP). RIP is executed as follows. Firstly image processing is executed to an array of pixel in the direction that is orthogonal to a luminal centerline, secondly, this image processing are performed repeatedly in the angle direction, and above step is performed repeatedly along a luminal centerline, finally, RIP image, which includes all directional information based on luminal centerline, is created.

Then, we have applied of RIP method to the clinical image data of a coronary angiography, which is scanned with the X-ray CT scanner, RIP method enable to check the existence of calcified plaque, which exists in the surroundings of a vessel wall without changing the view angle like CPR. And we have reconstructed RIP image of coronary, in which the stent was inserted, and have confirmed that RIP method is effective in observing the distribution of calcified plaque in the stent. Moreover, Bird's-Eye View three-dimensional image mapped RIP image to a half pipe object allowed us to gasp an orientation of calcified plaque more easily.

6142-173, Poster Session

Evaluation of an algorithm for simultaneous reconstruction of activity and attenuation in 3D PET

J. L. Soto, S. S. Furuie, Instituto do Coracão do Hospital das Clínicas (Brazil)

The main goal of this work is the performance evaluation of a tomographic reconstruction algorithm that estimates activity and attenuation images of the object of interest based only upon projections obtained from a regular Nuclear Medicine exam, without need of additional measurements. This evaluation was carried out for three-dimensional positron emission tomography, and for that purpose we used a number of numerical phantoms with random features; computer simulations that model realistically the physical processes inherent to Nuclear Medicine data acquisitions, through Monte Carlo techniques; and a comparison of the images yielded by the simultaneous reconstruction method with those provided by some of the most common tomographic reconstruction algorithms. This comparison was performed with use of figures of merit related to clinical applications, and of statistical significance tests over a large number of reconstructed objects. It was observed that this new method appears as an interesting alternative to the reconstruction methods currently in use, with promising improvement possibilities, even though fully satisfactory results are yet to be obtained.

6142-174, Poster Session

Image reconstruction from discrete Chebyshev moments via formation of lookup tables

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Moments are tools to quantify intrinsic information (e.g., shape, patterns) in an image. Discrete Chebyshev moments (due to discrete polynomial basis) do not have the discretization errors that continuous-domain Legendre and Zernike moments contain. Calculation of polynomial basis coefficients of discrete moments is generally performed using recurrence relationships. Such recurrence equations cause numerical error accumu-

lation especially for calculation of higher-order moments and for larger image sizes, causing significant degradation of image reconstruction from these moments. A method for better image reconstruction from high orders of discrete Chebyshev moments is demonstrated. This is accomplished by calculating Chebyshev polynomial coefficients directly from their definition formulas using arbitrary precision arithmetic and by forming lookup tables from these coefficients.

6142-175, Poster Session

An approximate cone beam reconstruction algorithm for gantry-tilted CT

M. Yan, C. Zhang, H. Liang, Nanyang Technological Univ. (Singapore)

FDK algorithm has been known to be a popular 3D approximate computed tomography (CT) reconstruction algorithm. However, it may not provide satisfactory image quality for large cone angle. Recently, it has been improved by performing ramp filtering along the direction tangent to the helix, so to provide improved image quality for large cone angle.

In this paper, we present an FDK type approximate reconstruction algorithm for gantry tilted CT imaging. The proposed method improves FDK algorithm by filtering the projection data along a proper direction. Its filtering direction is determined by CT parameters and gantry tilted angle. As a result the proposed gantry-tilted reconstruction algorithm can provide more flexibility in clinical CT scanning and is efficient in computation.

The performance of the proposed algorithm is evaluated with Turbell Clock phantom and Thorax phantom compared with the existing FDK algorithm and a popular 2D approximate algorithm for gantry tilted CT. The results show that our new algorithm can achieve better image quality than the existing gantry tilted algorithms.

6142-176, Poster Session

Implementing an iterative reconstruction algorithm for digital breast tomosynthesis on graphics processing hardware

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The Maximum Likelihood Expectation Maximization (MLEM) algorithm has been shown to produce the highest quality Digital Breast Tomosynthesis (DBT) images, but MLEM is computationally, intensive. Single-processor image reconstruction times for each breast were on the order of several hours; DBT requires faster reconstruction times, with cost effective software/hardware solutions, to be clinically useful. Recently the graphics processing units (GPUs) used for computer video output have been enhanced to give them general purpose computing power; this and their mass market economics make them suitable for complex clinical reconstruction tasks. This paper describes the design features and tradeoffs of general purpose GPUs, as well as the approach we took in implementing MLEM on such an architecture.

Due to the floating point support of the general purpose GPU we achieved image quality equivalent to that produced by standard C code; GPU and CPU images are visually the same. The parallel architecture and performance "sweet spots" of the GPU gave us a 66-fold reconstruction speedup compared to C code on a CPU. This, along with the rapid upgrade cycle in GPU hardware, allows us to add more sophistication to the reconstruction algorithm with little or no increase in processing time.

We conclude that if an algorithm fits the capabilities of GPU architecture, a GPU can be an excellent price-performance solution. New general purpose GPU capabilities enable GPU use in computational (non-display) problems. The solution must be designed to fit in the local GPU memory size and be balanced for the GPU's computation/bandwidth ratio.

6142-177, Poster Session

A correction method for unfuntional cell distortion using orthogonal polynomials

S. Tang, X. Mou, H. Yan, Xi'an Jiaotong Univ. (China)

In paper, we present a new correction algorithm for the unfunctional cell distortions in conventional CT imaging, based on the chebyshev orthogonal polynomials series expressions. This algorithm first reevaluates the projection sinograms by the least mean square algorithm, and then the filtered backprojection (FBP) algorithm are executed for the reconstruction of CT image. Through the simulation experiment, the feasibility of this method is validated.

6142-178, Poster Session

Implementation of a spiral CT backprojection algorithm on the cell processor

O. Bockenbach, Mercury Computer Systems GmbH (Germany); I. Goddard, Mercury Computer Systems, Inc.; S. Schuberth, M. Seebass, Mercury Computer Systems GmbH (Germany)

Over the last decades, the medical imaging community has passionately debated over different approaches to implement reconstruction algorithms for Spiral CT. Numerous alternatives have been proposed. Whether they are approximate, exact or iterative, those implementations generally include a backprojection step. Specialized compute platforms have been designed to perform this compute intensive algorithm within a timeframe compatible with hospital workflow requirements. Solving the performance problem in a cost effective way had driven designers to use a combination of digital signal processor (DSP) chips, general purpose processors, application-specific integrated circuits (ASICs) and field programmable gate arrays (FPGAs).

The Cell processor by IBM offers an interesting alternative for implementing the backprojection, especially since it offers a good level of parallelism and vast I/O capabilities. In this paper, we consider the implementation of a straight backprojection algorithm on the Cell processor to design a cost effective system that matches the performance requirements of clinically deployed systems. The effects on performance of system parameters such as pitch and detector size are also analyzed to determine the ideal system size for modern CT scanners.

6142-179, Poster Session

Cone-beam CT reconstruction using a nonlinear weighted filtered backprojection from half-scan data

T. Gomi, Shinshu Univ. (Japan); K. Koshida, T. Miyati, Kanazawa Univ. (Japan)

The goal is extend our previously published non-linear weighted type half-scan algorithm for reconstruction of a long object, which has important applications for clinical CT. We propose a non-linear weight based algorithm to increase the cone angle by several folds to achieve satisfactory image quality at the same radiation dose. In our scheme, we first weighting with respect to half-scan projection data at individual projection angles is changed. Then, three-dimensional back-projection of corrected half-scan projection data. Mathematical phantoms are used to assess image quality indexes. Comparison with Feldkamp-type half-scan reconstruction is conducted. Our non-linear weighted half-scan reconstruction algorithms allow minimization of redundant data and optimization of temporal resolution, and outperform Feldkamp-type half-scan reconstruction in terms on image artifacts. These algorithms seem promising for quantitative and dynamic biomedical applications of cone-beam tomography.

6142-180, Poster Session

The effect of detector resolution for quantitative analysis of neutron stimulated emission computed tomography

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Previous research has shown benign and cancerous tissues to have different concentrations of trace elements in their chemical make-ups. To measure the elemental concentration of biological samples noninvasively, we used neutron stimulated emission computed tomography (NSECT). When an incident neutron scatters inelastically from an atomic nucleus, it emits characteristic gamma energies, allowing for measurement of the elemental concentration of biological samples. The NSECT technology thus has the potential to be a method for precancer detection. There were three detectors that were analyzed: a high-purity germanium (HPGe) semiconductor, a bismuth germanate (BGO) scintillator, and a sodium iodide (NaI) scintillator. The effective energy resolutions for these detectors are 0.1%, 7%, and 12%, respectively. In Monte Carlo simulations, we bombarded both a benign human breast and a malignant human breast with 50 million neutrons and used HPGe for the detector. The resulting photon spectra were then blurred to model the detector resolutions of BGO and NaI. The original and blurred spectra were analyzed for peak detection. There were 17 significant energy element peaks ($p=0.05$) in the breast model using HPGe, but detectability was reduced drastically when the resolution increased from just 0.1% to 7%, and furthermore to 12%. These initial experiments are valuable in choosing optimal detectors for peak detection in future NSECT studies and indicate that high-resolution detectors, such as HPGe, are required for using spectral peak analysis for breast cancer prediction.

6142-181, Poster Session

Image quality simulation and verification of x-ray volume imaging systems

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Nowadays, 2D X-ray systems are used more and more for 3-dimensional rotational X-ray imaging (3D-RX) or volume imaging, such as 3D rotational angiography. However, it is not self-evident that the application of settings for optimal 2D images also guarantee optimal conditions for 3D-RX reconstruction results. In particular the everlasting search for a good compromise between patient dose and IQ may lead to deviant results in case of 3D imaging. For this purpose we developed an additional 3D-RX module for our full-scale image quality & patient dose (IQ&PD) simulation model, with specific calculations of patient dose under rotational conditions, and contrast, sharpness and noise of 3D images.

The complete X-ray system from X-ray tube up to and including the display device is modeled in separate blocks for each distinguishable component or process. The model acts as a tool for X-ray system design, image quality optimization and patient dose reduction. The model supports the decomposition of system level requirements, and takes inherently care of the prerequisite mutual coherence between component requirements. The short calculation times realized in this model, enable comprehensive multi-parameter optimization studies.

The 3D-RX IQ&PD performance is validated by comparing calculation results with actual measurements performed on volume images acquired with a state-of-the-art 3D-RX system. The measurements include RXDI dose index, signal and contrast based on Hounsfields units (H and ΔH), modulation transfer function (MTF) and noise power spectrum (NPS).

Further we developed a new 3D contrast-delta (3D-CΔ) phantom with details of varying size and contrast medium concentration. Simulation and measurement results show a significant correlation.

6142-182, Poster Session

Monte Carlo CT dose calculations and measurements based on a cylindrical gel phantom

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Monte Carlo is the most accurate method to predict distributions of absorbed dose. Penelope is a general purpose Monte Carlo code for transporting electrons, positrons, and photons. It is gaining popularity in the medical physics community due to its accuracy in both low and high energy regimes (50 eV to 1GeV) and its user friendliness. Since there is no prior work in CT dose calculation using Penelope, an initial benchmarking of the Penelope code was undertaken by calculating the single slice CT dose profiles of a 16 mm diameter cylindrical acrylic phantom. All except one calculation agreed to within 5% from those calculated by Atherton and Huda in 1995. The results demonstrate that Penelope is a viable candidate for CT dose calculation. Its validity will be further tested in the current work of dose calculations and measurements of a 16 cm diameter and 12 cm long cylindrical PresageTM plastic phantom. The dose from CT scans is measured by a dosimetry system consisting of an optical CT scanner and a Metal Oxide Semiconductor Field Effect Transistor (MOSFET). The optical CT scanner in conjunction with plastic phantom provide a high resolution 3D dosimetry system, while MOSFET provides an in vivo capability to measure the absolute dose accurately in real time. With this accurate 3D dosimetry system, the Monte Carlo calculations will be verified to a very high degree of accuracy.

6142-183, Poster Session

Correction of inter-crystal scatter effect in iterative image reconstruction of the jPET-D4

C. F. Lam, N. Hagiwara, T. Obi, M. Yamaguchi, Tokyo Institute of Technology (Japan); T. Yamaya, H. Murayama, National Institute of Radiological Sciences (Japan)

A novel 4-layered depth-of-interaction PET scanner, jPET-D4, is currently being developed at National Institute of Radiological Sciences, Japan. It aims to improve the spatial resolution of conventional PET scanner particularly at the edge of field of view while maintaining high sensitivity. However, inter-crystal scatter (ICS) phenomenon occurs due to Compton scatter in the detector block. Because of ICS, there are multiple scintillated positions for a single irradiation of gamma photon. As only one approximated position is output from the detector circuitry, this causes error in position detection which results in lowering the contrast of reconstructed image. The amount of mispositioned events in the jPET-D4 is significant due to the use of small discrete crystals. It is also impossible to obtain first interaction positions, which are desired for accurate image reconstruction. In this paper, we propose to model an ICS probability by using a Monte-Carlo simulator. The ICS probability maps the relationship between first interaction position and erroneously detected position statistically. This ICS probability was used to improve system matrix of statistical reconstruction algorithm in order to include the effect of ICS. Numerical simulations have been performed to evaluate the proposed method by using a cold rod and hot rod phantom. Cold and hot area contrast recovery coefficient and normalized standard deviation of background were examined and plotted for each of the iterations. Simulation result shows that the proposed method is effective in restoring the image contrast, thus improves the detectability of radio isotope distribution.

6142-185, Poster Session

A novel model of the geometric and detector response for limited angular sampling pinhole SPECT

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Reconstruction methodologies for data sets with a reduced angular sampling are essential for efficient dynamic or static preclinical animal imaging research using single photon emission computed tomography (SPECT). Modern iterative algebraic reconstruction methods can obtain 3D radiotracer distributions of the highest possible quality and resolution. Essential to these algorithms is an accurate model of the physical imaging process.

We developed a new point-spread function (PSF) model for the pinhole geometry and compared it to a Gaussian model with data from reduced angular sampling in silico simulations. The new model incorporates the geometric response of the pinhole and the detector response of the camera by simulating the system PSF using the error function. Reconstruction of simulated data was done with OS-EM and C-OSEM; a new converging OS-EM based algorithm.

Preliminary reconstruction results of a simulated point source show improved FWHM values using the new method compared to a standard Gaussian method. C-OSEM delivers similar results, although it converges slower than OS-EM. Projection images of two resolution phantoms (4mm and 5mm) were simulated. The reconstruction from only 40 projections and 3 iterations using the new method can resolve the 4 mm resolution phantom, where the Gaussian method is limited to a resolution of 5 mm. When compared to a Gaussian method, our new pinhole model applied to iterative reconstruction can reduce imaging time or the number of cameras needed in dynamic SPECT and improve resolution in small animal imaging.

6142-186, Poster Session

Scatter correction for kilovoltage cone beam computed tomographic (CBCT) images using Monte Carlo simulations

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In this work Monte Carlo simulations are used to correct kilovoltage (kV) cone beam computed tomographic (CBCT) images for scatter radiation. It is shown that various techniques can be applied to reduce the simulation time and hence render this correction technique useful in a clinical setting. All images were acquired using a kV CBCT bench-top system composed of an x-ray tube, a rotation stage and a flat-panel imager. The EGSnrc code was used to model the system. BEAMnrc was used to model the x-ray tube while a modified version of the DOSXYZnrc program was used to transport the particles through various phantoms and score phase space files with identified scattered and primary particles. The scatter correction was implemented by subtracting Monte Carlo predicted scatter distribution from measured projection images; these projection images were then reconstructed. Corrected reconstructions showed an important improvement in image quality, the contrast was found to increase by a factor of 2 for a 125 cm source-to-detector distance. Several approaches to reduce the simulation time were tested. To reduce the number of simulated scatter projections, the effect of varying the projection angle on the scatter distribution was evaluated for different geometries. It was found that the scatter distribution does not vary significantly over a 20-degree interval; the number of simulated projections can therefore be reduced by a factor of ~20. It was also established that increasing the size of the voxels in the voxelized phantom does not affect the scatter distribution but reduces the simulation time by up to a factor of 4. Different smoothing techniques were also investigated.

6142-187, Poster Session

Discrete and continuous description of a three-dimensional scene for quality control in radiotherapy

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Quality control is necessary to achieve accuracy in radiotherapy treatments. For that purpose, classical methods generally use physical phantoms. In this paper, we suggest the use of digital test objects (DTO). A DTO is a 3D scene description composed of simple and complex shapes from which we can obtain discrete descriptions (for instance in the DICOM format) for TPS input as well as continuous descriptions for Monte Carlo simulations (as with the PENELOPE package).

The aim of this work is to define an equivalence model between a continuous description of the three dimensional scene used to define the DTO, and the DTO characteristics. The purpose is to have a DTO description in XML format to compute discrete calculation from a continuous description and then translate DTO into PENELOPE format.

We propose a method based on XML format to store DTOs from an organization allowing a conversion to PENELOPE. The structure we defined allows also to obtain the three dimensional matrix of the DTO and then the series of slices stored in DICOM format. Thus, it is now possible to design DTO for quality control in CT simulation and dosimetry.

6142-188, Poster Session

Realistic modeling of raw data for image reconstruction

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An important step in assessing the quality of an image reconstruction algorithm is the simulation of the medical imaging process. For that purpose, the patient's anatomical structure is substituted in general by more or less simple geometrical objects, as, e.g., the Shep-Logan phantom. Furthermore, the attenuation of the human body and thus the resulting detector image (e.g., the sinogram in CT) is often computed by integrating the attenuation coefficient along various rays without considering the contribution of scattered photons in the detector signal. We therefore decided to improve the simulation by using an existing Monte-Carlo code (EGSnrc) to model the transport of numerous photons from the X-ray tube through the body to the detector. The deflection of photons and creation of secondary particles in scattering events occurs naturally in this program, but can also be avoided artificially. Besides the improved simulation of the irradiation process, this allows us to quantify the amount of scattered radiation in the detector image.

The patient is represented by a so-called voxel phantom, which is based on tomographic image data of a real person, adopted to represent ICRP Reference Man. Our improved modeling process is being applied to determine the amount of scatter radiation in helical multi-slice CT of the thorax compared to planned circular CT with large flat panel detectors. The new reconstruction algorithm OPED (orthogonal polynomial expansion on disc), developed at GSF and the University of Oregon, might reduce the scatter radiation considerably.

6142-189, Poster Session

Monte Carlo simulation for the hybrid detector design

S. Kim, J. K. Park, S. S. Kang, B. Y. Cha, S. H. Cho, E. S. Jeong, S. H. Nam, H. Lee, H. Choi, Inje Univ. (South Korea)

We study the SNR (Signal-to-Noise Ratio) of the hybrid detector using Monte Carlo method. Hybrid x-ray detectors consist of scintillator coupled photoconductor structure. The SNR of single layer detector with

photoconductor material depends on the number of absorbed photons. However, for the hybrid detectors with scintillator coupled photoconductor structure, total SNR is influenced by SNR of each layer. In this study, we simulated various thickness layers and investigated the optimized thickness of each layer via SNR for the hybrid detector design.

6142-190, Poster Session

Characterization of point spread function in linear digital tomosynthesis

G. B. Avinash, K. Israni, B. Li, GE Healthcare

Tomosynthesis is widely used for three-dimensional reconstruction of objects acquired from limited angle X-ray projection imaging with stationary digital detector. Traditionally, the point-spread function (PSF) in digital tomosynthesis is assumed to be symmetrical with respect to the central axis and shift invariant. The purpose of this research is to characterize the true nature of the PSF by intensity and shape considerations. We assumed that tomosynthesis PSF depended on the imaging geometry and the reconstruction algorithms. In this paper, we describe PSF characterization with respect to the linear geometry and back projection reconstruction. We considered the following parameters: source to image distance (SID) (mm), total number of slices reconstructed after reconstruction, distance (in z-direction) from the first and the last slice to the detector (mm), resolution in X, Y & Z (pix/mm), and total number of projections. Using these parameters, we determined the PSF at every location of the reconstructed volume. The PSF was contained in the plane formed by the linear source trajectory and the point under consideration that extended through all the slices. The results show that the PSF is shift variant and unique at every location and gradually changing over the entire reconstructed volume. The shift from the central axis and central reconstructed slice caused the PSF to exhibit shear corresponding to the X-shift, tilt with the Y-shift and asymmetry with the Z-shift. In summary, we have characterized tomosynthesis PSF to be globally shift variant exhibiting shear, tilt and asymmetry.

6142-191, Poster Session

Noise power spectrum analysis for several digital breast tomosynthesis reconstruction algorithms

Y. Chen, J. Y. Lo, J. T. Dobbins III, Duke Univ. and Duke Univ. Medical Center

Digital breast tomosynthesis is a three-dimensional imaging technique that allows the reconstruction of arbitrary set of planes in the breast from limited-angle series of projection images. Though several tomosynthesis algorithms have been proposed, no complete optimization and comparison of all available methods has been conducted as of yet. This paper presents an analysis of noise power spectrum to examine the noise characteristics of several tomosynthesis algorithms with different imaging acquisition techniques. Flat images were acquired with acquisition parameters: 13, 25, 49 projections with ±12.5 and ±25 degrees angular ranges. Currently three algorithms including Shift-And-Add (SAA), Matrix Inversion Tomosynthesis (MITS), and Filtered Back Projection (FBP) were investigated with reconstruction slice spacing of 1mm, 2mm, and 4mm. The noise power spectra of the reconstruction plane at 23.5mm above the detector surface were analyzed. Results showed that MITS has better noise responses with narrower slice spacing for low to middle frequencies. No substantial difference was noticed for SAA and FBP with different slice spacings. With the same acquisition technique and slice spacing, MITS performed better than FBP at middle frequencies, but FBP showed better performance at high frequencies because of applied Hamming and Gaussian low pass filters. For 49 projections and ±25 degrees specifically, FBP performed better than MITS at all frequencies. For different imaging acquisition techniques, MITS and FBP performed the best with 49 projections and ±25 degrees. FBP performed better with wider angular range and more projection numbers. SAA performed slightly better for 49 projections with ±25 degrees angular range.

6142-192, Poster Session

Low-contrast lesion detection in tomosynthetic breast imaging using a realistic breast phantom

L. Zhou, J. D. Oldan, P. R. Fisher, G. R. Gindi, Stony Brook Univ.

Tomosynthesis mammography is a potentially valuable technique for detection of breast cancer. In this simulation study, we investigated the efficacy of three different tomographic reconstruction methods (EM, SART and Backprojection) in the context of an especially difficult mammographic detection task. The task was the detection of a very low-contrast mass embedded in very dense fibro-glandular tissue — a clinically useful task for which tomosynthesis may be well suited. We used a realistic 3D digital breast phantom whose anatomic variability limited lesion conspicuity. We constructed a medium-sized phantom which modeled duct structures, adipose tissue, fibro-glandular tissue, Cooper's ligaments, the pectoralis muscle and lesions. We used power-law structural noise for small scale object variability. Realizations of 7-8mm irregular masses were generated by 3D random walk algorithm. We collected low-dose data using isocentric tomosynthetic geometry at 11 angles spaced over 50 degrees and added Poisson noise. The data was reconstructed using the three algorithms. Reconstructed slices through the center of the lesion were presented to human observers in a 2AFC test that measured detectability by computing AUC. In addition to the structural power law noise and Poisson data noise, we also include object variability in the ductal patterns, fibers and lesions. We found that for this difficult task that the AUC value for EM was greater than that for SART and Backprojection.

6142-193, Poster Session

Selective photon counter for digital x-ray mammography tomosynthesis

A. Goldan, K. S. Karim, Simon Fraser Univ. (Canada);
J. A. Rowlands, Sunnybrook and Women's Health Sciences Ctr. (Canada)

Conventional film screen mammography does not detect all cancers and some cancers that become clinically evident over the course of a year will not have been visible by screening mammography performed within that year. A major factor contributing to this limitation is the anatomical noise created by the overlap of normal structures within the breast, which are superimposed on each other in a standard two-dimensional mammogram. Tomosynthesis is an emerging x-ray imaging modality that can reveal more cancers and reduce false positives in screening mammography but at the cost of higher dose to the patient due to multiple exposures.

In order not to increase the patient dose beyond conventional mammography methods, the imaging system has to be able to readout multiple (ideally 100) images with each image using only 1% of the normal dose. The low dose puts an extreme requirement on the x-ray detector with regard to the parasitic amplifier noise level. In this research, we present a novel, selective photon counting device for mammography tomosynthesis. Theoretical calculations, simulation and experimental results of photon count rate, amplifier charge gain, and noise will be discussed.

6142-194, Poster Session

Preliminary assessment of the temporal subtraction of tomosynthesis images for improved detection of pulmonary nodules

C. M. Li, J. T. Dobbins III, Duke Univ.

Digital tomosynthesis is an imaging technique which reconstructs tomographic planes in an object from a set of projection images taken over a fixed angle 1. Results from our initial pilot study show that tomosynthesis increases the detectability of lung nodules; while only 50% of CT confirmed nodules were found on typical chest radiographs, 81% were found on tomosynthesis image sets2. Temporal subtraction is a method which takes two sequential images and subtracts one from another, emphasizing the appearance of interval change3-6. As an addition to conventional

chest radiography, it has been shown in several studies to significantly increase observer performance in detecting newly developed abnormalities7-10. Thus the combination of temporal subtraction and tomosynthesis may yield improved sensitivity of detection over either method alone. For this preliminary evaluation into the combination of these techniques, images were taken of an anthropomorphic chest phantom in different orientations and subtle lung nodules were simulated in order to emulate temporal discrepancies in anatomy. A visual method of registration and two approaches for image warping were employed to align corresponding ROI's of each image set. The temporal change of simulated nodules overlying vessels was more apparent if in-plane vasculature was used for registration. However, using bony structures for registration caused the simulated nodules by the chest wall to appear more definitively. By our subjective analysis, tomosynthesis substantially improved the visibility of nodules relative to conventional chest radiography; and tomosynthesis augmented by temporal subtraction even further enhanced the conspicuity of difficultly placed subtle nodules.

6142-195, Poster Session

Measurement of slice thickness and in-plane resolution on radiographic tomosynthesis system using modulation transfer function (MTF) method

B. Li, R. Saunders, R. Uppaluri, GE Healthcare

This paper presents the method to employ the measurement of MTF as a metric for two important IQ characteristics of a digital tomosynthesis system: in-plane resolution and slice thickness. Experiments are designed to collect image data sets using a clinical prototype Tomosynthesis system with the following configurations: sweep angle = 20, 40, 60 degrees, number of projections = 21, 41, 61, respectively. Tomo planes are reconstructed by a 3-D weighted cone-beam filtered backprojection (WCB-FBP) algorithm. The MTF is measured in the reconstructed planes of imaging a specially designed Tungsten ramp phantom. More specifically, MTF is measured as the HWHM of the Fourier transformation of the first derivative of edge profiles. The HWHM corresponding to the sharpest of edge profile represents the in-plane resolution of the system, and the slice thickness of the system is determined from the HWHM vs. z-distance curve. Results show that for a 40-degree sweep, 61 projections, and using the FBP algorithm, the in-plane resolution of the measured system is close to 1 lp/mm, and effective slice thickness is 2.1 mm and 3.9 mm at -3 DB and -5 DB, respectively. One of the applications of the described metric is to optimize sweep angle. The results show that the increase in sweep angle can intrinsically reduce slice thickness but less significantly impact in-plane resolution.

6142-196, Poster Session

Optimal acquisition techniques for digital breast tomosynthesis screening

T. Wu, B. Liu, R. H. Moore, D. B. Kopans, Massachusetts General Hospital

A second-generation digital breast tomosynthesis (DBT) system is used for a screening study that compares DBT with conventional two-view mammography. DBT acquires 15 projections of a breast at different angles using an a-Si-based detector. The total x-ray dose for DBT equals that for two-view mammography. This work explores acquisition techniques that optimize the quality of projection images with low x-ray exposures matching the DBT dose level.

Three target-filter combinations (Mo-Mo, Mo-Rh and Rh-Rh) were compared with tube voltage from 25kVp up to 40kVp. A thin disk was put on top of a mammography QC phantom and/or breast tissue equivalent slabs to compare techniques for different thickness. The squared CNR normalized by dose was used as the quality metrics. For each thickness, the techniques were compared with matched dose. The dependence of detector performance on detector entrance exposure (DEE) was also studied by varying the exposure with fixed target-filter and kVp. The optimal detector performance is achieved with 5-30mR DEE. Within this range, Mo-Mo gives the highest quality for 2cm; results are very close for 3 cm; Rh-Rh is slightly better for 4.5cm and apparently better than others for 6.5 and 8.5cm. The kVp does not show an impact except for 8.5cm, in which the quality metrics slightly rises at higher kVp. Rh-Rh is selected for >4cm thickness. Mo-Mo is selected for 2cm but its advantage diminishes at DBT exposure level because its DEE is less than others with the same dose. Mo-Rh is selected for 3 and 4cm.

6142-72, Session 14

Extension of the reconstruction field-of-view using sinogram decomposition

A. A. Zamyatin, M. D. Silver, Bio-Imaging Research, Inc.

Sinogram truncation is a common problem in tomographic reconstruction; it occurs when a scanned object or patient extends outside the scan field-of-view. The truncation artifact propagates from the edge of truncation towards the center, resulting in unacceptable image quality. Several methods have been proposed recently to reconstruct the image artifact-free within the scan field-of-view; however it is often necessary to recover image outside the scan field-of-view. We propose a novel truncation correction algorithm that accurately completes unmeasured data and allows us to extend the reconstruction field-of-view. Contrary to a simple 1D extrapolation, we perform interpolation in the view direction along the so-called sinogram curves. First, we propose an approach to parameterize the family of sinogram curves for efficient sinogram decomposition. Secondly, we propose two ways to estimate the truncated data outside the field-of-view. Both methods are combined for more accurate sinogram completion. Our extensive evaluation shows the validity of our approach with image quality superior to the current correction methods. Even objects completely outside the FOV can be accurately reconstructed, which is impossible with any current method. The proposed method can be used with any modality where sinogram truncation occurs, such as CT, C-arm, PET/CT, SPECT, etc.

6142-73, Session 14

Suppression of motion-induced streak artifacts along chords in fan-beam BPF-reconstructions of motion-contaminated projection data

M. King, D. Xia, L. Yu, X. M. Pan, M. L. Giger, The Univ. of Chicago

Fan-beam backprojection filtration (BPF) reconstructions from motion-contaminated data sets often exhibit streak artifacts along the direction of the chords. These streak artifacts, which are most pronounced at chords tangent to the edges of a moving object, can be suppressed by using full-scan, short-scan, and certain reduced-scan data redundancies for fan-beam data. For reduced-scan redundancies, we show how these artifacts can be re-introduced by decreasing the amount of redundant projection data used for reconstruction. Since we are capable of obtaining multiple different reconstructions of the same chord by varying the amount of projection data used, we have laid the groundwork for a possible method to characterize the amount of motion encoded within the projection data for reconstructing a particular chord. Furthermore, we demonstrate that BPF reconstructions using full-scan and short-scan redundancies exhibit similar motion artifacts as those in conventional fan-beam filtered-backprojection reconstructions (FFBP) using full-scan and short-scan weightings, respectively. Since motion artifacts generated from FFBP may be reproduced with BPF, BPF potentially may be used to arrive at a more fundamental characterization of how motion-artifacts appear in FFBP-reconstructions.

6142-74, Session 14

A new perspective for image reconstructions from parallel- and fan-beam data with truncations

D. Xia, Y. Zou, X. M. Pan, The Univ. of Chicago

Investigation of image reconstruction from parallel- and fan-beam data remains to be theoretically interesting and practically important. It can yields insights into the development of 3D image reconstruction and accurate and robust algorithms for image reconstruction from 2D data in, e.g., MRI and fan-beam CT. Recently Clackdoyle presents a general formula for image reconstruction from knowledge of its 2D Radon transform.This formula can exactly reconstruct an image within a region of interest (ROI) from parallel-beam projections containing truncations. This general formula depends upon a parameter t, and different values of t lead to different reconstructible ROI images. Most importantly, the role of the parameter in the formula remains unclear. In this work, we give an alternative, but much straightforward, derivation of the formula in contrast to the previous derivation. Our approach is based upon the rebinning perspective in which the parameter t can be related explicitly to the fan-beam focal length. Furthermore, we show that the parameter t determines the size of the reconstructible ROI from parallel-beam data containing truncations. We have also developed a backprojection-filtration algorithm to reconstruct the maximum ROI allowed by a set of truncated data.

6142-75, Session 14

Iterative reconstruction of a region of interest for transmission tomography

A. Ziegler, T. Nielsen, M. Grass, Philips Research Labs. (Germany)

Images reconstructed for transmission tomography with iterative Ordered Subsets Maximum Likelihood (OSML) algorithms have a higher signal-to-noise ratio than images reconstructed with filtered back-projection type algorithms. However, a drawback of OSML reconstruction is the requirement that a field-of-view has to be reconstructed that covers all objects, which contributed to the absorption. In the case of a high resolution reconstruction, this demands a huge number of voxels. This paper presents a solution, how an iterative OSML reconstruction of a region of interest can be designed without loosing the advantages of a OSML reconstruction.

6142-76, Session 14

An iterative algorithm for soft tissue reconstruction from truncated flat panel projections

D. A. Langan, B. E. Claus, P. M. Edic, GE Global Research; R. Vaillant, GE Healthcare (France); B. De Man, S. Basu, M. Iatrou, GE Global Research

The capabilities of flat panel interventional x-ray systems continues to expand, enabling a broader array of medical applications to be performed in a minimally invasive manner. Although CT is providing pre-operative 3D information, there is a need for 3D imaging of low contrast soft tissue during interventions in a number of areas including neurology and oncology.

Unlike a CT system, interventional angiographic x-ray systems provide real-time large field of view 2D imaging, patient access, and flexible gantry positioning to enable interventional procedures. However, these C-arm flat panel systems have additional technical challenges in 3D soft tissue imaging relative to CT, including slower rotation speed, gantry vibration, reduced patient FOV, and increased scatter. The reduced patient FOV often results in significant data truncation. Reconstruction of truncated (incomplete) data is known as the “interior problem”, and it is mathematically impossible to get an exact reconstruction. Nevertheless, it is an important problem in 3D imaging on a C-arm and there exists a need to generate a 3D reconstruction representative of the object being imaged with minimal artifact. In this work we investigate the application of an iterative Maximum Likelihood Transmission Reconstruction (MLTR) algorithm to truncated data. We also consider truncated data with limited views for imaging where the views are gated to combat motion artifacts.

6142-77, Session 15

Conjugate backprojection approach for cone beam artifact reduction

J. Hsieh, X. Tang, GE Healthcare

With the introduction of volumetric computed tomography (VCT), many studies have been conducted on cone beam reconstruction. Majority of research efforts was devoted to the reduction of cone beam artifacts by designing special weighting functions that treat the projection samples differently based on their cone angles. The selection of weighting function can be quite complex due to the cone beam helical geometry and is often designed through trial-and-error. In this paper, we present a conjugate backprojection approach (CBA) that is capable of significantly reducing cone beam artifacts without the application of pre-backprojection weighting function. Our approach utilizes CBA operation which simultaneously backprojects and interpolates conjugate sampling pairs. Unlike the conventional backprojection, the final backprojected value depends not only on the distance of these samples to the point-of-intersection, but also on the cone angles of these samples. Consequently, optimization can be performed on a pixel by pixel basis and is independent of the acquisition protocols, such as helical pitches or acquisition modes. The proposed approach is applicable to cone beam helical as well as step-and-shoot acquisitions. Extensive computer simulation and phantom experiments were conducted to demonstrate the efficacy of our approach. Experimental results have shown that the proposed approach significantly reduces the cone beam artifacts.

6142-78, Session 15

Cone-beam local tomography image reconstruction on chords

M. A. Anastasio, Illinois Institute of Technology; E. Y. Sidky, Y. Zou, X. M. Pan, The Univ. of Chicago

In recent years there have been numerous exciting developments in the reconstruction theory for X-ray cone-beam computed tomography (CT) employing helical scanning trajectories. One such important development was the establishment of a novel reconstruction paradigm by Zou and Pan [PMB,49, 2717-2731,2004] in which the reconstructed image is determined directly on a collection of so-called PI-line segments instead of on the usual Cartesian grid. These algorithms have been extended recently to accommodate generalized (e.g., non-helical) scanning trajectories. In that case, the image is reconstructed directly on a chord, which is a generalization of the PI-line segment for helical trajectories. The chords connect two points on a piece-wise differentiable scanning trajectory that does not intersect the support volume of the object, but is otherwise general. In this work, we demonstrate that the theory for image reconstruction on chords can be modified for use with local tomography problems. Our analysis reveals that discontinuities in the profiles of the object function along chords can be reconstructed readily. By consideration of all possible chords, an image that describes the locations of object boundaries can be reconstructed. An important feature of the developed algorithm is that, unlike available algorithms, it will not produce image artifacts that can be confused with true object structures. A preliminary numerical study is conducted to validate and demonstrate the proposed reconstruction algorithm.

6142-79, Session 15

3D-weighted cone beam filtered backprojection (CB-FBP) algorithm for image reconstruction at low-helical pitches to improve noise characteristics and dose efficiency

X. Tang, J. Hsieh, R. A. Nilsen, GE Healthcare

A 3D weighted cone beam filtered backprojection (CB-FBP) algorithm (namely original 3D weighted CB-FBP algorithm) has already been proposed by us to reconstruct images from the projection data acquired along a helical trajectory in angular ranges up to [0, 2π]. However, an over scan is usually employed in the clinic to provide premium image qualities for an accurate diagnosis at the most challenging anatomic structures, such as head and extremities. In an over scan, the corresponding normalized helical pitch is smaller than 1:1, under which the projection data acquired along a helical trajectory angular range larger than [0, 2π] can be utilized to reconstruct an image. To improve noise characteristics or dose efficiency in an over scan, we extended the 3D weighted CB-FBP algorithm to handle helical pitches that are smaller than 1:1, while the algorithm's other advantages, such as reconstruction accuracy and computational efficiency, are maintained. The novelty of the extended 3D weighted CB-FBP algorithm is the decomposition of an over scan with a helical trajectory angular range of [0, $2\pi + \Delta\beta$] ($0 < \Delta\beta < 2\pi$) into a union of full scans with a helical trajectory angular range of [0, 2π]. As a result, the extended 3D weighted function is a weighted sum of all 3D weighting functions corresponding to each overlapped full scan. An experimental evaluation shows that, the extended 3D weighted CB-FBP algorithm can significantly improve noise characteristics or dose efficiency of the original 3D weighted CB-FBP algorithm at helical pitch smaller than 1:1, while its reconstruction accuracy and computational efficiency are maintained. It is imortant to indicate that, the extended 3D weighting function is still applied on projection data before 3D backporjection, making the computational efficiency of the extended 3D weighted CB-FBP algorithm comparable to that of the original 3D weighted CB-FP algorithm. It is believed that, such an efficient CB reconstruction algorithm that can provide premium image qualities at low helical pitches will find its extensive applications in CT medical imaging.

6142-80, Session 15

ROI image reconstruction from truncated projections along a circle-arc trajectory

Y. Zou, D. Xia, X. M. Pan, The Univ. of Chicago

In this work, based upon our general formula for cone-beam CT reconstruction, we develop algorithms for image reconstruction from data acquired with a circle-arc trajectory. Furthermore, the derived algorithms can reconstruct images within regions of interest (ROIs) from data that may contain truncations along the longitudinal and transverse dimensions of the 2D detector plane. We consider two cases of image reconstruction from cone-beam data acquired with a circle-arc trajectory. In the first case, the projection data are truncated longitudinally, and it thus simulates a long object problem, whereas, in the second case, we reconstruct an ROI image from data containing both longitudinal and transverse truncations.

6142-81, Session 15

Accurate image reconstruction from few views in C-arm CT

E. Y. Sidky, X. Pan, C. Y. Kao, The Univ. of Chicago

Image reconstruction for x-ray projection data from a limited number of views is of practical interest in many applications of computed tomography (CT) such as C-arm CT and image guided radiation therapy. Few-view projection data poses a tremendous challenge for tomographic image reconstruction because there are a large number of very different images that could be consistent with the acquired few-view data. In order to narrow down the search space for the underlying image, we propose to incorporate two strong assumptions about the image. First, we assume that the attenuation map is non-negative - an assumption commonly made in medical imaging. Second, we seek the image with a minimum total variation that is consistent with the available projection data. A minimal total variation is often a reasonable assumption in medical imaging, because images are usually constant over large regions in the image such as inside individual internal organs. The second assumption is quite strong and it can be incorporated, along with the positivity constraint, into an iterative algebraic reconstruction technique (ART). We demonstrate the proposed algorithm on few-view fan-beam data in the support document, and we will present results on few-view cone-beam data at the conference.

6142-82, Session 15

A new reconstruction algorithm for Radon data

Y. Xu, Univ. of Oregon; O. Tischenko, C. Hoeschen, GSF-Forschungszentrum (Germany)

A new reconstruction algorithm for Radon data is introduced. We call the new algorithm OPED as it is based on Orthogonal Polynomial Expansion on the Disk. OPED is fundamentally different from the filtered back projection (FBP) method. It allows one to use fan geometry directly without the additional procedures such as interpolation or rebinning. It reconstructs high degree polynomials exactly and works for smooth functions without the assumption that functions are band- limited. Our initial test indicates that the algorithm is stable, provides high resolution images, and has a small global error. Working with the geometry specified by the algorithm and a new mask, OPED could also lead to a reconstruction method working with reduced x-ray dose (see the presentation by Oleg Tischenko).

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6143-01, Session 1

Structure and function relationship of Zebrafish embryonic heart from confocal microscopy images

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Confocal microscopy enables us to track myocytes in the embryonic zebrafish heart. The Zeiss Live high speed confocal microscope has been used to take optical sections (at 3 μm intervals and 151 frames per second) through a fluorescently labeled zebrafish heart at two developmental stages (26 and 34 hours post fertilization (hpf)). This data provides unique information allowing us to conjecture on the morphology and biomechanics of the developing vertebrate heart. Nevertheless, the myocytes, whose positions could be determined in a reliable manner, were located sparsely and mostly in one side of the heart tube. This difficulty was overcome using computational methods, that give longitudinal, radial and circumferential displacements of the myocytes as well as their contractile behavior. Applied strain analysis has shown that in the early embryonic heart tube, only the caudal region (near the in-flow) and another point in the middle of the tube can be active; the rest appears to be mostly passive. This statement is based on the delay between major strain and displacement which a material point experiences. Wave-like propagation of all three components of the displacement, especially in the circumferential direction, as well as the almost-periodic changes of the maximum strain support the hypothesis of helical muscle structure embedded in the tube. Changes of geometry in the embryonic heart after several hours are used to verify speculations about the structure based on the earlier images and aforementioned methods.

6143-02, Session 1

Quantification of adipose tissue in a rodent model of obesity

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Obesity is a global epidemic, and it is a comorbidity for many diseases. We are using MRI to compare a spontaneously hypertensive rat (SHR) and an obese variant (SHROB), especially with regard to visceral fat. Existing measurement techniques are limited in accuracy (body mass index) or are invasive (dissection). Rats were scanned in a Siemens Sonata 1.5T clinical scanner with two sequential 15 m acquisitions. A T1W, water-spoiled image (fat only, TR 1240 ms, TE 13 ms) was divided by a matched T1W image (fat + water) to yield a ratio image related to the fat in each voxel, which eliminated coil sensitivity heterogeneity. Rats were then sacrificed and dissected, and fat pad volumes measured by displacement in canola oil. Typical visceral fat volume was 23 mL by MRI and 20 mL by dissection. Visceral fat strongly correlated between MRI and dissection (R2 = 0.93), but subcutaneous fat did not (R2 = 0.66), probably due to dissection error. These first water suppression ratio measurements in this model were visceral fat (85±4% and 86±7%), subcutaneous fat (82±4% and 73±12%), and liver (20±9% and 10±5%), for SHROB and SHR, respectively. These measurements provide new information about the in vivo composition of fat pads. Future work will include studies of diet versus genetics, identification of new phenotypes, and corrective measures for obesity; technical efforts will focus on correction for motion and automation in quantification.

6143-03, Session 1

Precise imaging of small animals using a dual-head microPET scanner

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We are developing a small-animal PET scanner that employs two opposing large-area PET detector modules. Our design is intended to achieve high detection sensitivity and large imaging volume. Therefore, we favor the use of a small spacing between module and a stationary configuration so that the entire detection sensitive volume can potentially be used for imaging. The resulting imaging geometry, however, poses a challenging problem for reconstruction due to the presence of missing views and truncations in projection. We have developed a new reconstruction method that solves this challenge. We consider a stationary 2D scanner that employs two 25 cm long detectors and 7 cm spacing between detector, creating a 25 cm x 7 cm detection sensitive volume. An object consisting of three 5 cm-diameter disks separated by 2.5 cm is placed inside the scanner (simulating multi-subject imaging with three rodents). The object spans a 20 cm x 5 cm area and each of the disks contains a 1 cm-diameter high-contrast disk at its center. The simulated noise-free data are reconstructed by using the EM algorithm and the proposed method. Our results indicate that conspicuous image artifacts emanating from the high-contrast structures and at the outer disks are generated by the EM method while virtually exact reconstruction is obtained by the proposed method. The proposed method can therefore allow precise imaging of small animals placed anywhere inside the extended detection sensitive volume of the scanner. The proposed method can also be applied for producing accurate reconstruction in positron emission mammography.

6143-04, Session 1

Optimization of retrospectively respiratory-gated volume micro-CT techniques for imaging mice in less than one minute

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Technological advances in micro-CT scanners have introduced dynamic, flat-panel scanners, which allow the acquisition of volume images in a few seconds. However, motion artefacts associated with normal respiratory motion arise when imaging the thorax or abdomen. To reduce these artefacts and the accompanying loss of spatial resolution, and to enable the study of rodent respiratory function we developed a respiratory gating technique for volume micro-CT imaging of free-breathing rodents.

Anaesthetized male C57BL6 mice were placed in the prone position on a custom-made bed containing an embedded pressure chamber that was connected to a pressure transducer. Inhalation motion caused an increase in the chamber pressure, which was monitored as a surrogate for the respiratory waveform, and measured throughout the scan.

Projection images of the mouse thorax were acquired using a GE Locus Ultra micro-CT scanner, at 80 kVp, 50 mA (entrance exposure of approximately 2.7 cGy per rotation), over 10 rotations in less than 1 minute. Respiratory gating was performed retrospectively by reconstructing only the unique projections that were obtained during the same portion of the respiratory cycle; CT images reconstructed from 3 to 10 rotations were evaluated. The nominal voxel spacing was 0.15 mm isotropic.

Images were assessed for image noise, artefacts and measurement accuracy of physiologically relevant structures. These measurements showed no significant differences for images reconstructed from projection images from 5 to 10 rotations. The optimum number of rotations for imaging mouse lungs was found to be 6, corresponding to a 30 second scan.

6143-05, Session 1

In vivo micro-CT imaging of the murine lung via a computer controlled intermittent iso-pressure breath hold (IIBH) technique

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Micro-CT, a technique for imaging small objects at high resolution using micro focused x-rays, is becoming widely available for small animal imaging. With the growing number of mouse models of pulmonary pathology, there is great interest in following disease progression and evaluating the alteration in longitudinal studies. Along with the high resolution associated with micro CT comes increased scanning times, and hence minimization of motion artifacts is required. We propose a new technique for imaging mouse lungs in vivo by inducing an intermittent iso-pressure breath hold (IIBH) with a fixed level of positive airway pressure during image acquisition, to decrease motion artifacts and increase image resolution and quality.

Mechanical ventilation of the respiratory system for such a setup consists of three phases, 1) tidal breathing (hyperventilated), 2) a breath hold during a fixed level of applied positive airway pressure, 3) periodic deep sighs. Image acquisition is triggered over the stable segment of the IIBH period.

Comparison of images acquired from the same mouse lung using three imaging techniques (normal breathing / no gating, normal breathing with gating at End Inspiration (EI) and finally the IIBH technique) demonstrated substantial improvements in resolution and quality when using the IIBH gating. Using IIBH triggering the total image acquisition time increased from 15 minutes to 35 minutes, although total x-ray exposure time and hence animal dosage remains the same. This technique is an important step in providing high quality lung imaging of the mouse in vivo, and will provide a good foundation for future longitudinal studies.

6143-06, Session 2

Electrocardiographic imaging (ECGI): a new noninvasive imaging modality for cardiac electrophysiology and arrhythmia

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Cardiac arrhythmias are a major cause of death (7 million cases annually worldwide; 400,000 in the U.S. alone) and disability. Yet, a noninvasive imaging modality to identify patients at risk, provide accurate diagnosis and guide therapy is not yet available in clinical practice. In my conference presentation and proceedings article, I will describe examples of the application of Electrocardiographic Imaging (ECGI) in humans. ECGI is a new noninvasive imaging modality for cardiac arrhythmias developed in our laboratory. It combines recordings of 224 body-surface electrocardiograms and a thoracic CT scan to reconstruct potentials, electrograms and isochrones (activation sequences) on the heart surface. Examples include: (1) normal activation and repolarization; (2) activation during ventricular pacing; and (3) atrial flutter.

6143-07, Session 2

Analysis of four-dimensional cardiac ventricular magnetic resonance images using statistical models of ventricular shape and cardiac motion

H. Zhang, N. Walker, S. C. Mitchell, M. Thomas, A. Wahle, T. Scholz, M. Sonka, The Univ. of Iowa

Conventional analysis of cardiac ventricular magnetic resonance images is performed using short axis images and does not guarantee completeness and consistency of the ventricle coverage. In this paper, a four-dimensional (4D, 3D+time) left and right ventricle statistical shape model was generated from the combination of the long axis and short axis images. Iterative mutual intensity registration and interpolation were used to merge the long axis and short axis images into isotropic 4D images and simultaneously correct existing breathing artifact. Distance-based shape interpolation and approximation were used to generate complete ventricle shapes from the long axis and short axis manual segmentations. Landmarks were automatically generated and propagated to 4D data samples using rigid alignment, distance-based merging, and B-spline transform. Principal component analysis (PCA) was used in model creation and analysis. The two strongest modes of the shape model captured the most important shape feature of Tetralogy of Fallot (TOF) patients, right ventricle enlargement. Classification of cardiac images into classes of normal and TOF subjects performed on 3D and 4D models showed 100% classification correctness rates for both normal and TOF subjects using k-Nearest Neighbor (k=1 or 3) classifier and the two strongest shape modes.

6143-08, Session 2

Quantitative analysis of vascular dimension and plaque composition in coronary multidetector computed tomography images

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The noninvasive assessment of coronary atherosclerosis holds great promise for the future of cardiovascular medicine, and multidetector computed tomography (MDCT) has recently taken the lead in this area. Earlier studies have shown the ability of MDCT to visualize the coronary lumen and various types of atherosclerotic plaque. The aims of this project are to design, implement, and validate a complete system for the automated, quantitative analysis of coronary MDCT images. The developed system uses graph algorithms and knowledge-based cost functions to automatically segment the lumen and wall, and then uses pattern classification techniques to identify and quantify the tissue types found within the detected vascular wall. The system has been validated in comparison with expert tracings and labels and in comparison with intravascular ultrasound (IVUS). In the former, the radial position of the lumen and adventitia were compared at 360 corresponding angular locations in 299 vascular cross sections (from 13 vessels in 5 patients: 5 RCA, 4 LAD, 4 LCX). Results show a border positioning error of 0.150 ± 0.090 mm unsigned / 0.007 ± 0.001 mm signed for the lumen, and 0.210 ± 0.120 mm unsigned / 0.020 ± 0.030 mm signed for the vessel wall. In the comparison with IVUS, the luminal and vascular cross sectional areas were compared in 7 vessels; good correlation was shown for both the lumen (R=0.83) and the vessel wall (R=0.76). The plaque characterization algorithm correctly classified 92% of calcified plaques and 87% of non-calcified plaques.

6143-09, Session 2

Using Doppler intravascular ultrasound (IVUS) to analyze adventitial vasa vasorum distribution: considerations and recommendations

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The adventitia and outer media of large blood vessels are supplied with nutrients by microscopic blood vessels called vasa vasorum. While vasa vasorum have been implicated in a number of diseases, including atherosclerosis, knowledge of their functional anatomy and specific role in these diseases has been hindered due to the small size of the vasa vasorum, and difficulty in accessing them. Micro-CT and histological methods have been used in ex-vivo animal studies of the vasa vasorum, but these techniques are limited by their inability to be used for in vivo investigation. As such, there is very little in-vivo human data available. In intravascular ultrasound imaging (IVUS) procedures, an ultrasound imaging catheter is used for tis-

sue backscatter imaging as well as Doppler shift imaging which indicates areas of blood flow. Doppler IVUS is a relatively new and exciting prospect for in vivo studies of vasa vasorum functional anatomy. In this study, Doppler IVUS images of the human mid-left anterior descending coronary artery (LAD) were manually segmented to analyze the distribution of adventitial vasa vasorum proximal to intimal plaque. Previous animal studies suggest that formation of intimal plaque is accompanied by increased density of adventitial vasa vasorum: our study revealed a low positive correlation between the two. Qualitative examination suggests some trends. Further study of this imaging method thus seems warranted. Our experience may provide useful considerations for doing so.

6143-10, Session 3

Quantitative evaluation of carotid arterial plaque surface irregularity

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Recent studies have demonstrated that atherosclerotic plaque surface morphology in the carotid arterial system represents an independent risk factor for embolus formation and subsequent cerebrovascular occlusive events. The primary aim of the current retrospective study is to enhance the clinical utility of this key finding by developing and evaluating objective, quantitative methods for characterizing the plaque surface irregularity from Gadolinium-enhanced MRA studies. Nine metrics were analyzed for correlation with percent stenosis in 78 arteries from 43 patients with carotid artery disease. Most of the metrics comprised measurements obtained from a triangulated surface model of the stenotic lesion derived from the MRA via the Isosurface Deformable Model. Percent stenosis was determined through real-time volume rendering of 3D MIP MRA studies in Vitrea2. Six of the analyzed metrics revealed significant correlation to percent stenosis ($p<0.01$). Reproducibility of all metrics was evaluated in a set of 14 randomly selected arteries from 13 patients by way of a single-trial, two-observer analysis. Six of the nine metrics demonstrated significant inter-observer reproducibility by way of single-factor ANOVA analysis ($p<0.02$). Collectively, the findings reported herein demonstrate an objective and reliable method for quantifying carotid plaque surface irregularity from standard MRA techniques with possible future clinical application in refining risk of ischemic cerebrovascular events and associated need for prophylactic intervention.

6143-11, Session 3

Quantification of carotid vessel atherosclerosis

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Atherosclerosis is characterized by the development of plaques in the arterial wall, which ultimately leads to heart attacks and stroke. 3D ultrasound (US) has been used to screen patients' carotid arteries. Plaque measurements obtained from these images may aid in the management and monitoring of patients, and in evaluating the effect of new treatment options. Different types of measures for ultrasound phenotypes of atherosclerosis have been proposed. Here, we report on the development and application of a method used to analyze changes in carotid plaque morphology from 3D US images obtained at two different time points. We evaluated our technique using manual segmentations of the wall and lumen of the carotid artery from images acquired in two US scanning sessions. To incorporate the effect of intra-observer variability in our evaluation, manual segmentation was performed five times each for the arterial wall and lumen. From this set of five segmentations, the mean wall and lumen surfaces were reconstructed, with the standard deviation at each point mapped onto the surfaces. A correspondence map between the mean wall and lumen surfaces was then established, and the thickness of the atherosclerotic plaque at each point in the vessel was estimated to be the distance between each correspondence pairs. The two-sample Student's t-test was used to judge whether the difference between the thickness values at each pair corresponding points of the arteries in the two 3D US images was statistically significant.

6143-12, Session 3

Pulsatile pressure measurements via harmonics-based orthogonal projection of noisy pressure gradients

Y. Wang, Huazhong Univ. of Science and Technology (China); J. R. Cebral, George Mason Univ.; A. A. Amini, Washington Univ. in St. Louis

In the past, several methods based on iterative solution of pressure-Poisson equation have been developed for direct measurement of pressure from phase-contrast magneticresonance (PC-MR) data. Recently, we developed a non-iterative harmonics-based orthogonal projection method which keeps the pressures computed based on the Navier-Stokes equation independent of the path of integration [Y. Wang and A. Amini, "Integrable Pressure Gadients via Harmonics-Based Orthogonal Projection," IPMI 2005, LNCS Vol. 3565, pp. 431-442, Christensen and Sonka (Eds.), Glenwood Springs, Co, July 2005]. The gradient of pressure calculated with Navier-Stokes equation is expanded with a series of orthogonal basis functions and is subsequently projected onto an integrable subspace. Before the projection step however, a scheme is devised to eliminate the discontinuity at the vessel boundaries. The approach was applied to stenotic velocities for the case of constant steady flow obtained from computational fluid dynamics (CFD) simulations and compared with pressures independently obtained by CFD. Additionally, MR velocity data measured in in-vitro phantom models with different degree of stenoses and different flow rates were used to test the algorithm and results were compared with CFD simulations. In the SPIE paper, an overview of the method as applicable to both steady and pulsatile flows is given. It is shown that the non-iterative harmonics-based orthogonal project method results in significant improvements in terms of accuracy and computational time when compared with the iterative solution to the pressure-poisson equation.

6143-13, Session 3

Patient-specific models of wall stress in abdominal aortic aneurysm: a comparison between MR and CT

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Finite element method based patient-specific wall stress in abdominal aortic aneurysm (AAA) may provide a more accurate rupture risk predictor than the currently used maximum transverse diameter. In this study, we have investigated the sensitivity of the wall stress in AAA with respect to geometrical variations. We have acquired MR and CT images for four patients with AAA. Three individual users have delineated the AAA vessel wall contours on the image slices. These contours were used to generate synthetic feature images for a deformable model based segmentation method. We investigated the reproducibility and the influence of the user variability on the wall stress. For sufficiently smooth models of the AAA wall, the peak wall stress is reproducible for three out of the four AAA geometries. The 0.99 percentiles of the wall stress show excellent reproducibility for all four AAAs. The variations induced by user variability are larger than the errors caused by the segmentation variability. The influence of the user variability appears to be similar for MR and CT. We conclude that the peak wall stress in AAA is sensitive to small geometrical variations.

To increase reproducibility it appears to be best not to allow too much geometrical detail in the simulations. This could be achieved either by using a sufficiently smooth geometry representation or by using a more robust statistical parameter derived from the wall stress distribution.

6143-14, Session 3

Effects of parent vessel geometry on intraaneurysmal flow patterns

M. A. Castro, George Mason Univ.; C. M. Putman, Inova Fairfax Hospital; J. R. Cebral, George Mason Univ.

The purpose of this study was to demonstrate the importance of properly modeling the geometry of the parent vessel when constructing patient-specific, image-based hemodynamic models of cerebral aneurysms. It was found that truncating the parent vessel close to the neck of the aneurysm changed several important hemodynamic characteristics. For instance, in a lateral aneurysm of the internal carotid artery, the flow impaction zone moved from the body of the aneurysm to its neck and the aneurysm sac went from a state of elevated wall shear stress to a state of low shear stress. Truncating the vessel close to the aneurysm neck changes the secondary flows in the parent vessel and the way the blood flows into the aneurysm, and therefore the intraaneurysmal flow pattern and wall shear stress distribution. The proximal portion of the parent vessel of cerebral aneurysms should be appropriately modeled in order to accurately represent the intraaneurysmal hemodynamics. Theories of aneurysm growth and rupture are mostly based on observations made on idealized in vitro and animal models that show low wall shear stress and slowly recirculating flows in the aneurysm. However, as shown in this paper, idealized models or truncated patient-specific models do not accurately represent the in vivo hemodynamics. Therefore, new studies that properly model the parent vessel are needed in order to determine the role of hemodynamics in the processes of aneurysm growth and rupture.

6143-15, Session 3

Effects of segmentation on patient-specific numerical simulation of cerebral aneurysm hemodynamics

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One of the most important tasks in patient-specific, imaging-based numerical simulation of cerebrovascular blood flow is the extraction of vessel surface from the medical images, which is often referred to as segmentation. In this study, we investigated the effects of segmentation on numerical simulations conducted using patient-based cerebral aneurysm models. CTA images obtained for a patient-specific anterior communicating artery (ACoA) aneurysm and a patient-specific middle cerebral artery (MCA) aneurysm were used for the construction of models. For each aneurysm, two models were created, one using a different threshold value for image segmentation than the other. The average difference in vessel diameter between the two models was 4 voxels. However, our simulations revealed that these small differences led to entirely different pressure and shear stress distributions for the two models. These results suggest the need for more accurate and consistent vascular segmentation techniques.

6143-16, Session 4

Imaging and CFD in the analysis of vascular disease progression

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Hemodynamics plays an important role in the onset and progression of disease in individuals with cardiovascular disorders. Such individuals are at risk for devastating events such as aneurysm rupture or thromboembolic showering from ruptured plaque with subsequent stroke. However, little is known about the natural history of progression of aneurysms. In many cases, patients with these conditions are followed with conservative monitoring. A variety of imaging modalities are available for following these individuals. Computational tools are now available for predicting important hemodynamic descriptors. In recent years, a number of investigators have exploited the high resolution capabilities of three-dimensional imaging modalities to create patient-specific models with predictions that can be correlated with observable imaging findings in relation to disease progression.

6143-17, Session 4

Reproducibility of brain hemodynamic simulations: an inter-solver comparison

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The accuracy and reproducibility of cerebrovascular hemodynamic simulations were determined by comparison of experimental measurements made in a curved square duct with the corresponding simulations produced by three different solvers, and by inter-solver comparison of pulsatile flow in a patient-specific, middle cerebral artery aneurysm model. The simulation results from all of the solvers were in close agreement with the measurements made in the curved square duct. This suggests that the simulations were accurate for models with strong curvature. The results produced by the three solvers using the patient-specific aneurysm model were also consistent with each other, suggesting that hemodynamic simulations of aneurysm models were consistent and reproducible by different solvers. These results demonstrate that different solvers used for patient-specific, imaging-based simulations produce consistent results that are accurate within the limits of measured experimental error.

6143-18, Session 4

A study of the hemodynamics of anterior communicating artery aneurysms

M. A. Castro, George Mason Univ.; C. M. Putman, Inova Fairfax Hospital; J. R. Cebral, George Mason Univ.

The purpose of this study was to investigate the influence of unequal physiologic flow conditions in the carotid arteries on the hemodynamic patterns of anterior communicating artery aneurysms. Patient-specific computational fluid dynamics models of anterior communicating artery aneurysms were constructed from bilateral 3D rotational angiography. It was found that mean flow unbalances tend to shift the regions of elevated wall shear stress towards the dominant inflow jet. However, phase shifts and different waveform shapes have a more dramatic effect. In these cases, the regions of elevated wall shear stress travel along the surface of the aneurysm sac during the cardiac cycle, making the overall hemodynamic pattern more complex and unstable. Hemodynamic studies aimed at understanding the mechanisms of aneurysm growth and rupture should consider the conditions affecting the flow rates in the parent arteries of cerebral aneurysms with more than one avenue of inflow.

6143-19, Session 4

Flow modification in canine intracranial aneurysm model by an asymmetric stent: studies using digital subtraction angiography (DSA) and image-based computational fluid dynamics (CFD) analyses

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An asymmetric stent with low porosity patch across the intracranial aneurysm neck and high porosity elsewhere is designed to modify the flow to cause thrombotic occlusion and reduce the possibility of occluding the adjacent perforator vessels. The purposes of this study are to evaluate the flow field induced by asymmetric stent with both numerical and digital subtraction angiography methods and to quantify the flow dynamics of an asymmetric stent in an in vivo aneurysm model. We created a vein-

pouch aneurysm model on the canine carotid artery. An asymmetric stent was implanted at the aneurysm, with 25% porosity across the aneurysm neck and 80% porosity elsewhere. The aneurysm geometry, before and after stent implantation, was acquired using cone beam CT and reconstructed for Computational Fluid Dynamics (CFD) analysis. Both steady-state and pulsatile flow conditions using the measured waveforms from the aneurysm model were studied. To reduce computational costs, we modeled the asymmetric stent by specifying a pressure drop across the low porosity region of the stent. From the CFD results, we found the asymmetric stent reduced the inflow into the aneurysm by 71%, and created stasis environment which favors thrombus formation. The digital subtraction angiography sequences also showed substantial flow reduction into the aneurysm. In addition, the stent also reduced the wall shear stress in the CFD model, which may imply aneurysm growth mitigation. Asymmetric stents may be a viable image guided intervention for treating intracranial aneurysms with desired flow modification features.

6143-20, Session 4

Towards patient-specific modeling: hemodynamics is a growing aneurysm

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Understanding the growth and adaptation of intracranial aneurysms represents a very challenging problem. Predicting aneurysm growth using stress-mediated growth laws requires accurate knowledge of the hemodynamic stresses and strains acting on the aneurysm wall due to the internal blood flow and the external tissue support. Therefore, the solution of the coupled problem of blood flow and vessel wall deformation represents a critical step in the evaluation of these hemodynamic stresses. However, the solution of blood flow in large, patient-specific models of the vasculature is a computationally expensive problem. In this work, we present the application of a new formulation, the Coupled Momentum Method for Fluid-Solid Interaction (CMM-FSI), to compute blood flow and vessel wall deformation under realistic ranges of pressures for large patient-specific models of the vasculature. The method couples the equations of the deformation of the vessel wall at the variational level as a boundary condition for the fluid domain. We consider a strong coupling of the degrees-of-freedom of the fluid interface and the wall domains. The effect of the vessel wall boundary is therefore added in a monolithic way to the fluid equations, resulting in a remarkably robust and computationally-efficient scheme. The method is applied to an idealized model of a basilar artery aneurysm, using impedance outflow boundary conditions. The wall normal and shear stresses resulting from the simulation can then be used as the hemodynamic forces mediating the aneurysm wall adaptation according to the algorithm shown in the second part of this work.

6143-21, Session 4

Dynamic pressure at sites of virtually removed paraclinoid aneurysms: a computational fluid dynamics study

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Computational Fluid Dynamics (CFD) techniques were used to assess the dynamic pressure distribution at the sites of three virtually removed paraclinoid aneurysms. 3D Digital Subtraction Angiograms (3D-DSA) were used to create two computational meshes for each aneurysm. The first mesh was derived directly from the angiographic data containing the aneurysms. In the second mesh, the section of the artery across the aneurysm neck was virtually reconstructed by interpolation between the adjacent proximal and distal parts of the parent artery. This mesh is considered to be an approximation to the geometry of the parent artery before aneurysm formation. In the simulations with the meshes containing the aneurysm, high dynamic pressure values (10% of maximum static pressure differential) were found at the proximal neck of the aneurysm and at the arterial bends. However, low dynamic pressure distributions (less than 2 % of the maximum static pressure differential) were found at the location of the aneurysm ostium for each virtually removed artery. These results indicate that the dynamic pressure may not be the primary factor in the initiation and growth of paraclinoid aneurysms and that other factors may contribute to the creation of this kind of aneurysm.

6143-22, Session 5

Effect of mixing scanner types and reconstruction kernels on the characterization of lung parenchymal pathologies: emphysema, interstitial pulmonary fibrosis and normal non-smokers

Y. Xu, E. van Beek, M. Sonka, J. Guo, G. McLennan, E. A. Hoffman, The Univ. of Iowa

Purpose: Computer-aided detection (CAD) algorithms of multidetector-row CT (MDCT) have the potential to significantly alter clinical practice. In a previous study, we have shown that 3-dimensional texture features are better than 2-D features in the discrimination of emphysema severity. In this study, we developed a CAD tool to characterize interstitial lung diseases (including emphysema) based on MDCT generated volumetric data using 3-dimentional texture features. In addition, we tested whether the scanner and convolution kernel type would affect the classification of lung diseases.

Methods: We collected MDCT image in three subject groups: emphysema (n=9), interstitial pulmonary fibrosis (IPF) (n=10), and normal non-smokers (n=9). In each group, images were scanned either on a Siemens 16 or 64-slice scanner, (B50f or B30 recon. kernel) or a Philips 8 slice scanner (B recon. kernel). A total of 1517 volumes of interest (VOIs; 21x21 pixels in plane) were marked by a chest radiologist using the Iowa PASS software. VOIs included emphysema (n=436); ground-glass (n=276); honeycombing (n=346), and normal non-smokers (n=458). We calculated 24 volumetric features including statistical features (first order features and run-length and co-occurrence features), histogram and model-based features. Bayesian methods were used for training and classification. Images from different scanners/kernels were combined in all possible combinations to test how robust the tissue classification was relative to the differences in image characteristics. We used 10-fold cross validation for testing the result. Sensitivity, specificity and accuracy were calculated. One-way Analysis of Variances (ANOVA) was used to compare the classification result between the various combinations of scanner and reconstruction kernel types.

Results: Using our Bayesian classifier in a 10-fold cross validation on the combinations derived from three groups yielded a sensitivity of 94%, 91%, 97%, and 93% for emphysema, ground-glass, honeycombing, and normal non-smokers, respectively. The specificity for these characterizations was 97%, 99%, 99%, and 98%, respectively. The F test result of ANOVA shows there is no significant difference ($p<0.05$) between different combinations of data with respect to scanner and convolution kernel type.

Conclusion: We conclude that volumetric features including statistical features, histogram and model-based features can be successfully used in differentiation of both emphysema and interstitial lung diseases. Since different MDCT and convolution kernel types did not show significant differences in regards to the classification result, this approach can be generally introduced. The tissue types characterized in this study were quite distinct. A next step is to begin to evaluate the sensitivity to more subtle differences in parenchymal pathology.

6143-23, Session 5

A novel multipurpose tree and path matching algorithm with application to airway trees

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Tree matching methods have wide application in medical imaging, for purposes including registration, anatomical labeling, segmentation, and navigation of structures such as vasculature and airway trees. Typical methods for tree matching rely on conventional graph matching techniques, and can be sensitive to the accuracy of the extracted tree structures, as well as dependent upon the initial alignment. We present a novel path-based tree matching framework independent of graph matching. It is based on a point-by-point feature comparison of complete paths rather than branch points, and consequently is relatively/largely unaffected by false/spurious airways and/or missing branches. A matching matrix is used to enforce one-to-one matching. Moreover our method can reliably match irregular tree structures, which are a consequence of imperfect segmentation and centerline extraction. Also due to on the nature of these features, our method does not require a precise alignment or registration of the tree structures. To test our method we used two thoracic CT scans from each of ten patients, with a median inter-scan interval of 3 months (range 0.5 to 10 months). The bronchial tree structure was automatically extracted from each scan and a ground truth of matching paths was established between each pair of tree structures. The results show that overall 87% of 702 airway paths were correctly matched using the technique. Finally, preliminary results are shown in airway-to-artery matching using the proposed method.

6143-24, Session 5

Point-based methods for automatic bronchial tree matching and labeling

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When addressing the task of automatic tracheo-bronchial tree matching it seems natural to make use of the tree's graph structure and branching characteristics. In tracheo-bronchial trees that were automatically extracted from multi slice CT data, however, the graph information is not always reliable which lets the abovementioned class of approaches fail.

In this work we investigate what can be gained by using the spatial position of the bronchial centerline points. For this purpose we introduce, investigate, and compare two approaches to tree matching that are based on the use of centerline point positions alone with no additional connectivity information.

As features we use (1) the 3D shape context and (2) statistical moments of the local point distribution. Six tracheo-bronchial trees were matched to a given model tree. It could be shown that the 3D shape context feature labeled 66 % of centerline points correctly on the level of the 18 lung segments. On the level of the 5 lung lobes 90 % of the centerline points were labeled correctly. In the case of the statistical moment feature the corresponding numbers were 40 % and 70 % respectively.

We conclude that the set of centerline points alone allows correct labeling of a large portion of lung segments. We propose to combine this valuable information in future work with connectivity and branching information, where the latter is reliably available.

6143-25, Session 5

Quantification of tumor mobility during the breathing cycle using 3D dynamic MRI

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Respiration causes movement and shape changes in thoracic tumors, which has a direct influence on the radio-therapy planning process. Current methods for the estimation of tumor mobility are either two-dimensional (fluoroscopy, 2D dynamic MRI) or based on radiation (3D(+t) CT, implanted gold markers). With current advances in dynamic MRI acquisition, 3D+t image sequences of the thorax can be acquired covering the thorax over the whole breathing cycle. In this work, methods are presented for the interactive segmentation of tumors in dynamic images, the calculation of tumor trajectories, dynamic tumor volumetry and dynamic tumor rotation/deformation based on 3D dynamic MRI. For volumetry calculation, a set of 21 related partial volume correcting volumetry algorithms has been evaluated based on tumor surrogates. Conventional volumetry based on voxel counting yielded a root mean square error of 29% compared to a root mean square error of 11% achieved by the algorithm performing best among the different volumetry methods. The new workflow has been applied to a set of 26 patients. Preliminary results indicate, that 3D dynamic MRI reveals important aspects of tumor behaviour during the breathing cycle. This might imply the possibility to further improve high-precision radiotherapy techniques.

6143-26, Session 5

Automated airway evaluation system using airway lumen diameter, airway wall thickness and broncho-arterial ratio with multi-slice computed tomography

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Pulmonary diseases such as bronchiectasis, asthma, and emphysema are characterized by abnormalities in airway dimensions. Multi-slice computed tomography (MSCT) has become one of the primary means to depict these abnormalities, as the availability of high-resolution near-isotropic data makes it possible to evaluate airways at oblique angles to the scanner plane. However, currently, clinical evaluation of airways is typically limited to subjective visual inspection only: systematic evaluation of the airways to take advantage of high-resolution data has not proved practical without automation. We present an automated method to quantitatively evaluate airway lumen diameter, wall thickness and broncho-arterial ratios. In addition, our method provides 3D visualization of these values, graphically illustrating the location and extent of disease. Our algorithm begins by automatic airway segmentation to extract paths to the distal airways, and to create a map of airway diameters. Normally, airway diameters decrease as paths progress distally; failure to taper indicates abnormal dilatation. Our approach monitors airway lumen diameters along each airway path in order to detect abnormal profiles, allowing even subtle degrees of pathologic dilatation to be identified. Our method also systematically computes the broncho-arterial ratio at every terminal branch of the tree model, as a ratio above 1 indicates potentially abnormal bronchial dilatation. Finally, the airway wall thickness is computed at corresponding locations. These measurements are used to highlight abnormal branches for closer inspection, and can be summed to compute a quantitative global score for the entire airway tree, allowing reproducible longitudinal assessment of disease severity. Preliminary tests on patients diagnosed with bronchiectasis demonstrated rapid identification of lack of tapering, which also was confirmed by corresponding demonstration of elevated broncho-arterial ratios.

6143-27, Session 6

3D automatic segmentation of MR images applied to the rat uterus

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We introduce a 3D multi-channel multiscale automatic segmentation algorithm for delineating specific organs in MR images. The algorithm can process several modalities simultaneously, and handle both isotropic and anisotropic data with only linear complexity in time. Our method produces a hierarchical decomposition of MRI scans. During the segmentation process a rich set of features describing the segments in terms of intensity, shape and location is calculated, reflecting the formation of the hierarchical decomposition. Utilizing this method we delineate the uterus in 3D images of the rat abdomen. We further achieve high contrast between the uterus and other abdominal organs and observe the inner structure of the rat uterus horns. This may allow developing non-invasive imaging techniques to monitor the uterus in vivo. Indeed, MRI offers high spatial resolution, soft tissue contrast and multiple contrast mechanisms which can be simultaneously exploited. Both single and multi-channel automatic segmentation demonstrate high correlation to a manual segmentation. While the focus here is on the rat uterus the general approach can be applied to recognition in 2D, 3D and multi-channel medical images.

6143-28, Session 6

Semi-automatic segmentation and quantification of 3D spinal cord data

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Delineation of objects within medical images is often difficult to perform reproducibly when one relies upon hand-segmentation. To avoid inter- and intra-user variability, a semi-automatic segmentation method can more accurately and consistently determine the object boundaries. This paper presents a semi-automatic process for determining the length and volume of the spinal cord between adjacent pairs of intervertebral discs and the total length and volume of the spinal cord. A level set segmentation was performed on MRI data with user selected landmarks in order to obtain a segmentation of the spinal cord. The length and volume measurements were performed on 20 segments from C1 to L1 with five sets of user selected landmarks. Our results show that the average spinal cord segment length was 21.55 mm with a standard deviation of 25.11% and the average spinal cord segment volume was 2,217.16 mm3 with a standard deviation of 80.51%. The measurement variability of a single anatomical length across multiple trials of different sets of seed points was three orders of magnitude lower (0.06%) than the variability across different anatomical lengths (25.23%), while the measurement variability of a single anatomical volume across multiple trials of different sets of seed points was two orders of magnitude lower (0.37%) than the variability across different anatomical volumes (79.24%). Our method has been demonstrated to be potentially insensitive to intra- and inter-user variability.

6143-29, Session 6

Quantification of diffusion weighted images (DWI) and apparent diffusion coefficient maps (ADC) in the detection of acute stroke

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Introduction: MRI is increasingly used in the management and diagnosis of acute ischemic stroke, and techniques such as diffusion weighted imaging (DWI) and apparent diffusion coefficient maps (ADC) are used in the diagnosis of acute infarcts. Advances in radiology and imaging protocols have led to an overload of image information. Automated techniques to assist in the identification of acute ischemic stroke can prove beneficial to the physician and the patient.

Methods: DWI images and ADC maps were selected from various case studies. DW imaging was performed by using a single-shot spin-echo echo-planar imaging sequence. ADC maps were automatically generated using GE Signa Systems FuncTool software. A novel algorithm was developed that quantified the degree of relative difference map (RDM) between corresponding regions in the ipsilateral and contralateral hemispheres of the brain.

Results: We perform quantification of asymmetry, using the RDM method to process the DWI image and its corresponding ADC map. The ADC maps can confirm the presence or absence of a true infarct by depicting those areas with true diffusion coefficients. A true acute infarct with high signal intensity on DWI will remain hypointense on ADC map. Thus, DWI and ADC maps are used mutually in clinical practice.

Conclusions: A novel method to quantify and delineate infarct regions in DWI images and corresponding ADC maps that are mutually used in clinical practice is presented. Creating a computer aided diagnostic tool to provide a binary hint about absence or presence of a stroke would greatly improve patient outcome.

6143-30, Session 6

Feasibility study on quantitative analysis of multiple sclerosis

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Multiple Sclerosis (MS) is the most common inflammatory demyelinating disease of the central nervous system. For treatment of MS, the measurements of white matter (WM), gray matter (GM), and cerebral spinal fluid (CSF) are often used in conjunction with clinical evaluation to provide a more objective measure of MS burden. In this paper, we apply a new unifying automatic mixture-based algorithm for segmentation of brain tissues to quantitatively analyze MS. The method takes into account the following effects that commonly appear in MR imaging: 1) The MR data is modeled as a stochastic process with an inherent effect of smoothly varying intensity inhomogeneity; 2) A new PV model is built in establishing the MAP segmentation scheme; 3) Noise artifacts are minimized by a priori MRF penalty or constraint indicating neighborhood correlation for tissue mixture. The volumes of brain tissues (WM, GM) and CSF are extracted from the mixture-based segmentation. Experimental results of feasibility study on MS patients are presented.

6143-31, Session 6

A methodology to study multiple sclerosis based on distributions of standardized intensities in segmented tissue regions

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This paper presents (1) an improved hierarchical method for segmenting the component tissue regions in fast spin echo T2 and PD images of the brain of Multiple Sclerosis (MS) patients, and (2) a methodology to characterize the disease utilizing the distributions of standardized T2 and PD intensities in the segmented tissue regions.

First, the background intensity inhomogeneities are corrected and the intensity scales are standardized for all acquired images. The segmentation method imposes a feedback-like procedure on our previously developed hierarchical brain tissue segmentation method. With gradually simplified patterns in images and stronger evidences, pathological objects are recognized and segmented in an interplay fashion. After the brain parenchymal (BP) mask is generated, an under-estimated gray matter mask (uGM) and an over-estimated white matter mask (oWM) are created. Pure WM (PWM) and lesion (LS) masks are extracted from the all-

inclusive oWM mask. By feedback, accurate GM and WM masks are subsequently formed. Finally, partial volume regions of GM and WM as well as Dirty WM (DWM) masks are generated.

Intensity histograms and their parameters (peak height, peak location, and 25th, 50th and 75th percentile values) are computed for both T2 and PD images within each tissue region. Tissue volumes are also estimated. Spearman correlation coefficient rank test is then utilized to assess if there exists a trend between clinical states and the image-based parameters.

This image analysis method has been applied to a data set consisting of 60 patients with MS and 20 normal controls. LS related parameters and clinical Extended Disability Status Scale (EDSS) scores demonstrate modest correlations. Almost every intensity-based parameter shows statistical difference between normal control and patient groups with a level better than 5%. These results can be utilized to monitor disease progression in MS.

6143-32, Session 6

Micro-MRI-based image acquisition and processing system for assessing the response to therapeutic intervention

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Osteoporosis is the cause of over 1.5 million bone fractures annually. Most of these fractures occur in sites rich in trabecular bone, a complex network of bony struts and plates found throughout the skeleton. The three-dimensional structure of the trabecular bone network significantly determines mechanical strength and thus fracture resistance. Here we present a data acquisition and processing system that allows efficient noninvasive assessment of trabecular bone structure through a “virtual bone biopsy”. High-resolution MR images are acquired from which the trabecular bone network is extracted by estimating the partial bone occupancy of each voxel. A heuristic voxel subdivision increases the effective resolution of the bone volume fraction map and serves a basis for subsequent analysis of topological and orientational parameters. Semi-automated registration and segmentation ensure selection of the same anatomical location in subjects imaged at different time points during treatment. It is shown with excerpts from an ongoing clinical study of early post-menopausal women, that significant reduction in network connectivity occurs in the control group while the structural integrity is maintained in the hormone replacement group. The system described should be suited for large-scale studies designed to evaluate the efficacy of therapeutic intervention in subjects with metabolic bone disease.

6143-33, Session 7

Functional microimaging: an integrated approach for bone biomechanics

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Biomechanical testing is the gold standard to determine bone competence. We incorporated several imaging methods in our mechanical setups in order to get a better insight into bone deformation and failure mechanisms. Our aim was to develop an integrative approach for hierarchical bone investigation, working at different scales of resolution ranging from the whole bone to its ultrastructure.

At a macroscopic level, the use of high-resolution and high-speed cameras increases drastically the amount of information assessed from bone mechanical tests. Dealing with very small bones such as murine femora, the feedback of cameras in the process of aligning and positioning samples is indispensable for reproducibility. Global failure behavior and fracture location are visualized with high temporal resolution. Furthermore, cameras combined with surface markers provide powerful tools for surface strain computation.

Complementary to intrinsic material properties, bone microstructure (trabecular architecture and cortical porosity) influences bone strength and failure mechanisms significantly. We developed an image-guided failure assessment technique, also referred to as functional microimaging, allowing direct time-lapsed 3D visualization and computation of local strains for better quantification of fracture initiation and progression at the microscopic level.

Highly brilliant X-rays from synchrotron radiation allowed, for the first time, to uncover fully nondestructively 3D bone ultrastructure, including vascular and cellular structures, and to investigate their role in development of bone microcracks in an unprecedented nanometer resolution. Functional investigation of microcracks initiation and propagation will lead to better understanding of the relative importance of bone mass and bone quality in determination of bone competence.

6143-34, Session 7

Imaging mechanical properties of hepatic tissue with magnetic resonance elastography

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Purpose: To assess the feasibility of a modified phase-contrast MRI technique (MR Elastography) for quantitatively assessing the mechanical properties of hepatic tissues by imaging propagating acoustic shear waves.

Methods: Both phantom and human studies were performed to develop and optimize a practical imaging protocol by visualizing and investigating the diffraction field of shear waves generated from pneumatic longitudinal drivers. The effects of interposed ribs in transcostal approach were also investigated. A gradient echo MRE pulse sequence was adapted for shear wave imaging in the liver during suspended respiration, and then tested to measure hepatic shear stiffness in 12 healthy volunteers and a series of 12 patients with chronic liver disease and biopsy-proven fibrosis (grades I-IV) to determine the potential of non-invasively detecting liver fibrosis.

Results: Phantom studies demonstrate that longitudinal waves generated by the driver are mode-converted to shear waves in a distribution governed by diffraction principles. The transcostal approach was determined to be the most effective method for generating shear waves in human studies. Hepatic stiffness measurements in the 12 normal volunteers demonstrated a mean value of 1.94±0.28kPa. All shear stiffness measurements in 12 patients yielded significantly higher values (mean, 5.33±4.8kPa; range, 2.69-19.2kPa) and varied systematically with severity of fibrosis.

Conclusion: MR Elastography of the liver shows promise as a method to non-invasively detect and characterize diffuse liver disease, potentially reducing the need for biopsy to diagnose hepatic fibrosis.

6143-35, Session 7

MR elastographic methods for the evaluation of plantar fat pads: preliminary comparison of the shear modulus for shearing deformation and compressive deformation in normal subjects

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MR elastography (MRE) images the intrinsic mechanical properties of soft tissues; i.e., the shear modulus, μ. The μ of the foot is important in understanding the mechanisms whereby the forces induced during normal movement produce ulcers that lead to amputation in diabetic feet; a significant burden on the health care system costing $1.2 billion, annually. We are evaluating the compliance of the heel fat pad to compressive and shearing forces. High compressive forces are induced during heel-strike (early stance) and high shear forces are induced during push off (early swing). The design of prosthetics to protect the foot depends on the proper understanding of the mechanisms inducing damage.

We developed an apparatus to induce two modes of motion in the plantar soft tissues which is necessary for dynamic, steady-state MRE methods

to image the μ for shearing and compressive deformation. Our values of μ are accurate to within 10% to 20% and reproducible to 3.5%.

In the heel fat pads of six normal subjects, between 25 and 65 years of age, the μ for deformation perpendicular to the direction of weight bearing is very similar but not identical to that determined for deformation along the weight bearing axis. The average difference was less than one standard deviation as measured by the variations in the μ at positions where the direction of motion did not change. The variation between subjects was significant. It is important to understand any differences in shear modulus of the fat pads of the foot that are introduced by aging or disease in order for the technique to become of diagnostic value.

6143-36, Session 7

Application of multiresolution modality independent elastography for detection of multiple anomalous objects

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This work extends a recently realized inverse problem technique of extracting soft tissue elasticity information via nonrigid model-based image registration. The algorithm uses the elastic properties of the tissue in a biomechanical model to achieve maximal similarity between image data acquired under different states of loading. A new multi-resolution, nonlinear optimization framework has been employed which allows for improved performance and object detection. Prior studies have demonstrated successful reconstructions from images of a tissue-like thin membrane phantom with a single embedded inclusion that was significantly stiffer than its surroundings. For this investigation, a similar phantom was fabricated with two stiff inclusions to test the effectiveness of the method to discriminate multiple smaller objects. In both simulation and real data testing scenarios, the results show relevant, detectable contrast in elasticity values that allow for good localization of the inclusion areas.

6143-37, Session 7

Biomechanical registration of prostate images using statistical shape models

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Proper targeting of radiation therapy during the treatment of prostate cancer requires the successful alignment of initial, planning images with more recent ones taking during the treatment course. Prostatic deformation, if unaccounted for during the treatment course, can lead to underdosage of the target area. In numerous studies prostatic deformation has been directly correlated with changes in the volume of the rectum. We have developed an image registration system based on a biomechanical model of the prostate, rectum, and surrounding tissue that incorporates statistical shape information about changes in the volume of the rectum. Using finite-element analysis and statistical shape models, our deformable organ registration method defines a mapping between two prostate image volumes. Computing optimal boundary condition displacements along the rectum as well as estimating the relative Young's modulus of the prostate with the surrounding tissue maximizes the image registration quality. The method was tested on two intra-patient 2D MRI images. The dice similarity coefficient between the target and registered image were 0.86 after rigid body registration and 0.92 after our deformable image registration technique was applied. The method was also tested on ultrasound images of a three layer prostate phantom deformed using an inflatable probe. At small strains the mutual information was maximized when the correct displacement boundary conditions and Young's moduli were obtained.

6143-38, Session 7

A multi-organ biomechanical model to analyze prostate deformation due to large deformation of the rectum

K. K. Brock, C. Menard, J. Hensel, D. A. Jaffray, Univ. of Toronto (Canada)

Magnetic resonance imaging (MRI) with an endorectal receiver coil (ERC) provides superior visualization of the prostate gland and its surrounding anatomy at the expense of large anatomical deformation. The ability to correct for this deformation is critical to integrate the MR images into the CT-based treatment planning for radiotherapy. The ability to quantify and understand the physiological motion due to large changes in rectal filling can also improve the precision of image-guided procedures. The purpose of this study was to understand the biomechanical relationship between the prostate, rectum, and bladder using a finite element-based multi-organ deformable image registration method, 'Morfeus' developed at our institution. Patients diagnosed with prostate cancer were enrolled in the study. Gold seed markers were implanted in the prostate and MR scans performed with the ERC in place and its surrounding balloon inflated to varying volumes (0 - 100cc). The prostate and its substructure, bladder and rectum were then delineated, converted into finite element models, and assigned appropriate material properties. Morfeus was used to assign surface interfaces between the adjacent organs and deform the bladder and rectum from one position to another, obtaining the position of the prostate through finite element analysis. This approach achieves sub-voxel accuracy of image co-registration in the context of a large ERC deformation, while providing a biomechanical understanding of the multi-organ physiological relationship between the prostate, bladder, and rectum. The development of a deformable registration strategy is essential to integrate the superior information offered in MR images into the treatment planning process.

6143-59, Poster Session

Development and use of a kinetic FDG-PET dataset simulated from the MNI standard brain

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Simulated data is an important tool for evaluation of reconstruction and image processing algorithms in the frequent absence of ground truth, in-vivo data from living subjects. This is especially true in the case of dynamic PET studies, in which counting statistics of the volume can vary widely over the time-course of the acquisition. Realistic simulated datasets which model anatomy and physiology, and make explicit the spatial and temporal image acquisition characteristics, facilitate experimentation with a wide range of the conditions anticipated in practice, and which can severely challenge algorithm performance and reliability.

As a first example, we have developed a realistic dynamic FDG-PET dataset using the PET-SORTEO Monte Carlo simulation code and the MNI digital brain phantom. The phantom is a three-dimensional dataset that defines the spatial distribution of different tissues. Time activity curves were calculated using an impulse response function specified by generally accepted rate constants, convolved with an input function obtained by blood sampling, and assigned to grey and white matter tissue regions. We created a dynamic PET study using PET-SORTEO configured to simulate an ECAT Exact HR+. The resulting sinograms were reconstructed with all corrections, using variations of FBP and OSEM. Having constructed the dynamic PET datasets, we used them to evaluate the performance of intensity-based registration as part of a tool for quantifying hyper/hypo perfusion with particular application to analysis of brain dementia scans, and a study of the stability of kinetic parameter estimation.

6143-60, Poster Session

3D deformable image processing and integration for neuroanatomical analysis in FDOPA-PET studies

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Functional FDOPA-PET imaging, which displays aspects of tissue function but a poorly delineate anatomy can be used to investigate physiological activities of tissues for further quantitative analysis, is routinely used for neuroanatomic analysis of brain disorders. To exactly distinguish and define abnormal tissue regions from high noise FDOPA-PET image is an important issue of improving the diagnosis accuracy. In this study, a quantitative analysis based feature extraction and a deformable image processing methods are provided to construct a 3D brain FDOPA-PET image model. The novel feature extraction method based on physiological analysis of kinetic parameters, which generated from kinetic modeling analysis of dynamic FDOPA-PET studies, segments desired brain tissue regions, including striatum, gray and white matters. The proposed 3D multi-resolution optical flow estimation method (OFEM) integrates various normal FDOPA-PET studies and constructs the 3D brain image model. The errors of region difference and tissue physiological curves between the segmented result and the VOI in the striatum tissue perform less than 3% in average, respectively, and the constructed 3D FDOPA-PET model is also applied as a standard template for clinical use. With respect to the experiments, 25 Parkinson's disease studies are examined to perform the accuracy of proposed method. The results show the constructed FDOPA-PET model is effectively used to investigate and define the abnormal regions in brain. In summary, the developed feature extraction technique can exactly segment important tissue in FDOPA-PET images, and the constructed 3D image model can clearly define brain structure and improve clinical diagnosis accuracy simultaneously.

6143-61, Poster Session

EEG imaging methods applied to brain-computer interface

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Nowadays best Brain Computer Interface (BCI) methods are based on invasive recording of electrical brain activity. Surface electrodes methods are not as accurate. This is partially due to the filtering of the signal by the skull and to the distance to the sources. Surprisingly methods for solving the EEG inverse problem have seldom been used to overcome these limitations. Inverse solution methods can be adapted to either pre-process the data or as a classification method. In this paper we study the application of well-known Inverse Solution methods to the BCI. Methods are the Minimum Norm method, MUSIC, and LORETA, as well as a method based on covariance prior and a Laplacian. Data are processed with a inverse solution method. Then we classify the data by measuring the activation in preselected areas. Filtering with Inverse method always improve the classification obtained outside of the skull except for MUSIC. Furthermore these methods can be used without increasing the computation time. With our simple paradigm we obtained more than 80 % of good classification.

6143-62, Poster Session

Spatiotemporal analysis of ERP data in emotional processing

J. Hu, J. Tian, L. Yang, Institute of Automation (China); X. Pan, Beijing Normal Univ. (China); J. Liu, Institute of Automation (China)

The aim of this paper was to analyze spatiotemporal patterns of Event-related potential (ERP) in emotional processing by using fuzzy k-mean clustering method to segment ERP data into microstates.108 pictures (categorized as positive, negative and neutral) were presented to 24 healthy, right-handed subjects while 128-channel EEG data were recorded. For each subject, 3 artifact-free ERPs were computed under each condition. A modified fuzzy k-mean clustering method based on shape similarity was applied to the grand mean ERPs and the statistical analysis was performed to define the significance of each segmentation map. In the results, positive and negative conditions showed different spatiotemporal patterns of ERP. The results were in accord with other emotional study by fMRI or PET.

6143-63, Poster Session

Combination of PCA and LORETA for sources analysis of ERP data: an emotional processing study

J. Hu, J. Tian, L. Yang, Institute of Automation (China); X. Pan, Beijing Normal Univ. (China); J. Liu, Institute of Automation (China)

The purpose of this paper is to study spatiotemporal patterns of neuronal activity in emotional processing by analysis of ERP data. 108 pictures (categorized as positive, negative and neutral) were presented to 24 healthy, right-handed subjects while 128-channel EEG data were recorded. An analysis of two steps was applied to grand averaged ERP data. First, principal component analysis was performed in the data to obtain significant ERP components. Then LORETA was applied to each component to localize their brain sources. The first six principal components were extracted, each of which showed different spatiotemporal patterns of neuronal activity. The results are in agreement with other emotional study by fMRI or PET. The combination of PCA and LORETA can be used to analyze spatiotemporal patterns of ERP data in emotional processing.

6143-64, Poster Session

Neuronal fiber connections based on A*-pathfinding

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Diffusion tensor imaging has shown potential in providing information about the location of white matter tracts within the human brain. Based on this data, a novel approach is presented establishing connectivity between functional regions using pathfinding. The probability distribution function of the local tensor thereby controls the state space search performed by pathfinding. Additionally, it serves as an indicator for the reliability of the computed paths visualized by color encoding. Besides the capability to handle noisy data, the probabilistic nature of the approach is also able to cope with crossing or branching fibers. The algorithm thus guarantees to establish a connection between cortical regions and on the same hand provides information about the probability of the obtained connection. This approach is especially useful for investigating the connectivity between certain centers of the brain as demonstrated by reconstructed connections between motor and sensory speech areas.

6143-65, Poster Session

Spatial frequency modulates the human visual cortical response to temporal frequency variation: an fMRI study

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The brain response to temporal frequencies (TF) has been already reported, but with no study for different TF respect to various spatial frequencies (SF).

fMRI was performed by 1.5T GE-system in 14 volunteers (9 males and 5 females, range 19-26 years) during square-wave reversal checkerboard visual stimulation with different temporal frequencies of 4, 6, 8 and 10 Hz in two stats of low SF of 0.5 and high SF of 8 cycles/degree. All subjects had normal visual acuity of 20/20 based on snellen's fraction in each eye with good binocular vision and normal visual field based on confrontation test. The mean luminance of the entire checkerboard was 161.4 cd/m2 and the black and white check contrast was 96% The activation map was created using the data obtained from the block designed fMRI study. Pixels whose correlation coefficient value was above a threshold of 0.33, in significant level P <0.01 were considered activated. The average percentage bold signal change for all activated pixels within the occipital lobe, multiplied by the total number of activated pixels within the occipital lobe, was used as the criteria for the strength of the fMRI signal at each state of TF& SF. The results demonstrated the amplitude of the fMRI response to different TFs was maximum in 6Hz for high SF of 8cpd, while, it was maximum at TF of 8Hz for low SF of 0.5cpd. The results are useful for vision therapy (such as the treatment of Amblyopia) and visual task selecting in fMRI studies.

6143-66, Poster Session

Parameterization of motion artifacts in fMRI time series using autoregressive models for the construction of computer-generated phantoms

Y. Li, V. L. Morgan, D. R. Pickens, B. M. Dawant, Vanderbilt Univ.

Subject motion is a substantial source of artifacts in functional MRI (fMRI) data sets. Many fMRI analysis software packages, such as SPM, Brain Voyager, AFNI, FSL, etc., have incorporated rigid-body motion correction steps during their preprocessing process. Computer-generated phantoms, which consist of a series of fMRI volumes to which known activations and motions have been added, can be used to evaluate these motion correction and activation analysis algorithms. Here, we explore the use of scalar and multivariate autoregressive models to parameterize motion artifacts in fMRI time series. To do so, we acquire real fMRI data sets, measure rigid body motion in these data sets, and classify the type of observed motion in several categories such as random motion or motion correlated with activation. The measured motion sequences are then modeled and used to generate realistic image phantoms that can be used to validate fMRI data analysis packages. We compare phantoms generated with the original motion sequences and phantoms generated with simulated sequences. We show that both scalar and multivariate autoregressive models can be used to generate realistic motion sequences. An important difference between the two is the fact that multivariate models can capture correlations between motion parameters, which cannot be done with scalar models.

6143-67, Poster Session

Grid based virtual functional imaging laboratory for large-scale routine clinical fMRI processing

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Functional Magnetic Resonance Imaging (fMRI) has been widely adopted as a non invasive method to located brain activation in clinical research. However fMRI remains to be a challenge in the clinical setup because sophisticated knowledge and standards required for paradigm development and post-processing are missing. Here we introduce the concept of a Grid based virtual functional Imaging Laboratory (Grid funcLAB) for large-scale routine clinical fMRI which provides standardized fMRI task processing as a Grid service. Remote sites, hospitals or practices, without local fMRI processing capabilities, can join the fMRI Grid and securely submit images for processing over the Internet using state-of-the-art Grid technology. We conclude that Grid based fMRI services are an ideal solution to connect image providers which lack fMRI processing capabilities together with processing providers, fMRI expert centers. Such a concept may be the technical solution to overcome the current hesitation for clinical use of fMRI, caused by the technical burden and large variability in results due to missing standardized processing.

6143-68, Poster Session

The brain perfusion imaging in predicting the cerebral ischemia using vessel-around method

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Perfusion CT has been successfully used as a functional imaging technique for diagnosis of patients with ischemic stroke. Numerous researchers have investigated to what extent Perfusion CT can be used for the quantitative assessment of cerebral ischemia and to rapidly obtain comprehensive information regarding the extent of ischemic damage in acute stroke patients. The aim of this study is to show the cerebral flow imaging of the vessel and tissue in human brain and to propose an alternative approach to obtain the brain perfusion mapping. During the first pass of the contrast bolus through the brain, vasculature, local concentrations of iodine are simply reflected by changes in the attenuation values measured with CT. The measured attenuation values can be clarified to Vessel Candidate, Vessel-Around, Non Vessel, Non-perfusion Area using vessel around model and be mapped into the cerebral imaging proposed. The threshold for clarifying the measured attenuation values was determined by the analyzing the characteristics of values and modified as to the acquisition dataset. In order to restrict calculations to actual brain tissue the first pre-contrast scan is segmented using contour finding of the skull bone and CT value based exclusion of cerebro spinal fluid space (CSF). The defined vessel-around model was used to show the cerebral flow imaging and to specify the area of markedly reduced perfusion with loss of function of still viable neurons. We calculated the perfusion parameters using the GVF and the cerebral imaging with the vessel candidate and analyzed the mapping values using the TAC. To validate the mapping values, using many clinical cases, the Mapping results and the perfusion parameters was compared and validated by the physicians and medical staff. The statistical analysis was used to show the results reliable.

The results showed that cerebral imaging using the vessel-around model is the same reliable map as the perfusion imaging using the GVF. The proposed vessel-around model can be successfully applied to cerebral imaging for brain perfusion studies. Using the vessel-around model, the proposed cerebral imaging shows the reliable and rapid results of human brain perfusion. Moreover the vessel-around approach was found to be comprehensive and easy-to-interpret by physicians and medical staff, hence we conclude that our proposed vessel-around technique can be used for brain perfusion mapping.

6143-69, Poster Session

Constrained triple-component T2 quantification in vivo

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T2 relaxation decay curves from in vivo human brain tissue are rarely mono-exponential due to both physiology and partial volume averaging. We propose a tri-exponential model, parametric fitting of the T2 relaxation curve, restricting the range for the T2 in each compartment, and estimating the probability of the existence of each of the components on a pixel-by-pixel basis. The model quantifies the T2 into three discrete compartments: Myelin (T2 short = [20 50] ms), White / Gray Matter (T2 middle = [50 120] ms), and CSF (T2 long = [120 500] ms). A constrained nonlinear minimization technique using subspace trust-region methods was implemented. A pixel-by-pixel analysis was performed, and for any given pixel, the three T2 components were forced to lie within each compartment. However, the magnitude for each of these components was allowed to take any non-negative value including zero. As a result, if any component were absent, its magnitude would be zero and hence not contribute to the fit. Results from the processing of six healthy normal adults, imaged on a 3T magnet with clinically viable imaging protocols,

have been presented and are shown to be in excellent agreement with reported values. This technique is robust and accurate and may potentially be useful in aiding clinical diagnosis and follow-up of patients with white matter abnormalities.

6143-70, Poster Session

Regional gray matter abnormalities in patients with schizophrenia determined with optimized voxel-based morphometry

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This study examined regional gray matter abnormalities in the whole brain in 19 patients with schizophrenia (12 males and 7 females), comparing with 11 age-, sex- and handedness-matched normal volunteers (7 males and 4 females). The customized brain templates which represented the anatomical features of study-specific population at best, was created in order to improve spatial normalization and segmentation. Then automated preprocessing of magnetic resonance imaging (MRI) data from all subjects was conducted using optimized voxel-based morphometry (VBM). The statistical analysis was implemented in terms of two-sample t-test under the general linear model (GLM) framework. Compared with normal controls, regional gray matter concentration in patients with schizophrenia was significantly reduced in the bilateral superior temporal, middle frontal and inferior frontal, right insula, precentral and parahippocampal areas, left thalamus and hypothalamus as well as. Gray matter concentration reduction in the left hypothalamus is new findings. Significant increases in gray matter concentration were not observed across the whole brain in the patients. This study confirms and extends some earlier findings on gray matter abnormalities in schizophrenic patients. Previous behavior and fMRI researches on schizophrenia have suggested that cognitive capacity decreased and self-conscious weakened in schizophrenic patients, these regional gray matter abnormalities determined through structural MRI with optimized VBM may be potential anatomic underpinnings of schizophrenia.

6143-71, Poster Session

Investigation of a block matching algorithm for determining spatial constraints in morphometric analysis

T. K. Sinha, M. I. Miga, Vanderbilt Univ.

This work outlines a procedure for identification of brain structures not affected by prevailing global brain deformations. Such brain structures, when identified, provide useful boundary conditions for brain deformation modeling and analysis. The goal of this research is to compile a reliable set of speedy, robust methods for identification of undeformed brain structures for use in morphometric analysis. The methods presented in this paper compare segmented images of brain volumes before and after a global deformation (atrophy, for example). A rigid registration is first performed between corresponding before and after brain images. After registration, a block matching algorithm registers fractional size regions of the predeformed image to a local neighborhood of regions in the deformed images. Areas of the brain image containing regions of high similarity are further investigated through variation of region shape and region size. Preliminary experiments suggest a definite correlation between region type (size and shape) and structure identification. This work contains a survey of several grouping methods for automatic selection of effective region size and shape. These methods are applied in simulated data, and their effectiveness in each case analyzed. The results in this paper suggest that an automated method for discovering undeformed areas in the brain using block-matching is possible. Further work includes an increase in general efficacy of structure identification and implementation of current methods in a framework for morphometric analysis.

6143-72, Poster Session

Plexus structure imaging with thin slab magnetic resonance neurography

D. T. Raphael, D. McIntee, Univ. of Southern California; J. S. Tsuruda, The Neurography Institute; P. Colletti, Univ. of Southern California Medical Ctr.; J. F. Frazier, GORILLAgent

Magnetic resonance neurography (MRN), through the use of STIR and FSEIR sequences, can be used to highlight nerves in relation to neighboring structures. With 2-D MRN slices obtained with a 1.5 Tesla GE scanner, and using commercial imaging software, we explored a variety of segmentation approaches by to effect a three-dimensional visualization of a complex branching structure, such as the brachial plexus. These reconstructions consisted of colorized fly-throughs using saggital slices, dynamic true 3-D rotating structures of the upper limb with its associated neurovascular structures, and thin slab 3-D volume-rendered images that allow visualization of the entire brachial plexus within a single composite image. These visualizations can assist in evaluating brachial plexus injuries and aberrant anatomy, and have guidance value for intended surgical and regional anesthetic procedures.

6143-73, Poster Session

Integrated modeling of PET and DTI information based on conformal brain mapping

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Recent advances in imaging technologies, such as Magnetic Resonance Imaging (MRI), Positron Emission Tomography (PET) and Diffusion Tensor Imaging (DTI) have accelerated brain research in many aspects. In order to better understand the synergy of the many processes involved in normal brain function, integrated modeling and analysis of MRI, PET, and DTI is highly desirable.

Unfortunately, the current state-of-art computational tools fall short in offering a comprehensive computational framework that is accurate and mathematically rigorous. In this paper we present a framework which is based on conformal parameterization of a brain from high resolution structural MRI data to a canonical spherical domain. This model allows natural integration of information from coregistered PET as well as DTI data and lays the foundation for a quantitative analysis of the relationship between diverse data sets. Consequently, the system can be designed to provide a software environment able to facilitate statistical detection of abnormal functional brain patterns in patients with a large number of neurological disorders.

6143-74, Poster Session

Uterine fibroid segmentation and volume measurement in MRI

J. Yao, D. Chen, National Institutes of Health; W. Lu, Towson Univ.; A. Premkumar, National Institutes of Health

Uterine leiomyomata, also called fibroids, are the most common pelvic tumors in females. In this paper, we present a method to robustly segment the fibroids from MRI and accurately measure the 3D volumes to characterize their growth rate. Our method is based on a combination of fast marching level set and Laplacian level set. With a seed point placed inside the fibroid region, a fast marching level set is first employed to obtain a rough segmentation, followed by a Laplacian level set to refine the segmentation. We devised a scheme to automatically determine the parameters for the level set function and the Sigmoid function based on pixel statistics around the seed point. The segmentation is conducted on three concurrent views (axial, coronal and sagittal), and a combined volume measurement is computed to reduce the effect of artifacts in any single view. We carried out extensive tests on 13 patients, 25 MRI studies

and 133 fibroids. The segmentation result was validated with manual segmentation defined by experts. The average segmentation sensitivity (true positive fraction) among all fibroids was 92.3%, and the average segmentation specificity (1-false positive fraction) was 93.1%.

6143-75, Poster Session

Measurement of pelvic osteolytic lesions in follow-up studies after total hip arthroplasty

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Previous studies have demonstrated the plausibility of using volumetric computerized tomography to provide an accurate representation and measurement of volume for pelvic osteolytic lesions following total hip joint replacement. These studies have been performed manually (or computed-assisted) by expert radiologists with the disadvantage of poor reproducibility of the experiment. The purpose of this work is to minimize the effect of user interaction in these experiments by introducing Laplacian level set methods in the volume segmentation process and using temporal articulated registration in order to follow the evolution of a lesion over time. Laplacian level set methods reduce the inter and intra-observer variability by attaching the segmented contour to edges defined in the image while keeping smoothness. The registration process allows the information of the lesion from a previous visit to be used in the segmentation process of the follow-up studies. Preliminary results have shown that the proposed technique is able to track osteolytic lesions. This work will compare the automated results on 9 volunteers versus the volume measured manually. The comparison will include the estimation of the limits of agreement as well as the computation of correlation coefficients. The intra-reader and inter-observer metrics will also be provided.

6143-76, Poster Session

An intensity standardization-based method for inhomogeneity correction in MRI

Y. Zhuge, J. K. Udupa, J. Liu, P. K. Saha, Univ. of Pennsylvania

An automatic, simple, and image intensity standardization-based strategy for correcting background inhomogeneity in MR images is presented in this paper. Image intensities are first transformed to a standard intensity gray scale, standardized for a given imaging protocol, wherein the intensity intervals for different tissue regions can be roughly determined and fixed once for all. Different tissue sample regions are then obtained by simply thresholding based on these intensity intervals. For each tissue region, a polynomial is fitted to the intensity variation. Finally, a combined polynomial is estimated for correcting the intensity inhomogeneity in the whole image. The above procedure is repeated for the corrected image iteratively until the size of the extracted tissue regions do not change significantly from that in the previous iteration. Intensity scale standardization is effected to make sure that the corrected image is not biased by the fitting strategy. The method has been tested on a number of simulated and clinical MR images. These tests and a comparison with the method of non-parametric non-uniform intensity normalization (N3) indicate that the method is effective for background intensity inhomogeneity correction and seems to perform better than the N3 method.

6143-77, Poster Session

Optimized motion estimation for MRE data with reduced motion encodes

H. Wang, Dartmouth College; J. B. Weaver, Dartmouth Hitchcock Medical Ctr.; M. M. Doyley, Dartmouth College; Q. Feng, Medical Metrx Solutions; F. E. Kennedy, K. D. Paulsen, Dartmouth College

Motion estimation is an essential preliminary step in the elasticity reconstruction common to all MR Elastography (MRE) methods. The motion is obtained from a sinusoidal fit of the image phase at multiple, uniformly spaced relative phase offsets, φ, between the motion and the motion encoding gradients (MEGs). Generally, 4 to 8 uniformly spaced values of φ are used. We introduce a method of reducing the number of relative phases required, thereby reducing the imaging time. A frequency-domain algorithm was implemented using the Discrete Fourier Transform (DFT) to derive the general least-squares solution for the motion amplitude and phase given an arbitrary number of phase offsets φ with arbitrary values. Simulation result shows that the noise level decreases as the number of φ increases. The decrease is significant for small number of $\varphi\chi$ used and becomes negligible as the number increases. The noises were found minimum at the optimal phase intervals, where for specific n number of φ used, the phase is evenly distributed with interval μ/n. Phantom and patient study also show the similar trend in the noise level as obtained in simulations. Moreover, the noise level was compared with maximum motion amplitude which can be unwrapped safely for different phase interval. The optimal intervals that have smaller noise level and larger amplitude were found for different number of phase offsets used.

6143-78, Poster Session

Statistical parametric mapping for in-vivo MRI assessment of morphological changes in rat articular cartilage

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Cartilage volume measured with MRI has been proposed to assess drug efficacy in chemically induced Osteoarthritis (OA) in rats. However, the full extent of the cartilage surface and its spatial morphological variation cannot be accurately determined in MR images of rat knee because of mediocre image contrast and thin cartilage structure relative to the image resolution. Consequently, cartilage volume estimates are subject to large variability, limiting their statistical power and sensitivity in detecting changes. This paper explores the use of statistical parametric mapping, which has been widely used in brain imaging applications, in the analysis of morphological changes in rat articular cartilage during OA. This approach can not only quantify but also localize changes, effectively zooming in statistically more informative areas and therefore maximizing the sensitivity. The analysis of in-vivo MR images of rat articular cartilage demonstrates that the new approach is at least as sensitive as the cartilage volume analysis.

6143-79, Poster Session

3D shape description of the bicipital groove of the proximal humerus

A. D. Ward, Simon Fraser Univ. (Canada); M. E. Schweitzer, New York Univ.; G. Hamarneh, Simon Fraser Univ. (Canada)

Bicipital root and proximal tendon disorders are an important symptom generator in the shoulder. The accuracy for the diagnosis of many shoulder disorders by imaging is limited, motivating a clinical need for some ancillary method to access the proximal biceps. Because of the known inter-relationship of the bicipital groove (BG) with several types of disorders, we are motivated to develop an approach to the 3D shape description of the BG that captures information relevant to disorders of the shoulder (e.g. width, depth, angles of walls, presence of spurs). Medial representations are an attractive choice because they capture intuitive aspects of shape such as thickness, bending, and elongation. In this paper, we propose a method to overcome the well-known problem of boundary sensitivity in the medial representation as it is applied to representation and analysis of BG shape. We give preliminary quantitative results indicating that this representation does capture shape variation within our experimental data, providing motivation to explore more sophisticated statistical analysis based on this representation in future work. We also provide a method for semi-automatic segmentation of the BG from computed tomography (CT) scans of the shoulder; an important precursor step to BG shape analysis.

6143-80, Poster Session

Motion analysis of knee joint using dynamic volume images

H. Haneishi, T. Kouno, M. Suzuki, H. Moriya, Chiba Univ. (Japan); S. Mori, National Institute of Radiological Science (Japan); M. Endo, Chiba Univ. (Japan)

Acquisition and analysis of three-dimensional movement of knee joint is desired in orthopedic surgery. We have developed two methods to obtain dynamic volume images of knee joint. One is a 2D/3D registration method combining a bi-plane dynamic X-ray fluoroscopy and a static three-dimensional CT, the other is a method using so-called 4D-CT that uses a cone-beam and a wide 2D detector. In this paper, we show two analyses of knee joint movement obtained by these methods: (1) transition of the nearest points between femur and tibia (2) principal component analysis (PCA) of six parameters representing the three dimensional movement of knee.

As a preprocessing for the analysis, at first the femur and tibia regions are extracted from volume data at each time frame and then the registration of the tibia between different frames by rotation and translation are performed. This registration is applied to not only tibia but also femur. Using those image data, movement of femur relative to tibia can be analyzed. Six movement parameters of femur consisting of three translation parameters and three rotation parameters are obtained from those images.

In the analysis (1), axis of each bone is first found and then the flexion angle of the knee joint is calculated. For each flexion angle, the minimum distance between femur and tibia and the location giving the minimum distance are found in both lateral condyle and medial condyle. As a result, it was observed that the movement of lateral condyle is larger than medial condyle. In the analysis (2), it was found that the movement of the knee can be represented by the first three principal components with precision of 99.58% and those three components seem to strongly relate to three major movements of femur in the knee bend known in orthopedic surgery.

6143-81, Poster Session

Multi-angle deformation analysis of Hoffa's fat pad

K. Stevenson, Simon Fraser Univ. (Canada); M. E. Schweitzer, New York Univ. School of Medicine; G. Hamarneh, Simon Fraser Univ. (Canada)

Recent advances in medical research hypothesize that certain body fat, in addition to having a classical role of energy storage, may also have mechanical function. In particular, we analyzed the infrapatellar fat pad of Hoffa using 3D CT images of the knee at multiple angles to determine how the fat pad changes shape as the knee bends and whether the fat pad provides cushioning in the knee joint. The images were initially processed using a median filter then segmented using a region growing technique to isolate the fat pad from the rest of the knee. Next, rigid registration was performed to align the series of images to match the reference image. Finally, multi-resolution FEM registration was completed between the aligned images. The resulting displacements fields were used to determine the local volume change of the fat pad as the knee bends from extension to flexion through different angles.

This multi-angle analysis provides a finer description of the intermediate deformations compared to earlier work, where only a pair of images (full extension and flexion) was analyzed.

6143-82, Poster Session

Real-time deformations of organ based on structural mechanics for surgical simulators

T. Nakaguchi, M. Tagaya, N. Tamura, N. Tsumura, Y. Miyake, Chiba Univ. (Japan)

This research proposes the deformation model of organs for the development of the medical training system using Virtual Reality (VR) technology. First, the proposed model calculates the strains of coordinate axis. Secondly, the deformation is calculated by mapping the coordinate of the object to the strained coordinate. We assume the beams in the coordinate space to calculate the strain of the coordinate axis. The forces acting on the object are converted to the forces applied to the beams. The bend and the twist of the beams are calculated based on the theory of structural mechanics. The bend is derived by the finite element method. We propose two deformation methods which differs in the position of the beams in the coordinate space. One method locates the beams along the three orthogonal axes(x, y, z). The other method locates the beam in the area where the deformation is large. In addition, the strain of the coordinate axis is attenuated in proportion to the distance from the point of action to consider the attenuation of the stress which is a viscoelastic feature of the organs. The proposed model needs less computational cost compared to the conventional deformation method since our model does not need to divide the object into the elasticity element. The proposed model was implemented in the laparoscopic surgery training system, and a real-time deformation was confirmed.

6143-83, Poster Session

Image based haemodynamic modelling of cerebral aneurysms and the determination of the risk of rupture

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The risk of developing a cerebral aneurysm at some time during an individual's lifetime is estimated to be about 2%, with approximately half of those aneurysms resulting in subarachnoid haemorrhage (SAH). Literature reports that SAH, due to a ruptured aneurysm in the brain, is a serious clinical event with high mortality and morbidity rates. Two methods exist for treating aneurysms; surgical clipping and filling the aneurysmal sac with a platinum coil using micro-catheter techniques. However, like all surgical procedures, complications do occur. Therefore if the risk of rupture is very low, it is often preferable to leave the aneurysm untreated. Currently there is no method of quantifying the risk of rupture. Many factors have been suggested as possible predictors of rupture potential, e.g. genetic factors, lifestyle, aneurysm geometry and location, hemodynamics and blood flow parameters. This research project focuses on the haemodynamic modeling based on the angiographic images from diagnostic X-ray procedures. We have set up experiments with flow phantoms (collection of elastic latex tubes with added artificial aneurysms) guided by clinical material (i.e. the geometry of aneurysms and the surrounding vasculature). For this purpose a set of three-dimensional rotational angiography data has been investigated. We will report on the pressure and forces on the aneurysm in the models, the identification of patient data with respect to the model and the risk of rupture or the long term risk of reopening of the coiled aneurysm (impaction of the coil mesh due the bloodhammer effect).

6143-84, Poster Session

Towards a patient-specific modeling: biomechanics of a growing aneurysm

S. Baek, Texas A&M Univ.; C. A. Figueroa, C. A. Taylor, Stanford Univ.; J. D. Humphrey, Texas A&M Univ.

Recent advances in medical imaging, computational methods, and biomechanics have improved engineering-based decision making in clinical practice. To realize the full potential of patient-specific modeling, how-

ever, we must better synthesize these separate advances, particularly in computational biofluid mechanics and arterial wall mechanics. In this paper, we propose a new mathematical model of growing intracranial fusiform aneurysms that is well suited to test multiple competing hypotheses with regard to the basic means by which these lesions enlarge and rupture - the production, removal, and remodeling of intramural collagen. In order to apply this model to realistic cases, we must also enable computations of fluid-solid interactions. Hence, we also developed a method to transfer information on the highly nonlinear, anisotropic, and evolving material behaviors of the lesion into linearized stress-strain relations, which are well suited for inclusion in biofluid computations without compromising the description of wall mechanics of growing aneurysms. In combination with a companion presentation, we will illustrate the utility of this approach by examining the enlargement of multiple model lesions.

6143-85, Poster Session

Computational fluid dynamics of abdominal aortic aneurysms with patient-specific inflow boundary conditions

U. Kose, Philips Medical Systems (Netherlands); S. de Putter, Technische Univ. Eindhoven (Netherlands); R. Hoogeveen, M. M. Breeuwer, Philips Medical Systems (Netherlands)

In recent years, simulations of the vascular system with patient-specific boundary conditions by using computational fluid dynamics (CFD) and computational solid mechanics (CSM) have become important. A common goal of such simulations is to help predict the development of vascular diseases over time. However, the validity of the simulations and therefore the validity of the predictors are often questioned by physicians. The aim of the research reported in this paper is to validate CFD simulations performed on patient-specific models of abdominal aorta aneurysms (AAAs) using patient-specific blood velocity inflow profiles. Patient-specific AAA geometries can be derived from images originating from Computed Tomography (CT) or Magnetic Resonance (MR) imaging. Patient-specific flow profiles can be measured with Phase-Contrast MR imaging (Quantitative flow, Qflow). In our study, such a profile determined at the inflow site of the AAA was used as inflow boundary condition for the CFD simulation. Qflow images, that were taken on a number of planes along the AAA, were used for the validation of the simulation results. To compare the measured with the simulated flow we have generated synthetic Qflow images from the simulated velocities on cut-planes positioned and oriented according to the planes of the validation images. The comparison of the real with the simulated flow profiles was performed visually and by comparing flow values on cross sections of the AAA in the measured and the synthetic Qflow images. In a preliminary study on two patients we found a reasonable agreement between the measured and the simulated flow profiles.

6143-86, Poster Session

Local influence of calcifications on the wall mechanics of abdominal aortic aneurysm

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Finite element wall stress simulations on patient-specific models of abdominal aortic aneurysm (AAA) may provide a better rupture risk predictor than the currently used maximum transverse diameter. Calcifications in the wall of AAA lead to a higher maximum wall stress and thus may lead to an elevated rupture risk. The reported material properties for calcifications and the material properties actually used for simulations show great variation. Previous studies have focussed on simplified modelling of the calcification shapes within a realistic aneurysm shape. In this study we use an accurate representation of the calcification geometry and a simplified model for the AAA. The objective of this approach is to investigate the influence of the calcification geometry, the material properties and the modelling approach for the computed peak wall stress. For four realistic calcification shapes from standard clinical CT images of AAA, we performed simulations with three distinct modelling approaches, at five distinct elasticity settings. The results show how peak wall stress is sensitive to the material properties of the calcifications. For relatively elastic calcifications, the results from the different modelling approaches agree. Also, for relatively elastic calcifications the computed wall stress in the tissue surrounding the calcifications shows to be insensitive to the exact calcification geometry. For stiffer calcifications the different modelling approaches and the different geometries lead to significantly different results. We conclude that an important challenge for future research is accurately estimating the material properties and the rupture potential of the AAA wall including calcifications.

6143-87, Poster Session

A possible relationship between cerebral aneurysm hemodynamics and recannalization after endovascular coiling

J. R. Cebral, S. Appanaboyina, M. A. Castro, George Mason Univ.; C. M. Putman, Inova Fairfax Hospital

The purpose of this work was to study the possible relationship between hemodynamic patterns in cerebral aneurysms and recannalization after endovascular treatment with coils. A series of patients with cerebral aneurysms were imaged with 3D rotational angiography prior, immediately after coiling and at a follow up exam approximately a year after treatment. Patient-specific vascular computational fluid dynamics models of the aneurysm hemodynamics were constructed from the pre-treatment images. Although our sample was too small to achieve any statistical significance, an interesting trend was observed. Coils recompated in aneurysms that had large inflow jets, while they did not recompact in those with small inflow jets. Our preliminary results indicate that hemodynamic conditions may play an important role in the process of recannalization after endovascular treatment of cerebral aneurysms with coils. Further studies are needed to confirm these trends and to better understand the interplay between hemodynamics and the outcome of endovascular procedures.

6143-88, Poster Session

Evaluation of an asymmetric stent patch design for a patient specific intracranial aneurysm using computational fluid dynamic (CFD) calculations in the computed tomography (CT) derived lumen

M. Kim, C. Ionita, R. Venkatesan, K. R. Hoffmann, D. B. Taulbee, H. Meng, S. Rudin, SUNY/Univ. at Buffalo

Stenting may provide a new, less invasive therapeutic option for cerebral aneurysms. However, a conventional porous stent may be insufficient in modifying the blood flow for clinical aneurysms. We designed an asymmetric stent consisting of a low porosity patch welded onto a porous stent for an anterior cerebral artery aneurysm of a specific patient geometry to block the strong inflow jet. To evaluate the effect of the patch on aneurysmal flow dynamics, we “virtually” implanted it into the patient’s aneurysm geometry and performed Computational Fluid Dynamics (CFD) analysis. The patch was computationally deformed to fit into the vessel lumen segmented from the patient CT reconstructions. After the flow calculations, a patch with the same design was fabricated using laser cutting techniques and welded onto a commercial porous stent, creating a patient-specific asymmetric stent. This stent was implanted into a phantom, which was imaged with X-ray angiography. The hemodynamics of untreated and stented aneurysms were compared both computationally and experimentally. It was found from CFD of the patient aneurysm that the asymmetric stent effectively blocked the strong inflow jet into the aneurysm and eliminated the flow impingement on the aneurysm wall at the

dome. The impact zone with elevated wall shear stress was eliminated, the aneurysmal flow activity was substantially reduced, and the stasis was considerably increased. Experimental observations corresponded well qualitatively with the CFD results. The demonstrated asymmetric stent could lead to a new minimally invasive image guided intervention to reduce aneurysm growth and rupture.

6143-89, Poster Session

Vessel cross-section determination based on nonrigid registration and electric field model

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Diameters (or areas) of vessel cross-sections provide useful information for diagnosis and surgery planning. However, the ordinary centerline-perpendicular cross-sections are often inappropriate to use because the centerline may include unwanted local curvatures in irregular or asymmetric regions and high curvatures in sharply bended regions. In this paper, we try to improve the accuracy of vessel cross-section measurement by properly adjusting the centerline. To alleviate local curvatures in the centerline while preserving the global shape faithfully, we register a deformable cylindrical model onto the vessel lumen, and subsequently adopt the axis of the registered model as the adjusted centerline for determining cross-sections. In addition, by introducing the electric field model, we prevent undesirable intersection of cross-sections that is often found in sharply bended regions. Experiments are performed using various synthesized images that simulate abnormal vessels with stenoses or aneurysms. The results show that the registration process successfully eliminates unwanted local curvatures while preserving the global shape of the vessel, and obtained cross-sections do not intersect each other even in the region of high curvature.

6143-90, Poster Session

Digital densitometric determination of clinical relative coronary flow distributions

G. A. ten Brinke, C. H. Slump, Univ. Twente (Netherlands); C. J. Storm, Ziekenhuis Walcheren (Netherlands)

In clinical cardiology the measure of stenosis in a coronary artery is in standard practice still based on visual assessment leading to large inter and intra observer variability in reading coronary arteriograms. Image analysis and computer assistance do result in a more consistent judgment, however, this approach is mainly based upon static geometric parameters such as percentage of diameter and area reduction of a single segment of the stenosed artery. A more functional, physiological measure is to be preferred. This can be done by measuring the difference between rest and hyperaemic phase caused by exercise or more often by pharmacological intervention, resulting in coronary flow increase. This so-called Coronary Flow Reserve (CFR) technique yields a functional image in which the pixel values are proportional to difference in blood flow in a part of the heart muscle. However, in clinical practice this method is difficult and time consuming. This paper reports about a less demanding approach in which the relative flow distribution between e.g. the two main branches of the left coronary artery (i.e. Left Circumflex Artery (LCA) and Left Anterior Descending (LAD)) is determined densitometrically from acquired digital angiograms under basal and hyperaemic conditions. The proposition is that if the relative flow distribution in hyperaemic state is different from that during rest, the functional severity of a stenosis downstream of the bifurcation is indicated. This new approach is exemplified in five clinical cases where we have applied image processing techniques to segment the coronary tree and have tracked the motion of the pertinent coronary arteries. The flow ratios are obtained from integration of properly chosen Regions Of Interest (ROIs) at fixed relative positions over the tracked artery.

6143-91, Poster Session

Blood flow measurement by cone-beam tomography and stereology

Z. Chen, R. Ning, D. Conover, Univ. of Rochester

Blood flow behavior in vascular vessels can be described by flow volume and velocity distributed over vessel segments. This paper presents a new technique for blood flow measurement by cone-beam computed tomography and stereology. It consists of flow volume measurement by reconstructing vessel volume by cone-beam tomography, and flow velocity measurement by tracking the bolus passageway by two-view stereo reconstruction. The bolus flow in vessels in a vascular region of interest can be described by three phases: wash-in, equilibrium, and wash-out. The cone-beam scan during bolus flowing through the vessels produces a dataset of frames. The equilibrium frames are used for bolus volume reconstruction, and from the bolus volume the vessel centerlines are extracted by 3D skeletonization. The wash-in frames are used for tracking 3D bolus passageway by stereo reconstruction. The bolus passageway is matched with the vessel centerline and thereby to calculate flow velocity. The flow volume is readily available by using the vessel volume. In practice, the 3D bolus passage construction suffers from image noise and numerical instability, mainly due to bolus moving and non-simultaneous snapshots. We propose a nudge algorithm to deal with excursions of the 3D bolus passageway against the vessel centerline. In the result, we can measure the blood flow volume and velocity simultaneously by off-line computations over the angiographic cone-beam dataset (volume reconstruction and stereo point reconstruction). Adopting the half-scan cone-beam tomography, the blood flow measurement will minimize both bolus dose and radiation dose.

6143-92, Poster Session

Gender-specific statistical model of pathological coronary arteries for generating simulated angiograms

I. S. Kyprianou, L. Thompson, W. F. Pritchard, J. Karanian, K. J. Myers, U.S. Food and Drug Administration

Cardiovascular disease is considered the leading cause of death in the US, accounting for 38% of all deaths. There are gender differences in the size of coronary arteries and in the character and location of atherosclerotic lesions that affect the detection of coronary artery disease with the medical imaging modalities currently used (e.g. angiography, computed tomography). These differences also affect the safety and effectiveness of image-guided interventions using therapeutic devices. For the optimization of the medical imaging modalities used for this specific task we require the generation of clinically-realistic, gender-specific images of healthy and pathological coronary angiograms. For this purpose we have created a gender-specific statistical model of a pathological coronary artery tree. Starting from “healthy” heart-phantoms created from high resolution CT scans of cadaver hearts of both genders, the model uses information obtained from clinical studies of patients with significant (>50% stenosis) coronary artery disease (CAD) and randomly generates new images with a given measure of CAD severity using Monte-Carlo projection. The severity is determined from a set of rules that combines the geometrically increasing severity of lesions, the cumulative effects of multiple obstructions, the significance of their locations, the modifying influence of the collaterals, and the size and quality of the distal vessels. Using this information, angiograms can be simulated to contain plaque positioned using the Bernoulli random trees method, and random percent stenosis at each location. The simulated angiograms will consequently be read by model or human observers. The AUC derived in combination with the severity score will be used as a figure of merit for the imaging modality under investigation.

6143-93, Poster Session

Subtraction computed tomographic angiography: use of pre-contrast images for calcification removal

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Arterial stenoses may be obscured by calcified atherosclerotic plaque in computed tomographic angiography (CTA). A technique of subtraction computed tomographic angiography (sCTA) for calcification removal is proposed and evaluated in a preliminary manner. In the proposed sCTA method, the examination includes a pre-contrast computed tomogram (pcCT) and a CTA. The pcCT is performed using the CTA scan protocol. Subtraction of the registered pcCT from the CTA is performed after calcifications in the pcCT are registered to the CTA using a piecewise-rigid transformation model. The cost-function of the registration is defined to be the sum of the negative voxel intensities after subtraction of the registered pcCT from the CTA. This cost-function is maximized to obtain the desired registration. sCTA was evaluated using a calcified-artery phantom whose dimensions approximate those of the superficial femoral artery. The phantom represented both calcified plaque surrounding a normal lumen and surrounding a segment with 70% stenosis. pcCT and CTA's were obtained on a 4-multidetector-row CT system with 1.25-mm slice thickness and 0.7-mm in-plane resolution. The phantom was slightly displaced between the pcCT and the CTA. sCTA closely resembled a gold-standard image of the phantom that was obtained with the calcification material removed. The sCTA accurately demonstrated the degree of stenosis and artifacts in the sCTA were minimal. This study demonstrates in a preliminary manner that sCTA is feasible.

6143-95, Poster Session

On the assumption of cubic graphs of vascular networks

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A vascular network is often represented by a Reeb graph, which is a topological skeleton, and graph theory has been widely applied to analyze properties of a vascular network. Vascular networks develop by way of two biological mechanisms of vessel sprouting (budding) and splitting (intussusception). According to a graph theory modeling of two vascular network growth mechanisms, all nodes in the Reeb graph must be cubic in degree except for two special nodes: the afferent (A) and efferent (E) nodes. We define that a vascular network is cubic if all internal nodes are cubic in degree. We consider six normal adult rat renal glomerular networks and use their reeb graphs already constructed. We observe that five of them contain internal vertices of degree higher than three. Branch points in vascular networks may appear to be of a higher degree if the imaging resolution cannot differentiate between blood vessels that are very close in proximity. Essentially, the higher the resolution (for example, the more narrow the microtome spacing of the histological serial sections) the more likely the differentiation of the network in vertices of degree three. Here, we propose a random graph theory model that edits a non-cubic vascular network into a cubic graph. We observe that the edited cubic graph from a non-cubic vascular network has the similar size and order as the one cubic vascular network.

6143-96, Poster Session

Myocardial physiology measurements using contrast enhanced dynamic computed tomography: simulation of beam hardening effect

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Initial animal study for quantifying myocardial physiology through contrast-enhanced dynamic x-ray CT suggested that beam hardening is one of the limiting factors for accurate regional physiology measurement. In this study, a series of simulations were performed to investigate its deterioration effects and two correction algorithms were adapted to evaluate for their efficiency in improving the measurements.

The simulation tool consists of a module simulating data acquisition of a real polyenergetic scanner system and a heart phantom consisting of simple geometric objects representing ventricles and myocardium. Each phantom component was modeled with time-varying attenuation coefficients determined by ideal iodine contrast dynamic curves obtained from experimental data or simulation. A compartment model was used to generate the ideal myocardium contrast curve using physiological parameters consistent with measured values. Projection data of the phantom were simulated and reconstructed to produce a sequence of simulated CT images. Simulated contrast dynamic curves were fitted to the compartmental model and the resultant physiological parameters were compared with ideal values to estimate the errors induced by beam hardening artifacts.

The simulations yielded similar deterioration patterns of contrast dynamic curves as observed in the initial study. Significant underestimation of left ventricle curves and corruption of regional myocardium curves result in systematic errors of regional perfusion up to approximately 24% and overestimates of fractional blood volume (fiv) up to 13%. The correction algorithms lead to significant improvement with errors of perfusion reduced to 7% and errors of fiv within 2% which shows promise for more robust myocardial physiology measurement.

6143-97, Poster Session

A method for myocardial contraction force reconstruction for tissue viability assessment

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Myocardial infarction results in myocardial necrosis, usually caused by an imbalance in the oxygen supply and demand. To our knowledge there is no technique that can provide quantitative direct information concerning the intensity, extent and location of the infarction. Contraction forces generated by cardiac tissues represent a quantitative and direct measure of the myocardium functionality, since it is expected that infarcted tissue generate little or no contraction force. Our objective is to develop a biomechanics based reconstruction technique to image myocardial contraction forces, for the purpose of assessing the viability of cardiac tissues. This technique is designed to reconstruct the contraction forces by inverting myocardial tissue displacement data acquired throughout heart beat cycles using conventional imaging techniques. Recognizing that myocardial contraction forces distribution is 3D, we assumed an axisymmetric myocardial geometry and force distribution to demonstrate the concept. With this assumption, the inversion algorithm was developed and implemented in 2D space. As a preliminary analysis, a simulation involving a thin myocardial slice was carried out. The tissue was modeled as a homogeneous material with isotropic and linear elastic material properties. Assuming an axisymmetric contraction force distribution, a finite element analysis was performed on the tissue slice, and a 2D displacement field was generated. The developed inversion algorithm was then employed to reconstruct the force distribution, which was ultimately compared to the original force field. The reconstruction error, estimated as the difference between the difference between the two force fields normalized by the magnitude of the reference distribution, averaged to ±10%.

6143-98, Poster Session

Artifact reduction in HARP strain maps using anisotropic smoothing

K. Z. Abd-Elmoniem, V. Parthasarathy, J. L. Prince, Johns Hopkins Univ.

Harmonic phase (HARP) MRI is used to measure myocardial motion and strain from tagged MR images. HARP MRI uses limited number of samples from the spectrum of the tagged images to reconstruct motion and strain. The HARP strain maps, however, suffer from artifacts that limit the accuracy of the computations and degrade the appearance of the strain maps. Causes of these so called 'zebra' artifacts include image noise, Gibbs ringing, and interference from other Fourier spectral peaks. Computing derivatives of the HARP phase, which are needed to estimate strain, further accentuates these artifacts. Previous methods to reduce these artifacts include 1-D and 2-D nonlinear filtering of the HARP derivatives, and a 2-D linear filtering of unwrapped HARP phase. A common drawback among these methods is the lack of proper segmentation of the myocardium from the blood pool. The lack of segmentation allows noisy phase values from the blood pool to be incorporated in the smoothed strain maps, which produces artifacts. In this work, we propose a smoothing method based on anisotropic diffusion that filters the HARP derivatives strictly within the myocardium without the need for prior segmentation. The information about tissue geometry and the strain distribution is used to restrict the smoothing to within the myocardium, thereby ensuring minimum distortion of the final strain map. Preliminary results demonstrate the ability of anisotropic diffusion for better artifact reduction and lesser strain distortion than existing methods.

6143-99, Poster Session

Accurate recovery of 4D left ventricular deformations using volumetric B-splines incorporating phase based displacement estimates

J. Chen, N. J. Tustison, A. A. Amini, Washington Univ. in St. Louis

In this paper, an improved framework for estimation of 3-D left-ventricular deformations from tagged MRI is presented. Contiguous short- and long-axis tagged MR images are collected and are used within a 4-D B-Spline based deformable model framework to determine 4-D displacements and strains. This framework uses tagged short-axis (SA) and long-axis (LA) image sequences as input, fits a 4-D B-spline based model to the left ventricle of the heart by incorporating information from phase-based estimates of 2-D displacements from a number of short- and long-axis image slices over many frames, epicardial and endocardial contours, and triplets of reconstructed tag planes from short-axis and long-axis views, and volumetrically tracks the left ventricular deformations.

From the model, we can extract accurate 3-D myocardial deformation fields and corresponding strain maps which are local measures of non-rigid deformation. Lagrangian strains in simulated data are derived which show improvement over both phase-based estimates of strains as well as our prior work. The method is also applied to 3-D tagged MRI data collected in a canine and human.

6143-100, Poster Session

Variability of measuring airway morphometry in the lungs depicted in chest CT examinations

J. K. Leader, B. Zheng, F. C. Scuirba, Univ. of Pittsburgh; H. O. Coxson, The Univ. of British Columbia (Canada); J. L. Weissfeld, C. R. Fuhrman, G. S. Maitz, Univ. of Pittsburgh; D. Gur, Univ.of Pittsburgh

The purpose of the study is to improve the accuracy, increase reproducibility (consistency) and decrease the variability of measuring airway morphometry in the lungs depicted on chest CT examinations at the level of the lobar and segmental bronchi. Chronic obstructive pulmonary disease has been associated with changes in airway morphometry in certain types of patients. A computer scheme was developed that begins with manual selection of a seed point within the airway from which the airway wall and lumen are automatically segmented. An identified airway pixel may be assigned partial membership to the lumen or wall. Airway pixels not assigned full membership to the lumen (< -900 HU) or wall (> 0 HU) were assigned partial membership to the lumen and wall. In fifteen subjects with a range of pulmonary obstruction from none to severe and no visible signs of emphysema, airway measures were compared to pulmonary function parameters in a rank order analysis to evaluate measuring multiple airways versus a single airway. The quality of the automated airway segmentation was visually acceptable. The Intraclass Correlation Coefficients for ranking of FEV1 versus wall area percent (total airway percent) and FVC versus wall area percent were 0.164 and 0.175 for a single measurement, respectively, and were 0.361 and 0.371 for multiple measurements, respectively. We conclude that measuring multiple airways improves quantifying airway morphometry compared to the measure of a single airway.

6143-101, Poster Session

CT acquisition technique and quantitative analysis of the lung parenchyma: variability and corrections

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The fraction of lung voxels below a pixel value "cut-off" has been correlated with pathologic estimates of emphysema. We performed a "standard" quantitative analysis of the CT images (QCT) using a -950 HU cut-off to determine the volume fraction of emphysema (below the cut-off) and a "corrected" QCT analysis after removing group pixels ("blobs") below the cut-off and connected to other pixels in groups less than or equal to 5 and 10 pixels. The CT examinations used were from 15 subjects with a range of visible emphysema and pulmonary obstruction, acquired at "low-dose," and reconstructed using the high spatial frequency "lung" kernel at 2.5 mm section thickness. The "blob" size (i.e., connected-pixels) removed was inversely related to the computed fraction of emphysema. The slopes of emphysema fraction versus blob size were 0.0126, 0.0094, and 0.0045 for subjects with no emphysema and no pulmonary obstruction, moderate emphysema and moderate pulmonary obstruction, and severe emphysema and severe pulmonary obstruction, respectively. The small blobs of pixels removed by the correction are most likely CT image artifacts and do not represent actual emphysema. The magnitude of the blob correction was appropriately associated with COPD severity. Preliminary work indicates that the blob correction is applicable to QCT analysis in conventional CT exams (low noise). Quantitative analysis of COPD using noisy CT exams should be performed using a lower threshold (e.g., 950HU) and removing small blobs of connected pixels.

6143-102, Poster Session

Algorithm of pulmonary emphysema extraction using low dose thoracic 3D CT images

S. Saita, M. Kubo, Y. Kawata, N. Niki, The Univ. of Tokushima (Japan); Y. Nakano, Shiga Univ. of Medical Science (Japan); H. Omatsu, National Cancer Ctr. Hospital East (Japan); K. Tominaga, Tochigi Public Health Service Association (Japan); K. Eguchi, Tokai Univ. (Japan); N. Moriyama, National Cancer Ctr. Hospital East (Japan)

We describe a quantitative algorithm for extracting emphysematous lesions and quantitatively evaluate their distribution patterns using low dose thoracic 3-D CT images. The algorithm identified lung anatomies, and extracted low attenuation area (LAA) as emphysematous lesion candidates. Applying the algorithm to 100 thoracic 3-D CT images and ten

follow-up 3-D CT images, we demonstrate its potential effectiveness to assist radiologists and physicians to quantitatively evaluate the emphysematous lesions distribution and their evolution in time interval changes.

6143-103, Poster Session

A volumetric pulmonary CT segmentation method with applications in emphysema assessment

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A segmentation method is a mandatory pre-processing step in many automated or semi-automated analysis tasks such as region identification and densitometric analysis, or even for 3D visualization purposes. In this work we present a fully automated volumetric pulmonary segmentation algorithm based on intensity discrimination and morphologic procedures. Our method first identifies the trachea and primary bronchi, then the pulmonary region is identified by applying a threshold and morphologic operations. When both lungs are in contact, additional procedures are performed achieving two separated lung volumes. To evaluate the performance, we compared contours extracted from 3D lung surfaces with reference contours, using several figures of merit. Results show that the worst case generally occurs at the middle sections of high resolution CT exams, due the presence of aerial and vascular structures. Nevertheless, the average error is lower than the average error associated with radiologist inter-observer variability, which suggests that our method produces lung contours similar to those drawn by radiologists.

The information created by our segmentation algorithm is used by an identification and representation method in pulmonary emphysema that also classifies emphysema according to its severity degree. Two clinically proved thresholds are applied which identify regions with severe emphysema, and with highly severe emphysema. Based on this thresholding strategy, an application for volumetric emphysema assessment was built offering new display paradigms concerning the visualization of classification results. This framework is easily extendable to accommodate other classifiers namely those related with texture based segmentation as it is often the case with interstitial diseases.

6143-104, Poster Session

Unsupervised extraction and quantification of the bronchial tree on ultra-low-dose vs. standard-dose CT

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Automatic extraction of the tracheobronchial tree from high resolution CT data serves visual inspection by virtual endoscopy as well as computer aided measurement of clinical parameters along the airways. The purpose of this work is to show the feasibility of automatic extraction (segmentation) of the airway tree also in ultra-low-dose CT data (5-10 mAs), and to compare the performance of the airway extraction between ultra-low-dose and standard-dose (70-100 mAs) CT data. A direct performance comparison (instead of a mere simulation) was possible since for each patient both an ultra-low-dose and a standard-dose CT scan were acquired within the same examination session. The data sets were recorded with a multi-slice CT scanner at the Charité university hospital Berlin with 1 mm slice thickness.

An automated tree extraction algorithm was applied to both the ultra-low-dose and the standard-dose CT data. No dose-specific parameter-tuning or image pre-processing was used.

Our algorithm automatically identifies a seed point in the trachea and then grows successively into the airway segments of increasing generations, while avoiding leakage into the lung parenchyma by cutting off of erroneous branches.

For performance comparison, the total length of all visually verified centerlines of each tree was accumulated for all airways beyond the tracheal carina. Correlation of the extracted total airway length for ultra-low-dose versus standard-dose for each patient showed that on average in the ultra-low-dose images 84% of the length of the standard-dose images was retrieved. We also obsevered a good correlation between computer aided airway lumen measurements in ultra-low-dose and standard-dose CT data.

6143-105, Poster Session

Automated anatomical labeling algorithm of bronchial branches based on multislice CT images

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Multi-slice CT technology was developed, so, we can get clear contrast images and thin slice images. But doctors need to diagnosis many image, thus their load increases. Therefore, development of the algorithm that analyzes lung internal-organs is expected. When doctors diagnose lung internal-organs, they understand it. So, detailed analyze of lung internal-organs is applicant to early detection of a nodule. Especially, analyzing bronchus provides that useful information of detection of airway disease and classification of the pulmonary vein and artery. In this paper, we describe a method for automated anatomical labeling algorithm of bronchial branches based on Multi-Slice CT images.

6143-106, Poster Session

Feature amount calculation for pulmonary vein and artery classification algorithm

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Recently, multi-slice helical CT technology was developed. Unlike the conventional helical CT, we can obtain CT images with a clear contrast images and thin slice images in one time of scanning. The purpose of this prestudy is to evaluate the proposed automatic extraction of bronchus and pulmonary vein and artery on multi-slice CT images. The bronchus is extracted by application with region growing technique and the morphological filters, 3D distance transformation. These results indicate that the proposed algorithm provides the accurate ability to develop an automatic extraction algorithm of the bronchus on multi-slice CT images. In this report, we used pulmonary vein and artery marked by the doctor. It aims to discover an amount of the feature necessary for classifying the pulmonary vein and artery by using the anatomical feature.

6143-107, Poster Session

Quantification and visualization of relative local ventilation on dynamic chest radiographs

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Recently-developed dynamic flat-panel detector (FPD) with a large field of view is possible to obtain breathing chest radiographs, which provide respiratory kinetics information. This study was performed to investigate the ability of dynamic chest radiography to quantify relative ventilation in

local lung area, and to address the possibility of clinical use of our method based on respiratory physiology. Dynamic chest radiographs of 12 subjects involving abnormal subjects during respiration were obtained using a modified FPD system (30 frames in 10 seconds). Imaging was performed in three different positions (standing, and right and left decubitus positions) to change the distribution of local ventilation by changing the lung's own gravity in each area. The distance from the lung apex to the diaphragm (abbr. DLD) was measured by the edge detection technique for use as an index of respiratory phase. We measured pixel values in each lung area and calculated correlation coefficients with DLD. Differences in the pixel values between each frame and the maximum inspiratory or expiratory frame were calculated and the trend of distribution was evaluated by Friedman-test. Pixel value in each lung area was strongly associated with respiratory phase ($r>0.95$) and its time variation and distribution were consistent with known properties in respiratory physiology. Dynamic chest radiography using FPD combined with our computerized methods was capable of quantifying relative amount of ventilation during respiration, and of detecting closing volume and regional differences in ventilation. This method is expected to be a useful novel diagnostic imaging method for supporting diagnosis and follow-up of chronic obstructive pulmonary disease (COPD), which presents with abnormalities in local ventilation.

6143-108, Poster Session

High resolution multidetector CT aided tissue analysis and quantification of lung fibrosis

V. A. Zavaletta, R. A. Karwoski, B. Bartholmai, R. A. Robb, Mayo Clinic

Idiopathic pulmonary fibrosis (IPF, also known as idiopathic Usual Interstitial Pneumontis, pathologically) is a progressive diffuse lung disease which has a median survival rate of less than four years with a prevalence of 15-20/100,000 in the U.S. Global function changes are measured by pulmonary function tests and localized structural changes are analyzed by acquiring two-dimensional high resolution CT (HRCT) images. The analysis of volumetric high resolution Multi-Detector CT (MDCT) images offers the potential to measure both lung function and structure. This paper presents a new approach to three dimensional tissue analysis of normal and abnormal structures in lungs with IPF.

6143-109, Poster Session

Optimization of CT image reconstruction algorithms for the lung tissue research consortium (LTRC)

C. H. McCollough, J. Zhang, M. R. Bruesewitz, B. J. Bartholmai, Mayo Clinic

To create a repository of clinical data, CT images and tissue samples and to more clearly understand the pathogenetic features of pulmonary fibrosis and emphysema, the NHLBI launched a cooperative effort known as the Lung Tissue Resource Consortium (LTRC). The CT images for the LTRC effort must contain accurate CT numbers in order to characterize tissues, and must have high-spatial resolution to show fine anatomic structures. Quantitative analyses of phantom and clinical images were conducted to optimize the CT image reconstruction algorithms to achieve these criteria. The ACR CT accreditation phantom containing five materials (air, fat, water, marginally enhanced tissue, and dense bone) was scanned using both GE and Siemens CT systems. Phantom images were reconstructed using all relevant construction algorithms. Mean CT numbers and image noise were measured and compared for the five materials. Clinical images from a GE system were constructed using Bone and Standard algorithms and evaluated by a radiologist in terms of image quality. The clinical Bone images were processed with a low pass filter to simulate the standard algorithm. Using a threshold technique, the volumes of emphysema were computed for the Standard, Bone, and low-pass filtered Bone images. Bone (GE) and B46f (Siemens) showed higher spatial compared to Standard (GE) or B30 (Siemens) reconstruction algorithms. CT number were accurate for all data sets, however, only the sharper images were deemed clinically acceptable. Quantitative analyses showed a single sharp reconstruction (Bone/B46f) can be used to provide both accurate CT numbers and high spatial resolution.

6143-110, Poster Session

Multislice CT perfusion imaging of the lung in detection of pulmonary embolism

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In this paper, we propose a new subtraction technique for accurately imaging lung perfusion and efficiently detecting pulmonary embolism in chest MDCT angiography. Our method is composed of five stages. First, optimal segmentation technique is performed for extracting same volume of the lungs, major airways and vascular structures from pre- and post-contrast images with different lung density. Second, initial registration based on apex, hilar point and center of inertia (COI) of each unilateral lung is proposed to correct the gross translational mismatch. Third, initial alignment is refined by iterative surface registration. For fast and robust convergence of the distance measure to the optimal value, a 3D distance map is generated by the narrow-band distance propagation. Fourth, 3D nonlinear filter is applied to the lung parenchyma to compensate for residual spiral artifacts and artifacts caused by heart motion. Fifth, enhanced vessels are visualized by subtracting registered pre-contrast images from post-contrast images. To facilitate visualization of paranchymal enhancement, color-coded mapping and image fusion is used. Our method has been successfully applied to ten patients of pre- and post-contrast images in chest MDCT angiography. Experimental results show that the performance of our method is very promising compared with conventional methods with the aspects of its visual inspection, accuracy and processing time.

6143-111, Poster Session

Measuring blood delivery to solitary pulmonary nodule by perfusion magnetic resonance imaging

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In perfusion magnetic resonance imaging (pMRI), perfusion describes the amount of blood passing through a block of tissue in a certain period of time. In pMRI, tissue having more blood passing through will show higher intensity of gray value as more contrast-labeled blood arrives. It reflects the delivery of essential nutrients to the tissue, and is an important parameter for tissue status. Considering solitary pulmonary nodule (SPN), perfusion differences in malignant and benign nodules have been studied by different techniques. Much effort has been put into its characterization. In this study, we propose and implement the method of extracting SPN time intensity profile to measure blood delivery, which helps us to find the perfusion differences between malignant and benign nodules. In our method, we create SPN time intensity profile based on the intensity values of solitary pulmonary nodule in lung pMRI images over time. This method has two components: nodule tracking and profile clustering. Nodule tracking aligns solitary pulmonary nodule in the images taken at different time points, dealing with nodule movement resulted from breathing and body movement. Profile clustering implements segmentation of nodule region and extract the time intensity profile of solitary pulmonary nodule. SPN time intensity profile reflects the pattern of blood delivery to solitary pulmonary nodule, giving us a description of blood arrival and an indirect evidence of tumor angiogenesis.

6143-112, Poster Session

Growth-rate estimation of pulmonary nodules in three-dimensional thoracic CT images based on CT density histogram analysis and its application to nodule classification

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Abstract: In recent years, high resolution CT has been developed. CAD system as support is indispensable for pulmonary cancer screening. In research and development of computer-aided differential diagnosis, there is now widespread interest in the use of nodule doubling time for measuring the volumetric changes of pulmonary nodule. The evolution pattern of each nodule might depend on the CT density distribution pattern inside nodule such as pure GGO, mixed GGO, or solid nodules. This paper presents a computerized approach to measure nodule density variation inside small pulmonary nodule using CT images. The approach consists of four steps: (1) nodule segmentation, (2) computation of CT density histogram, (3) nodule categorization (α, β, γ, δ, and ε) based on CT density histogram, (4) computation of doubling time based on CT density histogram, and (5) classification between benign and malignant cases. Using our dataset of follow-up scans of 54 for whom the final diagnosis was known (27 benign and 27 malignant cases), we evaluated evaluation patterns of nodules on the basis of the predominant five nodule categorizations and designed the classification strategy between benign and malignant cases. In order to compare the performance between the proposed features and volumetric doubling time, the classification result was analyzed by an area under the receiver operating characteristic curve. The Az values of our proposed feature and the volumetric doubling time were 0.90 and 0.83, respectively. The preliminary experimental result demonstrated that our approach has a highly potential usefulness to assess the nodule evolution using 3-D thoracic CT images.

6143-113, Poster Session

Classifying pulmonary nodules using dynamic enhanced multislice CT images

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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 (α, β, γ, δ, and ε) on the basis of internal features extracted from CT number histograms inside nodules. We applied dynamic enhanced multi slice CT images to this classification algorithm and we analyzed it in each type.

6143-114, Poster Session

The effect of edge-preserving image smoothing on automatic colonic polyp detection for CT colonography

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The purpose of this work is to study whether image denoising with edge-preserving smoothing filters improves the performance of virtual colonoscopy (VC) computer-aided polyp detection. Three smoothing algorithms from the ITK Toolkit, GradientAnisotropicDiffusion (GrAD), CurvatureAnisotropicDiffusion (CurvAD), and Curvature Flow (CF), were applied to 162 VC CT scans using an array of parameter values above and below ITK recommendations. The cases were then processed with our CAD system using a clustering filter (Filter A) with restrictive criteria optimized for unsmoothed cases and another filter (Filter B) with less restrictive criteria producing more detections. Classifiers were trained for each smoothing algorithm setting using a support vector machine, and the results were analyzed using free-response operating characteristic (FROC) curves. The best FROC curves for each smoothing algorithm were bootstrapped to determine operating point variances and were compared with the unsmoothed cases at clinically significant conditions of 4 FP per patient and polyps ≥10mm using a one-tailed t test. The sensitivities using Filter A were: 84.8±8.6% for the unsmoothed cases, 81.1±5.7% with GrAD, 81.2±5.7% with CurvAD, and 82.8±5.9% with CF. Using Filter B, the sensitivities were: 83.2±4.9%, for the unsmoothed cases, 84.6±5.5% with GrAD, 89.1±5.3% with CurvAD, and 80.1±5.7% with CF. No statistically significant improvement ($p>0.05$) was observed. Although image smoothing improved the sensitivity of CAD by up to 5.9%, the differences were not statistically significant. At this sample size, we did not find evidence that image smoothing benefits CAD under the clinically relevant conditions of large polyps and low false positive rates.

6143-115, Poster Session

Wavelet analysis in virtual colonoscopy

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The computed tomographic colonography (CTC) computer aided detection (CAD) program is a new method in development to detect colon polyps in virtual colonoscopy. While high sensitivity is consistently achieved, additional features are desired to increase specificity. In this paper, a wavelet analysis was applied to CTCCAD outputs in an attempt to filter out false positive detections.

54 CTCCAD detection images were obtained using a screen capture application. 27 of these images were real polyps, confirmed by optical colonoscopy and 27 were false positive detections. A discrete wavelet transform of each image was computed with the MATLAB wavelet toolbox using the Haar wavelet at levels 1-3 in the horizontal, vertical and diagonal directions. From the resulting wavelet coefficients, a 72 feature vector was obtained for each image, consisting of descriptive statistics such as mean, variance, skew, and kurtosis at each level and orientation, as well as error statistics based on a linear predictor of neighboring wavelet coefficients. The vectors for each of the 54 images were then run through a support vector machine (SVM) classifier using leave-one-out training to determine its efficiency in distinguishing polyps from false positives.

The SVM results showed 100% sensitivity and 27% specificity in correctly identifying the status of a detection. If this technique were added to the filtering process of the CTCCAD polyp detection scheme, the number of false positive results could be reduced significantly.

6143-116, Poster Session

Determining patient 6-degrees-of-freedom motion from stereo infrared cameras during supine medical imaging

R. D. Beach, B. Feng, M. A. King, Univ. of Massachusetts Medical School

Patient motion during SPECT acquisition causes inconsistent projection data and reconstruction artifacts which can significantly affect the diagnostic accuracy of SPECT. The tracking of motion by infrared monitoring spherical reflectors (markers) on the patient's surface can provide 6-Degrees-of-Freedom (6-DOF) motion information capable of providing clinically robust correction. Object rigid-body motion can be described by 3 translational DOF and 3 rotational DOF. Polaris marker position information obtained by stereo infrared cameras requires algorithmic processing to correctly record the tracked markers, and to calibrate and map Polaris co-ordinate data into the SPECT co-ordinate system. Marker data then requires processing to determine the rotational and translational 6-DOF motion to ultimately be used for SPECT image corrections. This processing utilizes an algorithm involving least-squares fitting, to each other, of two 3-D point sets using singular value decomposition (SVD) resulting in the rotation matrix and translation of the rigid body centroid. We have demonstrated the ability to monitor 7 markers on 2 elastic belts worn by a volunteer while intentionally moving, and the determination of the 3 axis Euclidian rotation angles and centroid translation. An anthropomorphic phantom with Tc-99m added to the heart, liver, and body was simultaneously SPECT imaged and motion tracked using 4 rigidly mounted markers. The determined rotation matrix and translation information was used to correct the image resulting in virtually identical "no motion" and "corrected" images. We plan to initiate routine 6-DOF tracking of patient motion during SPECT imaging in the future.

6143-117, Poster Session

A new method for the quantitative analysis of gated SPECT polar scintigraphic maps

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Aim: We have developed a software, which allows to do non conventional percent quantitative analysis on scintigraphic polar map obtained from conventional processing of gated-SPECT acquisitions. Polar maps are 8 bit images of perfusion, motion, ejection fraction (EF) and thickening, of the heart

Methods: The software is written in Matlab, analyses the whole polar map and four ROIs corresponding to the theoretical LAD, LCX, RCA territories (perfused by these arteries) and extra-ROIs region. An intensity segmentation is performed. The area corresponding to pixels lower and higher than a varying cut-off are calculated on the whole image and for each ROI. The software calculates an intensity-area histogram, which is the analogous of the Dose-Volume Histogram used in radiation therapy: in this case, the histogram has the meaning of a Perfusion- or a Motion-Volume histogram. Then, the software applies the Lyman-Wolbarst algorithm, to calculate the area equivalent histogram reduction (e.g. the perfused area in the hypothesis that all pixels are perfused at 100%.). The makes a direct comparison between two different polar maps by choice. The comparison between the numerical quantification of motion and perfusion maps, allows the physicians to get a clinical evaluation of the stunned myocardium.

Results: We tested the software using test images in order to validate the algorithm of histogram and area equivalent calculations. We also tested the Lyman-Wolbarst algorithm on homogeneous images. The results show that there are no bugs in the calculation code.

We tested the software on clinical images of patients and we found a good agreement between results obtained with conventional analysis performed with commercial available software.

Conclusions: It seems possible to use the differences in the area equivalent parameter computed on perfusion and motion polar maps in order to compute an estimate of the so called "stunning".

6143-118, Poster Session

Comparing two electrical impedance tomography algorithms

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Electrical Impedance Tomography (EIT) seeks to recover the impedance distribution within a body using boundary data. More specifically, given the measured potentials, the model of the body - which corresponds to an elliptic partial differential equation - and the boundary conditions, this technique solves a non-linear inverse problem for the unknown impedance. EIT can be used in several applications, ranging from medical to geophysical, and several types of impedance reconstruction algorithms have been proposed. In this work, assuming a pure conductive medium, the conductivity distribution within a body was reconstructed in a discretized model of the body, by two different iterative algorithms: one based on Newton-Raphson scheme and the other on Topology Optimization Method. While the first method essentially combines a lot of matrix inversions, the second solves several linear programming problems, both following an iterative process for the solution of the EIT problem. The Finite Element Method provides the electric potential field through the numerical solution of the elliptic partial differential equation. Results using numerical and experimental data are shown and the quality of the images obtained and time and memory used are compared for both algorithms. We intend to select the best method which will be applied, in future works, to the visualization of a human lung subject to mechanical ventilation.

6143-119, Poster Session

Skin surface removal on breast microwave imagery

D. Flores-Tapia, G. Thomas, Univ. of Manitoba (Canada); S. Pistorius, CancerCare Manitoba (Canada)

In many parts of the world, breast cancer is the leading cause of morbidity and mortality among women and it is the major cause of cancer death, next only to lung cancer. In recent years, microwave imaging has shown its potential as an alternative approach for breast cancer detection. Although advances have improved the likelihood of developing an early detection system based on this technology, there are still limitations. One of these limitations is that target responses close to the surface are often obscured by surface reflections. Contrary to ground penetrating radar applications, a simple reference subtraction cannot be easily applied to alleviate this problem due to differences in the breast skin composition between patients. This paper proposes a novel surface removal technique for the attenuation of these high intensity reflections. The algorithm uses the Wavelet Transform to detect the singularities of the signals and is capable of performing signal decomposition at several scales. This property is used to obtain the product between the scales in order to preserve the singularities of the signal that correspond to target responses and eliminate the surface. The proposed algorithm showed a 20 dB decrease in the surface reflections and did not modify the responses from the interior of the phantom.

6143-120, Poster Session

Optimal segmentation of the optic nerve head from stereo retinal images

M. B. Merickel, Jr., X. Wu, M. Sonka, M. D. Abramoff, The Univ. of Iowa

Early detection of glaucoma is essential to minimizing the risk of visual loss. It has been shown that a good predictor of glaucoma is the cup-to-

disc ratio of the optic nerve head. This paper presents a highly automated method to segment the 'rim' (disc) and 'cup' from the optic nerve head in stereo images and calculate the cup-to-disc ratio. In this approach, the optic nerve head is 'unwrapped' and represented as a graph. Utilizing a novel and efficient graph searching technique for determining globally optimal closed-paths and an intelligent cost function, the rim and the cup are segmented from the stereo images. The results offer a more intuitive quantitative analysis compared to current planimetry-based technique because the ophthalmologist can view the segmented images along with the derived cup-to-disc ratio.

6143-121, Poster Session

Diagnosis of burn depth in skin using polarization sensitive optical coherence tomography

S. R. Sharma, R. Poddar, K. Bose, Birla Institute of Technology (India); P. Sen, Shri G.S. Institute of Technology & Science (India); J. T. Andrews, Birla Institute of Technology (India)

The mechanism behind an OCT system is based on low coherence interferometry, which resolves the surface microstructure of a biological system. The specificity of standard OCT can be improved by studying polarization properties of probing radiation when it propagates through a biological object. A form of OCT, polarization-sensitive (PS-OCT), has been developed for obtaining information about birefringence in addition to the intensity mapping of the backscattering. PS-OCT provides an important imaging modality to evaluate tissue birefringence, for example, which is associated with collagen organization, the fiber orientation, the density of collagen bundles, and the refractive - index mismatch between collagen fiber bundles contribute to the tissue birefringence. PS-OCT is a novel technique which uses the principle of change in birefringence and hence polarisation of the particular tissue for imaging purposes [1]. We are particularly concerned with the imaging of burnt tissue with the help of this technique. The thermal burns caused by flame or acids etc., affect the collagen birefringence properties, which in turn depends on the change in the orientation of the fibres in the collagen. PS-OCT can measure spatially resolved changes in polarized light backscattered from human skin up to a depth of 1-2 mm with 10-30μm resolution. Thermal denaturation between 56-650°C reduces birefringence by changing the collagen from a rod-like to random coil structure. Therefore, changes in collagen birefringence due to thermal denaturation can be used for burn depth determination in human skin [2]. Burns are classified into three degrees. First degree burns which affects the epidermis only, second degree burns affects the epidermis as well as some part of dermis and third degree burns affects the epidermis and whole of dermis. Third degree burns are dangerous leading to death of the patient. The only cure is grafting. But Second degree burns are more dangerous because it is difficult to analyse if grafting is needed at that stage or the wound will heal on its own. If there is any discrepancy in decision making it may lead to infection by {\it Pseudomonas aerugenosa\/} and thus death of the patient. Hereby, we will be concerned with the second degree burns only.

Our main aim of the study is to see the effects of heat with different temperatures and time periods on the birefringence of the skin and to investigate the correlation between thermal damage and collagen birefringence reduction using in-vitro tissue samples. For our experiment we use chunk of meat as a model. We induced burns on the meat chunk in the oven at different temperatures (58°C - 90°C) and for about 5 -15s. We expect that with increasing temperature and heating time the degree of polarisation.

The preliminary results with the PS-OCT suggest a more accurate estimation of burn depth in human skin.The detailed experimental results and numerical estimation based on Monte - Carlo simulation will be presented.

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6143-122, Poster Session

Validation of a fiber-based confocal microscope for interventional image-guided procedures: correlation with multispectral optical imaging

D. Herzka, Philips Research USA; J. Quijano, National Institutes of Health; J. Xie, National Institutes of Health; C. Burnett, National Institutes of Health; B. Abrat, A. Osdoit, Mauna Kea Technologies (France); S. N. Danthi, K. Li, National Institutes of Health

The concept of the biopsy is ubiquitous in current medical diagnosis of cancer and other diseases. The basic biopsy consists of removing a sample of tissue for evaluation and diagnosis, primarily to ascertain the presence of cancer cells, followed by (histo)pathogical analyses. However, the advent of new optical imaging modalities and targeted or "smart" agents that have affinity for a select ligand suggests the possibility of performing in vivo tissue characterization without the need for sample removal or the wait for histopathologic processing. Here we present work testing and validating a fiber-based confocal fluorescence microscopy system intended for combination with a larger scale imaging modality (i.e. MRI or CT) to be used in image-guided in vivo tissue characterization. A fiber-based confocal fluorescence microscope (Cell~vizio, Mauna Kea Technologies, Paris, France) was tested in mice bearing human melanoma tumors (M21) known to express $\alpha V\beta 3$, a widely known integrin protein marker for angiogenesis. A previously characterized targeted agent coupled to a fluorescent marker (FITC) was injected systemically. Contrast agent localization was verified by a multispectral imager (Maestro, CRI Inc, Woburn MA). The fiber-based tool was sensitive enough to detect the targeted FITC-coupled agent, and was found appropriate for use in interventional catheter-based procedures.

6143-123, Poster Session

Computation of brain neurodegeneration in the Alzheimer's fly

Y. Ching, P. Lee, National Chiao Tung Univ. (Taiwan); Y. R. Huang, A. Chiang, National Tsing Hua Univ. (Taiwan)

Expression of human Aβ42 peptide in the Drosophila brain induces pathological phenotypes resembling Alzheimer's disease (PNAS 101, 6623-6628). Three-dimensional confocal imaging reveals extensive vacuoles caused by neurodegeneration in the brain of aged but not young Aβ42 flies. Here, we report a three-dimensional computation algorism allowing automatic measurement of numbers and volumes of brain vacuoles. The method employed matched filters, α-shape, and the active-contour techniques. Using this method, a good result depicting the contours of the vacuoles can be obtained. A more accurate algorithm is still under development. Accurate evaluation of brain pathology in Alzheimer's flies may facilitate the understanding of molecular mechanisms underlying Aβ toxicity and the discovery of novel therapeutic targets for Alzheimer's disease.

6143-124, Poster Session

Validating renal physiology in murine model of polycystic kidney disease using functional x-ray CT against FITC-inulin and creatinine clearance

G. Krishnamurthi, K. M. Stantz, Purdue Univ.; V. H. Gattone, Indiana Univ.; M. Cao, Purdue Univ.; G. D. Hutchins, Y. Liang, Indiana Univ.

Aim: The goal of the study was to determine renal physiology in the pcy mouse model of the polycystic kidney disease (PKD) using functional X-ray computed tomography (fCT) and to validate the glomerular filtration rate (GFR) values against FITC-inulin (FITC-I) clearance and endogenous creatinine clearance.

Background: The pcy mouse model is orthologous to human adolescent Nephronophthisis a form of PKD marked by formation of cysts and leads

to end stage renal failure (ESRF). The progress to ESRF is marked by decline in renal physiologic parameters like GFR, perfusion and vascular volumes. Earlier studies have shown that fCT can reproducibly quantify mouse renal physiology in-vivo. We investigate the ability of fCT to monitor renal physiology in the pcy model. We also aim to correlate fCT-derived parameters against inulin clearance and endogenous creatinine clearance.

Methods: Three groups of mice, normal, early stage pcy (6-15 weeks) and late stage pcy (>30 weeks) mice were used for the study. The Siemens Bio-graph PET-CT scanner was used for performing fCT. A 6-parameter two compartmental model was formulated to model contrast kinematics in the kidney. Renal clearance was measured using FITC-I and endogenous creatinine.

Results: Functional X-ray CT shows significant decline in renal GFR in late stage pcy as compared to normal and early stage pcy. Both fCT and FITC-inulin clearance studies did not show significant difference in renal GFR between normal and early stage pcy. Inulin clearance and creatinine clearance studies are ongoing to validate GFR in late stage pcy mice.

6143-126, Poster Session

Reproducibility of 3D micro-CT gray-scale and dimensional data

S. M. Jorgensen, D. R. Eaker, A. J. Vercnocke, E. L. Ritman, Mayo Clinic

With the rapidly increasing use of micro-CT imaging it is important for establishing the accuracy and reproducibility of the spatial and density resolution. Repeated synchrotron-based micro-CT scanning of a number of iliac crest biopsies enabled us to quantitate the variation in CT image gray-scale and spatial geometry due to factors such as specimen orientation and projection magnification during the different scans as well as inherent heterogeneity of bone mineralization within any one biopsy. We rescanned several iliac crest bone biopsy specimens, and a test phantom made of calcium hydroxyapatite, at repeated scanning sessions and evaluated the reproducibility of the spatial and gray-scale characteristics of the specimens. We used the micro-CT scanner on Beam Line X2B at the Brookhaven National laboratory's National Synchrotron Light Source. This scanner consists of a Bragg diffraction source of monochromatic x-rays, a computer controlled high precision specimen rotation and translation stage, and a fluorescent crystal and CCD array system for imaging the specimen at each of the angles of view around its axis of rotation during the scanning sequence. The images were up to $1300x1024^2$ cubic voxels, each 16-bit gray-scale. We scanned four specimens three or more times each, one synthetic hydroxyapatite based cancellous bone phantom and an hydroxyapatite concentration calibration test phantom three times each.

The contrast and spatial reproducibility must be known for design of experiments aimed at determining the differences in mineralization and micro-architecture between biopsies of control and diseased bone.

6143-127, Poster Session

Finite element model-based deformable registration of microPET and high-resolution MR images for photodynamic therapy in mice

B. Fei, Univ. Hospitals of Cleveland and Case Western Reserve Univ.; H. Wang, R. F. Muzic, C. A. Flask, N. L. Oleinick, D. L. Wilson, J. L. Duerk, Case Western Reserve Univ.

We are investigating imaging techniques to study the tumor response to photodynamic therapy (PDT). Positron emission tomography (PET) can provide physiological and functional information. Magnetic resonance imaging (MRI) can provide anatomical and morphological changes. We are developing image registration methods to combine MRI and PET for improved tumor monitoring. We implanted RIF-1 tumors in C3H mice and treated them with Pc 4-based PDT. We acquired high-resolution MRI and microPET 18F-fluorodeoxyglucose (FDG) images from the mice after treatment. We developed two registration methods for this application. For registration of the whole mouse body, we used a rigid-body mutual information registration algorithm. For tumor registration, we developed a finite element model (FEM)-based deformable volume matching (DVM) method. To assess the quality of whole body registration, we performed slice-by-slice review of both image volumes; manually segmented feature organs, such as the left and right kidneys and the bladder, in each slice; and computed the distance between corresponding centroids. Over 40 volume registration experiments were performed with MRI and microPET images. For the whole body registration, the distance between corresponding centroids of organs was 1.5 ± 0.4 mm which is about 2 pixels of microPET images. For tumor registration, the volume overlap rates were 97% and 89% for the deformable and rigid registration methods, respectively. The mean consistence error is less than 0.1-mm for the deformable volume matching. Registration of high-resolution MRI and microPET images combines anatomical and functional information of the tumors and provides a useful tool for photodynamic therapy.

6143-39, Session 8

Real-time CT-video registration for continuous endoscopic guidance

S. A. Merritt, L. Rai, W. E. Higgins, The Pennsylvania State Univ.

CT-image-based guidance during bronchoscopy can improve the performance and decrease the skill variation of physicians. Previously, this could be done only using single-frame registration or buffered video-registration methods, which require the physician to wait several seconds for each registration result. We have devised a fast 2D/3D image registration method that is 100 times faster than previous methods, and performs single-frame CT-Video registration in under 1/15th of a second, allowing the system to be used in real-time at full frame-rates without significantly altering the physician's behavior.

The method achieves its speed through a two-phase gradient-based optimization method. In the offline phase, where the vast bulk of the processing is done, endoluminal renderings and gradients are computed at a set of reference sites within the segmented airway tree generated from the MDCT data. In the live phase, which proceeds at real-time during the procedure, each incoming video frame is warped and registered via a 6 degree-of-freedom Gauss-Newton optimization to the MDCT volume using only the previously processed views and the video frames themselves. The significant savings in computation time over previous methods stems from exploiting the redundant structure of the problem. This allows us to generate all necessary renderings and gradient computation in the offline phase, thus allowing us to avoid any rendering whatsoever during the live procedure.

Results were generated using both simulated bronchoscopic video data and pre-recorded video from live procedures and show that the method is accurate, robust, operates at over 15 frames per second, and therefore can be used to assist in continuous guidance of live bronchoscopic procedures.

6143-40, Session 8

Branch identification method for CT-guided bronchoscopy based on eigenspace image matching between real and virtual bronchoscopic images

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This paper presents a method for identifying branches for CT-guided bronchoscopy based on eigenspace image matching. This method outputs the current location of a real bronchoscope by displaying branches where a bronchoscope is currently observing or by presenting anatomical names of branches currently being observed. In the previous method for bronchoscope navigation, motion of a real bronchoscope (RB) is tracked by image registration between RB and virtual bronchoscopic (VB) images. Although bronchoscope tracking based on image registration gives us

very accurate tracking results, it requires a lot of computation time and it is difficult to perform real time tracking. If we focus only on navigation to a target branch, it is enough to identify a branch where a bronchoscope is currently located. This paper presents a method for identifying branches in which a bronchoscope is currently observing and presenting its anatomical name Branch identification is done by pattern matching between real bronchoscopic images and pre-generated VB images. VB images are pre-generated at each branching point based on structural analysis results of bronchi regions extracted from CT images. For each frame of a real bronchoscopic video, we find the most similar VB image to the input one from a learning dataset (pre-genrated VB image) and output the branch levels associate with the found image by using the eigenspace method. We have applied the proposed method to a pair of 3D CT images and real bronchoscopic video. The experimental results showed that the proposed method can identify branches for about 83% of input frames.

6143-41, Session 8

Synchronous navigation for CT colonography

A. Huang, R. M. Summers, D. Roy, National Institutes of Health

We present a synchronous navigation module to facilitate CT colonography (CTC) reading. The need for such a system arises because most CTC protocols require a patient to be scanned in both supine and prone positions to increase sensitivity in detecting colonic polyps. However, existing clinical practices are limited to reading one scan at a time. Such limitation is due to the fact that building a reference system between scans for the highly flexible colon is a nontrivial task. The conventional centerline approach, generating only the longitudinal distance along the colon, falls short in providing the necessary orientation information to synchronize the virtual navigation cameras in both scanned positions. In this paper we describe a synchronous navigation system by using the teniae coli as anatomical references. Teniae coli are three parallel bands of longitudinal smooth muscle on the surface of the colon. They are morphologically distinguishable and form a piecewise triple helix structure from the appendix to the sigmoid colon. Because of these characteristics, they are ideal references to synchronize virtual cameras in both scanned positions. Our new navigation system consists of two side-by-side virtual colonoscopic view panels (for the supine and prone data sets respectively) and one single camera control unit (which controls both the supine and prone virtual cameras). The capability to examine the same colonic region simultaneously in both scanned images can raise an observer's confidence in polyp identification and potentially improve the performance of CT colonography.

6143-42, Session 8

Virtual cardioscopy: interactive endocardial visualization to enhance accuracy of RF cardiac ablation

D. R. Holmes III, M. E. Rettman, B. M. Cameron, J. J. Camp, R. A. Robb, Mayo Clinic

Cardiac arrhythmias are a debilitating, potentially life threatening condition involving aberrant electrical activity in the heart which results in abnormal heart rhythm. Virtual cardioscopy can play an important role in the minimally invasive treatment of cardiac arrhythmias. Second and third generation image-guidance systems are now available for the treatment of arrhythmias using RF ablation catheters. While these 3D tools provide useful information to the clinician, additional enhancements to the virtual cardioscopy display paradigm are critical for optimal therapy guidance. Based on input from our clinical collaborators, several key visualization techniques have been developed to enhance the use of virtual cardioscopy during cardiac ablation procedures. We have identified, designed and incorporated several visual cues important to successful virtual cardioscopy. These features include the use of global reference maps, parametric mapping, and targeted identification of abnormal electro-physiologic activity. Our virtual cardioscopy system is designed for real-time use during RF cardiac ablation treatments. Several unique visualizations from our virtual cardioscopy system will be presented. Evaluation of the system with phantom and animal studies will be presented.

6143-43, Session 8

Fast and accurate tract unfolding based on stable volumetric image deformation

T. Truong, T. Kitasaka, K. Mori, Y. Suenaga, Nagoya Univ. (Japan)

This paper presents an improved method for virtually unfolding an organ and visualizing its entire luminal surface in only one view. Unfolded views of tracts can be very useful as they allow medical doctors to understand various kinds of information of the luminal surface intuitively, just as observing a pathological specimen. However, the previous method cannot correctly reproduce the luminal surface, as elasticity for organ walls is quite coarse-defined. Three improvements are proposed: (1) accurate elastic modeling using mass-points and Kelvin-Voigt visco-elastic elements, (2) stable image deformation by the Newmark-beta method, and (3) automatically directing organ walls to flat shapes by forces determined from their surface normals. Unfolded views generated from eighteen 3D CT image datasets are compared with those by the previous method based on virtual endoscopy (VE) images and pathological specimens. Several regions on the luminal surface, which could not be reproduced by the previous method, were accurately reproduced. Bending parts and concave parts of organ walls, which were difficult to unfold by the previous method, were satisfactorily flattened by introducing improved deformation processes. Computation time was reasonably reduced. Unfolded views from twelve of the cases were presented to medical doctors for surgical planning. The unfolded views generated by the proposed method were considered to be well reproducing all lesions as well as fold patterns which were observed in VE images.

6143-44, Session 9

Effects of filtering on colorectal polyp detection in ultra-low dose CT

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We have evaluated the feasibility of polyp detection on simulated ultra low dose CT Colonography data by a computer-aided polyp detection (CAD) algorithm. We compared the results of ultra low dose to normal dose data. Twenty extensively prepared patients were scanned in prone and supine position at 25 to 100 mAs (average 70 mAs) depending on their waist circumference. Noise was added and the scans were reconstructed at 6.25 and 1.39 mAs with a validated simulation technique. To evaluate the performance of the CAD system, polyps detected by an experienced reviewer and confirmed by colonoscopy were used as ground truth. Curvature, concavity and sphericity of the colon surface were used to detect polyp candidates. In order to reduce noise, bilateral filtering was used. We present results for 69 polyps of 5 mm or larger as measured during colonoscopy. The by-polyp sensitivity was 90% at a median value of 11 false-positives per scan for normal dose data. The by-polyp sensitivity was 90% at 14 false-positives per scan and 90% at 39 false-positives per scan for the simulated 6.25 and 1.39 mAs data, respectively. We found out that the increase in false-positives is partly due to the segmentation of the colon. The automated colon segmentation algorithm selected parts of the small bowel in the 1.39 mAs data. We expect that the false-positive rate will decrease when the small bowel is not segmented. The conclusion of our study is that CAD for polyp detection is feasible on ultra low dose CT colonography.

6143-45, Session 9

Automatic procedure to distinguish colonic polyps located on fold vs. not on fold

M. Franaszek, R. M. Summers, National Institutes of Health; P. J. Pickhardt, Univ. of Wisconsin/Madison; J. R. Choi, Uniformed Services Univ. of the Health Sciences and Walter Reed Army Medical Ctr.

Performance of computed-tomographic colonography (CTC) computer aided detection (CTC CAD) depends sensitively on a set of features chosen to characterize a polyp candidate. Most of the features are derived from some shape related characteristics which are calculated along or within the boundaries of a polyp candidate. This approach ignores information about the colonic wall in the local neighborhood of a polyp candidate.

We found that many shape related features determined for polyps located on haustral folds are statistically different ($p < 0.0001$) from the same features calculated for polyps which are not on a fold. This suggests that two different classifiers could be used which are better tuned to the local characteristics. Therefore, we developed an automated method to verify if a given polyp candidate is located on a fold. This is done by checking the intensity profile along normals originating from the points on the colonic wall adjacent to the polyp candidates. We tested the method on 62 CT scans containing 77 confirmed polyps. Each polyp was visually inspected to determine its location and compared with the output of the automated procedure. All polyp locations could be grouped into three categories: 1) clearly on a fold; 2) clearly not on a fold; 3) relationship to fold ambiguous (fold edge not clearly defined). The procedure classified correctly 32/33 (96%) polyps in the first and 17/19 (89%) in the second category. In the third category, the procedure reported 7/25 polyps as not on a fold. These results show that automatic determination of polyp position on a fold is feasible. As a consequence, one can use this method to design a CAD system that can use two different classifiers, which are better tuned to the local characteristics of the polyp.

6143-46, Session 9

Performance tuning of candidate determination methods for computer aided detection of colon polyps

I. Bitter, M. D. Kelsey, R. M. Summers, National Institutes of Health

We introduce an intuitive measure of computer aided detection (CAD) system performance that can handle simultaneous variation of multiple parameters. On the example of CAD of colon polyps we demonstrate how this measure was used to find the optimal parameters and make improvements to the "water-plane" algorithm that finds initial polyp candidates on the colon wall. In particular, we improved the merging of overlapping clusters to only create fused clusters if they shared at least 50% of their vertices and adjusted size and thickness filter criteria to retain more true positive detections. The system, containing all optimizations, improved significantly over the original system that found initial detections based only on colon surface curvature. This improvement was measured by both, free response operating curve (FROC) analysis and our new performance measure.

6143-47, Session 9

Quantitative assessment of colon distention for polyp detection in CT virtual colonoscopy

R. Van Uitert, I. Bitter, R. M. Summers, National Institutes of Health; J. R. Choi, Uniformed Services Univ. of the Health Sciences and Walter Reed Army Medical Ctr.; P. J. Pickhardt, Univ. of Wisconsin/Madison

Virtual colonoscopy is becoming a more prevalent way to diagnose colon cancer. One of the critical elements in detecting cancerous polyps using virtual colonoscopy, especially in conjunction with computer-aided detection of polyps, is that the colon be sufficiently distended. We have developed an automatic method to determine from a CT scan what percentage of the colon is distended by 1cm or larger and compared our method with a radiologist's assessment of quality of the scan with respect to successful colon polyp detection. A radiologist grouped 41 CT virtual colonoscopy scans into three groups according to the degree of colonic distention, "well", "medium", and "poor". We also employed a subvoxel accurate centerline algorithm and a subvoxel accurate distance transform to each dataset to measure the colon distention along the centerline. To summarize the colonic distention with a single value relevant for polyp detection, the distention score, we recorded the percentage of centerline positions in which the colon distention was 1cm or larger. We then compared the radiologist's assessment and the computed results. The sorting of all datasets according to the distention score agreed with the radiologist's assessment. The "poor" cases had a mean and standard deviation score of 78.4% ± 5.2%, the "medium" cases measured 88.7% ± 1.9%, and the "well" cases 98.8% ± 1.5%. All categories were shown to be significantly different from each other using unpaired two sample t-tests. The presented colonic distention score is an accurate method for assessing the quality of colonic distention for CT colonography.

6143-48, Session 9

A method for generating virtual unfolded view of colon using spring model

M. Oda, Y. Hayashi, T. Kitasaka, K. Mori, Y. Suenaga, Nagoya Univ. (Japan)

This paper presents a method for generating virtual unfolded (VU) views of the colon by using elastic modeling. The VU views generated here are less distorted and have less cuprous holes. Recently, virtual colonoscopy (VC) has got attention as a new diagnostic method for the colon according to the development of medical imaging devices. VC is considered as it is less-invasive and it can reduce diagnosing time. However, because the colon has many folds and its shape is long and convoluted, a physician has to change viewpoints and viewing directions many times. We have already proposed a new computer aided diagnosis system for the colon providing VU views and virtual endoscopic (VE) views. This system enables physicians to observe large area of the colonic wall on a VU view and it is synchronized to a VE view. If a physician finds suspicious regions on VU views, she or he can check detailed views of them on conventional VE views. In the previous method, we generated VU views by controlling ray directions of volume rendering. However, the previous method causes some spurious holes on VU views due to intersections of rays around sharp curves. In this paper, we present a method that can reduce ray intersections by introducing an elastic model. This method allocates springs between planes that are perpendicular to the medial axis. Then, the normal direction o each plane is updated according to the forces working on the plane. Final VU views are generated by casting rays along the updated planes. We applied this method to four cases of abdominal CT images. The experimental results show that the number of spurious holes on VU views generated by this method is significantly less than those of the previous method.

6143-49, Session 9

Geometric modeling, functional parameter calculation, and visualization of the in-vivo distended rectal wall

C. R. Haider, A. Manduca, R. A. Robb, S. J. Riederer, A. E. Bharucha, Mayo Clinic

The rectum can accommodate to hold stool, and contracts in response to distention, during defecation. Rectal motor dysfunctions are implicated in the pathophysiology of functional defecation disorders and fecal incontinence. These rectal motor functions can be studied by intra-luminal measurements of pressure alone or combined with volume, or by rectal imaging. Pressure-volume (p-v) relationships provide a global index of rectal mechanical properties. However, balloon distention alone does not measure luminal radius nor wall thickness, which are necessary to compute wall tension and stress respectively. It has been suggested that the elastic modulus, which is the linear slope of the stress-strain relationship, is a more accurate measure of wall stiffness. Also, measurements of compliance may not reflect differences in rectal diameter between subjects prior to inflation, and imaging is necessary to determine if, as has been suggested, rectal pressure-volume relationships are affected by extra-rectal structures.

We have developed a novel technique to measure rectal stress:strain relationships in humans, by simultaneous MRI during rectal balloon distention. After a conditioning distention, a rectal balloon was distended with water from 0 to 400 ml in 50 ml steps, and imaged at each step with MRI. After the fluid filled balloon was segmented from each volume, the phase-ordered binary volumes were transformed into a geometric characterization of the inflated rectal surface. Taken together with measurements of balloon pressure and of rectal wall thickness, this model of the rectal surface was used to calculate regional values of curvature, tension, strain and stress for the rectum. In summary, this novel technique has the unique ability to non-invasively measure the rectal strain:stress relationship, and also determine if rectal expansion is limited by extra-rectal structures.

6143-50, Session 10

Imaging system for creating 3D block face images of whole mice

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We have developed a cryomicrotome/imaging system suitable for block-face imaging of whole mice or excised organs at extremely high resolution and applied it to a variety of applications. Briefly, we sectioned cryo-preserved tissues at 2-40 μm thickness and acquired high resolution color and fluorescent block-face images with an in-plane resolution of up to 1.2 μm. Optionally, histology slices were collected for conventional immunohistochemistry staining and enzyme histochemistry staining using a novel tape transfer system. From this 3D episcopic image volume and registered histology microscopy images, multimodal data sets were created. We demonstrated this system by creating an episcopic color image volume of a large section of a cryo-preserved mouse and creating 3D reconstructions of specific organs. For Hoxb7 mice with polycystic kidney disease, we compared episcopic image volumes to MRI. The high resolution color images provided greater contrast and enhanced visualization of cysts as compared to in vivo MRI. We note that color episcopic images are closer to what a researcher sees in dissection, making it easier for them to interpret the image data. The combination of field of view, depth of field, ultra high resolution and contrast in color imaging enables episcopic volumes to provide anatomical details that cannot be found through in-vivo imaging or other ex-vivo optical imaging approaches. We believe that this novel imaging system will have applications ranging from identifying mouse phenotypes, disease characterization like blood vessel disease, kidney disease, assessment of drug and gene therapy efficacy and to use as a routine validation tool.

6143-51, Session 10

Evaluating dynamic contrast-enhanced and photoacoustic CT to assess intra-tumor heterogeneity in wild-type and VEGF enhanced MCF-7 breast tumors

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Purpose: The purpose of this study is to evaluate the intra-tumor physiological and hemoglobin properties by implementing contrast-enhanced dynamic CT (CED-CT) and photoacoustic CT (PCT).

Method and materials: CED-CT and PCT imaging was performed to quantify vascular physiology and hemoglobin distribution in both wild-type and VEGF-enhanced MCF-7 tumors. These tumors were surgically implanted into the fat pads of immune deficient nude mice, and allowed to grow to 12-17 mm. CT was used to image the time-dependence of a radio-opaque contrast agent for each voxel within the tumor and then fit to a two-compartment model to estimate physiological parameters. The intra-tumor distribution of hemoglobin was imaged using PCT scanner by stimulating hemoglobin at its isobestic peak.

Results: The physiological results show three features: (1) significant increase in tumor perfusion for VEGF-enhanced tumors - 0.33 mL/min/mL to 1.6 mL/min/mL; (2) noticeable development of saccular regions throughout the MCF-7/VEGF tumors; and (3) a radial heterogeneity similar to that observed in wild-type tumors. Periphery versus core variations in physiological parameters were measured to range from -30 to -75 percent while VEGF-enhanced tumors showed similar changes in PS and fractional interstitial volumes (-50% and -55%) while perfusion and fractional plasma volumes remained relatively unchanged (14% and 27%). In-vivo PCT acquired images display a similar pattern of intra-tumor heterogeneity of hemoglobin to the fractional plasma volume distribution seen in CT images.

Conclusions: CED-CT and PCT has been shown to image the variation of intra-tumor heterogeneity in wild-type and VEGF-enhanced MCF-7 breast tumor xenografts.

6143-52, Session 10

Understanding the origins of near-infrared optical contrast by combining diffuse optical spectroscopy with contrast-enhanced MRI

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Diffuse Optical Spectroscopy (DOS) is a non-invasive technique that employs harmless levels of non-ionizing near-infrared light to measure absolute concentrations of tissue deoxy-hemoglobin, oxy-hemoglobin, water, and lipids in biological tissues. The separation of absorption from scattering, which was a key limiting factor for diaphanography in the 1980's, is achieved by using broadband frequency-domain photon migration techniques that effectively model light propagation of light in biological tissues. Our DOS technique combines both frequency-domain and broadband steady-state spectroscopies, which allows for complete characterization of tissue optical properties across the entire near-infrared spectral region (600 to 1000 nm). Broadband spectral and temporal techniques enable precise physiological characterization of thick biological tissues.

In pilot clinical studies, DOS has demonstrated sensitivity to tumor angiogenesis, edema, hypoxia, and cellularity. A precise quantitative understanding of the origins of near-infrared contrast in biological tissues is a vital step towards advancing DOS in the clinical setting.

In order to better understand tissue biochemistry reported by DOS, we have performed DOS measurements alongside high-resolution contrast-enhanced (CE) MRI. Quantitative comparisons have been made between the techniques in both tissue and phantom systems, using relatively simple coregistration efforts. We will demonstrate the sensitivity of DOS to important physiological processes in cancer by direct comparisons of DOS

and MRI measurements in the breast tissues of normal, cancerous, and cancer lesions treated with chemotherapy.

6143-53, Session 10

3D in-vivo imaging of GFP-expressing T-cells in mice with non-contact fluorescence molecular tomography

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Optical tomography has been proposed as a promising technique for probing deep in tissue with many medical applications. Recently, the adaptation of fluorescent probes by the radiologists, gave rise to a new imaging tool in the area of molecular imaging. Optical tomography can, provide three-dimensional images of fluorescent concentrations inside living systems of sizes in the order of many cm.

Our optical tomographer was based on a technique which is called Fluorescence Molecular Tomography (FMT) and can quantify fluorescent signals in mice. The imaging procedure is performed in a non-contact geometry so that living subjects of arbitrary shapes can be imaged with no fibers attached to them. We have developed a way to reconstruct the 3D surface of the subject and we use theoretical models to account for the propagation of the emerging signal in the free space. The system consists of a rotating sample holder and a CCD camera in combination with a laser-scanning device. An Argon-ion laser is used as the source and different filters are used for the detection of various fluorophores or fluorescing proteins.

So far, we have observed of the distribution of GFP expressing T-lymphocytes in-vivo for the study of the function of the immune system in a murine model. Then we investigated the performance of the FMT setup to quantify the different amounts of migrated cells in the different organs by comparing our results with the FACS measurements. Further experiments included the measurement of the variations of the T cell's concentration in-vivo, over time.

6143-54, Session 10

Image quantification of high-throughput tissue microarray

J. Wu, Wellcome Trust Sanger Institute (United Kingdom); J. Dong, Ocean Univ. of China (China); H. Zhou, Univ. of Essex (United Kingdom)

Tissue microarray (TMA) technology allows rapid visualization of molecular targets in thousands of tissue specimens at a time and provides valuable information on expression of proteins within tissues at a cellular and sub-cellular level. TMA technology overcomes the bottleneck of traditional tissue analysis and allows it to catch up with the rapid advances in lead discovery. Studies using TMA on immunohistochemistry (IHC) can produce a large amount of images for interpretation within a very short time. Manual interpretation does not allow accurate quantitative analysis of staining to be undertaken. Automatic image capture and analysis has been shown to be superior to manual interpretation. The aims of this work is to develop a truly high-throughput and fully automated image capture and analysis system. We develop a robust colour segmentation algorithm using hue-saturation-intensity (HSI) colour space to provide quantification of signal intensity and partitioning of staining on high-throughput TMA. Segmentation results and quantification data have been achieved on 16,000 TMA colour image over 30 different tissue types.

6143-55, Session 11

Time domain optical molecular imaging of small animals in vivo

D. J. Hall, Univ. of California/San Diego

The advent of optical molecular probes has taken optical imaging beyond approaches limited to intrinsic optical contrast mechanisms. Fluorophores are typically used as the source of contrast for optical molecular probes and the field of optical molecular imaging is concerned with measuring and quantifying their in vivo biodistribution and pharmacokinetics. Most optical molecular imaging systems are based on Continuous Wave (CW) approaches which enable rapid, full-body imaging of small animals and readily yield images of probe location, however quantification of probe concentration is challenging. Time Domain (TD) approaches, although more expensive and complicated than CW, provide more information to assist in determining the probe location and concentration. Moreover, the TD approach permits access to measuring the fluorophore lifetime which can be indicative of the probe's environment. The eXplore Optix(tm) system, developed by ART (Canada) and distributed by GE Healthcare, has enabled TD optical molecular imaging of small animals in vivo and preliminary studies conducted with the system will be presented. In addition, the initial research and development of a full-field TD optical molecular imaging system incorporating a high-power laser for area illumination and a gated-intensified CCD camera for area detection will be presented.

6143-56, Session 11

Near infrared spectroscopy and tomography for tumor prognosis and treatment monitoring

H. Liu, J. G. Kim, B. Wang, The Univ. of Texas at Arlington; R. P. Mason, The Univ. of Texas Southwestern Medical Ctr. at Dallas

It is crucial and advantageous if tumors under therapy can be functionally monitored and imaged at different treatment stages. We have developed a broadband, near infrared spectroscopy (NIRS) and tomography system for treatment monitoring of cancers, demonstrating the usefulness of NIRS for cancer research.

Our studies include two sub-sections: 1) development of a broadband, NIRS imaging system and the corresponding imaging reconstruction algorithms to obtain hemodynamic parameters, and 2) animal study to investigate the changes in tumor hemodynamics during oxygen intervention before and after chemotherapy so as to monitor the effects of chemotherapeutic agents in tumor hemodynamics.

In the first part of our study, besides the development of hardware, we have utilized the Semi-Analytical Complex Variable Method (SACVM) joined with the Hyper Radial Basis Function (HRBF) for tumor parameterization in the imaging reconstruction. This approach does not depend on mashes, gives better spatial resolution for hidden tumors, and allows determination of tumor location, size and strength simultaneously. In the animal studies, we have treated two groups of rats bearing breast tumors: one group with cyclophosphamide (CTX), and the other with Combretastatin (CA4P) to see the drug effects in tumor hemodynamics.

Overall, our study supports that the effects of chemotherapy in tumor may be monitored non-invasively using NIRS by detecting the changes of hemodynamics induced with respiratory challenges. Such hemodynamic images may provide prognostic information, for clinical cancer treatment practice, on inhomogeneous responses of the tumor to the therapy and intervention as well as on the effectiveness of the therapy.

6143-57, Session 11

Functional imaging of small tissue volumes with diffuse optical tomography

A. D. Klose, A. H. Hielscher, Columbia Univ.

Imaging of dynamic changes in blood parameters, functional brain imaging, and breast imaging are the most advanced application areas of diffuse optical tomography (DOT). When dealing with the image reconstruction problem one is faced with the fact that near-infrared photons, unlike X-rays, are highly scattered when they traverse biological tissue. Image reconstruction schemes are required that model the light propagation inside biological tissue and predict measurements on the tissue surface. By iteratively changing the tissue-parameters until the predictions agree with the real measurements, a spatial distribution of optical properties inside the tissue is found. The optical properties can be related to the tissue oxygenation, inflammation, or the fluorophore concentration of an endogenous biochemical marker. If the model of light propagation is inaccurate, the reconstruction process will lead to an inaccurate result as well. We focus on difficulties that are encountered when DOT is employed for functional imaging of small tissue volumes, for example, in cancer studies involving small animals, or human finger joints for early diagnosis of rheumatoid arthritis. Most of the currently employed image reconstruction methods rely on the diffusion theory that is an approximation to the equation of radiative transfer. But, in the cases of small tissue volumes and tissues that contain low scattering regions diffusion theory has been shown to be of limited applicability Therefore, we employ a light propagation model that is based on the equation of radiative transfer which promises to overcome the limitations. We are going to present image reconstruction results obtained with our light propagation model.

6143-58, Session 11

Laminar optical tomography: high-resolution 3D functional imaging of superficial tissues

E. M. Hillman, A. K. Dunn, Massachusetts General Hospital; A. M. Dale, Univ. of California/San Diego; D. A. Boas, Massachusetts General Hospital

Laminar Optical Tomography (LOT) is a new medical imaging modality for high-resolution, depth-resolved, functional imaging of superficial tissue such as rodent cortex, skin and the retina. LOT uses visible laser light image to depths of >2mm (far deeper than microscopy) and is highly sensitive to absorption and fluorescence contrast, enabling spectroscopic functional information such as hemoglobin oxygenation to be imaged with 100-200 micron resolution.

LOT has been used to image the hemodynamic response to stimulus in the somatosensory cortex of rats. The resulting three-dimensional (3D) images through the depth of the cortex delineate the arterial, capillary and venous responses, revealing new information about the intricacies of the oxygenation and blood flow dynamics related to neuronal activation. Additional applications of LOT are being explored, including the integration of 3D Voltage Sensitive Dye fluorescence imaging.

LOT imaging uses a system similar to a confocal microscope, quickly scanning a focused beam of light over the surface of the tissue (~8Hz frame rate). Light is detected from both the focus of the scanning beam, and also at increasing distances from the beam's focus. This scattered light has penetrated more deeply into the tissue, and allows features at different depths to be distinguished. An algorithm that includes photon migration modeling of light scattering converts the raw data into 3D images. The motivation for functional optical imaging will be outlined, the basic principles of LOT imaging will be described, and the latest in-vivo results will be presented.

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6144-01, Session 1

Image segmentation using local shape and gray-level appearance models

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A new generic model-based segmentation scheme is presented, which can be trained from examples akin to the Active Shape Model (ASM) approach in order to acquire knowledge about the shape to be segmented and about the gray-level appearance of the object in the image. While the ASM is represented by a single shape model that captures correlations between all landmark points on the shape, in our approach the shape information is described by multiple landmark-specific statistical models that capture local dependencies between adjacent landmarks on the shape.

Because in the ASM approach the intensity and shape models are typically applied alternately during optimizing as first an optimal target location is selected for each landmark separately based on local gray-level appearance information only to which the shape model is fitted subsequently, the ASM may be misled in case of wrongly selected landmark locations. Instead, the proposed approach optimizes for shape and intensity characteristics simultaneously. Local gray-level appearance information at the landmark points extracted from feature images is used to automatically detect a number of plausible candidate locations for each landmark. The shape and intensity models are combined in a single cost function that is optimized non-iteratively using dynamic programming which allows to the optimal landmark positions using combined shape and intensity information, without the need for initialization. The proposed algorithm is compared to an ASM scheme with a similar gray-level appearance model for lungfield segmentation in chest radiographs and validated against manual expert delineations. Our results show a significant improvement of the new method with respect to the ASM scheme. The method has also been successfully applied to segment 11 different hand bones in hand radiographs, which demonstrates the generic nature of the method.

6144-02, Session 1

Towards fully automatic object detection and segmentation

H. Schramm, O. Ecabert, J. Peters, V. Philomin, J. Weese, Philips Research Labs. (Germany)

An automatic procedure for detecting and segmenting anatomical objects in 3-D images is necessary for achieving a high level of automation in many medical applications, like orthopedic measurement or angiography. Since today's segmentation techniques typically rely on user input for initialization, they do not allow for a fully automatic workflow. Although specific localization algorithms exist for some anatomical objects like the heart or the lung, a general detection technique that can be easily adapted to new objects is lacking.

In this work, the generalized Hough transform is used for detecting anatomical objects with well defined shape in 3-D CT images. The generally huge computational and memory requirements of this technique are limited by excluding shape deformation and rotation variability and using object prior information during the feature extraction. The technique allows to address the detection of a new object with little manual effort since it basically uses a mean shape to represent an object class. In a number of experiments the approach is demonstrated to allow for a coarse 3-D delineation of the femur, vertebra and heart with acceptable runtime performance. Furthermore, it is shown that the achieved object detection information is sufficiently exact to initialize a subsequent segmentation procedure, allowing for a fully automatic segmentation of the said objects. Since both the detection and segmentation technique are based on shape information, the same geometric model can be applied.

6144-03, Session 1

Automatic generation of dynamic 3D models for medical segmentation tasks

L. Dornheim, J. Dornheim, K. D. Tönnies, Otto-von-Guericke-Univ. Magdeburg (Germany)

Segmentation target structures in medical images may be very complex. Furthermore, they may often be depicted incompletely by the image data, due to the pathological or anatomical situation, deficiencies in the imaging technique or signal gaps in functional images. In these cases, a model-based technique is needed for segmentation, providing a-priori knowledge about the expected shape of the target structure. The success of such a segmentation task depends on the incorporated model knowledge.

We present an automatic method to generate such a model for a given target structure. This knowledge is created in the form of a 3D Stable Mass-Spring Model (SMSM) and can be computed from a single sample segmentation. The model is built from different image features using a bottom-up strategy which allows for different levels of model abstraction.

We show the adequacy of the generated models in two practical medical application cases: the segmentation of the left ventricle in myocardial perfusion SPECT, and the segmentation of the thyroid cartilage of the larynx in CT datasets. In both cases, the model generation was performed in a few seconds.

6144-04, Session 1

Oriented active shape models

J. Liu, J. K. Udupa, Univ. of Pennsylvania

Active Shape Models (ASM) are widely used to search for (recognize) anatomic objects and to delineate them in medical images. In this paper, we present a novel strategy called Oriented Active Shape Model (OASM) in an attempt to overcome the following three major limitations of ASM: (1) poor delineation accuracy, (2) the requirement of a large number of landmarks, (3) the problem of initial search to recognize the object boundary. OASM effectively combines the rich statistical shape information embodied in ASM with the boundary orientedness property and the globally optimal delineation capability of live wire. The latter allow live wire to effectively separate an object boundary from other non object boundaries with similar properties that come very close. Our approach leads us to a 2-level dynamic programming method, wherein the first level corresponds to boundary recognition and the second level corresponds to boundary delineation. Our experiments in segmenting breast, liver, bones of the foot, and cervical vertebrae of the spine in MR and CT images indicate the following: (1) The accuracy of segmentation via OASM is considerably better than that of ASM. (2) The number of landmarks can be reduced by a factor of 3 in OASM over that in ASM. (3) OASM becomes largely independent of initialization. All three benefits of OASM ensue mainly from the severe constraints brought in by the orientedness property of live wire and the globally optimal solution of dynamic programming.

6144-05, Session 1

Segmentation by surface-to-image registration

Z. Xie, VirtualScopics LLC; P. Chiao, Pfizer Inc.; J. Tamez-Pena, VirtualScopics LLC; S. Liachenko, S. Dhamija, M. Gieseg, Pfizer Inc.

This presentation describes a new image segmentation algorithm using surface-to-image registration. The algorithm employs multi-level transformations and multi-resolution image representations to progressively register atlas surfaces (modeling anatomical structures) to subject images based on weighted external forces in which weights and forces are determined by gradients and local intensity profiles obtained from im-

ages. The algorithm is designed to prevent atlas surfaces converging to unintended strong edges or leaking out of structures of interest through weak edges where the image contrast is low. Segmentation of bone structures on MR images of rat knees analyzed in this manner performs comparably to technical experts using a semi-automatic tool.

6144-06, Session 2

Robust local intervertebral disc alignment for spinal MRI

J. G. Reisman, J. Hoeppner, Siemens Corporate Research; S. Huang, National Tsing Hua Univ. (Taiwan); L. Zhang, Siemens Corporate Research; S. Lai, National Tsing Hua Univ. (Taiwan); C. L. Novak, Siemens Corporate Research

Magnetic resonance (MR) imaging is frequently used to diagnose abnormalities in the spinal intervertebral discs. Owing to the non-isotropic resolution of typical MR spinal scans, physicians prefer to align the scanner plane with the disc in order to maximize the diagnostic value and to facilitate comparison with prior and follow-up studies. Commonly a planning scan is acquired of the whole spine, followed by a diagnostic scan aligned with selected discs of interest. Manual determination of the optimal disc plane is tedious and prone to operator variation. A fast and accurate method to automatically determine the disc alignment can decrease examination time and increase the reliability of diagnosis. We present an automatic spine alignment method for determining the orientation of intervertebral discs in MR studies, and demonstrate its effectiveness by comparison with human observers. 12 MR spinal scans of adult spines were tested. Two observers independently indicated the intervertebral plane for each disc, and then repeated the procedure on another day, in order to determine the inter- and intra-observer variability associated with manual alignment. Results were also collected for the observers utilizing the automatic spine alignment system, in order to determine the method's consistency and its accuracy with respect to human observers. We found that the results from the automatic alignment system are comparable with the alignment determined by human observers, with the computer showing greater speed and consistency.

6144-07, Session 2

Level set based vertebra segmentation for the evaluation of Ankylosing Spondylitis

S. Tan, J. Yao, M. M. Ward, L. Yao, R. M. Summers, National Institutes of Health

Ankylosing Spondylitis is a disease of the vertebra where abnormal bone structures (syndesmophytes) grow at intervertebral disk spaces. Because this growth is so slow as to be undetectable on plain radiographs taken over years, it is necessary to resort to computerized techniques to complement qualitative human judgment with precise quantitative measures on 3-D CT images. Very fine segmentation of the vertebral body is required to capture the small structures caused by the pathology. We propose a segmentation algorithm based on a cascade of three level set stages and requiring no training or prior knowledge. First, the noise inside the vertebral body that often blocks the proper evolution of level set surfaces is attenuated by a sigmoid function whose parameters are determined automatically. The 1st level set (geodesic active contour) is designed to roughly segment the interior of the vertebra despite often highly inhomogeneous and even discontinuous boundaries. The result is used as an initial contour for the 2nd level set (Laplacian level set) that closely captures the inner boundary of the cortical bone. The last level set (reversed Laplacian level set) segments the outer boundary of the cortical bone and also corrects small flaws of the previous stage. We carried out extensive tests on 30 vertebrae (5 from each of 6 patients). Two medical experts scored the results at intervertebral disk spaces focusing on end plates and syndesmophytes. Only two minor segmentation errors at vertebral end plates were reported and two syndesmophytes were considered slightly under-segmented.

6144-08, Session 2

Segmentation of hand radiographs using fast-marching methods

H. Chen, Michigan State Univ.; C. L. Novak, Siemens Corporate Research

Rheumatoid Arthritis is one of the most common chronic diseases. Joint space width in hand radiographs is evaluated to assess joint damage in order to monitor progression of disease and response to treatment. Manual measurement of joint space width is time-consuming and highly prone to inter- and intra-observer variation. We propose a method for automatic extraction of finger bone boundaries using fast marching methods for quantitative evaluation of joint space width. The proposed algorithm includes two stages: location of hand joints followed by extraction of bone boundaries. By setting the propagation speed of the wave front as a function of image intensity values, the fast marching algorithm extracts the skeleton of the hands, in which each branch corresponds to a finger. The finger joint locations are then determined by using the image gradients along the skeletal branches. In order to extract bone boundaries at joints, the gradient magnitudes are utilized for setting the propagation speed, and the gradient phases are used for discriminating the boundaries of adjacent bones. The bone boundaries are detected by searching for the fastest paths from one side of each joint to the other side. Finally, joint space width is computed based on the extracted upper and lower bone boundaries. The algorithm was evaluated on a test set of 8 two-hand radiographs, including images from healthy patients and from patients suffering from arthritis, gout and psoriasis. Using our method, 97% of 208 joints were accurately located and 89% of 416 bone boundaries were correctly extracted.

6144-09, Session 2

Knowledge-based segmentation of the heart from respiratory-gated CT datasets acquired without cardiac contrast-enhancement

J. Dey, Univ. of Massachusetts Medical School; T. Pan, The Univ. of Texas M.D. Anderson Cancer Ctr.; D. J. Choi, M. Smyczynski, P. H. Pretorius, M. A. King, Univ. of Massachusetts Medical School

Respiratory motion degrades image quality in PET and SPECT imaging. Patient specific information on the motion of structures such as the heart if obtained from CT slices from a dual-modality imaging system can be employed to compensate for motion during emission reconstruction. Such CT datasets may not include cardiac contrast enhancement. Since each patient typically has gated datasets from 10 points during the respiratory cycle and each dataset has 40-100 slices, automating the segmentation of the heart is important. We have developed a segmentation algorithm with 3 steps. In the first step we place a prior shape with an initial pose on one slice of one of the gated datasets. It then tracks the object through the other slices of the same dataset and the other gated datasets of the patient. In the second step, a local edge-based radial force is used to draw the contour to the edges for all the slices of all the datasets. At the third step, the shape is further optimized by incorporating statistical variations according to an assumed point-wise correlation on the curve. When applied, the first two steps of the algorithm got within 2 pixels of the interactively defined boundary. The third shape-optimizing step is expected to further improve the results.

6144-10, Session 2

Automatic cardiac MRI myocardium segmentation using graphcut

G. Kedenburg, Univ. Hamburg (Germany); C. A. Cocosco, Philips Research Labs. (Germany); U. Koethe, Univ. Hamburg (Germany); W. J. Niessen, Erasmus Univ. Medical Ctr. (Netherlands); E. P. Vonken, M. A. Viergever, Univ. Medical Ctr. Utrecht (Netherlands)

Segmentation of the left myocardium in four-dimensional (space-time) cardiac MRI data sets is a prerequisite of many diagnostic tasks. We propose a fully automatic method based on global minimization of an energy functional by means of the Graphcut algorithm. Starting from automatically obtained segmentations of the left and right ventricles and a cardiac region of interest, a spatial model is constructed using simple and plausible assumptions. This model is used to learn the appearance of different tissue types by non parametric robust estimation. Our method does not require previously trained shape or appearance models. Processing takes 30-40s on current hardware. We evaluated our method on 11 clinical cardiac MRI data sets acquired using cine balanced fast field echo. Linear regression of the automatically segmented myocardium volume against manual segmentations (performed by a radiologist) showed an RMS error of about 12ml.

6144-11, Session 2

Anatomical-based segmentation with stenosis bridging and gap closing in atherosclerotic cardiac MSCT

R. D. Merges, Siemens Medical Solutions (Germany) and Univ. Karlsruhe (Germany); D. Rinck, Siemens Medical Solutions (Germany); O. Dössel, Univ. Karlsruhe (Germany); M. Scheuering, Siemens Medical Solutions (Germany)

In the diagnosis of coronary artery disease 3D-multi-slice computed tomography (MSCT) has become a viable alternative to the more invasive conventional examinations. We present an anatomical-based method for the segmentation of atherosclerotic coronary arteries in MSCT. This technique is able to bridge severe stenosis, image artifacts or even full vessel occlusions. Different anatomical structures (aorta, aortic valve, blood-pool of the heart chambers, coronary arteries and their orifices) are detected successively to incorporate anatomical knowledge into the algorithm. The whole procedure minimizes user interaction by requiring one click in the aorta above the orifices of the coronary arteries. After segmenting the aorta down to the automatically detected aortic valve plane, the orifices are detected utilizing a distance coded region-growing algorithm starting from the hull of the aorta. The coronary arteries are then segmented by a simulated wave propagation method to be able to extract anatomical spatial relationships from the result and define an estimated centerline according to the arrival time of the wavefront. In order to bridge segmentation breaks caused by stenosis or image artifacts, the spatial location and its anatomical relation are taken into account to find appropriate endpoints of the vessel which could resemble stenotic regions. From these endpoints a search space for stenosis bridging and gap closing is initialized. Within this adaptively shaped search space candidates for continuation of the coronary vessel are detected. This allows the prevention of vessel misidentifications and improves segmentation results significantly. The robustness of this method is proven on representative medical data sets.

6144-12, Session 3

Quantifying changes in the bone microarchitecture using Minkowski-functionals and scaling vectors: a comparative study

C. W. Raeth, Max-Planck-Institut für extraterrestrische Physik (Germany); D. Mueller, Technische Univ. München (Germany); T. Link, Univ. of California/San Francisco; H. F. Boehm, Ludwig-Maximilians-Univ. München (Germany); R. Monetti, Max-Planck-Institut für extraterrestrische Physik (Germany)

Osteoporosis is a metabolic bone disease leading to de-mineralization and increased risk of fracture. The two major factors that determine the biomechanical competence of bone are the degree of mineralization and the micro-architectural integrity. Today, modern imaging modalities exist that allow to depict structural details of trabecular bone tissue.

Recently, non-linear techniques in 2D and 3D based on the scaling vector method (SVM) and the Minkowski functionals (MF) have been introduced, which show excellent performance in predicting bone strength and fracture risk. However, little is known about the performance of the various parameters with respect to monitoring structural changes due to progression of osteoporosis or as a result of medical treatment.

We test and compare the two methodologies using realistic two-dimensional simulations of bone structures, which model the effect of osteoblasts and osteoclasts on the local change of relative bone density. Different realizations with slightly varying control parameters are considered. Our results show that even small changes in the trabecular structures, which are induced by variation of a control parameter of the system, become discernible by applying both the MF and the locally adapted scaling vector method. The results obtained with SVM are superior to those obtained with the Minkowski functionals. A multiplicative combination of both measures drastically increases the sensitivity to slight changes in bone structures. These findings may be especially important for monitoring the treatment of patients, where the early recognition of (drug-induced) changes in the trabecular structure is crucial.

6144-13, Session 3

Variogram methods for texture classification

O. M. Jeromin, M. Pattichis, Univ. of New Mexico; C. S. Pattichis, E. Kyriacou, Univ. of Cyprus; A. Nicolaides, Cardiovascular Disease Educational and Research Trust (Cyprus) and Imperial College (United Kingdom) and Univ. of Cyprus (Cyprus)

Stroke is the third leading cause of death in the western world and the major cause of disability in adults. The type and stenosis of extracranial carotid artery disease is often responsible for ischemic strokes, transient ischemic attacks (TIAs) or amaurosis fugax (AF). The identification and grading of stenosis can be done using gray scale ultrasound scans. The appearance of B-scan pictures containing various granular structures makes the use of texture analysis techniques suitable for computer assisted tissue characterization purposes.

The objective of this study is to investigate the usefulness of variogram analysis in the assessment of ultrasound plague morphology. The variogram estimates the variance of random fields, from arbitrary samples in space. We explore stationary random field models based on the variogram, which can be applied in ultrasound plaque imaging leading to a Computer Aided Diagnosis (CAD) system for the early detection of symptomatic atherosclerotic plaques.

Non-parametric tests on the variogram coefficients show that the coefficients coming from symptomatic versus asymptomatic plaques come from distinct distributions. Furthermore, we show significant improvement in class separation, when a log point-transformation is applied to the images, prior to variogram estimation. Model fitting using least squares is explored for anisotropic variograms along specific directions. Comparative classification results, show that variogram coefficients can be used for the early detection of symptomatic cases, and also exhibit the largest

class distances between symptomatic and asymptomatic plaque images, as compared to over 60 other texture features, used in the literature.

6144-15, Session 3

Analysis of parenchymal patterns using conspicuous spatial frequency features in mammograms and applied to the BI-RADS density rating scheme

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Automatic classification of the density of breast parenchyma is shown using a measure that is correlated to the Bi-RADS density rating. Increasingly popular in the United States, the Breast Imaging Reporting and Data System (BI-RADS) is used to draw attention to the increased screening difficulty associated with greater breast density; however, the Bi-RADS rating scheme is subjective and is not intended as an objective measure of breast density. So, while popular, BI-RADS does not define density classes using a standardized measure, which leads to substantial variability among observers. We calculate an objective density rating that is derived using a measure of local feature salience. Previously, this measure was shown to correlate well with radiologists' localization and discrimination of true positive and true negative regions-of-interest. Based upon conspicuous spatial frequency features, an objective density rating is obtained and correlated with the subjectively ascertained BI-RADS density rating. Using 100 cases, obtained from the University of Central Florida's DDSM database, we show that an automated breast density measure can be derived, and that a regression model can be obtained that uses this objective measure successfully to predict the BI-RADS density rating.

6144-16, Session 3

Mammographic density measured as changes in tissue structure caused by HRT

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Numerous studies have investigated the relation between mammographic density and breast cancer risk. These studies indicate that women with dense breasts have a four to six fold risk increase. An investigation of whether or not this relation is causal is important for, e.g., hormone replacement therapy (HRT), which has been shown to actually increase the density.

No gold standard for automatic assessment of mammographic density exists. Manual methods such as Wolfe patterns and BI-RADS are helpful for communication of diagnostic sensitivity, but they are both time consuming and crude. They may be sufficient in certain cases and for single measurements, but for serial, temporal analysis it is necessary to be able to detect more subtle changes and, in addition, to be more reproducible.

In this work an automated method for measuring the effect of HRT w.r.t. changes in biological density in the breast is presented. This measure is a novel, intensity invariant measure, which provides structural information orthogonal to intensity-based methods. Hessian eigenvalues at different scales are used as features and a clustering of these is employed to divide a mammogram into four structurally different areas. Subsequently, based on the relative size of the areas, a density score is determined.

In the experiments, two sets of mammograms of 50 patients from a double blind, placebo controlled HRT experiment were used. The method shows that the change in density for the HRT group was significantly higher ($p = 0.0002$) than the change in the control group.

6144-17, Session 3

Optimizing texture measures quantifying bone structures as well as MR-sequences at 3 Tesla: an integrative statistical approach

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High resolution MR-scanners working with magnetic field strengths of 3 Tesla are clinically available nowadays. They offer the possibility to obtain 3D images with unprecedented spatial resolution and/or signal-to-noise-ratio (SNR) allowing for an accurate visualization of the trabecular bone structure. It has been demonstrated that scaling indices are well suited to quantify these structures, especially to discriminate between plate-like and rod-like structural elements, which is crucial for the diagnosis of osteoporosis.

Until now image quality has mainly been assessed by the visual impression or by measures based on SNR. In this work we present a methodology to assess different MR-sequences with respect to the texture measure that is used later in the image analysis. We acquired for a bone specimen HR-MR-sequences with different spatial resolution and signal to noise ratio. For these data sets we selected two volumes of interest (VOI) of same size located in the trabecular bone and in the background of the image. For both VOIs the scaling indices are calculated for different scale parameters. Subsequently the 'texture contrast' between structure and background is calculated by comparing the probability distributions of the scaling indices using a quadratic distance measure. By means of the contrast the optimal set of scale parameters is determined. By comparing the contrast for the different MR sequences the best suited ones are determined. It turns out that sequences with slightly lower spatial resolution but better signal to noise ration yield a better texture contrast than sequences with the best spatial resolution.

6144-201, Session 3

Early detection of glaucoma using fully automated disparity analysis of the optic nerve head (ONH) from stereo fundus images

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Early detection of structural damage to the optic nerve head (ONH) is critical in diagnosis of glaucoma, because such glaucomatous damage precedes clinically identifiable visual loss. Early detection of glaucoma can prevent progression of the disease and consequent loss of vision. Traditional early detection techniques involve observing changes in the ONH through an ophthalmoscope. Stereo fundus photography is also routinely used to detect subtle changes in the ONH. However, clinical evaluation of stereo fundus photographs suffers from inter- and intra-subject variability. Even the Heidelberg Retina Tomograph (HRT) has not been found to be sufficiently sensitive for early detection. A semi-automated algorithm for quantitative representation of the optic disc and cup contours by computing accumulated disparities in the disc and cup regions from stereo fundus image pairs has already been developed using advanced digital image analysis methodologies. A 3-D visualization of the disc and cup is achieved assuming camera geometry. High correlation among computer-generated and manually segmented cup to disc ratios in a longitudinal study involving 159 stereo fundus image pairs has already been demonstrated. However, clinical usefulness of the proposed technique can only be tested by a fully automated algorithm. In this paper, we present a fully automated algorithm for segmentation of optic cup and disc contours from corresponding stereo disparity information. Because this technique does not involve human intervention, it eliminates subjective variability encountered in currently used clinical methods and provides ophthalmologists with a cost-effective and quantitative method for detection of ONH structural damage for early detection of glaucoma.

6144-18, Session 4

Automatic segmentation of vessels in breast MR as a false positive elimination technique for lesion detection and segmentation using the shape tensor

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We present a new algorithm for automatic detection of bright tubular structures and its performance for automatic segmentation of vessels in breast MR sequences. This problem is interesting because vessels are the main type of false positive structures when automatically detecting lesions as regions that enhance after injection of the contrast agent. Our algorithm is based on the eigenvalues of what we call the shape tensor. It is new in that it does not rely on image derivatives of either first order, like methods based on the eigenvalues of the mean structure tensor, or second order, like methods based on the eigenvalues of the mean Hessian. It is therefore more precise and less sensitive to noise than those methods. In addition, the smoothing of the output which is inherent to approaches based on the mean Hessian or structure tensor is avoided. The output of our filter does not present the typical over-smoothed look of the output of the two differential filters that affects both their precision and sensitivity. The scale selection problem appears also less difficult in our approach compared to the differential techniques. Our algorithm is fast, needing only a few seconds per sequence. We present results of testing our method on a large number of motion-corrected breast MR sequences. These results show that our algorithm reliably segments vessels while leaving lesions intact. We also compare our method to the differential techniques and show that it significantly out-performs them both in sensitivity and localization precision and that it is less sensitive to scale selection parameters.

6144-19, Session 4

A dorsolateral prefrontal cortex semi-automatic segmenter

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Morphological changes in the dorsolateral prefrontal cortex (DLPFC), or Brodmann area 46, have been implicated in schizophrenia. Since the boundaries of the DLPFC are not explicit in MRI brain imagery, the structure can not be segmented automatically with a generic segmenter and is therefore usually segmented manually by experts to produce a 3D model and conduct morphological studies. In this work, we present for the first time the inclusion of expert rules in a semi-automatic algorithm for the DLPFC segmentation. The algorithm uses a combination of user-defined seed points and a knowledge-based automatic segmentation algorithm to produce a 3D surface model of the DLPFC. Our results show that we are able to segment the DLPFC semi-automatically in a reproducible way and reduce the segmentation time from an average of 45 minutes with a manual segmentation to 5 minutes with excellent segmentation results.

6144-20, Session 4

Competitive segmentation of the hippocampus and the amygdala from MRI data: validation on young healthy controls and Alzheimer's disease patients

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The hippocampus (HC) and the amygdala (A) are two cerebral structures that play a central role in main cognitive processes. Their segmentation allows atrophy in specific neurological illnesses to be quantified, but is made difficult by the complexity of the structures. In this work, a new algorithm for the simultaneous segmentation of HC and A based on competitive homotopic region deformations is presented. The deformations are constrained by relational priors derived from anatomical knowledge, namely probabilities for each structure around automatically retrieved landmarks at the border of the objects. The approach is designed to perform well on data from diseased subjects. The segmentation is initialized by extracting a bounding box and positioning two seeds; total execution time for both sides is between 10 and 15 minutes including initialization for the two structures. We present the results of validation based on comparison with manual segmentation, using volume error, spatial overlap and distance measures. For 8 young healthy subjects the mean volume error was 7% for HC and 11% for A, the overlap: 84% for HC and 83% for A, the maximal distance: 4.2mm for HC and 3.1mm for A; for 4 Alzheimer's disease patients the mean volume error was 9% for HC and A, the overlap: 83% for HC and 78% for A, the maximal distance: 6mm for HC and 4.4mm for A. We conclude that the performance of the proposed method compares favourably with that of other published approaches in terms of accuracy and has a short execution time.

6144-21, Session 4

Improved 3D live-wire segmentation for 3D CT chest image analysis

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The definition of regions of interests (ROIs) in 3D imaging scans is often difficult because of the complexity of the phenomena that give rise to them. Manual slice tracing has been used widely for years for such problems, because it is easy to implement and guaranteed to work. But it is subject to operator biases and is extremely time consuming, especially for high-solution 3D images which may have hundreds of slices. Numerous automated image-segmentation methods have been proposed, but they are typically application dependent, and even the "most robust" methods have difficulty in defining complex anatomical ROIs.

To address this problem, the semi-automatic interactive paradigm referred to as "live wire" segmentation is used and modified in this paper to segment both 2D and 3D objects. Our main contributions are as follows:

(1) Modify the standard 2D live-wire algorithm. A new gradient direction cost is introduced to make the 2D live-wire method perform better for noisy and blurry ROI boundaries.

(2) Define a new 3D live-wire formulation that enables rapid definition of 3D ROIs. The method only requires the human operator to consider a few slices in general, and it can be implemented conveniently in various viewing directions in 3D CT images.

The proposed 2D and 3D live-wire methods are capable of segmenting many different kinds of 2D and 3D objects. We have found that they are efficient, allow for high reproducibility, and are reliable for 2D and 3D object segmentation.

6144-22, Session 4

Automatic segmentation of pulmonary nodules on CT images by use of NCI lung image database consortium

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Accurate segmentation of solitary pulmonary nodules (SPNs) on thoracic CT images is an important technique for volumetric doubling time estimation and feature characterization for the diagnosis of SPNs. Most of the nodule segmentation algorithms that have been previously presented were designed to handle solid pulmonary nodules. However, SPNs with ground-glass opacity (GGO) also affects a diagnosis. Therefore, we have developed an automated volumetric segmentation algorithm of SPNs with GGO on thoracic CT images. This paper presents our segmentation algo-

rithm with multiple fixed-thresholds, template-matching method, a distance-transformation method, and a watershed method. For quantitative evaluation of the performance of our algorithm, we used the first dataset provided by NCI Lung Image Database Consortium (LIDC). In the evaluation, we employed the coincident rate which was calculated with both the computerized segmented region of a SPN and the matching probability map (pmap) images provided by LIDC. As the result of 23 cases, the mean of the total coincident rate was 0.546 ± 0.253. From these results, we concluded that our algorithm is useful for extracting SPNs with GGO and solid pattern as well as wide variety of SPNs in size.

6144-23, Session 4

Automatic segmentation of pulmonary fissures in X-ray CT images using anatomic guidance

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The human lungs are divided into five distinct anatomic compartments called lobes. The physical boundaries between the lobes are called the lobar fissures. Detection of lobar fissure positions in pulmonary X-ray CT images is of increasing interest for the early detection of pathologies, and also for the regional functional analysis of the lungs. We have developed an automatic method for the accurate segmentation of the three pulmonary fissures, in a two step process. In the first step, an approximation of the actual fissure locations is made using a 3-D watershed transform on the distance map of the segmented vasculature. Information from the anatomically labeled human airway tree is used to guide the watershed segmentation. These approximate fissure boundaries are then used to define the ROI for a more exact 3-D graph search to locate the fissures. Within the ROI the fissures are enhanced by computing a ridgeness measure, and this is used as the cost function for the graph search. The fissures are detected as the optimal surface within the graph defined by the cost function, which is computed by transforming the problem to finding a minimum $s-t$ cut on a derived graph. The accuracy of the lobar borders is assessed by comparing the automatic results to manually traced lobe segments. Averaged over all volumes for all five lobes, the mean similarity index, which is an area overlap measure based on the kappa statistic, is 0.9763 (SD 0.037). The mean RMS distance error between manually traced and computed detected fissures is 2.2530 mm (± 2.2306 mm SD).

6144-24, Session 5

PET molecular imaging biomarkers for molecular therapeutics

M. E. Phelps, Univ. of California/Los Angeles

No abstract available

6144-25, Session 5

A pseudo wavelets-based method for accurate tagline tracing on tagged MR images of the tongue

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Tagged MRI has been used to study tissue motion in the human tongue during oral motor acts. Existing analysis methods, particularly in tagline detection, fall short in accuracy for lingual strain analysis due to the curvature of the tongue, its highly complex tissue architecture, and interference from surrounding structures. To achieve accurate tagline tracing, we have developed a robust method that employs multi-resolution pseudo wavelets synthesis coupled with automatic tagline clustering and fitting algorithms. In our method, tagged MR images of the tongue are mapped to the wavelets domain. Given the a priori knowledge of the gross tagline plane (horizontal or vertical) set during image acquisition, subbands that contain prominent tag coefficients are retained while others are suppressed. By segmenting the reconstructed image, significant stripes are extracted, which are mixtures of taglines and anatomical boundaries that resemble lines. A refinement step is then implemented to group or eliminate broken lines or isolated points. To recover tagline continuity, Spline interpolation is applied to each tagline. Our method has been validated for tagged MR images of the tongue during maximum voluntary isometric linguopharyngeal contraction for effortful swallowing, and comparison with existing methodology showed significant improvement in tagline pixel displacement measurement (p=.0011). Without assumption about the underlying tagline insertion mechanism or tagline intensity model, our method extracts both straight and highly curved lingual taglines automatically with precision and robustness regardless of line width and spacing.

6144-26, Session 5

An improved method of wavelet image fusion for extended depth-of-field microscope imaging

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Narrow depth-of-field is a prominent problem in microscope imaging where different parts of a thick specimen cannot be viewed in-focus at once. In order to visualize the specimen objects within the field of view, one often has to acquire and review a stack of images focused at different focal planes. Digital image fusion is an effective technique that can be applied to achieve extended depth-of-field imaging for microscopy applications under such situations. The central idea is to incorporate from multiple input images the regions that contain most in-focus signals and combine them into a single composite image. The amount of signal content of a particular region is estimated by an activity measure in general. To date, all existing approaches in the literatures rely on estimates based on the strength of high frequency signal components as the activity measure. However, these measures do not distinguish true image signals from noise. Consequently, image artifacts are produced as result of the fusion. In this paper we propose a new scheme of activity measure for the purpose of image fusion based on the multiscale point-wise product of a wavelet transform. This new measure is devised to help improve the accentuation of image signals without amplifying the noise. Preliminary results show that the new scheme yields a significant improvement on imaging of cytological specimens in terms of both subjective and objective quality even under a noise-free environment. More importantly, the scheme has a desirable advantage over existing methods in the presence of noise.

6144-27, Session 5

Three-band MRI image fusion utilizing the wavelet-based method optimized with two quantitative fusion metrics

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In magnetic resonance imaging (MRI), there are three bands of images available, which are T1-, T2- and PD-weighted images. The three images provide complementary structure information and therefore it is useful for diagnosis and subsequent analysis to combine three-band images into one. We propose an advanced discrete wavelet transform (aDWT) for three-band MRI image fusion and the aDWT algorithm is further optimized utilizing two quantitative fusion metrics - the image quality index (IQI) and ratio spatial frequency error (rSFe). In the aDWT method, principle component analysis (PCA) and morphological processing are incorporated into a regular DWT fusion algorithm. Furthermore, the aDWT has two adjustable parameters - the level of DWT decomposition (Ld) and the length of the selected wavelet (Lw) that determinately affect the fusion result. The fused image quality can be quantitatively measured with the established metrics - IQI and rSFe. Varying the control parameters (Ld and Lw), an iterative fusion procedure can be implemented and running until an optimized fusion is achieved. We fused and analyzed several three-band MRI images from the Visible Human Project(r) female data. From the quantitative evaluations of fused images, we found that (1) the aDWT-IQI algorithm produces a smoothed image whereas the aDWT-rSFe algorithm

yields a sharpened image, (2) fused image "T1+T2" is the most informative one in comparison with other two-in-one fusions (PD+T1 and PD+T2), and (3) for three-in-one fusions, no significant difference is observed among the fusions of (PD+T1)+T2, (PD+T2)+T1 and (T1+T2)+PD, thus the order of fusion does not play an important role.

6144-28, Session 6

Large-scale validation of non-rigid registration algorithms for atlas-based brain

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In this paper, we evaluate different non-rigid image registration (NRR) methodologies in the context of atlas-based brain image segmentation. Three non-rigid voxel-based registration regularization schemes (viscous fluid, elastic and curvature-based registration) combined with the mutual information (MI) similarity measure are compared. We conduct large-scale atlas-based segmentation experiments on a set of 20 anatomically labelled MR brain images in order to find the optimal parameter settings for each scheme. The performance of the optimal registration schemes is evaluated in their capability of accurately segmenting 49 different brain sub-structures of varying size and shape.

6144-29, Session 6

Multimodal inter-subject registration of mouse brain images

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The importance of small animal imaging in fundamental and clinical research is growing rapidly. These studies typically involve micro PET, micro MR, and micro CT tomographic images as well as optical or fluorescence images. Histological images are also often used to complement this in vivo data. As is the case for human studies, automatic registration of these imaging modalities is a critical component of the overall analysis process. But, the small size of the animals and thus the limited spatial resolution of the in vivo images present specific challenges. In this paper, we propose a series of methods and techniques that permit the inter-subject registration of micro MR and histological images. We then compare results obtained by registering directly MR volumes to each other using a non-rigid registration algorithm we have developed at our institution with results obtained by registering first the MR volumes to their corresponding histological volume, which we reconstruct from 2D cross-sections, and then registering histological volumes to each other. We show that the second approach is preferable.

6144-30, Session 6

Improved method for correction of systematic bias introduced by the sub-voxel image registration process in functional magnetic resonance imaging (fMRI)

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Functional magnetic resonance imaging (fMRI) offers great opportunities for clinical application and scientific investigation of the brain. Accurate fractional positioning between sequentially acquired images by convolution-based interpolation allows direct comparison of identical anatomical locations after patient movement. Unfortunately, current subvoxel image registration techniques applied in standard fMRI software can introduce significant systematic bias in the variance estimator when fractional positional shifts are applied. These shifts introduce an artificially created 'non-stationarity' condition that as a consequence violates assumptions of the general linear model (GLM).and event-related design. We introduce a novel correction scheme that improves the in fMRI image registration. This is achieved by a corrected overall sum of squares in the variance estimator. Our analysis and newly introduced correction method was performed both in simulation and human sensory motor studies. We also tie our overall GLM design introduced by Friston (1991) and event-related designs to the well-developed 'roughness measures' by Worsley (1995) that apply spatial Gaussian random fields described by Adler (1981). This formalism enhances better understanding of statistical map relationships with topological geometrical properties of thresholded stochastic activation fields. The performance of our simulations illustrated that there was as high as a 350% reduction in false activation patterns. For the human studies there was a 98% reduction in activation in nine finger-tapping sensory motor patient studies. This work demonstrates the importance of improving the integrity of statistical tests conformance to implicit assumptions. Ideally, this leads to better overall specificity of fMRI subvoxel registration procedures.

6144-31, Session 6

Quantification of the migration and deformation of abdominal aortic aneurysm stent grafts

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A minimal invasive method to treat abdominal aortic aneurysms is to place a stent graft inside the aorta in order to cover the weakened regions of its wall. During a time interval of one or more years the stent can migrate and deform with the risk of occlusion and rupture. In this work we developed several strategies to quantify the migration and deformation in order to assess by the quantified values the risk coming with these movements and especially to characterize appearing endoleaks by them.

We calculated the rigid movement of the stent and the aorta relative to the spinal canal. For this purpose, we initially registered the spinal canals, extracted for the different points in time, rigidly in order to establish a reference system. All objects have been segmented first and surface points have been determined before applying a rigid and non-rigid point set registration algorithm. The residual error after the registration of the stent indicates the amount of change in morphology of the stent.

We investigated a sample of 9 patients all of which have been treated with the same kind of stent device (Zenith). In one case an endoleak (type 3) has been detected by a clinical expert. This case could be clearly identified by the quantified parameters: a high global migration and a strong reduction of the residual error after nonrigid registration. However, we observed a considerable change in the residual error also for a second patient for which a strong bending of one of the parts of the stent could be confirmed by a 3D visualization after its registration.

6144-32, Session 6

Dual-resolution deformable registration for matching abdominal CT images

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One method of modelling respiratory motion of the abdomen is to acquire CT images at different points in the respiratory cycle and develop a deformation model that gives a mapping between corresponding anatomical points in the images. In this work, we use such a method, and the target application is radiosurgery, specifically radiosurgical treatment of lesions that move during respiration, for example those in the lung, liver, or pancreas. In order to accurately calculate the treatment dose, it is nec-

essary to have a good deformation map both globally and locally (in the vicinity of the treatment target). The problem with existing deformable registration methods is that large intensity differences at interfaces such as the skin-air and lung-chest wall boundaries dominate local intensity differences, giving a deformation result that is grossly satisfactory, but poor near the treatment target. In our proposed solution, we use a B-spline deformation model optimized by a gradient descent method for both the global and local deformation. The local deformation is computed first; to avoid discontinuity artifacts at the boundary of the local deformation field, we sample the results of the local deformation, and use these as point constraints for the global registration to ensure continuity. We demonstrate that this registration method gives good results both locally and globally.

6144-33, Session 6

Multimodal 2D-3D non-rigid registration

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In this paper, we propose a multi-modal non-rigid 2D-3D registration technique. This method allows a non-rigid alignment of a patient preoperatively computed tomography (CT) to few intraoperatively acquired fluoroscopic X-ray images obtained with a C-arm system. This multi-modal approach is especially focused on the 3D alignment of high contrast reconstructed volumes with intra-interventional low contrast X-ray images in order to make use of up-to-date information for surgical guidance and other interventions. The key issue of nonrigid 2D-3D registration is how to define the distance measure between high contrast 3D data and low contrast 2D projections. In this work, we use algebraic reconstruction theory to handle this problem. We modify the Euler-Lagrange equation by introducing a new 3D force. This external force term is computed from the residual of the algebraic reconstruction procedures. In the multi-modal case we replace the residual between the digitally reconstructed radiographs (DRR) and observed X-ray images with a statistical based similarity meassure. We integrate the algebraic reconstruction technique into the variational registration framework, so that the 3D displacement field is driven to minimize the “reconstruction distance” between the volumetric data and its 2D projections using mutual information (MI). The benefits of this 2D-3D registration approach is its scalability in the number of used X-ray reference images and the MI similarity measure that can handle low contrast fluoroscopes as well. Experimental results are presented on both artificial phantom and 3D CT head data.

6144-34, Session 7

Explicit rigid and similarity image registration

O. Skrinjar, M. Khan, Georgia Institute of Technology

Presented is an explicit method for unimodal rigid and similarity image registration that is fast and accurate, applicable to images of any dimensions, it does not require the images to be segmented or preprocessed in any way, and it does not need to be initialized, i.e. it can accurately recover the true transformation from any initial image misalignment as long as there is some overlap. The registration methods suggested in the literature usually cannot register the images if the misalignment is more than 45° around any axis. Since the proposed registration method is an explicit method, there is no optimization involved and no problem of local minima. It satisfies the identity, symmetry, transitivity, and distortion properties. The problem of partial image overlap is resolved by iteratively running the algorithm. Unless the image misalignment is extreme, typically several iterations are enough to accurately register the images. We have tested the method on several 2D and several 3D images, each with a number of rigid and similarity transformations applied to them. The angle of rotation was always recovered within one degree from the true angle, and the translation components were recovered with an error of up to one voxel. Tests show that scale factors of at least 20 can be recovered accurately. The computational complexity of the method is O(N) where N is the total number of voxels in both images. The execution time of a Matlab implementation of the 2D method is about .5 seconds for 256x256 images and of the 3D method it is about 20 seconds for 256x256x200 images.

6144-35, Session 7

On the alignment of shapes represented by Fourier descriptors

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The representation of shapes by Fourier descriptors is a time-honored technique that has received relatively little attention lately. Nevertheless, it has many benefits and is applicable for describing a range of medical structures in two dimensions. Delineations in medical applications often consist of continuous outlines of structures, where no information of correspondence between samples exist. In this article, we discuss an alignment method that works directly with the functional representation of Fourier descriptors, and that is optimal in a least-squares sense. With corresponding starting points, the alignment of one shape onto another consists of a single expression. If the starting points are arbitrary, we present a simple iterative scheme to bring a set of shapes into correspondence.

Results are given for three different data sets; 62 outlines of the corpus callosum brain structure, 61 outlines of the brain ventricles, and 50 outlines of the right lung. The results show that even though starting points, translations, rotations and scales have been randomized, the alignment succeeds in all cases.

As an application of the proposed method, we show how high-quality shape models represented by common landmarks can be constructed in an automatic fashion. If the aligned Fourier descriptors are inverse transformed from the frequency domain to the spatial domain, a set of roughly aligned landmarks are obtained. The positions of these are then adjusted along the contour of the objects using the minimum description length criterion, producing ample correspondences. Results on this are also presented for all three data sets.

6144-36, Session 7

Mjolnir: deformable image registration using feature diffusion

L. M. Ellingsen, J. L. Prince, Johns Hopkins Univ.

Image registration is the process of aligning separate images into a common reference frame so that they can be compared visually or statistically. In order for this alignment to be accurate and correct it is important to identify the correct anatomical correspondences between different subjects. We propose a new approach for a feature-based, inter-subject deformable image registration method using a novel displacement field interpolation. Among the top deformable registration algorithms in the literature today is the work of Shen et al. called HAMMER. This is a feature-based, hierarchical registration algorithm, which introduces the novel idea of fusing feature and intensity matching. The algorithm presented in this paper is an implementation of that method, where significant improvements of some important aspects have been made. A new approach to the algorithm will be introduced as well as clarification of some key features of the work of Shen et al. which have not been elaborated in previous publications. The new algorithm, which is referred to as Mjolnir (Thor’s hammer), was validated on both synthesized and real T1 weighted MR brain images. The results were compared with results generated by HAMMER and show significant improvements in accuracy with reduction in computation time.

6144-37, Session 7

Non-rigid brain image registration using a statistical deformation model

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In this paper a new algorithm for non-rigid image registration is presented, in which the deformation field mapping the source onto the target image is modelled as a linear combination of the principal modes of variation of a database of 64 deformations. These have been obtained using a viscous fluid algorithm, as described in~\cite {ViscousFluid,Dieter}. A steepest descent method is used to adjust the coefficients of the linear combination in order to maximize mutual information between the deformed source image and the target image. The feasibility of the method was tested by registering 16 images of the database (experiment 1) and 3 new images (not belonging to the database, experiment 2) with a brain atlas. The deformations computed in the first experiment are compared to those computed using the viscous fluid algorithm: these were recovered with a mean error inferior to 0.5 voxels and a maximal error smaller than 3 voxels. Mutual information between source and target images, after registration with our new algorithm was higher than after registering with the viscous fluid algorithm. In the second experiment, the overlap of manually segmented grey matter (gm), white matter (wm) and cerebrospinal fluid (csf) with corresponding atlas priors was computed. An increase in overlaps of respectively 6\%, 6\% and 16\% for wm, gm and csf was obtained after non-rigid registration.

6144-38, Session 7

Nonrigid registration using regularization that accomodates local tissue rigidity

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Regularized nonrigid medical image registration algorithms usually estimate the

deformation by minimizing a cost function, consisting of a similarity measure and a penalty term that discourages "unreasonable" deformations. Conventional regularization methods enforce homogeneous smoothness properties of the deformation field; less work has been done to incorporate tissue-type-specific elasticity information. Yet ignoring the elasticity differences between tissue types can result in non-physical results, such as bone warping. Bone structures should move rigidly (locally), unlike the more elastic deformation of soft issues.

Existing solutions for this problem either treat different regions of an image independently, which requires precise segmentation and incurs boundary issues; or use an empirical spatial varying "filter" to "correct" the deformation field, which requires the knowledge of a stiffness map and departs from the cost-function formulation.

We propose a new approach to incorporate tissue rigidity information into the nonrigid registration problem, by developing a space variant regularization function that encourages the local Jacobian of the deformation to be a nearly orthogonal matrix in rigid image regions, while allowing more elastic deformations elsewhere

For the case of X-ray CT data, we use a simple monotonic increasing function of the CT numbers (in HU) as a "rigidity index" since bones typically have the highest CT numbers. Unlike segmentation-based methods, this approach is flexible enough to account for partial volume effects. Results using a B-spline deformation parameterization illustrate that the proposed approach improves registration accuracy in inhale-exhale CT scans with minimal computational penalty.

6144-39, Session 7

Nonrigid registration using a rigidity constraint

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Nonrigid registration is commonly used in the field of medical imaging. A drawback of most current nonrigid registration techniques is that they model all tissue as being nonrigid. When a nonrigid registration is performed, the rigid objects in the image, such as bony structures or surgical instruments, may also deform nonrigidly. Other consequences are that tumour growth between follow-up images may be concealed, or that structures containing contrast material in one image and not in the other may be compressed by the registration algorithm.

In this paper we propose a novel regularisation term, which is added to the optimisation function in order to penalise nonrigid deformations of rigid objects. This regularisation term can be used for any representation of the deformation field capable of modelling locally rigid deformations. When a B-spline representation of the deformation field is used, this can be exploited to devise a fast algorithm. We show on 2D synthetic data and clinical CT slices that the proposed rigidity constraint is successful, thus improving registration results.

6144-40, Session 8

Reconstruction of 4D-CT data sets acquired for modeling and analysis of breathing motion

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Respiratory motion is a significant source of error in radiotherapy treatment planning. 4D—CT data sets can be useful to measure the impact of organ motion caused by breathing. But modern CT scanners can only scan a limited region of the body simultaneously and patients have to be scanned in segments consisting of multiple slices. For studying free breathing motion multislice CT scans can be collected simultaneously with digital spirometry over several breathing cycles. The 4D data set is assembled by sorting the free breathing multislice CT scans according to the couch position and the tidal volume. But artifacts can occur because there are no data segments for exactly the same tidal volume and for all couch positions.

We present an optical flow based method for the reconstruction of 4D—CT data sets from multislice CT scans, which are collected simultaneously with digital spirometry. The optical flow between the scans is estimated by a non—linear registration method. The calculated velocity field is used to reconstruct a 4D—CT data set by interpolating data at user-defined tidal volumes. By this technique, artifacts can be reduced significantly. The reconstructed 4D—CT data sets are used for studying inner organ motion during the respiratory cycle.

The procedures described were applied to reconstruct 4D—CT data sets for four tumour patients who have been scanned during free breathing. The reconstructed 4D data sets were used to quantify organ displacements and to visualize the abdominothoracic organ motion.

6144-41, Session 8

Globally optimal model-based matching of anatomical trees

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MDCT and micro-CT scanners are able to produce high-resolution three-dimensional (3D) images of various anatomical trees, such as the airway tree and the heart and liver vasculature. An important problem arising in many contexts is the matching of trees depicted in two different images. This matching task is complicated by several problems associated with current segmentation and axial-analysis methods. Most notably, extracted

trees suffer from missing or broken branches, as well as extra false branches and ill-defined bifurcation regions.

To overcome these difficulties, we propose a model-based approach to tree matching. There are three main steps to our approach:

(1) Define a set of "valid" matches between the two trees. A match is considered to be valid if the two extracted trees can be recovered from a common tree via a sequence of modeled topological deformations.

(2) Define a similarity measure that takes the two extracted trees and any valid match as inputs. The similarity measure used in our experiments is based upon geometrical attributes, such as branch lengths, branching angles, and branchpoint locations measured from the 3D image data.

(3) Locate the valid match that globally maximizes this similarity measure via an efficient dynamic programming algorithm.

The proposed method is capable of locating the globally optimal match between two trees consisting of several hundred branches each in just a few seconds. We have found that the resulting matches are in good agreement with correspondences defined by human experts.

6144-42, Session 8

A comparison of FFD-based nonrigid registration and AAMS applied to myocardial perfusion MRI

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Little work has been done on comparing the performance of statistical model-based approaches and nonrigid registration algorithms. This paper deals with the qualitative and quantitative comparison of active appearance models (AAMs) and a nonrigid registration algorithm based on free-form deformations (FFDs). AAMs are known to be much faster than nonrigid registration algorithms. On the other hand nonrigid registration algorithms are independent of a training set as required to build an AAM. To obtain a further comparison of the two methods, they are both applied to automatically register multi-slice myocardial perfusion images. The images are acquired by magnetic resonance imaging, from infarct patients. A registration of these sequences is crucial for clinical practice, which currently is subjected to manual labor. In the paper, the pros and cons of the two registration approaches are discussed and qualitative and quantitative comparisons are provided. The quantitative comparison is obtained by an analysis of variance of landmark errors, i.e. point to point and point to curve errors. Even though the FFD-based approach does not include a training phase it gave similar accuracy as the AAMs in terms of point to point errors. For the point to curve errors the AAMs provided higher accuracy. In both cases AAMs gave higher precision due to the training procedure.

6144-43, Session 8

Cardiac motion estimation by using high-dimensional features and k-means clustering method

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Tagged Magnetic Resonance Imaging (MRI) is currently the reference modality for myocardial motion and strain analysis. Normalized Mutual Information (NMI) based non rigid registration has proven to be an accurate method to retrieve cardiac motion and overcome many drawbacks present on previous approaches. In a previous work, we used wavelet features instead of pixel intensity to measure similarity between frames. Since the curse of dimensionality forbids the use of classic histograms to estimate NMI of high dimensional features, k Nearest Neighbors (kNN) Graphs were applied to calculate alpha-MI. Given that NMI is less sensitive to changes in overlap than MI, it is important to be able to estimate it for high dimensional features as well. In order to cope with this problem, in this paper we apply k-means clustering method to compute MI and NMI from a set of high dimensional features. The basic idea behind the methodology is to group the set of features into clusters which would play the role of histogram bins when working with pixel intensity. Thus, MI and NMI can be calculated in the usual way from this partition. The proposed method is applied to five tagging MRI sequences, and the resulting displacements are compared with respect to manual measurements made by two observers. A comparison with the results obtained with kNN Graphs and classic NMI is also presented.

6144-44, Session 8

Registration of 2D cardiac images to real-time 3D ultrasound volumes for 3D stress echocardiography

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Three-dimensional stress echocardiography is a novel technique for diagnosing cardiac dysfunction, by comparing wall motion of the left ventricle under different stages of stress. For quantitative comparison of this motion, it is essential to register the ultrasound data. We propose an intensity based rigid registration method to retrieve 2-D long-axis four-chamber (4C), two-chamber, and short-axis planes from the 3-D data set acquired in the stress stage, using manually selected 2-D planes in the rest stage as reference. The algorithm used the Nelder-Mead simplex optimization to find the optimal transformation of one uniform scaling, three rotation, and three translation parameters. We compared registration using the SAD, SSD, and NCC metrics, performed on four resolution levels of a Gaussian pyramid. The registration's effectiveness was assessed by comparing the 3-D positions of the registered apex and mitral valve midpoints and 4C direction with the manually selected results. The registration was tested on data from 20 patients. Best results were found using the NCC metric at full resolution: mean registration errors were 7.8mm, 5.6mm and 6.9° in the apex position, mitral valve position, and 4C direction respectively. The errors were close to the interobserver (7.4mm, 4.1mm, 8.3°) and intraobserver variability (4.1mm, 3.4mm, 6.6°), and better than the error before registration (9.9mm, 8.7mm, 8.6°). We demonstrated that the registration algorithm visually and quantitatively improves the alignment of rest and stress data sets, performing similar to manual alignment. This will improve automated analysis in 3-D stress echocardiography.

6144-45, Session 8

Real time registration by tracking for MR guided cardiac interventions

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Cardiac interventional procedures such as myocardial stem cell delivery and electrophysiological (EP) ablation require a high degree of accuracy and efficiency. Real-time 2D MR technology is being developed to guide such procedures; associated challenges include the relatively low resolution and image quality in real-time images. Real-time MR guidance would be enhanced by acquiring a 4D (3D + phase) volume prior to the procedure and aligning it to the 2D real-time images, so that corresponding features in the prior volume can be integrated into the real-time image

visualization. This could provide spatial context with high resolution and SNR. A left ventricular (LV) myocardial wall contour tracking system was developed to maintain spatial alignment of a 4D prior volume to real-time MR images. Over 100 frames of simulated motion, the tracking system was shown to maintain alignment with a displacement error of 2.3mm in the LV region of interest, versus displacement error of 16.5mm without tracking.

Our evaluation indicates that our proposed real-time registration by tracking technique is able to robustly align real-time MR images to a 4D prior volume. Future refinement of this approach may allow us to perform real-time characterization of changes in myocardial function during intervention, by monitoring changes in wall thickness. This could be potentially crucial during MR guided interventions where ECG suffers from artifacts.

6144-46, Session 9

A homomorphic filtering framework for DT-MRI

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In this paper we develop a new filtering framework for tensor signal processing using the theory of vector spaces. From this point of view, signals are regarded as elements of vector spaces and operators as mappings from the input space to the output space. Hence, it is possible to generalize the principle of superposition to any operator defined on the signal spaces. Systems that obey that generalization of the principle of superposition are referred to as homomorphic and they can be decomposed in a cascade of three homomorphic subsystems: the first one operates on the input signal space, the second one is a linear system in the usual sense and the third one operates on the output signal space. Thus, suitable input and output subsystems can be chosen to deal with input signals, which defines a whole family of homomorphic filters. To apply this idea for DT-MRI signals, which consist of positive semi-definite matrices, we identify input and output signal spaces as the set of those real symmetric positive semi-definite matrices. Our homomorphic filtering framework not only guarantees a positive-semidefinite output tensor field whatever linear filter is used to regularize the noisy input, but also reduces the swelling effect produced by a faster regularization of diffusivities rather than orientations, as demonstrate the encouraging results that have been carried out.

6144-47, Session 9

Theoretical framework for analyzing MR imaging of dynamic objects using filters and downsamplers

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Reconstruction methods for MR imaging of dynamic objects have traditionally been analyzed using the projection slice theorem. In this paper, we present a new theoretical framework for analyzing MR imaging of dynamic objects. Our framework reinterprets the object stationarity constraint and MR reconstruction techniques as filtering and downsampling operations over the acquired k space data. We have analyzed our results in x-f (spatial coordinate and temporal frequency) space using a time-sequential analysis to generate tiling in x-f space. While the projection slice theorem has only be used to analyze the Cartesian sampling trajectory, the new framework can analyze any arbitrary sampling trajectory with a given regridding algorithm. As well, the new theoretical framework can be used to analyze the effect of relaxing the object stationarity constraint over the reconstructed MR images. We have demonstrated the use of our framework by analyzing two popular image reconstruction techniques, namely view sharing and UNFOLD. In the analysis of view sharing, we have confirmed the fact that interleaved and bit reversed k-space sampling patterns provide better artifact suppression for dynamic MR imaging. We then propose to use a different filter to further reduce artifacts in the reconstructed images. In the case of UNFOLD, we have analyzed the effect of relaxing the object stationarity assumption and have shown that it leads to an increase in motion artifacts.

6144-48, Session 9

A novel strategy for segmentation of magnetic resonance (MR) images corrupted by intensity inhomogeneity artifacts

W. Chen, M. L. Giger, The Univ. of Chicago

Magnetic resonance images are often corrupted by intensity inhomogeneity (i.e., bias field effects), which manifests itself as slow intensity variations over the image domain. Such shading artifacts must be corrected before performing computerized analyses such as intensity-based segmentation and quantitative analysis. In this paper, we present a novel strategy in the fuzzy c-means (FCM) framework that simultaneously estimates the bias field while segmenting the image. An additive field term that models the bias field is incorporated into the FCM objective function. We proposed a new term based on the spectral parameterization (i.e., wavelet coefficients) of the bias field that serves as a regularizer to enforce the smoothness of the estimated bias field. We also introduce a second regularization term that causes the labeling of each pixel to be influenced by its immediate neighborhood pixels. The latter regularization term renders the algorithm less sensitive to noise. We show that the novel objective functional could be optimized efficiently using an iterative process, taking advantage of existing fast wavelet transform algorithms. The efficacy of the algorithm is demonstrated on synthesized images as well as on clinical breast MR images. With the synthesize images, segmentation accuracy using standard FCM is 89.07% while segmentation accuracy with the proposed algorithm is 99.95%.

6144-49, Session 9

Apparent diffusion coefficient estimation from high-angular resolution diffusion images

M. Descoteaux, R. Deriche, Institut National de Recherche en Informatique et en Automatique (France)

High angular resolution diffusion imaging (HARDI) has recently been of great interest to characterize non-Gaussian diffusion process. In the white matter of the brain, this occurs when fiber bundles cross, kiss or diverge within the same voxel. One of the important goal is to better describe the apparent diffusion process in these multiple fiber regions, thus overcoming the limitations of classical diffusion tensor imaging (DTI). In this paper, we design the appropriate mathematical tools to describe noisy HARDI data. Using a meaningful modified spherical harmonics basis to capture the physical constraints of the problem, we propose a new regularization algorithm to estimate a smoother and closer diffusivity profile to the true diffusivities without noise. We exploit properties of the spherical harmonics to define a smoothing term based on the Laplace-Beltrami for functions defined on the unit sphere. An additional contribution of the paper is the derivation of the general transformation taking the spherical harmonics coefficients to the high order tensor independent elements. This allows the careful study of the state of the art high order anisotropy measures computed from either spherical harmonics or tensor coefficients. We analyze their ability to characterize the underlying diffusion process. We are able to recover voxels with isotropic, single fiber anisotropic and multiple fiber anisotropic diffusion. We test and validate the approach on diffusion profiles from synthetic data and from a biological rat phantom.

6144-50, Session 9

Restoration of 3D medical images with total variation scheme on wavelet domains (TVW)

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The multiplicity of sensors used in medical imaging leads to different noises. Non informative noise can damage the image interpretation process and the performance of automatic analysis. The method proposed in this paper allows compensating highly noisy image data from non informative noise without sophisticated modeling of the noise statistics.

This generic approach uses jointly a wavelet decomposition scheme \cite{donoho94} and a non-isotropic Total Variation filtering \cite{rudin92} of the transform coefficients. This framework benefits from both the hierarchical capabilities of the wavelet transform and the well-posed regularization scheme of the Total Variation. This algorithm has been tested and validated on test-bed data, as well as different clinical MR and 3D ultrasound images, enhancing the capabilities of the proposed method to cope with different noise models.

6144-51, Session 9

A pixelwise inpainting-based refinement scheme for quantizing calcification in the lumbar aorta on 2D lateral x-ray images

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In this paper we seek to improve the standard method of assessing the degree of calcification in the lumbar aorta visualized on lateral 2-D X-rays. The semiquantitative method does not take density of calcification within the individual plaques into account and is unable to measure subtle changes in the severity of calcification over time. Both of these parameters would be desirable to assess, since they are the keys to assessing important information on the impact of risk factors and candidate drugs aiming at the prevention of atherosclerosis.

We previously proposed a method to estimate the background of a calcification using inpainting-based methods and measure the plaque density as the difference between the background estimation and the original image. This work describes a pixelwise refinement scheme that, starting from a coarse manual initialization at the calcification contour, finds the contour that optimizes the Signal-to-Noise Ratio (SNR) of the image w.r.t. the estimated background; thus improving the measurements of calcified area and plaque density. Furthermore, we compare total variation inpainting with harmonic inpainting and discuss the potential implications of inpainting and intensity averaging for characterizing aortic calcification.

6144-52, Session 10

Sparse modeling of landmark and texture variability using the orthomax criterion

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In the past decade, statistical shape modeling has been widely popularized in the medical image analysis community. Predominantly, principal component analysis (PCA) has been employed to model biological shape variability. Hence a reparameterization with orthogonal basis vectors is obtained such that the variance of the input data is maximized. This property drives models toward global shape deformations and has been highly successful in fitting shape models to new images. However, recent literature has indicated that this uncorrelated basis may be suboptimal for exploratory analyses and disease characterization.

This paper explores the orthomax class of statistical methods for transforming variable loadings into a simple structure which is more easily interpreted by favoring sparseness. Further, we introduce these transformations into a particular framework traditionally based on PCA; the Active Appearance Models (AAMs). We note that the orthomax transformations are independent of domain dimensionality (e.g. 2D/3D) and spatial structure. Decompositions of both shape and texture models are carried out. Further, issues of component selection and ordering are treated by establishing a set of relevant criteria and discussing their merits in relation to medical image interpretation. Experimental results are given on chest radiographs, magnetic resonance images of the brain, and face images. Since pathologies are typically spatially localized, either with respect to shape or texture, we anticipate many medical application areas where the presented sparse parameterizations are preferable to the conventional global PCA approach.

6144-53, Session 10

A representation and classification scheme for tree-like structures in medical images: an application on branching pattern analysis of ductal trees in x-ray galactograms

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We propose a multi-step approach for representing and classifying tree-like structures in medical images. Examples of such tree-like structures are encountered in the bronchial system, the vessel topology and the breast ductal network. We assume that the tree-like structures are already segmented. To avoid the tree isomorphism problem we obtain the breadth-first canonical form (BFCF) for each tree. Our approach is based on employing tree encoding techniques, such as the Prufer encoding, to obtain a symbolic string representation of the trees. Thus, the problem of classifying the trees is reduced to string classification where node labels comprise the string terms. We employ the tf-idf text mining technique to assign a weight of significance to each string term (i.e., tree node label), indicating terms that form discriminative branching patterns. We perform k-nearest neighbor classification of the tree-like structures using the cosine similarity metric to calculate the distances of the tf-idf weight vectors. We applied our approach to breast ductal network trees manually extracted from clinical x-ray galactograms. The goal was to characterize the ductal tree-like parenchymal structures and perform classification to distinguish among patients with reported galactographic findings and normal subjects. The classification accuracy reached up to 95% for certain experimental settings (k=1) illustrating the effectiveness of the proposed approach for analyzing tree-like patterns in breast images. Developing automated tools for effectively characterizing and classifying tree-like structures in medical images would provide great insight to the relationship between the topology of branching and function or pathology.

6144-54, Session 10

Three-dimensional analysis of alveolar bone resorption by image processing of 3D dental CT images

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We have developed a novel system that provides a total support for assessment of alveolar bone resorption, caused by periodontitis, based on three-dimensional (3-D) dental CT images. In spite of the difficulty in perceiving the complex 3-D shape of resorption, assessment of its location and severity has been relying on two-dimensional radiography and probing, which merely provides one-dimensional information (depth) on the shape of resorption. However, there has been little work on assisting assessment of the disease by 3-D image processing and visualization techniques.

Our system provides quantitative evaluation results and figures regarding the three-dimensional shape and spread of the resorption. It has the following functions: (1) measurement of the depth of resorption by virtually simulating probing in the 3-D CT images, taking advantage of image processing of not suffering from the teeth on the inter-proximal sides and much smaller measurement intervals than the conventional examination, (2) visualization of the disposition of the depth by movies and graphs, (3) producing a quantitative index and intuitive virtual representation of the spread of resorption in the inter-radicular region in terms of area, and (4) calculation of the volumes of resorption as another severity indexes in the inter-radicular region and the region outside of it.

Experimental results on a 3-D dental CT data set and the comparison with the clinical examination results of the corresponding patient confirmed that the proposed system gives satisfying results, including 0.4 mm of resorption measurement (probing) error and fairly intuitive presentation of measurement and calculation results.

6144-55, Session 10

Optimal landmark distributions for statistical shape model construction

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Minimizing the description length (MDL) is one of the most promising methods to automatically generate 3D statistical shape models. By modifying an initial landmark distribution according to the MDL cost function, points across the different training shapes are brought into correspondence. A drawback of the current approach is that the user has no influence on the final landmark positions, which often do not represent the modeled shape adequately. We extend an existing remeshing technique to work with statistical shape models and show how the landmark distribution can be modified anytime during the model construction phase. This procedure is guided by a control map in parameter space that can be set up to produce any desired point distribution, e.g. equally spaced landmarks. To compare our remeshed models with the original approach, we generalize the established generalization and specificity measures to be independent of the underlying landmark distribution. This is accomplished by switching the internal metric from landmark distances to the Tanimoto coefficient, a volumetric overlap measure. In a concluding evaluation, we generate models for two medical datasets with and without landmark redistribution. As the outcome reveals, redistributing landmarks to an equally spaced distribution during the model construction phase improves the quality of the resulting models significantly if the shapes feature prominent bulges or other complex geometry.

6144-56, Session 10

An iso-surface folding analysis method applied to premature neonatal brain development

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Preterm birth often results in learning and neuromotor disabilities. There is limited understanding of the process of brain development in full-term and preterm infants, and of how brain abnormalities are associated with adverse outcome.

Specifically, it is not known how cortical folding, or gyrification, in the preterm brain changes over time. The goal of this study is to provide a formal, sensitive, and quantitative methodology for the assessment of cerebral folding in the premature infant. Traditional 2D methodologies neglect valuable 3D information and are potentially insensitive to subtle changes in gyrification. In this study, nine measures of folding, computed either from curvature or geometric properties, were applied to cortical gray and white matter surfaces extracted from ten magnetic resonance images of seven neonatal preterms. Age ranged from 28 to 36 weeks, a period of intense changes that has not been previously studied with curvature. Some of the measures have been previously applied to cortical gray matter, but none has been applied to in-vivo data nor cortical white matter.

Curvature and geometric properties were calculated from iso-intensity surfaces of cortical gray and white matter. All folding measures increased significantly with age, and followed an approximately linear form. A preliminary validation of parameter selection and measure behavior was done on analytic surfaces. In conclusion, two surface-based and three curvature-based measures were among the most reliable to assess gyrification in the premature brain. Cortical white matter appears to be as suitable as cortical gray matter to study folding.

6144-57, Session 10

Image-based metrology of porous tissue engineering scaffolds

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Tissue engineering is an interdisciplinary effort aimed at the repair and regeneration of biological tissues through the application and control of cells, porous scaffolds and growth factors. The regeneration of specific tissues guided by tissue analogous substrates is dependent on diverse scaffold architectural indices that can be derived quantitatively from the microCT and microMR images of the scaffolds. However, the randomness of pore-solid distributions in conventional stochastic scaffolds presents unique computational challenges. As a result, image-based characterization of scaffolds has been predominantly qualitative. In this paper, we discuss quantitative image-based techniques that can be used to compute the metrological indices of porous tissue engineering scaffolds. While bulk averaged quantities such as porosity and surface are derived directly from the optimal pore-solid delineations, the spatially distributed geometric indices are derived from the medial axis representations of the pore network. The computational framework proposed (to the best of our knowledge for the first time in tissue engineering) in this paper might have profound implications towards unraveling the symbiotic structure-function relationship of porous tissue engineering scaffolds.

6144-58, Session 11

Automated planning of MRI neuro scans

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In clinical MRI examinations, the geometry of diagnostic scans is defined in an initial planning phase. The operator plans the scan volumes (off-centre, angulation, field-of-view) with respect to patient anatomy in low-resolution survey images. Often multiple plans are required for a patient, further distracting attention from the patient waiting in the scanner. A novel and robust method is described for automated planning of neurological MRI scans, capable of handling strong shape deviations from healthy anatomy. The expert knowledge required to position scan geometries is learned from previous example plans, allowing site-specific styles to be readily taken into account.. The proposed method first fits an anatomical model to the scout data, and then new scan geometries are positioned with respect to extracted landmarks. The accuracy of landmark extraction was measured to be comparable to the inter-observer variability, and automated plans are shown to be highly consistent with plans created by expert operators using clinical data. The evaluation results demonstrate the robustness and applicability of the proposed approach, which has the potential to significantly improve clinical workflow.

6144-59, Session 11

A classification framework for content-based extraction of biomedical objects from hierarchically decomposed images

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Multi-scale analysis provides a complete hierarchical partitioning of images into visually plausible regions. Each of them is formally characterized by a feature vector describing shape, texture, and scale properties. Consequently, object extraction becomes a classification of the feature vectors. Classifiers are trained by relevant and irrelevant regions labeled as object and remaining partitions, respectively. A trained classifier is applicable to yet uncategorized partitionings to identify the corresponding region's classes. Such an approach enables retrieval of a-priori unknown objects within a point-and-click interface. In this work, the classification pipeline consists of a framework for data selection, feature selec-

tion, classifier training, classification of testing data, and evaluation. According to the no-free-lunch-theorem of supervised learning, the appropriate classification pipeline is determined experimentally. Therefore, each of the steps is varied by state-of-the-art methods and the respective classification quality is measured. Selection of training data from the ground truth is supported by bootstrapping, variance pooling, virtual training data, and cross validation. Feature selection for dimension reduction is performed by linear discriminant analysis (LDA), principal component analysis (PCA), and greedy selection. Competing classifiers are k-Nearest-Neighbor, Bayesian Classifier, and the Support Vector Machine (SVM). Quality is measured by precision and recall to reflect the retrieval task. A set of 105 hand radiographs from clinical routine serves as ground truth, where the metacarpal bones have been labeled manually. In total, 368 out of 39.017 regions are identified as relevant. In initial experiments for feature selection with the support vector machine have been obtained recall, precision and F-measure of 0.60, 0.71, and 0,65, respectively.

6144-60, Session 11

A pattern recognition approach to enhancing structures in 3D CT data

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In medical image processing, several attempts have been made to develop filters which enhance certain structures in 3D CT data using information from the Hessian matrix. These filters also tend to respond to other structures, e.g. most vessel enhancement filters also enhance nodule-like objects. In this paper, we use pattern recognition techniques to design more optimal filters. The essential difference with previous approaches is that we provide a system with examples of what it should enhance and suppress. These examples are used to train a classifier that determines the probability that a voxel in an unseen image belongs to the desired structures. The advantages of such an approach are excellent performance and flexibility: it can be used for any structure by providing the appropriate examples. We evaluated our approach on enhancing pulmonary fissures, which appear as plate-like structures in 3D CT chest scans. We compared our approach to the results of a recently proposed fissure enhancement filter. The results show that both methods are able to enhance the fissures, but our approach shows better performance; the areas under de ROC curves are 0.9044 for our method and 0.7650 for the fissure enhancement filter.

6144-61, Session 11

Blood detection in wireless capsule endoscopy using expectation maximization clustering

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Wireless Capsule Endoscopy (WCE) is a relatively new technology (FDA approved in 2002) allowing doctors to view most of the small intestine. Other endoscopies such as colonoscopy, upper gastrointestinal endoscopy, push enteroscopy, and intraoperative enteroscopy could be used to visualize up to the stomach, duodenum, colon, and terminal ileum, but there existed no method to view most of the small intestine without surgery. With the miniaturization of wireless and camera technologies came the ability to view the entire gestational track with little effort. A tiny disposable video capsule is swallowed, transmitting two images per second to a small data receiver worn by the patient on a belt. During an approximately 8-hour course, over 55,000 images are recorded to a worn device and then downloaded to a computer for later examination. Typically, a medical clinician spends more than two hours to analyze a WCE video. Research has been attempted to automatically find abnormal regions (especially bleeding) to reduce the time needed to analyze the videos. The manufacturers also provide the software tool to detect the bleeding called Suspected Blood Indicator (SBI), but its accuracy is not high enough to replace human examination. It was reported that the sensitivity and the specificity of SBI were about 72% and 85%, respectively. To address this problem, we propose a technique to detect the bleeding regions automatically utilizing the Expectation Maximization (EM) clustering algorithm. Our experimental results indicate that the proposed bleeding detection method achieves 92% and 98% of sensitivity and specificity, respectively.

6144-62, Session 11

Functional feature subspace mapping of fMRI data in the spectral domain

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We propose a new method for the analysis of functional magnetic resonance imaging (fMRI) which is called functional feature subspace mapping (FFSM). We mainly focused on the experimental design with periodic stimuli which can be described by a number of Fourier coefficients in the spectral domain. Then the subspace is obtained through the dimension reduction technique. Finally, the presence of activated time series is identified by the clustering method. Experiments with simulated data and the real human experiments are conducted to demonstrate that the algorithm we proposed is feasible. Although we focus on analyzing periodic fMRI data, the approach could be extended to analyze non-periodic fMRI data (event-related fMRI) by replacing the spectral analysis with a wavelet analysis.

6144-63, Session 11

Analysis of first-pass myocardial perfusion MRI using independent component analysis

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Myocardial perfusion MRI has emerged as a suitable imaging technique for the detection of ischemic regions of the heart. However, manual post-processing is labor intensive, seriously hampering its daily clinical use. We propose a novel, data driven analysis method based on Independent Component Analysis (ICA). By performing ICA on the complete perfusion sequence, physiologically meaningful feature images, representing events occurring during the perfusion sequence, can be factored out. Results obtained using our method are compared with results obtained using manual contouring by a medical expert. The estimated weight functions are correlated against the perfusion time-intensity curves from manual contours, yielding promising results.

6144-64, Session 11

Learning image similarity to detect breast cancer

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Radiologists often use the differences between the left and right breasts, or asymmetry, in mammograms to detect certain malignant breast cancers. An image similarity method is introduced to make use of this knowledge base to recognize breast cancer. Image similarity is determined using a contextual and then a spatial comparison. The mammograms are filtered to find the most contextually significant points, and then the resulting point set is analyzed for spatial similarity. We develop the analysis through a combination of modeling and supervised learning of model parameters. This process correctly classifies mammograms 80% of the time and thus asymmetry is a measure that can play an important role in significantly improving computer-aided breast cancer detection systems.

6144-65, Session 12

Probabilistic nodule filtering in thoracic CT scans

G. Agam, C. Wu, Illinois Institute of Technology

Automated detection of lung nodules in thoracic CT scans is an important clinical challenge. Blood vessels form a major source of false positives in automated nodule detection systems. Hence, the performance of such systems may be improved by enhancing nodules while suppressing blood vessels. Ideally, nodule enhancement filters should enhance nodules while suppressing vessels and lung tissue. A distinction between vessels and nodules is normally obtained through eigenvalue analysis of the Hessian matrix. The Hessian matrix is a second order differential quantity and so is sensitive to noise. Furthermore, by relying on principal curvatures alone, existing filters are incapable of distinguishing between nodules and vessel junctions, and are incapable of handling cases in which nodules touch vessels. In this paper we develop novel nodule enhancement filters that are capable of suppressing junctions and are capable of handling cases in which nodules appear to touch or even overlap with vessels. The proposed filters are based on optimized probabilistic models derived from eigenvalue analysis of the structure tensor which is a first order differential quantity and so are less sensitive to noise compared with known vessel enhancement filters. The proposed filters are evaluated and compared to known techniques both qualitatively, quantitatively. The evaluation includes both synthetic and actual clinical data.

6144-66, Session 12

Development of computerized scheme for detection of very subtle lung nodules located in opaque areas on chest radiographs

J. Shiraishi, K. Doi, The Univ. of Chicago

The detection of lung nodules located in opaque areas including mediastinum, retrocardiac lung and lung projected below or on diaphragm was very difficult, because the contrast of these nodules was commonly extremely low, and sometimes their locations were out of radiologists' visual fields. In this study, we have developed a new computer-aided diagnostic (CAD) scheme designated specifically for the detection of these difficult lung nodules located in opaque areas. The database of 73 chest images (73 very difficult lung nodules) was selected from 1000 chest images with 1076 lung nodules by taking into account their locations. In this computerized scheme, a lung field including opaque areas was segmented with a ribcage detection technique first, and then opaque areas were segmented by use of an adoptive multi-thresholding method based on edge gradient values. Initial candidates were identified by use of a nodule-enhancement filter technique based on radial gradient values. Forty-five image features extracted from the original and nodule-enhancement images were employed for the rule-based scheme to remove some false positive candidates. Finally, linear discriminant analysis (LDA) and/or artificial neural network (ANN) was applied in order to remove some of remaining false positive candidates. Preliminary results obtained by use of the LDA classifier indicated that the average sensitivity in detecting lung nodules was 54.8 % with 1.62 false positives per image, which was considered "acceptable", because these nodules were very subtle and difficult to be detected. By combining this advanced CAD scheme with our standard CAD scheme for lung nodule detection, we assumed that the clinical usefulness of the CAD scheme would be significantly improved.

6144-67, Session 12

Computerized detection of pulmonary nodules using a combination of 3D global and local shape information based on helical CT images

X. Zhang, M. Sonka, The Univ. of Iowa

A new method for computerized detection of pulmonary nodules based on helical CT images was proposed. This scheme uses a combination of 3D global and local shape information. By combining local shape properties into the global tracking procedure of normal overlap, the proposed method solves the ambiguities of normal overlap between a small size sphere and a possible large size cylinder, as the normal overlap technique can only measures the 'density' of normal overlapping, while how the normal vectors are distributed in 3D is ignored. Testing showed that this method can be utilized to do small size pulmonary nodule detection, giveing a better results compared to the orignal normal overlap technique. 40 clinical thoracic CT cases collected in lung cancer early screening program with 106 small nodules (most of them are smaller than 10mm forms our datebase. This method is able to give a sensitivity around 90% with about 30 FPs, which is much better than the results of the original surface normal overlap method, a same sensitivity with more than 100 FPs.

6144-68, Session 12

Automated detection of ureter abnormalities on multidetector row CT urography

L. M. Hadjiiski, B. Sahiner, E. M. Caoili, R. H. Cohan, H. Chan, Univ. of Michigan

We are developing a CAD system for automated detection of ureter abnormalities on multi-detector row CT urography, which potentially can assist radiologists in detecting ureter cancer. In the first stage of our CAD system given an initial starting point, the ureter is tracked based on the CT values of the contrast-filled lumen. In the second stage, lesion candidates are detected using histogram and shape analysis to separate the abnormality from the background, which is the ureter filled with contrast material. A uniformity measure is designed to detect non-uniformity of the CT values within the ureter volume. If ureter abnormality is present, the CT values uniformity will be distorted, resulting in a reduced uniformity measure. The smoothness of the ureter wall is also estimated using a shape measure. A rule-base system is used to combine the two measures. In this pilot study, a limited data set of 11 patients with biopsy-proven lesions was used. Nine patients had 12 ureter cancers and 6 benign lesions. Two patients had 2 benign lesions. The average lesions size for the 12 cancers was 7.8 mm (range: 2.1 mm - 19.5mm). The tracking program successfully tracked the ureters in 10 of the patients. Our system detected 75% (15/20) of the ureter lesions with 2.6 (28/11) false positives per patient. 83% (10/12) of the ureter cancers were detected. The preliminary results show that our detection system can track the ureter and detect ureter cancer of medium conspicuity and relatively small size.

6144-69, Session 12

Biplane correlation imaging for lung nodule detection: initial human subject results

N. Majdi Nasab, E. Samei, J. T. Dobbins III, Duke Univ. Medical Ctr.

In this paper, we present performance of Biplane Correlation Imaging (BCI) on set of chest x-ray projections of human data. BCI significantly minimized the number of False Positives (FPs) when used in conjunction with Computer Aided Detection (CAD) by eliminating non-correlated nodule candidates.

Sixty-one low exposure posterior projections were acquired from more than 20 human subjects with small angular separations (0.32 degree) over a range of 20 degrees along the vertical axis. All patients were previously diagnosed for the presence of lung nodules based on Computed Tomography (CT) examination. Images were processed following two steps. First, all images were analyzed using our CAD routine for chest radiography. This process proceeded with a BCI processing in which the results of CAD on each single projection were examined in terms of their geometrical correlation with those found in the other 60 projections based on the predetermined shift of possible nodule locations in each projection. The suspect nodules with a geometrical correlation that coincided with the known location of the lesions were selected as nodules; otherwise they were ignored. An expert radiologist with reference to the associated CT dataset determined nodule location and sizes.

The preliminary results indicated that the best performance was obtained when the angular separation of the projection pair was greater than about 6.7 degrees. Within the range of optimum angular separation, the number of FPs per image was 0-1 without impacting the number of TPs, averaged around 92%.

6144-70, Session 12

A method to increase the number of masses cued by a CAD scheme on both CC and MLO views

B. Zheng, G. Maitz, J. K. Leader, D. Gur, Univ. of Pittsburgh

In currently clinical practice, radiologists often discard CAD-cued masses, in particular when a subtle finding is cued only on one view. In this study, we presented a method to increase the number of masses cued by CAD on both ipso-lateral views. An image database involving 235 positive and 200 negative cases was used. A CAD scheme with an image registration module was applied to process these images. For each detected suspicious region with score ≥0.55 (a pre-optimized threshold), the scheme defined a matched strip located on the corresponding ipso-lateral image and searched for another suspicious region located inside the strip by gradually reducing the detection threshold (increasing detection sensitivity). Once a region was found inside the strip, a matched pair of two regions was cued on both views. Otherwise, unmatched regions were deleted. CAD scheme initially detected 172 masses and 576 false-positives. In 172 masses, 90 were detected on two views (52%) and 82 were detected on only one view. In false-positive detections, 72 pairs (14%) were considered "matched" and 432 were not, which resulted in 504 "independent" cues. The case-based sensitivity and false-positive rate of CAD scheme were 73.2% and 1.16 per case. By increasing detection sensitivity inside the matched strips, 160 masses and 308 false-positives were cued on two views. By reducing the operating threshold to 0.49, CAD scheme cued 172 masses and 413 false-positives on two views, which maintained the same sensitivity and reduced false-positive rate by 18%. The study suggested that cueing only the matched regions could substantially eliminate false-positive cues and the reduction in false positive cues could then be used to reduce CAD operating threshold to regain sensitivity with "more subtle" (lower score) masses that are now cued on both views.

6144-71, Session 13

Reconstruction-independent 3D CAD for mass detection in digital breast tomosynthesis using fuzzy particles

G. Peters, S. L. Muller, S. Bernard, R. Iordache, GE Healthcare (France); I. Bloch, Ecole Nationale Supérieure de Télécommunications (France)

In this paper we present a novel approach for masses detection in Digital Breast Tomosynthesis (DBT) datasets. A reconstruction-independent approach, working directly on the projected views, is proposed. Wavelet filter responses on the projections are thresholded and combined to obtain candidate masses. For each candidate, we create a fuzzy contour through a multi-level thresholding process. We introduce a fuzzy set definition for the class "mass contour" that allows the computation of fuzzy membership values for each candidate contour. Then, an aggregation operator is presented that combines information over the complete set of projected views, resulting in 3D fuzzy particles. A final decision is made taking into account in-formation acquired over different successive processing steps. The performance assessment is then con-ducted on the 3D fuzzy particles in 3D space. Preliminary results on a database of 11 DBT cases (7 malignant mass lesions, 4 cases with no mass lesion) resulted in a sensitivity of 0.86 at 3.5 false positives per im-age set.

6144-72, Session 13

Micro-calcification detection in digital tomosynthesis mammography

F. W. Wheeler, A. A. Perera, B. E. Claus, GE Global Research; S. L. Muller, G. Peters, GE Healthcare (France); J. P. Kaufhold, Science Applications International Corp.

A novel technique for the detection and enhancement of microcalcifications in digital tomosynthesis mammography (DTM) is presented. In this method, the DTM projection images are used directly, instead of using a 3D reconstruction. Calcification residual images are computed for each of the projection images. Calcification detection is then performed over 3D space, based on the values of the calcification residual images at projection points for each 3D point under test. The quantum, electronic, and tissue noise variance at each pixel in each of the calcification residuals is incorporated into the model-based detection algorithm. The 3D calcification detection algorithm finds a minimum variance estimate of calcification attenuation present in three-dimensional space based on the signal and variance of the calcification residual images at the corresponding points in the projection images. The method effectively detects calcifications in 3D in a way that both ameliorates the difficulties of joint tissue/microcalcification tomosynthetic reconstruction (streaks artifacts, etc.) and exploits the well understood image properties of microcalcifications in 2D mammograms. In this method, three-dimensional reconstruction and calcification detection and enhancement are effectively combined to create a calcification detection specific reconstruction. Motivation and details of the technique and statistical results for DTM data are provided.

6144-73, Session 13

Computer-aided detection of breast masses on mammograms: bilateral analysis for false positive reduction

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

In this study, our purpose was to develop an FP reduction method for mass detection CAD systems based on the analysis of bilateral mammograms. We first detect the mass candidates on each view by utilizing our single-view mass detection CAD system. For each detected object, we applied our regional registration technique and defined a region of interest (ROI) that was "symmetrical" to the object location on the contralateral mammogram. Spatial gray level dependence matrices (SGLD) texture features were extracted from both the ROI containing the detected object and its corresponding ROI on the contralateral mammogram. Similarity measures of the texture features were formed and a symmetry classifier was trained to differentiate symmetric from asymmetric ROIs. To evaluate bilateral FP reduction, we used a lax threshold at which the single-view mass detection system detected 91% (71/78) of the masses with an average of 3.8 FPs/image. It was found that the symmetry classifier achieved a test Az of 0.83±0.03. 15% of the FPs could be eliminated without missing any additional masses (100% sensitivity) and 34% of the FPs could be excluded at 97% (69/71) sensitivity.

6144-74, Session 13

Digital bowel cleansing for computer-aided detection of polyps in fecal-tagging CT colonography

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Tagging of feces by an X-ray-opaque oral contrast agent opacifies residual solid stool and fluid in the colon, and thus it is a promising method for differentiating residual feces from polyps and improving specificity in the detection of polyps in CT colonography (CTC). Digital bowel cleansing (DBC) is an emerging method to segment the tagged fecal material,

effectively removing it from the CTC images. Existing DBC approaches tend to use simple thresholding-based methods for the removal of tagged feces; however, because of the pseudo enhancement of the polyps caused by the surrounding tagged feces, such methods tend to erroneously remove a part or the entire polyps submerged in tagged feces, causing false negatives in computer-aided detection (CAD) of polyps. In this study, we developed a novel DBC method that preserves the soft-tissue structures submerged in or partially covered by tagged feces. In our approach, submerged soft-tissue structures are characterized by their local shape signatures calculated based on the eigenvalues of Hessian matrices. A structure-enhancement function is formulated to enhance the soft-tissue structures, and the values of the function are integrated into the speed function of a level-set method to delineate the submerged soft-tissue structures while removing the tagged feces. In an analysis of 16 CTC cases including 26 submerged polyps, our new DBC method was able to delineated all of the polyps while eliminating most of the tagged stool. Application of our CAD to the digitally cleansed colon detected all but one polyp, yielding 96% sensitivity.

6144-75, Session 13

Quantitative analysis of two-phase 3D and time aortic MR images

F. Zhao, H. Zhang, N. E. Walker, F. Yang, M. E. Olszewski, T. D. Scholz, M. Sonka, The Univ. of Iowa

Automated and accurate segmentation of the aorta in 3D+time MR image data is important for early detection of connective tissue disorders leading to aortic aneurysms and dissections. A computer-aided diagnosis method is reported that allows the objective identification of subjects with connective tissue disorders from two-phase 3D+time aortic MR images. Our automated segmentation method combines level-set and optimal border detection. The resulting aortic lumen surface was registered with an aortic model followed by calculation of modal indices of aortic shape and motion. The modal indices reflect the differences of any individual aortic shape and motion from an average aortic behavior. The indices were input to a Support Vector Machine (SVM) classifier and a discrimination model was constructed. 3D+time MR image data sets acquired from 22 normal and connective tissue disorder subjects at end-diastole (R-wave peak) and at 45% of the R-R interval were used to evaluate the performance of our method. The automated 3D segmentation result produced accurate aortic surfaces covering the aorta from the left-ventricular outflow tract to the diaphragm and yielded subvoxel accuracy with signed surface positioning errors of -0.09±1.21 voxel (-0.15±2.11 mm). The computer aided diagnosis method distinguished between normal and connective tissue disorder subjects with a classification correctness of 90.1 %.

6144-76, Session 13

Two-view information fusion for improvement of computer-aided detection (CAD) of breast masses on mammograms

J. Wei, B. Sahiner, L. M. Hadjiiski, H. Chan, M. A. Helvie, M. A. Roubidoux, C. Zhou, J. Ge, Y. Zhang, Univ. of Michigan

We are developing an information fusion method to improve the performance of our CAD system for mass detection by using information from two mammographic views. Mass candidates on each mammogram were first detected with our single-view CAD system. In our information fusion scheme, we first identified potential object pairs on the two-view mammograms by using the object size and the distance between the object and the nipple. These object pairs can include TP-TP, TP-FP, or FP-FP pairs. Morphological features and correlation coefficients between the two paired objects were then used as input to train a similarity classifier that estimated a similarity score for each pair. Finally, the linear discriminant classifier (LDA) score of an object from the single-view CAD system was modified by adding a weighted average of the similarity scores of all paired objects on the other view to fuse the two-view information. A data set of 331 patients containing 662 mammograms with 331 biopsy-proven masses was used to evaluate the CAD system. All cases contained the CC view and the MLO or LM view. We randomly divided the data set into two independent sets: 166 cases for training and 165 cases for testing. The area under the ROC curve was 0.88 when the similarity measures were used to distinguish the TP-TP pairs from the TP-FP and FP-FP pairs on the independent test set. At the case-based sensitivities of 90%, 85% and 80% on the test set, the single-view CAD system achieved an FP rate of 2.0, 1.6, and 1.1 FPs/image, respectively. With the two-view fusion system, the FP rates were reduced to 1.6, 1.1, and 0.7 FPs/image, respectively, at the corresponding sensitivities. The improvement was found to be statistically significant (p=0.003) by the AFROC method. Our results indicate that the two-view fusion scheme can improve the performance of mass detection on mammograms.

6144-77, Session 13

Comparison of breast ductal branching pattern classification using x-ray galactograms and MR autogalactograms

P. R. Bakic, M. A. Rosen, A. D. Maidment, Univ. of Pennsylvania

We have analyzed the branching patterns of the breast ductal network visible in magnetic resonance (MR) autogalactograms - images of breast ducts which appear enhanced due to the presence of proteinacous or hemorrhagic material in the ducts. The enhanced portions of the ductal network were segmented separately in MRI slices acquired with a 3D GRASS sequence. A semi-automated ITK-based region growing algorithm was used for segmentation. The ductal network was manually constructed from the segmented portions in each slice. The branching pattern was analyzed by calculating ramification (R-)matrices, whose elements represent probabilities of branching at various levels of a ductal network. The calculated R-matrix elements have been used to classify the analyzed cases into those with and without radiological findings. The classification accuracy was estimated using the radiologists' reports as ground truth. Six analyzed cases have been correctly classified; four patients had malignant or benign findings reported by radiologists and two had no reported findings. In a previously published study, we observed 87% accuracy of classifying 2D x-ray galactograms of 15 patients, based on the corresponding R-matrix elements as in our current MR study. The two studies differed in the number of visible ducts since MRI has a lower spatial resolution compared to x-ray galactography. In addition, x-ray galactograms also had more uniform enhancement of the ductal network because an iodinated contrast agent is injected directly into ductal network, while in MR autogalactograms there is only partial enhancement of the ductal network.

6144-601, Session W4B

Current performance levels of CADe and CADx systems: without and with the human

D. Gur, Univ. of Pittsburgh; H. Chan, Univ. of Michigan

No abstract available

6144-602, Session W4B

Opportunities for improved computer performance

R. M. Nishikawa, The Univ. of Chicago; J. Y. Lo, Duke Univ.

No abstract available

6144-603, Session W4B

What actually do radiologists want?

H. L. Kundel, S. C. Horii, Univ. of Pennsylvania

No abstract available

6144-78, Poster Session

Validation of elastic registration algorithms based on adaptive irregular grids for medical applications

A. Franz, I. C. Carlsen, S. Renisch, H. Wischmann, Philips Research Labs. (Germany)

Elastic registration of medical images is an active field of current research. Registration algorithms have to be validated in order to show that they fulfill the requirements of a particular clinical application.

Furthermore, validation strategies compare the performance of different registration algorithms and can hence judge which algorithm is best suited for a target application. In the literature, validation strategies for rigid registration algorithms have been analyzed. For a known ground truth they assess the displacement error at a few landmarks, which is not sufficient for elastic transformations described by a huge number of parameters. Hence we consider the displacement error averaged over all pixels in the whole image or in a region-of-interest of clinical relevance.

Using artificially, but realistically deformed images of the application domain, we use this quality measure to analyze an elastic registration based on transformations defined on adaptive irregular grids for the following clinical applications: Magnetic Resonance (MR) images of freely moving joints for orthopedic investigations, abdominal Computed Tomography (CT) images for adaptive radiation therapy planning, and transmission images as used for the attenuation correction and registration of independently acquired Positron Emission Tomography (PET) and CT images.

The definition of a region-of-interest allows to restrict the analysis of the registration accuracy to clinically relevant image areas. The behaviour of the displacement error as a function of the number of transformation control points and their placement can be used for identifying the best strategy for the initial placement of the control points.

6144-79, Poster Session

A strategy based on maximum spanning trees to stitch together microscope images

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Assembling partial views is an attractive means to extend the field of view of microscope images. In this paper, we propose a semi-automated solution to achieve this goal. Its intended audience is the microscopist who desires to scan a large area while acquiring a series of partial views, but who does not wish—or cannot—planify the path of the scan. In a first stage, this freedom is dealt with by interactive manipulation of the resulting partial views, or tiles. In a second stage, the position of the tiles is refined by a fully automatic pairwise registration process. The contribution of this paper is a strategy that determines which pairs of tiles to register, among all possible pairs.

The central tenet of our proposed strategy is that two tiles that happen to possess a large common area will register with higher accuracy than two tiles with a smaller overlap. Our strategy is then to minimize the number of pairwise registrations while maximizing the global amount of overlap, and while ensuring that the local registration efforts are sufficient to link all tiles together to yield a global mosaic. By stating this requirement in a graph-theoretic context, we are able to derive the optimal solution thanks to Kruskal's algorithm.

6144-80, Poster Session

Weighted medical image registration with automatic mask generation

H. Schumacher, Univ. zu Lübeck (Germany); A. Franz, Philips Research Labs. (Germany); B. Fischer, Univ. zu Lübeck (Germany)

Registration of images is a crucial part of many medical imaging tasks. The problem is to find a transformation which aligns two given images. The resulting displacement fields may be described by a parametric approach, or, as in our case, by a non-parametric approach. Here, the underlying functional consists of a smoothness term ensuring that the transformation is anatomically meaningful and a similarity measure. To be successful, the registration scheme has to be tuned for the problem under consideration. One way of incorporating user knowledge is the employment of weighting masks into the distance measure, and thereby enhancing or hiding dedicated image parts. In general, these masks are based on a given segmentation of both images. We present a method which generates a weighting mask for the second image, given the mask for the first image. The scheme is based on active contours and makes use of a gradient vector flow method. As an example application, we consider the registration of abdominal computer tomography (CT) images used for radiation therapy. The reference image is acquired well ahead of time and is used for setting up the radiation plan. The second image is taken just before the treatment and its processing is time-critical. We show that the proposed automatic mask generation scheme yields similar results as compared to the approach based on a pre-segmentation of both images. Hence for time-critical applications, as intra-surgery registration, we are able to significantly speed up the computation by avoiding a pre-segmentation of the second image.

6144-81, Poster Session

Dedicated registration for DCE MRI mammography

S. Renisch, T. Buelow, I. C. Carlsen, A. Franz, Philips Research Labs. (Germany)

Dynamic contrast enhanced (DCE) MR mammography is currently receiving much interest in clinical research. It bears the potential to discriminate between benign and malignant lesions by analysis of the contrast uptake of the lesion. However, a registration of the individual images of a contrast-uptake series is crucial in order to avoid motion artifacts in the uptake curves, which would affect the diagnosis.

It is on the other hand well known from the registration literature that a registration that uses a standard similarity measure (e.g. mean sum of squared differences, cross-correlation) may cause artifacts if contrast agent is taken up between the images to be registered. Thus we propose a registration on the basis of an application-specific similarity measure that explicitly uses features of the contrast uptake. We report initial results using this registration method.

6144-82, Poster Session

A linear programming based algorithm for determining corresponding point-pairs (k-tuples) in multiple vascular images

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Multi-view imaging is the primary modality for high-spatial-resolution imaging of the vasculature. The 3D vascular structure can be reconstructed if the imaging geometries are determined using known corresponding point-pairs (or k-tuples) in two or more views. Because accuracy improves with more input corresponding point-pairs, we propose a technique to determine corresponding point-pairs in k-view images, from 2D vessel image centerlines. We formulate the problem, first as a multi-partite graph-matching problem. Each 2D centerline point is a vertex; each individual graph contains all vessel-points in an image.

The edge-cost between vertices is the shortest distance between the points' projection-lines. Using this construction, a universe of mappings (k-tuples) is created, each k-tuple having k vertices. A k-tuple's weight is the sum of pair-wise 'costs' of its members. We desire a set of mappings that preserves the ordering along the vessel and minimizes an appropriate global cost function, such that all vertices participate in at least one mapping. We formulate this problem as a special case of Set-Cover problem with additional constraints.

Then, the equivalent linear program is solved and randomized rounding techniques are used to yield a feasible set of mappings. Our algorithm runs in near-linear and achieves ~98% accuracy in simulations and about 90% accuracy in clinical cases. This method should provide the basis for improving the calculated 3D vasculature from multi-view data-sets.

6144-83, Poster Session

Non-rigid registration for fusion of carotid vascular ultrasound and MRI volumetric datasets

R. C. Chan, S. Sokka, Philips Research North America; D. Hinton, S. L. Houser, Massachusetts General Hospital; R. M. Manzke, Philips Research North America; A. Hanekamp, Philips Research USA; V. Reddy, Massachusetts General Hospital; M. R. Kaazempur-Mofrad, Univ of California/Berkeley; V. Rasche, Philips Medical Systems

In carotid plaque imaging, MRI provides exquisite soft-tissue characterization, but lacks the temporal resolution for tissue strain imaging that real-time 3D ultrasound (3DUS) can provide. On the other hand, real-time 3DUS currently lacks the spatial resolution of carotid MRI. Non-rigid alignment of ultrasound and MRI data is essential for integrating complementary morphology and biomechanical information for carotid vascular assessment. We assess non-rigid registration for fusion of US and MRI carotid data based on segmented arterial surface morphology and deformable models which are warped to maximize voxel similarity. We perform validation in vitro using vessel phantom and isolated carotid artery imaging. These samples are subjected to soft-tissue deformations during real-time 3DUS. They are also imaged in the static configuration with standard MR carotid pulse sequences. A subset of image slices with fiducials identified prior to alignment are excluded from use during registration and reserved for validation. Registration of the source ultrasound sequences to the target MR dataset is performed and the mean absolute distance between fiducials within the ultrasound and MR datasets is measured to determine inter-modality alignment quality. Our results indicate that sub-millimeter registration errors are possible for in vitro studies and efforts are underway to characterize in vivo performance with clinical datasets.

6144-84, Poster Session

Evaluation of similarity measures for 3D/2D image registration

D. Skerl, B. Likar, F. Pernu_, Univ. v Ljubljana (Slovenia)

Several 3D/2D registration algorithms for image-guided therapy have been introduced in the past years. Recently, we have proposed a method which first reconstructs a 3D image from a few intraoperative 2D X-ray images and then establishes the rigid transformation between the preoperative 3D CT or MR image and the 3D reconstructed image. The similarity measure applied in this registration method should be able to cope, among others, with the low quality of the reconstructed image. Using the recently proposed similarity measure evaluation protocol, we have evaluated the behavior of five similarity measures. The measures have been evaluated with respect to: a) preoperative imaging modalities (CT and MR); b) number of 2D images used for reconstruction; and c) number of reconstruction iterations. Increasing the number of 2D projections or reconstruction iterations improves the accuracy but slightly worsens the robustness. We have shown that almost all similarity measures have better properties if the optimal parameters are chosen. The most appropriate similarity measure for this type of registration is the asymmetric multi-feature mutual information.

6144-85, Poster Session

Deformable registration using scale space keypoints

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In this paper, we describe a new methodology for keypoint-based deformable medical image registration. This fast and computationally efficient method does not need any segmentation or geometric and anatomical keypoint extraction procedures. Keypoint pixels used in this technique are extreme points in the scale space (formed by applying Gaussian kernels to the images). Extracted from the two images to be registered, keypoints are each characterized by a descriptor vector which summarizes the intensity gradient profile around the pixel. For each of the keypoints, the nearest neighbor in the feature space formed by the keypoints of the other image is chosen as the matching point. A multi-level B-splines method is used to extrapolate a regular deformation grid for all of the pixels in the image based on the relative displacement vectors of the matching pairs. This approach results in fast and accurate registration in brain MRI images. We have also studied the affine registration problem in liver ultrasound and brain MRI images and have acquired precise registrations using a mean square solution for affine parameters based on only around 30 matching keypoint pairs. Inspired by Scale Invariant Feature Transform (SIFT) method recently proposed in computer vision literature, the keypoint extraction and description approach used in the current study proves promising for deformable and affine registration of medical images.

6144-86, Poster Session

Automatic sub-volume registration by probabilistic random search

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Registration of a specific individual's image data set to an anatomical atlas provides valuable information to the physician. In many cases, the individual image data sets are partial data, which may map to one part or one organ among the entire atlas data. However, the most existing intensity based image registration approaches are designed to align the images of entire view. When they are applied on the registration with partial data, the manual pre—registrations are usually required. This paper proposes a fully automatic approach to address the registration of the incomplete image data to the anatomical atlas. The spatial transformations between images are modeled as any parametric functions. The proposed method is built upon a random searching mechanism, which allows to finding the optimal transformation randomly and globally without a close initialization. It works more reliably than the existing methods for the partial data registration because it successfully overcomes the local optimum problem. With appropriate similarity measures, this framework is applicable to both mono—modal and multi—modal registrations with partial data. The contribution of this work is the description of the mathematical framework of the proposed algorithm. The medical evaluation on the MRI data and the comparison of the proposed method with different existing registration methods shows the feasibility and superiority of the proposed method.

6144-87, Poster Session

Physics-based constraints for correction of geometric distortions in gradient echo EP images via nonrigid registration

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Geometric distortion is a well-recognized problem in echo planar (EP) images. One strategy for the correction of these distortions is to register an EP image to a reference image, such as a high resolution anatomical MR image in which geometric distortion is minimal. Non-rigid registration methods, which warp images locally, have been used for this purpose [1-2]. While a physics-based distortion model for spin-echo (SE) EP image has been developed and used as a constraint in nonrigid registration algorithms [2], such a model for gradient-echo (GE) EP image has not been investigated. Here, we propose to use a physics-based model for GE EP image that incorporates a term that takes dephasing into consideration. To evaluate this technique, we generate a distortion-free EP image using an MR simulator we have developed. We then distort the image and modify its intensity values using a real field map and an analytical expression that includes dephasing. The distortion map used to generate these images is the ground truth, which we compare to the deformation field estimated with our non-rigid registration algorithm.

6144-88, Poster Session

An ITK framework for deterministic global optimization for medical image registration

F. T. Dru, M. P. Wachowiak, T. M. Peters, Robarts Research Institute (Canada)

Similarity metric optimization is an essential step in intensity-based rigid and nonrigid medical image registration. For clinical applications, such as image guidance of minimally invasive procedures, registration accuracy and efficiency are prime considerations. In addition, clinical utility is enhanced when registration is integrated into image acquisition, visualization, and post-processing frameworks, such as the popular Insight Toolkit (ITK). ITK is a well-tested software environment increasingly used to aid the development, testing, and integration of new imaging algorithms. In this paper, we present a new ITK-based implementation of the DIRECT (Dividing rectangles) deterministic global optimization approach for medical image registration. Previously, it has been shown that DIRECT improves the capture range and accuracy for rigid registration. Our ITK class also contains enhancements over the original algorithm by improving stopping criteria and by incorporating Powell's method for local refinement. 3D-3D registration experiments with "ground-truth" brain volumes and clinical cardiac volumes show that combining DIRECT with Powell's method improves registration accuracy (for the BrainWeb volumes, < 1 mm and $< 1°$ error, compared to much higher errors with Powell's method), is less sensitive to initial misorientation errors, and, with the new stopping criteria, facilitates adequate exploration of the search space without expending expensive iterations on non-improving function evaluations. Finally, in this framework, a new parallel implementation for computing mutual information is presented, resulting in near-linear speedup with two processors.

6144-89, Poster Session

Interpolation of temporal image sequences by optical flow-based registration

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Modern tomographic imaging devices enable the acquisition of temporal image sequences. In our project, we study cine MRI sequences of patients with myocardial infarction. Because the sequences are acquired with different temporal resolutions, a temporal interpolation is necessary to compare the images at predefined phases of the cardiac cycle.

This paper presents an interpolation method for temporal image sequences. We derive our interpolation scheme from the optical flow equation. The spatiotemporal velocity field between the images is determined using an optical flow based registration method. Here, an iterative algorithm is applied, using the spatial and temporal image derivatives and a spatiotemporal smoothing step. In contrast to other registration-based interpolation approaches [1,2], more than two consecutive slices can be taken into account for the calculation of the velocity field. Afterwards, the calculated velocity field is used to generate an interpolated image at the desired time by averaging intensities between corresponding points.

The behavior and capability of the algorithm is demonstrated on synthetic image examples. Furthermore, quantitative measures are calculated to compare this optical flow-based interpolation method to linear interpolation and shape-based interpolation in 5 cine MRI data sets. Results indicate that the presented method statistically significantly outperforms both linear and shape-based interpolation.

[1] Goshtasby, A., et al.: Matching of tomographic slices for interpolation. IEEE Trans. Medical Imaging 11 (1992)

[2] Penney, G.P., et al.: Registration-based interpolation. IEEE Trans. Medical Imaging 23 (2004)

6144-90, Poster Session

Modeling lung motion using consistent image registration in 4D computed tomography for radiation therapy

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Respiratory motion is a significant source of error in conformal radiation therapy for the thorax and upper abdomen. Four-dimensional computed tomography (4D CT) has been proposed to reduce the uncertainty caused by internal respiratory organ motion. A 4D CT dataset is retrospectively reconstructed at various stages of a respiratory cycle. An important tool for 4D treatment planning is deformable image registration. An inverse consistent image registration is used to model lung motion from one respiratory stage to another during a breathing cycle. This diffeomorphic registration jointly estimates the forward and reverse transformations providing more accurate correspondence between two images. Registration results and modeled motions in the lung are shown for three example respiratory stages. The results demonstrate that the consistent image registration satisfactorily models the large motions in the lung, providing a useful tool for 4D planning and delivering.

6144-92, Poster Session

Enhancing skeletal features in digitally reconstructed radiographs

D. Fu, G. R. Kuduvalli, Accuray Inc.

Generation of digitally reconstructed radiographs (DRR) is a critical part of 2D-3D image registration that is utilized in patient position alignment for image-guided radiotherapy/radiosurgery. The DRRs are generated from a pre-operative CT scan and used as the references to match the X-ray images for determining the change of patient position. Skeletal structures are the primary image features to facilitate the registration between the DRR and X-ray images. In this paper, we present a method to enhance skeletal features of spinal regions in DRRs. The attenuation coefficient at each voxel is first calculated by applying an exponential transformation of the original attenuation coefficient in the CT scan. This is a preprocessing step that is performed prior to DRR generation. The DRR is then generated by integrating the newly calculated attenuation coefficients along the ray that connects the X-ray source and the pixel in the DRR. Finally, the DRR is further enhanced using a weighted top-hat filter. During the entire process, because there is no original CT information lost, even the small skeletal features contributed by low intensity part of CT data are preserved in the enhanced DRRs. Experiments on clinical

data were conducted to compare the image quality of DRRs with and without enhancement. The results showed that the image contrast of skeletal features in the enhanced DRRs is significantly improved. This method has potential to be applied for more accurate and robust 2D-3D image registration.

6144-93, Poster Session

Fully automatic hybrid registration method based on point feature detection without user intervention

B. Koo, J. Lee, Hanyang Univ. (South Korea); J. Kim, Seoul National Univ. (South Korea); I. Kim, Hanyang Univ. (South Korea); J. Kwon, Seoul National Univ. (South Korea); S. I. Kim, Hanyang Univ. (South Korea)

In earlier work (KIM, J.S, MBEC, 2003), we demonstrated the registration method with a non-linear transformation using intensity similarity and feature similarity. Although the former approach showed good match in global shape of brain and feature-defined region, method contains user interventions for defining appropriate and sufficient number features. While manual delineating the region of interests for sufficient number of feature is a very time-consuming and can provide intra-, inter-rater variability, we proposed fully automatic hybrid registration via automatic feature defining method. Automatic feature definition was performed on the cortical surface from CLASP (KIM, J.S, Neuroimage, 2005) with using cortical surface matching algorithm (Robbins, S., MIA, 2004) and then applied to hybrid registration. The object of this work is to develop fully automated hybrid registration method which reveals enhanced performance in comparison to previous automated registration methods. In the result, our proposed scheme showed efficient performance from maintaining the strong points of hybrid registration without any user intervention.

6144-94, Poster Session

A variational approach to spatially dependent non-rigid registration

F. Jäger, J. Han, J. Hornegger, T. Kuwert, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany)

In this paper we propose a new variational non-rigid registration method that introduces prior knowledge about non-homogeneous deformation properties into the matching process. State-of-the-art medical image registration approaches usually assume that the whole image domain is associated with a homogeneous deformation property, thus bone structure and soft tissue have the same stiffness for instance. However, this assumption is not valid in the majority of cases. In many applications the deformation properties can be estimated manually by the physician or by segmentation, beforehand. The presented non-rigid registration method integrates knowledge about the tissue directly into the deformation field computation. For this reason, no additional post-processing steps, like filtering of the defortomation field, are required. In order to integrate the tissue constraints the regularizer is replaced by a novel spatially dependent smoother. Dependent on the location within the image, the smoother is able to explicitly adjust the rigidity. Thus, different tissue classes can be treated in the registration process. In order to pass the stiffness coefficients to the algorithm an additional mask image is used. The registration results are illustrated on synthetic data first to give a good intuition about the effectiveness of the proposed method. Finally, we illustrate the improvement of the registration using real clinical data. It is shown that the mono-modal intra-patient registration of PET images yields more reasonable results using a spatially dependent regularizer constraining the deformations of regions with high activity than using a normal curvature regularizer. Furthermore, the method is evaluated on multi-modal PET/CT registration problems.

6144-95, Poster Session

A practical salient region feature based 3D multimodality registration method for medical images

D. A. Hahn, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany); Y. Sun, Siemens Corporate Research; J. Hornegger, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany); C. Xu, Siemens Corporate Research; G. Wolz, T. Kuwert, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany)

We present a novel representation of 3D salient region features and its integration into a hybrid rigid-body registration framework. We adopt the scale, translation and rotation invariance of those intrinsic features to 3D and use their properties to estimate a transform between underlying mono- or multi-modality 3D medical images. In addition, we demonstrate the robustness of our approach to image overlap, missing information and artefacts. Our method combines advantageous aspects of both feature- and intensity-based approaches and consists of three steps: an automatic extraction of a set of 3D salient region features on each image, a robust estimation of a correspondence set and its sub-pixel accurate refinement, which includes the elimination of outliers. We propose a region-growing based approach for the extraction of 3D salient region features, a solution for the problem of feature clustering and a reduction of the correspondence search space complexity. Results of the developed algorithm are presented for both mono- and multi-modality intra-patient 3D image pairs (CT, PET and SPECT) that have been acquired for change detection, tumor localization or time based intra-person studies. The accuracy of the method is clinically evaluated with an approach that measures the distance between both corresponding anatomical and functional structures and lesions. We conclude with a discussion of potential medical applications and possibilities for integrating this approach into a non-rigid registration framework.

6144-96, Poster Session

A framework for parameter optimization in mutual information (MI)-based registration algorithms

G. Gopalakrishnan, B. Kumar SV, R. Mullick, A. Narayanan, S. Suryanarayanan, GE Global Research (India)

Image fusion (registration), a classical problem in medical image understanding for patient care, involves mapping/associating data points from different images for diagnosis. Registration involves the search for a suitable transform so as to maximize/minimize a chosen metric given certain input parameters. A key metric for registration is Mutual Information (MI): an information theory-based measure, suitable especially for multi-modality registration. Its final convergence is dependent upon different parameters that are involved in the process of registration. Though, there have been experiments describing the influence of such parameters on MI, specific to MR and SPECT brain images , they are not comprehensive as they assume the parameters influencing MI to be independent.

We present a framework that one could use to set optimized parameter values, while performing image registration using mutual information as a metric to be maximized. The study is motivated by the desire to compute an optimum set of parameters for a given modality by conducting Design of Experiments. Our experiment details these steps for the registration of X-ray Computer Tomography (CT) images with Positron Emission Tomography (PET) images.

6144-97, Poster Session

Seed-based registration for intraoperative brachytherapy dosimetry: a comparison of methods

Y. Su, B. J. Davis, M. G. Herman, R. A. Robb, Mayo Clinic

Several approaches for registering a subset of imaged points to their true origins were analyzed and compared for seed based TRUS-fluoroscopy registration. The methods include the Downhill Simplex method (DS), the Powell's method (POW), the Iterative Closest Point (ICP) method, the Robust Point Matching method (RPM) and variants of RPM. Several modifications were made to the standard RPM method to improve its performance. One hundred simulations were performed for each combination of noise level, seed detection rate and spurious points and the registration accuracy was evaluated and compared. The noise level ranges from 0 to 5mm, the seed detection ratio ranges from 0.2 to 0.6, and the number of spurious points ranges from 0 to 20. A real clinical post-implant dataset from permanent prostate brachytherapy was used for the simulation study. The experiments provided evidence that our modified RPM method is superior to other methods, especially when there are many outliers. The RPM based method performed the best at all noise levels and seed detection rates. The DS based method performed reasonably well, especially at low noise levels without spurious points. There was no significant performance difference between the standard RPM and our modified RPM methods without spurious points. The modified RPM methods outperformed the standard RPM method with large number of spurious points. The registration error was within 2mm, even with 20 outlier points and a noise level of 3mm.

6144-98, Poster Session

Image registration using shape-constrained mutual information and genetic algorithms

X. Yuan, G. Chi-Fishman, National Institutes of Health

To fuse MR images acquired at different times, registration is an important prerequisite for accurate fusion. In this paper, we present a shape-constrained MI-based image registration method using a Genetic Algorithm (GA) for aligning 2D MR images of the in vivo human tongue. The novelty of our method lies in the integration of tongue shape into the mutual information (MI) metric and the development of a real-coded genetic algorithm that performs rapid optimization. The computation of MI is based on pixels that are enclosed by a contour resulting from segmentation performed only on the reference image. The transformation parameters of this contour are encoded into the chromosome of GA. During the optimization process, a group of pixels in the to-be-registered image are selected and a MI value is calculated. This shape constrained MI (sMI) serves as the fitness function in GA, which conducts function optimization by imitating the natural evolution. Each chromosome in the GA population pool encodes translation and rotation parameters and is associated with a fitness value. A gene is represented by a real value. Our method has been validated with MR images of the human tongue. The experiments have demonstrated high speed, robustness and accuracy in image registration.

6144-99, Poster Session

Automatic lung nodule matching for the follow-up in temporal chest CT scans

H. Hong, J. Lee, Seoul National Univ. (South Korea)

We propose a fast and robust registration method for matching lung nodules of temporal chest CT scans. Our method is composed of four stages. First, the lungs are extracted from chest CT scans by the automatic segmentation method. Second, the gross translational mismatch is corrected by the optimal cube registration. This initial registration does not require extracting any anatomical landmarks. Third, initial alignment is step by step refined by the iterative surface registration. To evaluate the distance measure between surface boundary points, a 3D distance map is generated by the narrow-band distance propagation, which drives fast and robust convergence to the optimal location. Fourth, nodule correspondences are established by the pairs with the smallest Euclidean distances. The results of pulmonary nodule alignment of twenty patients are reported on a per-center-of mass point basis using the average Euclidean distance (AED) error between corresponding nodules of initial and follow-up scans. The average AED error of twenty patients is significantly reduced to 4.7mm from 30.0mm by our registration. Experimental results show that our registration method aligns the lung nodules much faster than the conventional ones using a distance measure. Accurate and fast result of our method would be more useful for the radiologist's evaluation of pulmonary nodules on chest CT scans.

6144-100, Poster Session

Distance transform for automatic dermatologic images composition

C. Grana, R. Cucchiara, Univ. degli Studi di Modena e Reggio Emilia (Italy)

In this paper we focus on the problem of automatically registering dermatological images, because even if different products are available, most of them share the problem of a limited field of view on the skin. A possible solution is then the composition of multiple takes of the same lesion with digital software, such as that for panorama images creation.

In this work, to perform an automatic selection of matching points the Harris Corner Detector is used, and to cope with outlier couples we employed the RANSAC method. Projective mapping is then used to match the two images. Given a set of correspondence points, Singular Value Decomposition was used to compute the transform parameters.

At this point the two images need to be blended together. One initial assumption is often implicitly made: the aim is to merge two rectangular images. But when merging occurs between more than two images iteratively, this assumption will fail. To cope with differently shaped images, we employed the Distance Transform and provided a weighted merging of images.

Different tests were conducted with dermatological images, both with standard rectangular frame and with not typical shapes, as for example a ring due to the objective and lens selection. The successive composition of different circular images with other blending functions, such as the Hat function, doesn't correctly get rid of the border and residuals of the circular mask are still visible. By applying Distance Transform blending, the result produced is insensitive of the outer shape of the image.

6144-101, Poster Session

Registration and 3D visualization of large microscopy images

K. R. Mosaliganti, T. Pan, R. Sharp, Jr., R. Ridgway, R. Machiraju, K. Huang, J. H. Saltz, The Ohio State Univ.

Inactivation of the retinoblastoma gene in mouse embryos results in morphological changes in the placenta, which has been shown to affect fetal survivability. Mutant (Rb-) placenta was harvested at 13.5 days of gestation and serial sections were prepared using a standard histological protocol. The sections were digitized using a high resolution scanner to construct a 3D virtual placenta. Quantification of the structural changes using image analysis was accomplished using a suite of registration, segmentation, 3D reconstruction and visualization algorithms. In this work, we discuss our registration pipeline in detail. The placenta dataset consisted of 786 images totaling 550 GB in size, which were registered into a volumetric dataset. The registration process faces many challenges arising from the large image sizes, damages during sectioning, staining gradients both within and across sections, and background noise leading to local solutions. In this work, we implement a rigorous preprocessing pipeline consisting of k-means based clustering, shape detecting level sets and PCA alignment for removing noise and optimizing the registration pipeline. Nevertheless, standard Mutual Information based registration

procedures still converge to local solutions owing to the noise that often mislead optimization procedures. We employ a novel 2-level optimization strategy whose core idea is based on perturbing converged solutions. This leads us to satisfactory results in the placenta registration. We provide 3D visualizations of the placenta and numerical comparisons to the standard Mutual Information registration to demonstrate our improvements. All our algorithms was implemented using the National Library of Medicine's (NIH/NLM) Insight Segmentation and Registration Toolkit (ITK).

6144-102, Poster Session

Registration of knee joint surfaces for the in-vivo study of joint injuries based on magnetic resonance imaging

R. Cheng, A. Habib, R. Frayne, J. Ronsky, Univ. of Calgary (Canada)

In-vivo quantitative assessments of joint conditions and health status can help to increase understanding of the pathology of osteoarthritis, a degenerative joint disease that affects a large population each year. Magnetic resonance imaging (MRI) provides a non-invasive and accurate means to assess and monitor joint properties, and has become widely used for diagnosis and biomechanics studies. Quantitative analyses and comparisons of MR datasets require accurate alignment of anatomical structures, thus image registration becomes a necessary procedure for these applications. This research focuses on developing a registration technique for MR knee joint surfaces to allow quantitative study of joint injuries and health status. It introduces a novel idea of translating techniques originally developed for geographic data in the field of photogrammetry and remote sensing to register 3D MR data. The proposed algorithm works with surfaces that are represented by randomly distributed points with no requirement of known correspondences. The algorithm performs matching locally by identifying corresponding surface elements, and solves for the transformation parameters relating the surfaces by minimizing normal distances between them. This technique was used in three applications to: 1) quantify patellar movement with respect to the femur based on the transformation parameters, 2) quantify changes in contact area locations between the patellar and femoral cartilage at different knee flexion angles, and 3) register temporal MR data to verify the feasibility of the algorithm to help monitor diseases. The results indicate accurate registration and the proposed algorithm can be applied for in-vivo study of joint injuries with MRI.

6144-103, Poster Session

A unified framework for segmentation-assisted image registration

J. Liu, Ohio Univ.

In this paper, we present a unified framework for segmentation- assisted registration. The registration component of the method relies on two forces for aligning the input images: one from the image similarity measure, and the other from an image homogeneity constraint. The former, based on local correlation, aims to find the detailed intensity correspondence for the input images. The latter, generated from the evolving segmentation contours, provides an extra guidance in assisting the alignment process towards a more meaningful, stable and noise-tolerant procedure. We present several 2D/3D example on synthetic and real data.

6144-104, Poster Session

Elastic registration using 3D chainmail: application to virtual colonoscopy

C. R. Castro-Pareja, B. Daly, R. Shekhar, Univ. of Maryland/ Baltimore

We present an elastic registration algorithm based on local deformations modeled using cubic B-splines and controlled using 3D ChainMail. Our algorithm eliminates the appearance of folding artifacts and allows local rigidity and compressibility control independent of the image similarity metric being used. 3D ChainMail propagates large internal deformations between neighboring B-Spline control points, thereby preserving the topology of the transformed image without requiring the addition of penalty terms based on rigidity of the transformation field to the equation used to maximize image similarity. A novel application to virtual colonoscopy is presented where the algorithm is used to significantly improve cross-localization between colon locations in prone and supine CT images.

6144-105, Poster Session

Automated feature-based alignment for 3D volume reconstruction of CLSM imagery

S. Lee, P. Bajcsy, Univ. of Illinois at Urbana-Champaign

We address the problem of automated image alignment for 3D volume reconstruction from a sequence of consecutive histological sections represented by stacks of fluorescent confocal laser scanning microscope (CLSM) imagery acquired at multiple confocal depths. We focus on automated image alignment based on centroid and area shape features by solving feature correspondence problem, also known as Procrustes problem, in a weakly-constrained feature space characterized by intensity and morphological variations. The correspondence problem is solved by estimating a coarse rigid transformation using Euclidean distances between features, and then refining the obtained transformation using vector distances. The performance evaluation is conducted by comparing image alignment accuracy obtained by the proposed fully automated method with registration accuracy achieved by human subjects using a manual alignment method. Based on our experi-ments, manual (pixel-based) image alignment is less accu-rate and less consistent (large standard deviation) than the fully automated alignment (on average, 22.8 times larger alignment error and 166.8 times larger standard deviation in 99.73% confidence interval).

6144-106, Poster Session

Automatic 3D image registration using voxel similarity measurements based on a genetic algorithm

W. Huang, J. M. Sullivan, Jr., P. Kulkarni, M. Murugavel, Worcester Polytechnic Institute

An automatic 3D non-rigid body registration system based upon the genetic algorithm (GA) process is presented. The system has been successfully applied to 2D and 3D situations using both rigid-body and affine transformations. Conventional optimization techniques and gradient search strategies generally require a good initial start location. The GA approach avoids the local minima/maxima traps of conventional optimization techniques. Based on the principles of Darwinian natural selection (survival of the fittest), the genetic algorithm has two basic steps: 1. Randomly generate an initial population. 2. Repeated application of the natural selection operation until a termination measure is satisfied. The natural selection process selects individuals based on their fitness to participate in the genetic operations; and it creates new individuals by inheritance from both parents, genetic recombination (crossover) and mutation. Once the termination criteria are satisfied, the optimum is selected from the population. The algorithm was applied on 2D and 3D magnetic resonance images (MRI). It does not require any preprocessing such as threshold, smoothing, segmentation, or definition of base points or edges. To evaluate the performance of the GA registration, the results were compared with results of the Automatic Image Registration technique (AIR) and manual registration which was used as the gold standard. Results showed that our GA implementation was a robust algorithm and gives very close results to the gold standard. A pre-cropping strategy was also discussed as an efficient preprocessing step to enhance the registration accuracy.

6144-107, Poster Session

Improved 2D/3D registration robustness using local spatial information

E. De Momi, Politecnico di Milano (Italy); K. Eckman, Carnegie Mellon Univ.; B. Jaramaz, A. M. Di Gioia III, The Western Pennsylvania Hospital

Xalign is a tool that measures implant orientation by co-registering a projection of an implant model and a digitally reconstructed radiograph of the patient's anatomy with a post operative x-ray [1,2].

A mutual information [3] based registration method is used to automate alignment. When using basic mutual information, the presence of local maxima can result in misregistration.

To increase robustness, our research is aimed at improving the similarity function by modifying the information measure and incorporating local spatial information.

We decided to combine the entropy information of regional mutual information [4] and the gradient information coming from Pluim's method [5], which takes into account the orientation of the gradient vectors of each image.

The new cost function to be maximized is then:

RMIG = RMI x G

where RMI is the regional mutual information and G is the gradient term.

In order to evaluate the performance of the measure a synthetic x-ray image was built from a preoperative pelvic CT scan. This image acts as the gold standard. The voxel weights used to generate the image were then modified. New images were generated with the CT rigidly transformed. These were compared with the reference image. In particular, roll, pitch and yaw angles span a range of -10/+10 degrees, while x, y and z translations go from -10mm to +10mm. The cost function proposed in this work does not fail in correctly aligning the images and did not exhibit any local minima which would slow or prevent locating the global maximum.

6144-108, Poster Session

Vessel-based registration with application to nodule detection in thoracic CT scans

G. Agam, C. Wu, Illinois Institute of Technology

Volume registration is fundamental to multiple medical imaging algorithms. Specifically, non-rigid registration of thoracic CT scans taken at different time instances can be used to detect new nodules more reliably and assess the growth rate of existing nodules. Voxel-based registration techniques are generally sensitive to intensity variation and structural differences, which are common in CT scans due to partial volume effects and naturally occurring motion and deformations. The approach we propose in this paper is based on vessel tree extraction which is then used to infer the complete volume registration. Vessels form unique features with good localization. Using extracted vessel trees, a minimization process is used to estimate the motion vectors at vessels. Accurate motion vectors are obtained at vessel junctions whereas vessel segments support only normal component estimation. The obtained motion vectors are then interpolated to produce a dense motion field using thin plate splines. The proposed approach is evaluated on both real and synthetically deformed volumes. The obtained results are compared to several standard registration techniques. It is shown that by using vessel structure, the proposed approach results in improved performance.

6144-109, Poster Session

Mathematical properties of information theoretic image similarity measures

O. Škrinjar, Georgia Institute of Technology

Joint entropy, mutual information, and normalized mutual information are widely used image similarity measures in multimodality image registration and other problems that involve comparing images with arbitrary intensity relationships. While these image similarity measures have been successfully used in various applications, their mathematical properties have not been studied thoroughly. This paper analyzes several properties of practical interest of the three image similarity measures. It is shown that mutual information, despite its popularity, and joint entropy have a few undesirable properties. On the other hand, normalized mutual information does not suffer from these problems. The properties are proven mathematically, which renders the conclusions independent of image type, noise, and artifacts. While the described problems of JE and MI are not their dominant behaviors and are not necessarily always encountered in practice, the undesired behaviors of JE and MI can lead to problems, e.g they can cause false local extrema in the optimization of image registration. The conclusions are in line with the results of previous experimental studies, in which normalized mutual information outperformed other information theoretic image similarity measures. Mutual information has gained a lot of popularity in the medical image analysis and related communities. Nevertheless, since so far neither theoretical nor experimental evidence has been found that NMI is inferior to JE and MI in any way, and NMI has been shown to have advantages over JE and MI, any application that uses MI or JE is likely to have equal or improved performance by using NMI instead and it is guaranteed to avoid the problems described in this paper.

6144-110, Poster Session

Fast surface alignment for cardiac spatio-temporal modeling: application to ischemic cardiac shape modeling

H. Huang, Dartmouth College; L. Shen, Univ. of Massachusetts/ Dartmouth; R. Zhang, F. Makedon, J. D. Pearlman, Dartmouth College

Each year, approximately 565,000 Americans experience a new myocardial infarction; of these, 75% of men and 62% of women survive for at least one year. The accurate diagnosis is required for effective treatment of ischemic cardiac disease (ICD). Use of Magnetic resonance imaging (MRI) for assessing the cardiovascular system has gradually become more widespread over the past two decades and provides a promising new method to study ICD dysfunction. More accurate three dimensional modeling analysis of heart based on MRI could provide invaluable diagnostic information to clinicians on disease severity and long-term prognoses.

In order to compare different cardiac models, a surface registration step is often necessary for aligning these models together and extracting their shape descriptors. In order to solve this problem, we use the surface alignment algorithm to generate our effective and accurate computational model including the valuable ischemic tissues behavior to help the diagnosis and prognosis in ICD.

6144-111, Poster Session

Iterative deformable FEM model for nonrigid PET/MRI breast image coregistration

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It is expected that accurate coregistration of PET and MRI breast images will result in increased specificity and sensitivity for non-invasive breast cancer detection. Therefore, we developed new approach to reach this aim.

Data were acquired using a dedicated PET/CT scanner and a 1.5 T MRI system. PET images were obtained with patient prone, after intravenous administration of F-18-FDG, and with nine fiducial skin markers (FSMs; containing Ge-68). For MRI scans, with FSMs placed similarly as in PET, both breasts were suspended into a well housing a clinical breast RF

receiver coil, and a high-resolution 3D Fast Field Echo technique was applied. We implemented an iterative approach to nonrigid registration, in which PET provides the target image and MRI provides the moving images. In the first iteration, corresponding FSMs are identified on both PET and MRI images, and their centroids are located to help estimate FSM displacements between PET and MRI. Patient-specific breast geometry from MRI analysis is input into ANSYS(tm) finite element method (FEM) software, by exploiting an analogy between steady-state heat transfer (SSHT) and the dense displacement field here. The MRI breast mesh is deformed and a warped MRI breast image is registered to the target PET breast volume. After a surface refinement step, the nonrigidly registered moving (MRI) and target (PET) images are fused. Based on several qualitative and quantitative measures, our iterative FEM deformable model for nonrigid registration of PET MRI breast images yielded favorable results, allowing accurate nonrigid registration of functional (PET) and anatomical (MRI) data.

6144-112, Poster Session

Temporal registration of 2D x-ray mammogram using triangular B-splines finite element method (TBFEM)

K. Wang, Y. He, H. Qin, P. R. Fisher, W. Zhao, Stony Brook Univ.

In this paper, we develop a novel image processing technique to register two dimensional temporal mammograms for effective diagnosis and therapy. Our registration framework is founded upon triangular B-spline finite element method (TBFEM). In contrast to tensor-product based B-spline that is widely used in medical imaging, Triangular B-spline is much more powerful with many unique advantages such as flexible triangular domain, local control, space-varying smoothness, and discontinuous feature modeling. Empowered by the rigorous theory of triangular B-spline, TBFEM explicitly models the transformation between temporal mammograms, using a collection of triangular B-splines. Our unique approach is able to accurately infer the underlying deformation over any irregular region of interest (ROI). In addition, TBFEM is also capable of accurate description of sharp features at the interfaces between different tissue types. Our registration algorithm consists of two consecutive steps: 1) A TBFEM model is first built upon the template image, which is later deformed nonlinearly using pre-identified feature-based constraints; 2) The image forces, derived from the intensity-based difference, are applied to reduce the discrepancies between corresponding images furthermore.. We have tested our method on practical clinical data and the results demonstrate that TBFEM helps to achieve better registration accuracy than conventional FEM. Besides, with the ability of sharp feature modeling, TBFEM can increases the registration quality even further.

6144-113, Poster Session

Establishing multimodality datasets with the incorporation of 3D histopathology for soft tissue classification

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The development of multi-modality image analysis has gained increasing popularity over recent years. Multi-modality image databases are being developed to benefit patient clinical care, research and education. The incorporation of histopathology in these multi-modality datasets is complicated by the large differences in image quality, content and spatial association. We have developed a novel system, the large-scale image microtome array (LIMA), to bridge the gap between non-structurally destructive and destructive imaging such that reliable registration and incorporation of three-dimensional (3D) histopathology can be achieved. We have developed registration algorithms to align the micro-CT, LIMA and histopathology data to a common coordinate system. Using this multi-modality image dataset we have developed a classification algorithm to identify on a pixel basis, the tissue types present. The output from the classification processing is a 3D color coded map of tissue distributions. The resulting complete dataset provides an abundance of valuable information relating to the tissue sample including density, anatomical structure, color, texture and cellular information in three dimensions. In this study we have chosen to use normal and diseased lung tissue, however the flexibility of the image acquisition and subsequent processing algorithms makes it applicable to any soft organ tissue.

6144-114, Poster Session

Initial comparison of registration and fusion of CmT-SPECT mammotomography images

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A new hybrid, dual modality x-ray computed mammotomography (CmT) and single photon emission computed tomography (SPECT) scanner for dedicated breast and axillary imaging is under development. CmT imaging provides high resolution anatomical images whereas SPECT provides functional information, but with coarser resolution. It is expected that the benefits that have been demonstrated with hybrid whole body imaging (including attenuation correction of emission data, and co-localization of lesions) will also be found in a dedicated breast device. The registration of these images considers variations in object positions between the different modalities, and imaging parameters (pixel size, acquisition conditions, scan limitations). Automatic methods can be used which find the geometric transformations of the different imaging modalities involved. Here we demonstrate the initial stages of the registration of CmT and SPECT for mammotomography with images acquired independently by each system. Two registration algorithms are used: the first is an intrinsic algorithm based on mutual information; the second is a rigid body transform based on identification of fiducial markers visible to both emission (SPECT) and transmission (CmT) imaging modalities. Experiments include use of a range of different breast sizes (240-1700ml) with offset cone-beam acquisition geometry for the CmT system and parallel beam geometry for SPECT. Initial results with geometric phantoms indicate faithful registration with high degree of accuracy.

6144-115, Poster Session

Motion correction via nonrigid coregistration of dynamic MR mammography series

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The objectives of this investigation are to improve quality of subtraction MR breast images and improve accuracy of time-signal intensity curves (TSIC) related to local contrast agent concentration in dynamic MR mammography. The patients, with up to nine fiducial skin markers (FSMs) taped to each breast, were prone with both breasts suspended into a single well housing the receiver coil. After a preliminary scan, Gd-DTPA was delivered intravenously, followed by physiological saline. The field of view (360 mm square) was centered over the breasts. We used a gradient recalled echo (GRE) technique for pre-Gd baseline, and five more measurements at 90 s intervals. Centroids were determined for corresponding FSMs visible on pre-Gd and any post-Gd images. This was followed by segmentation of breast surfaces in all dynamic series images, and meshing of all post-Gd breast images. Tetrahedral volume and triangular surface elements were used to construct a finite element method (FEM) model. We used ANSYS software and an analogy between orthogonal components of the displacement field and the temperature differences in steady-state heat transfer (SSHT). The floating images were warped to a fixed image using an appropriate shape function for interpolation from mesh nodes to voxels. To reduce any residual misregistration, we performed surface matching between the previously warped floating image and the target image. Our method of motion correction via nonrigid coregistration yielded

excellent differential image series that clearly revealed lesions not visible in unregistered differential image series. Further, it produced clinically useful maximum intensity projection (MIP) 3D images.

6144-116, Poster Session

Alignment of full and partial CT thoracic scans using bony structure

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Diagnostic thoracic procedures using computed tomography (CT) often include comparisons of scans acquired with different slice thicknesses. In this manuscript, we investigate the potential for alignment of such scans using skeletal knowledge of the thoracic region, which is less susceptible to sources of errors such as differences in patient breath hold, positioning and cardiac motion. Our study employed the positioning of the ribs relative to the vertebra and a morphological description of the scapula. Rib positioning was described by the angles formed between the vertebra centroid and combinations of pairs of rib centroids visible on a CT slice. Scapula morphology was described using a feature based on the local maxima of the distance transform, which measures the distance of object pixels to the nearest background pixel. Since the scapula is not visible in all slices of a full scan, its description contributed in limiting the range of similar slices whereas rib positioning relative to the vertebra provided a more specific description. A cost function incorporating the difference of features from rib positioning and scapula morphology between two slices was derived and used to match slices. The method was evaluated on an independent set of 10 pairs of full and partial CT scans. Assessment was based on whether or not slices containing known nodules between each pair of scans were overlapping after the alignment procedure. Results showed that the proposed metric correctly aligned 9 out of 10 scans. The results are encouraging for using this method as a first step towards temporal analysis of lung nodules.

6144-117, Poster Session

Image registration of proximal femur with substantial bone changes: application in 3D visualization of bone loss of astronauts after long-duration spaceflight

W. Li, M. Sode, I. Saeed, T. Lang, Univ. of California/San Francisco

We recently studied bone loss in crewmembers making 4 to 6 months flights on the International Space Station. We employed Quantitative Computed Tomography (QCT) technology (Lang et. al., J Bone Miner Res. 2004; v. 19, p. 1006), which measured both cortical and trabecular bone loss that could not be obtained by using 2-dimensional dual x-ray absorptiometry (DXA) imaging technology. To further investigate the bone loss after spaceflight, we have developed image registration technologies to align serial scans so that bone changes can be directly visualized in a sub-regional level, which can provide more detailed information for understanding bone physiology during long-term spaceflight. To achieve effective and robust registration when large bone changes exist, we have developed technical adaptations to standard registration methods. Our automated image registration is mutual-information based. We have applied an automatically adaptive binning method in calculating the mutual information. We have also developed a heuristic transformation initialization scheme to start the search process. After the pre- and post-flight scans are geometrically aligned, the interior bone changes can be clearly visualized. Image registration can also be applied to Finite Element Modeling (FEM) to compare bone strength change, where consistent loading conditions must be applied to serial scans.

6144-118, Poster Session

Evaluation of similarity measures for intensity-based 2D registration in radiotherapy

J. Wu, S. S. Samant, Univ. of Florida

Our studies involve the evaluation of nine similarity measures for use in intensity-based two-dimensional image alignment in radiotherapy. These measures include negated mean pixel wise product, normalized cross correlation, partitioned intensity uniformity, mutual information, normalized mutual information, entropy of the difference image, gradient correlation, gradient difference, and pattern intensity. Separate studies were carried out by varying two of the three in-plane transformation parameters. The translations vary from -1 cm to +1 cm with 0.2 mm increment. The rotation varies from -10 deg to +10 deg with 0.2 deg increment. To investigate the performance of various measures when a multiresolution optimization algorithm is used, the objective functions were calculated using images with different down-sampling ratios. We also investigated how imaging modality, DRR type (i.e., conventional DRR or megavoltage DRR), and treatment site affect the performances of various measures. In these studies, both phantom images and patient images were used. Contrary to some conclusions in literature, we found out the choice of an appropriate measure is problem dependent. We suggest one should carry out a study and choose a measure for his/her specific application.

6144-119, Poster Session

Supporting registration decisions during 3D medical volume reconstructions

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We propose a methodology for making optimal registration decisions during 3D volume reconstruction in terms of (a) anticipated accuracy of aligned images, (b) uncertainty of obtained results during the registration process, (c) algorithmic repeatability of alignment procedure, and (d) computational requirements. We researched and developed a web-enabled, web services based, data-driven, registration decision support system. The registration decisions include (1) image spatial size (image sub-area or entire image), (2) transformation model (e.g., rigid, affine or elastic), (3) invariant registration feature (intensity, morphology or a sequential combination of the two), (4) automation level (manual, semi-automated, or fully-automated), (5) evaluations of registration results (multiple metrics and methods for establishing ground truth), and (6) assessment of resources (computational resources and human expertise, geographically local or distributed). Our goal is to provide mechanisms for evaluating the tradeoffs of each registration decision in terms of the aforementioned impacts. First, we present a medical image registration methodology for making registration decisions that lead to registration results with well-understood accuracy, uncertainty, consistency and computational complexity characteristics. Second, we have built software tools that enable geographically distributed researchers to optimize their data-driven registration decisions by using web services and supercomputing resources. The support developed for registration decisions about 3D volume reconstruction is available to the general community with the access to the NCSA supercomputing resources. We illustrate performance by considering 3D volume reconstruction of blood vessels in histological sections of uveal melanoma from serial fluorescent labeled paraffin sections labeled with antibodies to CD34 and laminin. The specimens are studied by fluorescence confocal laser scanning microscopy (CLSM) images.

6144-120, Poster Session

An automatic segmentation method for multispectral microscopic cervical cell images

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We have been developing a computer-aided diagnosis (CAD) system for

automatically recognizing cervical cancer cells from Papanicolaou smear. Considering that pathological changes of cervix can be indicated by the abnormity of the nucleus of intermediate cell, the key task of this system is to find the intermediate cells and segment the nucleus precisely. This paper presents a novel approach for automatic segmentation of microscopic cervical cell images using multispectral imaging techniques. In order to capture images at different wavelengths, a Liquid Crystal Tunable Filter (LCTF) device is used to provide wavelength selection from 400nm to 720nm with an increment of 10nm. Considering the spectral variances of background, nucleus and cytoplasm, background is extracted firstly from the microscopic images by calculating pixel intensity variance at 470nm, 530nm, 570nm, 580nm and 650nm. Then superficial cells are extracted apart from intermediate cells easily at 530nm 650nm because of the different pixel intensity distribution of the two kinds of cells at these two wavelengths. To segment the nucleus from intermediate cells, we adopt two procedures. Firstly, the nuclei are roughly segmented apart by using an iterative maximum deviation between-cluster algorithm. Secondly, a novel rigorous algorithm based on active contour model is adopted to achieve more exact nuclei segmentation. Using the method proposed in this paper, we did experiments on over 300 cervical smears, and the results show that this method is more robust and precise.

6144-121, Poster Session

Characterization of the optic disc in retinal imagery using a probabilistic approach

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The application of computer based imaging to the diagnosis of retinal disease is rapidly becoming a reality. Advances in the imaging of ocular anatomy and pathology can now provide data to diagnose and quantify specific diseases such as diabetic retinopathy (DR). Visual disability and blindness have a profound socioeconomic impact upon the diabetic population and DR is the leading cause of new blindness in working-age adults in the industrialized world. Robust automation is required to achieve productive computer-based screening of large populations. Through this research we are developing automation methods for locating and characterizing important structures in the human retina such as the optic disc, macula, and the vascular arcades. We will present results for the automatic detection of the optic disc using red-free fundus photography. Our method relies on the accurate segmentation of the vasculature of the retina and spatial probability distributions describing the vascular density, average thickness, and average orientation of in relation to the position of the optic disc. Understanding the location and morphology of these and other structures - such as dot hemorrhages, cotton wool spots, drusen, and exudates - is required to develop effective medical screening processes for large populations.

6144-122, Poster Session

Automatic segmentation method which divides a cerebral artery tree in time-of-flight MR-angiography into artery segments

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2D/3D registration methods between DSA and MRA of cerebral artery have required an automatic extraction method which can isolate wanted segments from a cerebral artery tree to achieve sufficient accuracy.

In this paper, we described an automatic segmentation method which divides a cerebral artery tree in time-of-flight magnetic resonance angiography (TOF-MRA) into each artery.

This method requires a 3D data set of a cerebral artery tree which is isolated from TOF-MRA. Processes of this method are: 1) every branch in a cerebral artery tree is labeled with an unique index number, 2) the 3D center of the Circle of Willis is detected by using the 2D and 3D templates, and 3) the labeled branches are classified by referring the 3D territory map of cerebral arteries centered on the center of the Circle of Willis. This method classifies all branches into any of intra carotid arteries (ICA), basilar artery (BA), middle cerebral artery (MCA), A1 segment of anterior cerebral artery (ACA-A1), the other segments of anterior cerebral artery (ACA), posterior communication artery (PcomA), and posterior cerebral artery (PCA). The eleven cases were carried out and manually classified arteries of each case were taken as truth. Mean correct-segmented pixel ratio (%) for each artery was calculated.

The mean values were 87.6% for ACA, 44.9% for R-ACA-A1, 30.4% for L-ACA-A1, 82.4% for R-MC, 79.0% for L-MC, 0.5% for R-Pcom, 0.0% for L-Pcom, 77.2% for R-PCA, 80.0% for L-PCA, 78.6% for R-ICA, 93.05 for L-ICA, 77.1% for BA and 78.9% for total arteries.

6144-123, Poster Session

SIBS, a powerful concept for automatic segmentation of electron tomograms

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A new approach for Scaling Index Based image Segmentation (SIBS) in electron tomography is proposed. Based on the Scaling Index Method [1], a number α is assigned to each voxel, that characterizes the dimensionality of the structural component the voxel belongs to. For example voxels that belong to a point-like structure have $\alpha \approx 0$ and voxels that are part of a line have $\alpha \approx 1$. Flat distributions are characterized by $\alpha \approx 2$ and compact volumes by $\alpha \approx 3$. There are two parameters that have to be specified, one for scaling the gray level range and a radius r defining a neighborhood around each voxel with respect to space and gray scale. The value of α strongly depends on the selection of r. The selection of r determines the length scale on which the structures are analyzed so if r approaches zero, each voxel “sees” no neighbors. Thus the selection of r should be associated with the size of the structures to be identified. Segmentation now can be performed by dividing the voxels into different categories according to what kind of structure they belong to. Appropriate thresholding of the scaling index image creates a binary mask around the object. In case of small, comparing to the object’s size, spurious features, isotropic and non-isotropic morphological operators can be used in order to eliminate them and the resulting mask can now be used in the tomogram to segment the desired object for iso-surface representation.

[1] F. Jamitzky et al., Ultramicr. 86 (2001) 241

6144-124, Poster Session

Generalized expectation-maximization segmentation of brain MR images

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Manual segmentation of medical images is unpractical because it is time consuming, not reproducible, and prone to human error. It is also very difficult to take into account the 3D nature of the images. Thus, semi- or fully-automatic methods are of great interest.

Current segmentation algorithms based on an Expectation-Maximization (EM) procedure (Van Leemput et al., 1999; Ashburner et al., 2005) present some limitations. The algorithm by Ashburner et al. does not allow multichannel inputs, e.g. 2 MR images of different contrast, and does not use spatial constraints between adjacent voxels, e.g. Markov random field (MRF) constraints. The solution of Van Leemput et al. employs a simplified model (mixture coefficients are not estimated and only 1 Gaussian is used by tissue class, with 3 for the image background). We have thus implemented an algorithm that combines the features of these two approaches\,: multichannel inputs, intensity bias correction, multi-Gaussian histogram model, and Markov random field constraints.

Our proposed method classifies tissues in three iterative main stages by way of a Generalized-EM (GEM) algorithm: (1) estimation of the Gaussian parameters modeling the histogram of the images, (2) correction of image intensity non-uniformity, and (3) modification of prior classification knowledge by MRF techniques. The goal of the GEM algorithm is to maximize the log-likelihood across the classes and voxels.

Our segmentation algorithm was validated on synthetic data (with the Dice metric criterion) and real data (by a neurosurgeon) and compared to the original algorithms by Ashburner et al. and Van Leemput et al. Our combined approach leads to more robust and accurate segmentation.

6144-125, Poster Session

Texture-based instrument segmentation in 3D ultrasound images

M. G. Linguraru, R. D. Howe, Harvard Univ.

New real-time 3D ultrasound promises to enable intracardiac beating heart and fetal procedures, because of its high speed and ability to represent human anatomy in the presence of blood. However, the distorted appearance of surgical instruments is a major challenge and tissue and instruments have similar gray levels in US images. Furthermore, the interface between instruments and tissue is fuzzy and confusing to the surgeon. Our work estimates from expert-segmented images the statistical distributions of blood, tissue and instrument in intracardiac procedures. The labeling of voxels is done through an iterative expectation-maximization algorithm using information from the neighboring voxels through a smoothing kernel. Once the three groups of voxels are separated, more neighboring information is used to give spatial information based on the shape of instruments in order to correct for misclassifications. We analyze the major axis of segmented data through their principal components and refine the results by a watershed transform by immersion, which corrects the results at the contact between instrument and tissue. We used both 3D in-vitro data, from a tank trial with instrument and tissue in water, and in-vivo data, from a surgical operation in a porcine beating heart. The results on expert-annotated images show the correct segmentation and position of the instrument shaft oriented towards the ultrasound probe in both situations. The instrument orientation is extracted from its principal components.

6144-126, Poster Session

Vasculature segmentation for radio frequency ablation of non-resectable hepatic tumors

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Proper treatment of liver tumors in Radio Frequency Ablation (RFA) procedures requires heating diseased tissue to a temperature where necrosis is insured. However, recent results suggest that adequate liver tissue heating is complicated because major blood vessels provide a cooling effect on nearby treatment regions. Therefore, it is fundamentally important for physicians to perform a careful analysis of the proximity of diseased tissue to that of the larger blood vessels, which act as heat sinks.

In this paper we describe a novel technique for quickly and simply segmenting the larger blood vessels of the liver. In our system, the images of the liver have been segmented from an anatomical computerized tomography (CT) scan of the abdomen and chest. The images containing only the liver are then processed with a median filter and a coherence enhancing diffusion filter to emphasize tubular structures. The filtered image set of the liver is then projected onto a plane with a Maximum Intensity Projection (MIP) scheme. Intensity values in the MIP image corresponding to appropriate Hounsfield units for contrast enhanced blood are located and displayed on the MIP. The user selects a point in the MIP image corresponding to the vessels of interest and a three-dimensional connected component analysis is performed. Further manual editing can be done in both the MIP image and segmented liver image set to insure vessel connectivity in and around the treatment regions. We have applied our novel liver vessel segmentation method to a variety of contrast enhanced liver images and have demonstrated that this scheme provides the physician with important geometric information necessary for proper therapy.

6144-127, Poster Session

kNN-based multispectral MRI brain tissue classification: manual training versus automatic Atlas-based training

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Conventional k-Nearest-Neighbor (kNN) classification, which has been successfully applied to classify brain tissue, requires training on manually labeled subjects.. In this work, the performance of kNN-based segmentation of gray matter (GM), white matter (WM) and cerebrospinal fluid (CSF) using manual training is compared with a new method, in which training is automated using an atlas. . From 12 subjects, low-resolution T2 and PD scans and a high-resolution, high-contrast T1-weighted scan (Siemens sequence) were used as feature sets. For the conventional kNN method, manual segmentations were used for training, and classifications were evaluated in a leave-one-out study. The performance as a function of the number of samples per tissue, and k was studied. For fully automated training, scans were registered to a probabilistic brain atlas. Initial training samples were randomly selected per tissue based on a threshold on the tissue probability. These initials were processed to keep the most reliable samples. Performance of the method for varying the threshold on the tissue probability method was studied. By measuring the percentage overlap (SI), classification results of both methods were validated. For conventional kNN classification, varying the number of training samples did not result in significant differences, while increasing k gave significantly better results. In the method using automatic training, there is an overestimation of GM at the expense of CSF at higher thresholds on the tissue probability maps. The difference between the conventional method (k=45) and the observers was not significantly larger than inter-observer variability for all tissue types. The automated method performed slightly worse, and performed equal to the observers for WM, and less for CSF and GM. From these results it can be concluded that conventional kNN classification may replace manual segmentation, and that atlas-based kNN segmentation has strong potential for fully automated segmentation, without the need of laborious manual training.

6144-128, Poster Session

Fully-automated analysis of multiresolution four-channel micro-array genotyping data

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We present a fully automated and robust microarray image analysis system for handling multi-resolution image data (down to 3-micron with sizes up to 80 MB per channel). The system is developed to provide rapid and accurate data extraction for our recently developed microarray analysis and quality control tool (SNP Chart). Currently available commercial microarray image analysis applications are unable to process large high-resolution microarray images and in particular cannot handle more than two-channel data. They are also inefficient, due to the considerable user interaction typically required.

Four-channel DNA microarray technology is a robust and accurate tool for determining genotypes of multiple genetic markers in individuals. It plays an important role in the state of the art trend where traditional medical treatments are to be replaced by personalized genetic medicine i.e. individualized therapy based on the patient's genetic heritage. However, fast, robust and precise image processing tools are required for the prospective practical use of microarray-based genetic testing for predicting disease susceptibilities and drug effects in clinical practice, which require a turn-around timeline compatible with clinical decision-making. This paper presents an automatic image analysis platform for the rapid investi-

gation of hundreds of genetic variations across multiple genes. Validation tests indicate very high accuracy levels for genotyping results, comparable to that of state-of-the-art software products (none of which can handle our high resolution four-channel data). Our method achieves a significant reduction in analysis time, from several hours to just a few minutes, and is completely automated requiring no manual interaction or guidance at all.

6144-129, Poster Session

Iterative live wire and live snake: new user-steered 3D image segmentation paradigms

A. D. Souza, J. K. Udupa, Univ. of Pennsylvania; G. J. Grevera, Saint Joseph's Univ.; Y. Sun, D. Odhner, M. D. Schnall, Univ. of Pennsylvania

During any image segmentation process, two distinct tasks are performed - recognition and delineation. Recognition consists of the searching phase which roughly identifies a particular object of interest among other neighboring structures present in the image. Delineation consists of precisely defining the spatial extent of the object region. Well designed interactive segmentation methods, such as live wire (LW) and snakes, exploit the synergy between the user knowledge (for recognition) and the underlying computer processing done automatically (for delineation). We present in this paper two new methods, referred to as iterative live wire and live snake, for interactive 3D segmentation of medical images. In both methods, the segmentation initiated by the LW or snake method is propagated under user control to subsequent slices by projecting the anchor points. In iterative LW (ILW), the LW segments are iteratively updated in the new slice by selecting the mid points of previous LW segments as new anchor points. In live snake (LS), the snake method is first applied in the new slice for the projected anchor points and ended with an application of ILW. The methods have been evaluated on 30 3D MRI data sets of the breast and foot. The results indicate that, on average, a fewer number of user interventions during segmentation and anchor point specification are needed by using the new methods than by using snakes propagation or live wire. The ILW segmentations were slightly more accurate, with statistical significance ($P<0.01$), than LS segmentations, and the former were more efficient than the latter ($P<0.03$), both being more efficient than pure live wire and snake methods.

6144-130, Poster Session

Automatic LV volume measurement in low dose multiphase CT by shape tracking

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Three-dimensional automated methods promise to accurately estimate cardiac functional parameters as they exploit spatial and temporal coherence in the image series. An automatic method of tracking the endocardial border in multi-slice computed tomography images is presented. A deformable surface model was propagated through ten different cardiac phases using local image appearance probes to track each surface patch. It was used to measure left ventricular blood volume in a total of 62 image series made from 8 pig subjects. The robustness of the method was technically evaluated by consistency tests. The surface model propagated through the cardiac cycle and finally adapted to the initial image again showed a mean vertex distance of 2.4mm to the initial model. In addition, clinical numbers like the ejection fraction (EF) of the left ventricle as derived from the automatic volume calculations were compared to those from semi-automatic expert delineation in short axes slices. The correlation coefficient for EF between both methods was 0.89. The study included one quarter of the examinations that were made with a low dose protocol. This variant only slightly degraded the results when compared to those of the remaining normal dose examinations.

6144-131, Poster Session

Fast, shape-directed, landmark-based deep gray matter segmentation for quantification of iron deposition

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This paper introduces image processing methods to automatically detect the 3D volume-of-interest (VOI) and 2D region-of-interest (ROI) for deep gray matter organs (thalamus, globus pallidus, putamen, and caudate nucleus) of patients with suspected iron deposition from MR dual echo images. Prior to the VOI and ROI detection, cerebrospinal fluid (CSF) region is segmented by a clustering algorithm. For the segmentation, we automatically determine the cluster centers with the mean shift algorithm that can quickly identify the modes of a distribution. Then, we employ the K-Harmonic means clustering algorithm to segment the volumetric MR data into CSF and non-CSF. Having the CSF mask and observing that the frontal lobe of the lateral ventricle has more consistent shape accross age and pathological abnormalities, we propose a shape-directed landmark detection algorithm to detect the VOI in a speedy manner. The proposed landmark detection algorithm utilizes a novel shape model of the front lobe of the lateral ventricle for the slices where the organs of interest are expected to appear. After this step, for each slice in the VOI, we use horizontal and vertical projections of the CSF map to detect the approximate locations of the relevant organs for the ROI. We demonstrate the robustness of the proposed algorithms to abnormalities, including severe amounts of iron accumulation and white matter lesions, and anatomical variations. The proposed algorithms achieved very high detection accuracy, 100% in the VOI detection, over a large set of a challenging MR dataset.

6144-132, Poster Session

Automated brain segmentation using neural networks

S. Powell, V. A. Magnotta, H. J. Johnson, N. C. Andreasen, The Univ. of Iowa

Automated methods to delineate brain structures of interest are required to analyze large amounts of imaging data like that being collected in several on going multi-center studies. We have previously reported on using artificial neural networks (ANN) to define subcortical brain structures such as the thalamus (0.825), caudate (0.745), and putamen (0.755). One of the inputs into the ANN is the apriori probability of a structure existing at a given location. In this previous work, the apriori probability information was generated in Talairach space using a piecewise linear registration. In this work we have increased the dimensionality of this registration using a Thirion Demons registration algorithm. The input vector consisted of apriori probability, spherical coordinates, and an iris of surrounding signal intensity values. The output of the neural network determined if the voxel was defined as one of the N regions used for training. Training was performed using a standard backpropagation algorithm. The ANN was trained on a set of 15 images for 750,000,000 iterations. The resulting ANN weights were then applied to 6 test images not part of the training set. Relative overlap calculated for each structure was 0.875 for the thalamus, 0.845 for the caudate, and 0.814 for the putamen. With the modifications on the neural net algorithm and the use of multi-dimensional registration, we found substantial improvement in the automated segmentation method. The resulting segmented structures are as reliable as manual raters and the output of the neural network can be used without additional rater intervention.

6144-133, Poster Session

Modeling shape variability for full heart segmentation in cardiac CT images

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Deformable models are successfully used to segment organs from medical images. Most approaches minimize an objective function to determine the optimal shape of the organ being segmented. This objective function is usually composed of two terms, the first attracting the model to the organ boundaries in the image, while the second imposes some smoothness or shape constraints. Smoothness constraints alone (i.e. without shape knowledge) require very accurate initialization for proper convergence, which inhibits fully automated segmentation. Much work on active shape models has shown that constraining the model deformation with a priori shape knowledge (e.g. mean shape plus some allowed variability) improves robustness of the segmentation while being flexible enough to capture a large amount of the inter-patient variability. Shape constrained deformable models embed the active shape models into a deformable model framework with the aim to combine the advantages of both approaches.

In this work, we investigate how the modeling of the shape variability in shape-constrained deformable models influences both the robustness and the quality of the segmentation of cardiac multi-slice CT images. Experiments are performed for a complex triangulated heart model, which comprises 7 anatomical parts, namely the four chambers, the myocardium, and trunks of the aorta and the pulmonary artery. The mean shape was derived from 28 images. Discriminative boundary detection features were optimized for each of the 14771 triangles of the model. Four approaches for modeling the shape variability are compared: 1) rigid transformation, 2) affine transformation, 3) principal component analysis (using the 28 training images), and 4) multiple affine transformations. In the last point, each anatomical region of the heart model is assigned by an individual affine transformation.

We conclude that the multiple affine transformations modeling offers the largest flexibility without the need for many training data sets covering the range of possible shape variability. Using the shape knowledge in a shape-constrained deformable model framework we find that variability modeling does not necessarily play a central role if the correct boundaries can be robustly detected, since the model is allowed to deviate locally from the learned shape.

6144-134, Poster Session

Comparison of color clustering algorithms for segmentation of dermatological images

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Automatic segmentation of skin lesions in clinical images is a very challenging task; it is necessary for visual analysis of the edges, shape and colors of the lesions to support the melanoma diagnosis, but, at the same time, it is cumbersome since lesions (both naevi and melanomas) do not have regular shape, uniform color, or univocal structure. Most of the approaches adopt unsupervised color clustering. This works compares the most spread color clustering algorithms, namely median cut, k-means, fuzzy-c means and mean shift applied to a method for automatic border extraction, providing an evaluation of the upper bound in accuracy that can be reached with these approaches. Different tests have been performed to examine the influence of the choice of the parameter settings with respect to the performances of the algorithms. Then a new supervised learning phase is proposed to select the best number of clusters and to segment the lesion automatically. Examples have been carried out in a large database of medical images, manually segmented by dermatologists. From these experiments mean-shift was resulted the best technique, in term of sensitivity and specificity. Finally, a qualitative evaluation of the goodness of segmentation has been validated by the human experts too, confirming the results of the quantitative comparison.

6144-135, Poster Session

MATLAB-ITK interface for medical image filtering, segmentation, and registration

V. Chu, G. Hamarneh, Simon Fraser Univ. (Canada)

To facilitate high level analysis of medical image data in research and clinical environments, a wrapper for the ITK toolkit is developed to allow ITK algorithms to be called in MATLAB. ITK is a powerful open-source toolkit implementing state-of-the-art algorithms in medical image processing and analysis. However, although ITK is rapidly gaining popularity, its user base is mostly restricted to technically savvy developers with expert knowledge of C++ and advanced programming concepts. MATLAB, on the other hand, is well-known for its easy-to-use, powerful prototyping capabilities that significantly improve productivity. Unfortunately, the 3D image processing capabilities of MATLAB are very limited and slow to execute. With the help of the wrapper we introduce in this paper, biomedical computing researchers familiar with MATLAB can harness the power of ITK while avoiding learning C++ and dealing with low-level programming issues. We strongly believe this functionality will be of considerable interest to the medical image computing community. In this paper we provide details about the design and usage of this interface in medical image filtering, segmentation, and registration.

6144-136, Poster Session

An adipose segmentation and quantification scheme for the intra abdominal region on minipigs

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This article describes a method for automatic segmentation of the abdomen into three anatomical regions: subcutaneous, retroperitoneal and visceral. For the last two regions the amount of adipose tissue (fat) is quantified. According to recent medical research, the distinction between retroperitoneal and visceral fat is important for studying metabolic syndrome, which is closely related to diabetes. However previous work has neglected to address this point, treating the two types of fat together. We use T1-weighted three-dimensional magnetic resonance data of the abdomen of obese minipigs. The pigs were manually dissected right after the scan, to produce the “ground truth” segmentation. We perform automatic segmentation on a representative slice, which on humans has been shown to correlate with the amount of adipose tissue in the abdomen. The process of automatic fat estimation consists of three steps. First, the subcutaneous fat is removed with a modified active contour approach. The energy formulation of the active contour exploits the homogeneous nature of the subcutaneous fat and the smoothness of the boundary. Subsequently the retroperitoneal fat located around the abdominal cavity is separated from the visceral fat. For this, we formulate a cost function on a contour, based on intensities, edges, distance to center and smoothness, so as to exploit the properties of the retroperitoneal fat. We then globally optimize this function using dynamic programming. Finally, the fat content of the retroperitoneal and visceral regions is quantified based on a fuzzy c-means classification of the intensities within the segmented regions. The segmentation proved satisfactory by visual inspection, and closely correlated with the manual dissection data. The correlation was 0.84 for the retroperitoneal fat, and 0.76 for the visceral fat.

6144-137, Poster Session

Automated method for measurement of gray matter thickness in Alzheimer's patients for 3D MRI

H. Arimura, T. Yoshiura, S. Kumazawa, H. Koga, S. Sakai, F. Mihara, H. Honda, M. Ohki, F. Toyofuku, Y. Higashida, Kyushu Univ. (Japan)

Alzheimer's disease (AD) is associated with the atrophy of certain gray matter regions in the cerebrum such as the entorhinal cortex and hippocampus, which could lead to the changes on volume, shape and gray level in gray matter regions in magnetic resonance imaging (MRI). In the early stage of AD, these changes would gradually develop in the local gray matter regions. Our purpose was to develop an automated method for measurement of gray matter thickness in Alzheimer's patients for three-dimensional (3D) MRI. High-resolution 3D T1-weighted images of the whole brain were analyzed. Regions of white matter and gray matter were segmented based on a gray level thresholding technique and a level set method. Normal vectors were determined on all voxels on a segmented white matter surface. We defined a reference line (one voxel width) on each voxel of the white matter surface along the normal vector for measuring the thickness of gray matter. We applied the computerized method to 7 clinically diagnosed AD cases and 8 non-AD cases. Our preliminary results show that the MRI-based computerized estimation of gray matter atrophy may be promising for detecting AD.

6144-138, Poster Session

A two-stage segmentation method for lesion segmentation on digital mammograms

Y. Yuan, M. L. Giger, K. Suzuki, H. Li, A. R. Jamieson, The Univ. of Chicago

Lesion segmentation is an essential step in computer-aided diagnosis for digital (or digitized) mammograms. As mass lesions are usually embedded in and camouflaged by varying densities of parenchymal tissue structures, lesion segmentation is not trivial. In this paper, we present a two-stage segmentation method that uses an active contour algorithm that minimizes an energy function based on the homogeneities inside and outside of the evolving contour. The minimization algorithm solves, by the level set method, the Euler-Lagrange equation that describes the contour evolution. Prior to the application of the active contour algorithm, radial gradient index (RGI) based segmentation method is applied to yield an initial contour closer to the lesion boundary location in a computationally efficient manner. This initial segmentation also estimates an effective background by using the values of the image within a given radius of the initial contour. By using a digitized screening database with 96 biopsy-proven, malignant lesions, we quantitatively compare this two-stage segmentation algorithm with a RGI-based method and a conventional region-growing algorithm by measuring the area similarity. At an overlap threshold (ratio of intersection to union of contours) of 0.30, the new method correctly segments 95% of the lesions while both the RGI and region growing methods delineate only 83% of the lesions. This assessment demonstrates that the two-stage segmentation algorithm possesses closer agreement with manually contoured lesion boundaries.

6144-139, Poster Session

Automatic determination of the imaging plane in lumbar

M. Tsurumaki, Nakajo Central Hospital (Japan) and Niigata Univ. (Japan); Y. Lee, D. Tsai, M. Sekiya, Niigata Univ. (Japan); K. Kazama, Nakajo Central Hospital (Japan)

In this paper we describe a method for assisting radiological technologists in their routine work to automatically determine the imaging plane in lumbar MRI. The method is first to recognize the spinal cord and the intervertebral disk (ID) from the lumbar vertebra 3-plane localizer image, and then the imaging plane is automatically determined according to the recognition results.

To determine the imaging plane, the spinal cord and the ID are automatically recognized from the lumbar vertebra 3-plane localizer image with a series of image processing techniques. The proposed method consists of three major steps. First, after removing the air and fat regions from the 3-plane localizer image by use of histogram analysis, the rachis region is specified with Sobel edge detection filter. Second, the spinal cord and the ID were respectively extracted from the specified rachis region making use of global thresholding and the line detection filter. Finally, the imaging plane is determined by finding the straight line between the spinal cord and the ID with the Hough transform.

Image data of 10 healthy volunteers were used for investigation. To validate the usefulness of our proposed method, manual determination of the imaging plane was also conducted by five experienced radiological technologists. Our experimental results showed that the concordance rate between the manual setting and automatic determination reached to 90%. Moreover, a remarkable reduction in execution time for imaging-plane determination was also achieved.

6144-140, Poster Session

White matter fiber tractography based on a density field in diffusion tensor MRI

S. Kumazawa, T. Yoshiura, H. Arimura, F. Mihara, H. Honda, Y. Higashida, F. Toyofuku, Kyushu Univ. (Japan)

Diffusion tensor (DT) MRI provides directional information of diffusion which can be utilized to estimate the connectivity of white matter (WM) tract pathways in the human brain. However, a voxel in DT-MRI including several WM fiber directions denotes an averaged direction due to the effect of partial volume averaging of the fibers. Consequently, the measured directions would be ambiguous in the crossing and branching regions. Thus, it would be very difficult to trace passing through the fiber crossing and branching regions with conventional methods, which use the major eigenvector of tensor as the local fiber direction. The purpose of this study was to develop a new WM tractography method which permits WM tract crossing and branching. For estimating the connectivity of WM tract pathways, we introduced a three-dimensional density field of WM tract into the DT-MRI voxel space. The tract density field was generated by summing up the effects of a three-dimensional density distribution based on the shape of the diffusion ellipsoid within each tract candidate voxel, and then the fiber tracts were traced along the three-dimensional tract density field instead of the major eigenvector field. In our method, the connectivity between voxels was described as a one-to-many relation, and thus our method allows for branching of the fiber tracts. To investigate the usefulness of our method, we applied it to DT-MRI data of normal subjects and patients with brain tumors. With our tractography method, the detailed anatomy of WM tracts was depicted more appropriately than conventional methods.

6144-141, Poster Session

Fuzzy C-mean clustering on kinetic parameter estimation with generalized linear least square algorithm in SPECT

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Dynamic Single Photon Emission Computed Tomography (SPECT) has the potential to quantitatively estimate physiological parameters by fitting compartment models to the tracer kinetics. The generalized linear least square method (GLLS) is an efficient method to estimate unbiased

kinetic parameters and parametric images. However, due to the low sensitivity of SPECT, noisy data can cause voxel-wise parameter estimation by GLLS to fail. Fuzzy C-Mean (FCM) clustering and modified FCM, which also utilizes information from the immediate neighboring voxels, have been proposed to improve the voxel-wise parameter estimation of GLLS. Monte Carlo simulations were performed to generate dynamic SPECT data with different noise levels and processed by general and modified FCM clustering. Parametric images were estimated by Logan and Yokoi graphical analysis and GLLS. The influx rate (K1), volume of distribution (Vd) were estimated for the cerebellum, thalamus and frontal cortex. Our results show that (1) FCM can improve parameter estimates for noisy data as compared with graphical approaches, (2) GLLS provides estimates of micro parameters (K1-k4) as well as macro parameters, such as volume of distribution (Vd) and binding potential (BP1 & BP2) and (3) FCM clustering incorporating neighboring pixel information does not improve the parameter estimates. These findings indicated that it is desirable for pre-segmentation with FCM clustering to generate voxel-wise parametric images with GLLS from dynamic SPECT data.

6144-142, Poster Session

Segmentation of ground glass opacities by asymmetric multiphase deformable model

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Recently ground glass opacities (GGOs) have become noteworthy in lung cancer diagnosis. It is crucial to define the boundary a GGO accurately and consistently, since the growth rate is the most manifest evidence of its malignancy. The indefinite and irregular boundary of a GGO makes deformable models adequate for its segmentation. Among deformable models a level set method has the ability to handle topological changes. For the exact estimation of GGO's volume change, the pulmonary vessels and airways inside GGO should be excluded in its volume estimation, which necessitate the segmentation into more regions than two of the object and the background. Hence, we adopted a multi-phase deformable model of two level set functions and modified its energy functional into an asymmetric form for better convergence. Besides, the gradient information was added to the partial differential equations to capture the proper boundary not affected by the partial volume effect. The proposed model segments the input image into three regions of the inner and outer regions, and the background. It means that the model can exclude vessels as the inner region and airways as the background, thus finally segment out only GGO tissues as the outer region except the inner region. Our experiment showed the feasibility of the proposed method as a pre-processing step for 3 dimensional volume measurement of the GGO.

6144-144, Poster Session

Semi-automatic knee cartilage segmentation

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Osteo-Arthritis (OA) is a very common age-related cause of pain and reduced range of motion. The central effect of OA is wear-down of the articular cartilage that otherwise ensures smooth joint motion. Quantification of the cartilage breakdown is central in monitoring disease progression and therefore cartilage segmentation is required.

Recent advances allow automatic cartilage segmentation with high accuracy in most cases. However, the automatic methods still fail in some problematic cases. For clinical studies, even if a few failing cases will be averaged out in the overall results, this reduces the accuracy and precision and thereby necessitates larger/longer studies. Since the severe OA cases are often most problematic for the automatic methods, there is even a risk that the quantification will introduce a bias in the results. Therefore, interactive inspection and correction of these problematic cases is desirable. For diagnosis on individuals, this is even more crucial since the diagnosis will otherwise simply fail.

We introduce and evaluate a semi-automatic cartilage segmentation method combining an automatic pre-segmentation with an interactive step that allows inspection and correction. The automatic step consists of voxel classification based on supervised learning. The interactive step combines a watershed transformation of the original scan with the posterior probability map from the classification step at sub-voxel precision. We evaluate the method for the task of segmenting the tibial cartilage sheet from low-field magnetic resonance imaging (MRI) of knees.

The evaluation shows that the combined method allows accurate and highly reproducible correction of the segmentation of even the worst cases in approximately ten minutes of interaction.

6144-145, Poster Session

Fast and robust extraction of centerlines in 3D tubular structures using a scattered-snakelet approach

C. T. Spuhler, M. Harders, G. Szekely, ETH Zürich (Switzerland)

We present a fast and robust approach for automatic centerline extraction of tubular structures. The underlying idea is to cut traditional snakes into a set of shorter, independent segments - so-called snakelets. Following the same variational principles, each snakelet acts locally and extracts a subpart of the overall structure. After a parallel optimization step, outliers are detected and the remaining segments then form an implicit centerline. No manual initialization of the snakelets is necessary, which represents one advantage of the method. Moreover, computational complexity does not directly depend on dataset size, but on the number of snake segments necessary to cover the structure of interest, resulting in short computation times. Lastly, the approach is robust even for very complex datasets such as the small intestine. Our approach was tested on several medical datasets (CT datasets of colon, small bowel, and blood vessels) and yielded smooth, connected centerlines with few or no branches. The computation time needed is less than a minute using standard computing hardware.

6144-146, Poster Session

Analysis of brain images using the 3D-CSC segmentation method

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The Color Structure Code (CSC) is a fast region growing segmentation technique where overlapping(!) segments grow into larger (also overlapping) segments steered by a hierarchical hexagonal topology. This method was developed at the image recognition lab in Koblenz and is recently generalized to segmentation of 3D images. A mathematical challenge is the non-existence of a smooth hierarchical overlapping topology in 3D. Thus, steering the region growing process becomes much more involved in 3D and over-segmentation can occur.

The 3D-CSC is used for an analysis of 3D MR and CT images. We will report here on our progress in MR brain images where we proceed as follows:

Given a 3D MR image I, we (1) apply a 3D Kuwahara filter, (2) compute an optimal gray value similarity threshold t(I) (using the variance of the background noise), (3) apply a 3D-CSC segmentation with threshold t(I) (4) automatically classify the found segments using

- scale space filtering and expectation maximization techniques for a first assignment of the segments to one of the the five classes background, CSF, gray matter, white matter and fat,
- morphological operations to correct false assignments of muscles and nerves as gray matter

The results are very promising and it looks as if this method can beat the state-of-the-art program SPM. An evaluation of our classification in gray

matter, white matter and non-brain tissues and that of SPM is currently taking place in the BWZK (military hospital Koblenz) and will be presented at the conference.

6144-147, Poster Session

3D echocardiographic segmentation using the mean-shift algorithm and an active surface model

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The anatomical and functional cardiac cavities information obtained by Ultrasound images allows a qualitative and quantitative analysis to determine patient's health and detect possible pathologies. Several approaches have been proposed for semiautomatic or fully automatic segmentation . Texture based pre-segmentation combined with an active contour model have proven to be a promising way to extract cardiac structures from echographic images. In this work a novel procedure for 3D cardiac image segmentation is introduced. A robust pre-processing step that reduces noise and extracts an initial frontier of cardiac structures is combined with an Active Surface Model to obtain final 3D segmentation. Pre-processing is performed by the Mean Shift algorithm that integrates 3D edge confidence map and includes entropy, echoes intensity and spatial information as input features. This procedure locates adequately homogeneous regions in 3D echocardiographic images. The external energy terms included in the Active Surface Model are the 3D edge confidence map and the entropy component obtained by the Mean Shift pre-segmentation. The results demonstrate that the pre-processing provides homogeneous regions and a good initial frontier between blood and myocardium. The Active Surface Model adjusts the initial surface computed by the mean-shift algorithm to the cardiac border. Finally, the obtained results are compared with the experts' manual segmentation and the Tanimoto index between these segmentations is calculated.

6144-148, Poster Session

Level sets and shape models for segmentation of cardiac perfusion MRI

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Dynamic MRI perfusion studies have proven to be useful for detecting and characterizing myocardial ischemia. Accurate segmentation of the myocardium in the dynamic contrast-enhanced (DCE) MRI images is an important step for the estimation of regional perfusion.

Although a great deal of research has been done for segmenting MRI scans of heart wall motion, relatively little work has been done to segment DCE MRI studies. We propose a new semi-automatic robust level set based segmentation technique that uses both the spatial

and temporal information. The evolution of level sets is based on an intensity based speed function which is a function of the Mahalanobis distance between each pixel's time curve and the time curves of user-determined seed points in the myocardium. A curvature penalty term is included in the evolution of the contours. We also make use of shape information to constrain the evolution of the level sets. Shape

models were created by using signed distance maps from manually segmented images and used with principal component analysis. Thus the algorithm has the qualities of evolving an active contour both locally, based on image values and curvature, and globally to a maximum a posteriori estimate of the left ventricle shape in order to segment the left ventricle myocardium from DCE cardiac MRI images.

The algorithm was tested on 16 DCE MRI datasets and compared to manual segmentations. The results matched the manual segmentations well in most cases.

6144-149, Poster Session

Detection of joint space narrowing in hand radiographs

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Radiographic assessment of joint space narrowing in hand radiographs is important for determining the progression of rheumatoid arthritis in an early stage. Clinical scoring methods are based on manual measurements that are time consuming and subjected to intra-reader and inter-reader variance. The goal is to design an automated method for measuring the joint space width with a higher sensitivity to change than manual methods.

The large variability in joint shapes and textures, the possible presence of joint damage, and the effects of projection make it difficult to detect joint margins accurately. We developed a method that uses a modified active shape model to scan for margins within a predetermined region of interest. Possible joint space margin locations are detected with a Mahalanobis distance classifier. To prevent the detection of false edges, we use a dynamic programming approach. The shape model and the classifier are trained with a set of 50 hand radiographs, in which the margins have been outlined by an expert.

We tested our method on a test set of 50 images. The method was evaluated by calculating the mean square error with manual readings by an expert. 90% of the joint margins were detected within 0.20 mm.

We found that our joint margin detection method is robust and accurate in cases where the joint margin is clearly visible. For cases where the joint space width is (close to) zero, the algorithm is unable to find both margins correctly. In these cases it would be necessary to use a different method to quantify joint damage.

6144-151, Poster Session

Vesselness propagation - A fast interactive vessel segmentation method

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With the rapid development of multi-detector computed tomography (MDCT) resulting in increasing temporal and spatial resolution of data sets, clinical use of computed tomographic angiography (CTA) is rapidly increasing. Therefore, analysis vascular structures is much needed in CTA images; however, the basis of the analysis, vessel segmentation, can be still quite challenging. In this paper a fast interactive method for CTA vessel segmentation, called vesselness propagation, is presented. This method is a two-step procedure, a pre-processing step and an interactive step. During the pre-processing step, a vesselness volume is computed by applying a CTA transfer function followed by a multi-scale Hessian filter. At the interactive stage, the propagating is controlled interactively in terms of the priority of the vesselness. This method was successfully applied to many CTA applications, such as circle-of-wills, carotid artery, coronary artery, and peripheral arteries. It takes less than one minute for a user to segment the entire vascular structure. The proposed method provides an effective way to obtain an overview of vascular structures.

6144-152, Poster Session

Chroma analysis for quantitative immunohistochemistry using active learning

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Protein expression analysis has traditionally relied upon visual evaluation of immunohistochemical reaction by a pathologist, who analyzes the grade of staining intensity and estimates the percentage of cells stained in the area of interest. This method is effective in experienced hands but has potential limitations in its reproducibility due to subjectivity between and

within operators. These limitations are particularly pronounced in gray areas where a distinction of weak from moderate protein expression can be clinically significant. Some research also suggests that sub localization of the protein expression into different components such as nuclei versus cytoplasm may be of great importance. This distinction can be particularly difficult to quantify using manual methods. In this paper, we formulate the problem of quantitative protein expression analysis as an active learning classification problem, where a very small set of presampled user data is used for understanding expert evaluation. The expert coveted confidence is mapped to derive an uncertainty region to select the supplemental learning data. This is done by posing a structured query to the unknown data set. The newly identified samples are then augmented to the training set for incremental learning. The strength of our algorithm is measured in its ability to learn with minimum user interaction. Chroma analysis results of a Tissue Micro-array (TMA) images are presented to demonstrate the user interaction and learning ability. The chroma analysis results are then processed to obtain quantitative results.

6144-153, Poster Session

Probabilistic minimal path for automated esophagus segmentation

M. Rousson, Siemens Corporate Research; Y. Bai, Johns Hopkins Univ.; C. Xu, F. Sauer, Siemens Corporate Research

In this paper, we introduce a probabilistic shortest path approach to extract the esophagus from CT images. In this modality, the absence of strong discriminative features in the observed image make the problem ill-posed without the introduction of additional knowledge constraining the problem. The solution presented in this paper relies on learning and integrating contextual information. The idea is to model spatial dependency between the structure of interest and neighboring organs that may be easier to extract. Observing that the left atrium and the aorta are such candidates for the esophagus, we propose to learn the esophagus location with respect to these two organs. This dependence is learned from a set of training images where the three structures have been segmented. Each training esophagus is registered to a reference image according to a warping that maps exactly the reference organs. From the registered esophagi, we define the probability of the esophagus centerline relative to the aorta and left atrium. To extract a new centerline, a probabilistic criterion is defined from a Bayesian formulation that combines the prior information with the image data. Given a new image, the aorta and left atrium are first segmented and registered to the reference shapes and then, the optimal esophagus centerline is obtained with a shortest path algorithm. Finally, relying on the extracted centerline, a grow-out strategy allows a robust detection of inner/outer boundaries.

6144-154, Poster Session

Variational segmentation framework in prolate spheroidal coordinates for 3D real time echocardiography

B. Vallet, Columbia Univ.; E. D. Angelini, Ecole Nationale Supérieure des Télécommunications (France); A. F. Laine, Columbia Univ.

This paper presents a new formulation of a deformable model segmentation problem, in prolate spheroidal coordinates, applied to real-time 3D (RT3D) cardiac ultrasound. The coordinate system enables a representation of the segmented surface with descriptors specifically adapted to the ellipsoidal shape of the ventricle.

The segmentation process is initialized with an ellipsoid, encoded as an iso-surface. External energy terms, based on gray-level information, and internal energy terms, based on surface curvature, control the deformation process. The proposed reformulation of the deformable model segmentation framework provides a very efficient algorithm for the segmentation of closed-shape ventricular surfaces. It lays down the mathematical foundations of a generic variational deformable model, for ellipsoidal iso-surfaces, expressed in prolate spheroidal coordinates. Computational performances, with near real-time deformations of the ellipsoid surface, overcome know limitations of standard level set implementations. This work was motivated by the need for ultra-fast segmentation tools to apply to echocardiographic RT3D ultrasound data. Formulation of the deformable model in prolate spheroidal coordinates was well suited for this problem for three reasons: (1) iso-surfaces are ellipsoid that well approximate ventricular shapes, (2) RT3D ultrasound data is acquired in spherical coordinates, which is similar in nature to prolate spheroidal coordinates (3) this coordinate system is widespread within the cardiac modeling community. With this respect, this method opens a new path in the assimilation of cardiac clinical ultrasound data with anatomical cardiac modeling.

6144-156, Poster Session

A new, general method of 3D model generation for active shape image segmentation

S. Lim, Gwangju Institute of Science and Technology (South Korea); J. K. Udupa, A. D. Souza, D. A. Torigian, Univ. of Pennsylvania; Y. Jeong, Chonnam National Univ. Hospital (South Korea); Y. Ho, Gwangju Institute of Science and Technology (South Korea)

Statistical models of shape variability via active shape models (ASMs) have been successfully utilized to perform segmentation and recognition tasks in two-dimensional (2D) images, and to a lesser extent, in three-dimensional (3D) images. 3D model-based approaches are more promising than 2D approaches since they can bring in more and realistic shape constraints for recognizing and delineating the object boundary. For 3D model-based approaches, however, building the 3D shape model from a training set of segmented instances of an object is a major challenge and currently remains an open problem. In this paper, we propose a novel, general method for the generation of 3D statistical shape models. Given a set of training 3D shapes, 3D model generation is achieved by 1) building the mean model from the distance transform of the training shapes, 2) utilizing a tetrahedron method for automatically selecting landmarks on the mean model, and 3) subsequently propagating these landmarks to each training shape via a distance labeling method. In this work, we investigate the accuracy and compactness of the 3D model for the human liver built from 17 segmented individual CT data sets. The training shapes were generated by segmenting the liver in these data sets by using live wire. Previous 3D modeling efforts all had severe limitations in terms of the object shape, geometry, and topology. The proposed method is very general without such assumptions and can be applied to any data set.

6144-157, Poster Session

A fast algorithm for body extraction in CT volumes

G. Guetat, Univ. of Illinois at Urbana-Champaign; J. Stoeckel, M. Wolf, Siemens Medical Solutions

Computed Tomography (CT) modality shows not only the body of the patient in the volumes it generates, but also the clothing, the cushion and the table. This might be a problem especially for two applications. The first is 3D visualization, where the table has high density parts that might hide regions of interest. The second is registration of acquisitions obtained at different time points; indeed, the table and cushions might be visible in one data set only, and their positions and shapes may vary, making the registration less accurate. An automatic approach for extracting the body would solve those problems. It should be robust, reliable, and fast. We therefore propose a multi-scale method based on deformable models. The idea is to move a surface across the image that attaches to the boundaries of the body. We iteratively compute forces which take into account local information around the surface. Those make it move through the table but ensure that it stops when coming close to the body. Our model has elastic properties; moreover, we take into account the fact that some regions in the volume convey more information than

others by giving them more weight. This is done by using normalized convolution when regularizing the surface. The algorithm, tested on a database of over a hundred volumes of whole body, chest or lower abdomen, has proven to be very efficient, even for volumes with up to 900 slices, providing accurate results in an average time of 6 seconds. It is also robust against noise and variations of scale and table's shape.

6144-158, Poster Session

Investigation on an EM framework for partial volume image segmentation

D. Eremina, Stony Brook Univ.; X. Li, Columbia Univ.; Z. Liang, Stony Brook Univ.

This work investigates a partial volume (PV) image segmentation framework, which utilizes the EM (expectation-maximization) algorithm to estimate (1) tissue fractions in each image voxel and (2) statistical model parameters of the image under the principle of maximum a posteriori probability (MAP). A previous EM approach models the PV effect by down-sampling a voxel and then labels each sub-voxel by a pure tissue type it fully belongs to. The number of sub-voxels labeled by a given tissue type over the total number of sub-voxels reflects the fraction of that tissue type inside the original voxel. The tissue fractions in each voxel in this discrete PV model are usually represented by a limited number of percentage values. In this work, we investigate an alternative EM approach which models the PV effect in a continuous space and directly estimates the fraction of each tissue type in the original voxel. Mathematically if the down-sampling is repeated infinite times so that an infinite number of sub-voxels can be labeled in the original voxel, the previous discrete PV model would converge to our proposed continuous PV tissue-mixture model. However, in practice a voxel is usually down-sampled once or twice for computational reasons. Furthermore, mathematical operations, such as partial differentiation, may not be accurately implemented in the discrete model. A comparison study between this limited down-sampling approach and our continuous PV model reveals, by computer simulations, that our continuous PV model can improve the PV segmentation over the discrete PV model with more efficient computing speed.

6144-159, Poster Session

Shortest path adjusted similarity metrics for resolving boundary perturbations in scaffold images for tissue engineering

S. Rajagopalan, R. A. Robb, Mayo Clinic

The degree of match between the delineation result produced by a segmentation technique and the ground truth can be assessed using robust "presence-absence" resemblance measures. However, these measures are highly sensitive to even minor boundary perturbations which imminently manifest in the segmentations of random biphasic spaces reminiscent of the stochastic pore-solid distributions in the tissue engineering scaffolds. This paper presents a graph theory approach which emphasizes global resemblances and ignores minor local dissimilarities by performing controlled local mutations in order to maximize the similarities. The effect of this adjustment is investigated on a comprehensive list (forty seven) of similarity indices sensitive to the over- and under- estimation errors associated with image delineation tasks. We also investigate the use of different association and agreement measures to assess the joint agreement of the similarity indices.

6144-160, Poster Session

Intelligent data splitting for volume data

H. Shen, Siemens Corporate Research; E. K. Bartsch, Siemens Medical Solutions (Germany)

We describe a system that automatically extracts body sections of interest from volume data sets obtained from major medical modalities. This is critical as an effort to save storage and transmission bandwidth and improve data sharing efficiency. The data to be split is stored in a series of files, and each of the files contains one axial slice image. This is how the DICOM data is stored. The splitting of volume data will therefore be applied in the axial direction. The core of the system is an algorithm module that automatically detects lines of separation in the axial direction of the data. Afterwards, the system will copy the files that contain the desired section of slice images to the destination, according to the detected separation lines. To obtain the split lines, features are extracted from human anatomies that are specific to each body section. The method and principle can be applied to major modalities where the extraction of various data sections is needed.

6144-161, Poster Session

Single click volumetric segmentation of abdominal organs in computed tomography images

N. J. Backman, Whitworth College; B. W. Whitney, Northern Kentucky Univ.; J. Furst, D. Raicu, DePaul Univ.

Current segmentation techniques require user intervention to fine-tune thresholds and parameters, plot initial contours, refine seed placement, and engage in other optimization strategies. This can cause difficulties for physicians trying to use segmentation tools as they may not have the time or resources to overcome steep learning curves. In order to segment volumetric regions from sequential slices of computed tomography (CT) images with minimal user intervention, we propose an algorithm based on volumetric seeded region growing that employs an adaptive and prioritized expansion. This algorithm requires a user only to identify a voxel in an organ to perform volumetric segmentation. This approach overcomes the need to manually select threshold values for specific organs by analyzing the histogram of voxel similarity to automatically determine a stopping criterion. The homogeneity criterion used for region growth in this approach is calculated from volumetric texture descriptors derived from co-occurrence matrices which consider voxel-pairs in a 3-dimensional neighborhood of a given voxel. Preliminary segmentation results of the kidneys, spleen, and liver were obtained on 3D data extracted from 700 sequential CT images from various studies collected by Northwestern Memorial Hospital. We believe this approach to be a viable segmentation technique that requires significantly less user intervention when compared to other techniques by necessitating only one user intervention, namely the selection of a single seed point.

6144-162, Poster Session

Fully automatic segmentation of left ventricular myocardium in real time 3D echocardiography

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Purpose: We report a deformable model (DM)-based fully automatic segmentation of the left ventricular (LV) myocardium (endocardium + epicardium) in real-time three-dimensional (3D) echocardiography.

Methods: Initialization of the DM is performed through automated mutual information-based registration of the image to be segmented with a 3D template (image + corresponding endo-epicardial wiremesh). The initialized endocardial and epicardial wiremesh templates are then simultaneously refined iteratively under the joint influence of mesh-derived internal forces, image-derived external (gradient vector flow-based) forces, and endo-epicardium mesh-interaction forces. Incorporation of adaptive mesh-interaction forces into the DM refinement, a novelty of the current work, ensures appropriate relative endo-epicardial orientation during simultaneous refinement. Repeating for the entire cardiac sequence provides the segmented myocardium for all phases. Preliminary comparison is presented between automatic and expert-defined myocardial segmentation for one subject imaged in clinical settings using a Philips SONOS 7500 scanner.

Results: RMS radial distance error between the algorithm-determined and expert-traced endocardial and epicardial contours in six predetermined planar views was 3.5 mm (end-diastole) and 3.7 mm (systole), and 3.7 mm (end-diastole) and 3.8 mm (systole), respectively. Mean absolute error between average myocardial thickness calculated using automatic and expert-defined contours was 1.9 mm (apical), 1.1 mm (mid) and 1.3 mm (basal). The absolute difference in ejection fraction calculated using our algorithm and by the expert using the TomTec software was 7%.

Conclusion: We demonstrate successful segmentation of LV myocardium, which allows tracking of clinically important LV structure and function (e.g. wall thickness, LV volume, ejection fraction) over the cardiac cycle.

6144-163, Poster Session

Pre-operative segmentation of neck CT datasets for the planning of neck dissections

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Therapeutically relevant anatomical structures of the neck are to be segmented from CT and MRI image data for visualizing the patient-specific pathology in 3D to support preoperative surgical decisions.

In this paper, we examine the appropriateness of elementary segmentation techniques based on gray values and contour information for segmenting structures in the neck region. Region Growing, Interactive Watershed Transformation and Live-Wire are employed for segmentation. It is also examined, which of these methods can be automated. The integration of these segmentation techniques into the software assistant NeckVision is described.

6144-164, Poster Session

Brain extraction using geodesic active contours

A. Huang, R. Abugharbieh, The Univ. of British Columbia (Canada); R. Tam, MS/MRI Research Group (Canada); A. Traboulsee, The Univ. of British Columbia (Canada)

Extracting the brain cortex from magnetic resonance imaging (MRI) head scans is an essential preprocessing step of which the accuracy greatly affects subsequent image analysis. The currently popular Brain Extraction Tool (BET) produces a brain mask which may be too smooth for practical use. This paper presents a novel brain extraction tool based on three-dimensional geodesic active contours, connected component analysis and mathematical morphology. Based on user-specified intensity and contrast levels, the proposed algorithm allows an active contour to evolve naturally and extract the brain cortex. Experiments on synthetic MRI data and scanned coronal and axial MRI image volumes indicate successful extraction of tight perimeters surrounding the brain cortex. Quantitative evaluations on both synthetic phantoms and manually labeled data resulted in better accuracy than BET in terms of true and false voxel assignment. Based on these results, we illustrate that our brain extraction tool is a robust and accurate approach for the challenging task of automatically extracting the brain cortex in MRI data.

6144-165, Poster Session

Unsupervised definition of the tibia-femoral joint regions on the human knee and its applications to cartilage analysisa

J. G. Tamez-Peña, M. Barbu-McInnis, S. M. Totterman, VirtualScopics, LLC

Abnormal MR image-based findings on the knee joint like cartilage defects, cartilage denuded areas, osteophytes, and bone marrow edema (BME) are very useful in staging and evaluating the degree of osteoarthritis (OA) in the human beings. Because the locations of the abnormal findings have been correlated to the degree of pain and stiffness of the joint the location of these abnormal finding is very important for the correct evaluation of the disease. The definition of the abnormality location is not always an objective task, due to the lack of clear anatomical features. This uncertainly can cause some miss-registration of abnormal findings among readers or among subject time points. Therefore, it is very important to have an objective definition of the different anatomical regions present in the knee. This works present a computerized approach to the definition of the different knee regions. The approach it is based on an algorithm unique femur features and their relation to the extended knee. The femur's features are found from users supplied segmentations of the femur and the tibia. From the segmentation the algorithm automatically divides the knee into five anatomical regions: Trochlea, medial weight bearing, lateral weight bearing, posterior medial femur's condyle, and posterior lateral femur's condyle. The unsupervised definition of the knee regions allows for a reproducible way to do the evaluation of regional OA changes. This works will present the application of this automated algorithm for the regional analysis of the cartilage tissue.

6144-166, Poster Session

Binning strategies evaluation for tissue classification in computed tomography images

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Binning strategies have been used in much research work for image compression, feature extraction, classification, segmentation and other tasks, but rarely is there any rigorous investigation into which binning strategy is the best. Binning becomes a "hidden parameter" of the research method. This work rigorously investigates the results of two different binning strategies, linear binning and clipped binning, for co-occurrence texture-based classification of the backbone, liver, heart, renal, and splenic parenchyma in high-resolution DICOM Computed Tomography (CT) images of the human chest and abdomen. Linear binning divides the gray-level range of [0..4095] into k1 equally sized bins, while clipped binning allocates one large bin for low intensity gray-levels [0..855] (air), one for higher intensities [1368..4095] (bone), and k2 equally sized bins for the soft tissues between [856..1368]. These bins are further used to calculate the co-occurrence statistical model and its ten Haralick descriptors for texture quantification of gray-level images. The results of the texture quantification using each one of the two strategies and for different values of k1 and k2 are evaluated with respect to their discrimination power using a decision tree classification algorithm and four classification performance metrics (sensitivity, specificity, precision and accuracy). Our preliminary results obtained on 1368 segmented DICOM images show that the optimal number of gray-levels is equal to 128 and 64 for linear binning and clipped binning, respectively. Furthermore, when comparing the results of the two approaches, clipped binning approach shows significantly improvement for liver and spleen, tissues known to have similar gray-levels and texture.

6144-168, Poster Session

Interactive lesion segmentation on dynamic contrast enhanced breast MRI using a Markov model

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The purpose of this study is to segment lesions on Dynamic Contrast-Enhanced (DCE) breast MRI. DCE breast MRI, in which the breast is imaged before, during, and after the administration of a contrast agent, enables a truly 3D examination of breast tissues. This functional angiogenic imaging technique provides noninvasive assessment of microcirculatory characteristics of tissues in addition to traditional anatomical structure information. Since morphological features and kinetic curves from segmented lesions are to be used for diagnosis and treatment decisions,

lesion segmentation is a key pre-processing step for classification. The ROI is defined by a bounding box containing the enhancement region in the subtraction image, which is generated by subtracting the pre-contrast image from 1st post-contrast image. A maximum a posteriori (MAP) estimate of the class membership (lesion vs. non-lesion) for each voxel is obtained using the Iterative Conditional Mode (ICM) method. The prior distribution of the class membership is modeled as a Pott's model, a Markov Random Field model in which the class membership of each voxel is assumed to depend upon its nearest neighbors only. The likelihood distribution is assumed to be Gaussian. The parameters of each Gaussian distribution are estimated from a dozen voxels manually selected as representative of the class. The experimental segmentation results demonstrate anatomically plausible breast tissue segmentation and the predicted class membership of voxels from the interactive segmentation algorithm agrees with the manual classifications made by inspection of the kinetic enhancement curves. The proposed method is is advantageous in that it is efficient, flexible and robust.

6144-169, Poster Session

Automatic tracking of neuro vascular tree paths

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3-D Vessel Analysis is an integral part of CTA or MRA clinical workflow for the interpretation, diagnosis, and treatment planning of vascular pathologies such as aneurysms. Stent treatment planning, placement, and follow-up of Abdominal Aortic Aneurysms (AAA) require detailed measurement of diameter, area, and length of the aorta tree structure. Centerline and path tracking is a fundamental step towards analysis and quantification of vessel trees that enables such measurements. In this paper we demonstrate an automated algorithm for tracking the path of the major Neuro arteries that have been previously segmented. The algorithm combines anatomical intelligence and automatic identification of the start and terminal point of arteries to track the important arterial segments, and identify junctions that are common locations for aneurysms. A start point is automatically detected in the distal end of the volume. The entire vessel tree is coded such that a geodesic distance is computed for the voxel to the start point, called distance from reference (DFR). The cranium is sub-segmented to identify the end points for the major cerebral arteries. The end points are identified as local maximas in the DFR coded tree. The end points are connected to the start point using a shortest path algorithm. Since each end point is located in a specific anatomical zone, the path originating from the end point is also assigned the corresponding anatomical label. Results are demonstrated for CTA and MRA with variations in anatomy and location of the pathology.

6144-170, Poster Session

Robust optic disk detection in retinal images using vessel structure and radon transform

K. Huang, Michigan State Univ.; M. Yan, Siemens Corporate Research

A robust and computationally efficient algorithm is proposed for optic disk detection in retinal fundus images. The algorithm includes two steps: optic disk localization and boundary detection. In the localization step, vessels are modeled as a tree structure. The root of a vessel tree is automatically detected and served as the location of the optic disk, which is obtained by an efficient multi-level binarization and A* search algorithm. In the boundary detection step, a circle is used to model the shape of an optic disk, and radon transform is applied to estimate the center and radius of the circle. Experimental results of 48 digital fundus images with varying image qualities show 100% accuracy in localization and an accuracy of 92.36% in boundary detection. The success of the proposed algorithm is attributed to the robust features extracted from retinal images.

6144-171, Poster Session

Prior-shape based segmentation of various objects in ultrasound images after speckle-reduction using level-set-based curvature evolution

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Medical ultrasound images are noisy with speckle and artifacts. Reduction of speckle is useful for CAD algorithms. We use curvature evolution along surface normal of the ultrasound image surface to reduce speckle. The premise is that when we view the ultrasound image as a surface, the speckle appears as a high-curvature jagged layer over the true objects intensities and will reduce quickly on curvature evolution. We apply this to an image of a cyst, kidney and heart. All show significant, if not complete, speckle reduction, while keeping the relevant organ boundaries intact. On the speckle-reduced images, we apply a segmentation algorithm to detect objects. The segmentation algorithm is three-phased. In the first phase we choose a prior-shape and optimize the pose parameters to the fit edge-image, using gradient ascent. For cyst, kidney, or heart boundary detection, we take a mixture of ellipses and semi-ellipses. In the second phase, a radial motion is used to draw the contour points to the local-edges. At the third phase the shape optimization is enhanced by using an existing technique of incorporating statistical variations according to an assumed correlation between the points on the curve. We apply the first two phases of the algorithm on a cyst and kidney and obtain satisfactory results. 96% of contour points fall within a pixel of the true cyst boundary. The third shape-optimizing step is expected to further improve the results.

6144-172, Poster Session

Automatic pulmonary vessel segmentation in 3D computed tomographic pulmonary angiographic (CTPA) images

C. Zhou, H. Chan, L. M. Hadjiiski, S. Patel, P. N. Cascade, B. Sahiner, J. Wei, J. Ge, E. A. Kazerooni, Univ. of Michigan

Automatic and accurate segmentation of the pulmonary vessels in 3D computed tomographic angiographic images (CTPA) is an essential step for computerized detection of pulmonary embolism (PE) because PEs only occur inside the pulmonary vessels. We are developing an automated method to track and segment the pulmonary vessels in 3D CTPA images.

The lung region is first extracted using thresholding and morphological operations. 3D multiscale filters in combination with a newly developed response function derived from the eigenvalues of Hessian matrices are used to enhance all vascular structures including the vessel bifurcations and suppress non-vessel structures such as the lymphoid tissues surrounding the vessels. At each scale, a volume of interest (VOI) containing the response function value at each voxel is defined. The voxels with a high response indicate that there is an enhanced vessel whose size matches the given filter scale. A hierarchical expectation-maximization (EM) estimation is then applied to the VOI to segment the vessel by extracting the high response voxels at this single scale. The vessel tree is finally reconstructed by combining the segmented vessels at all scales based on a "connected component" analysis.

Two experienced thoracic radiologists provided the gold standard of pulmonary arteries by manually tracking the arterial tree and marking the center of the vessels using a computer graphical user interface. Two CTPA cases containing PEs were used to evaluate the performance. One of these two cases also contained other lung diseases. The accuracy of vessel tree segmentation was evaluated by the percentage of the "gold standard" vessel center points overlapping with the segmented vessels. The result shows that 97.3% (1868/1920) and 92.0% (2277/2476) of the manually marked center points overlapped with the segmented vessels for the cases without and with other lung disease, respectively. The re-

sults demonstrate that vessel segmentation using our method is not degraded by PE occlusion and the vessels can be accurately extracted.

6144-173, Poster Session

Automated segmentation method of 3D MR brain image using iterative 3D morphological processing

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In order to analyze the brain which is complex and important organ in human body, many brain segmentation algorithms have been proposed. However, brain segmentation remains a challenging problem due to the complexity of the brain. In this paper, we propose an automated brain segmentation method for 3D brain magnetic resonance (MR) images which are obtained as a sequence of 2D brain images. The proposed method consists of three steps: preprocessing, segmentation of non-brain regions (e.g., the skull, meninges, other organs, etc), and spinal cord restoration. Preprocessing takes care of variable characteristics of each MR brain image and enhances the robustness of the algorithm. In segmentation process, the algorithm iteratively uses 3D morphological operations and masking to remove non-brain regions. In other words, we apply 3D morphological operations to a whole 3D MR image. We can perform brain segmentation using masking operations for mid-sagittal slices. In order to eliminate non-brain regions such as meninges which are difficult to remove, we use posterization. Finally we reconstruct the spinal cord truncated during the segmentation processes. Experiments are performed with fifteen 3D MR Brain image sets with 8-bit gray-scale. Experiment results show the proposed algorithm is fast and provides robust and satisfactory results, because our algorithm is based on morphological operations and masking operation which is simple to implement and considers variable characteristics of each MR brain image.

6144-174, Poster Session

Unsupervised clustering of dynamic PET images on the projection domain

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Segmentation of dynamic PET images is an important preprocessing step for kinetic parameter estimation. A single time activity curve (TAC) is extracted for each segmented region. This TAC is then used to estimate the kinetic parameters of the segmented region. Current methods perform this task in two independent steps; first dynamic PET images are reconstructed from the projection data using classical tomographic reconstruction methods, then the time activity curves of the pixels are clustered into a predetermined number of clusters.

In this paper, we propose to cluster the regions of dynamic PET images directly on the projection data and simultaneously estimate the TAC of each region. This method does not require an intermediate step of tomographic reconstruction for each time frame. Therefore the dimensionality of the estimation problem is reduced. We compare the proposed method with weighted least squares (WLS) and expectation maximization with Gaussian mixtures methods (GMM-EM). Filtered backprojection is used to reconstruct emission images required by these methods. Our simulation results show that the proposed method can substantially decrease the number of misclassified pixels and the RMSE of the cluster centers.

6144-175, Poster Session

Quantification of liver fibrosis on MR images

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A non-invasive technique to quantify and image liver fibrosis is proposed. A combined-contrast enhanced (CCE) magnetic resonance (MR) image is modeled as a two-dimensional binary source corrupted by Gaussian noise. The parameters of the Gaussian noise are estimated by a mixed-Gaussian fit algorithm. The discrete universal denoiser is used to segment voxels into normal and abnormal voxels. The problem of collecting reliable statistics on small medical images having high voxel dynamics is addressed and solved with a novel method that collects the contexts in the frequency domain. The estimated amount of fibrosis and the segmented map correlate well with pathology. The proposed method suggests that CCE-MR is suitable for objective non-invasive monitoring of disease progression and therapy response.

6144-176, Poster Session

Content analysis of uterine cervix images: initial steps towards content based indexing and retrieval of cervigrams

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This work is motivated by the need for visual information extraction and management in the growing field of medical image archives. In particular the work focuses on a unique medical repository of digital cervicographic images ("Cervigrams") collected by the National Cancer Institute (NCI) in a longitudinal multi-year study carried out in Guanacaste, Costa Rica. 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. Such a database requires specific tools that can analyze the cervigram content and represent it in a way that can be efficiently searched and compared.

We present a multi-step scheme for segmenting and labeling regions of medical and anatomical interest within the cervigram, utilizing statistical tools and adequate features. The multi-step structure is motivated by the large diversity of the images within the database. The algorithm identifies the cervix region within the image. It than separates the cervix region into three main tissue types: the columnar epithelium (CE), the squamous epithelium (SE), and the acetowhite (AW), which is visible for a short time following the application of acetic acid. The algorithm is developed and tested on a subset of 120 cervigrams that were manually labeled by NCI experts. Initial segmentation results are presented and evaluated.

6144-177, Poster Session

Topological analysis of 3D cell nuclei using finite element template-based spherical mapping

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For quantitative analysis of the 3D topology of cell nuclei, it is necessary to map the images into the same coordinate system. To obtain biologically relevant information from different cell images or time series of the same cell, the superimposed global motions and deformations of the cell have to be removed from the observed motion of tracked particles. Since cells and subcellular structures are composed of soft tissue and constantly changes their shape under the impact of external and internal forces, non-rigid transformations are generally required for the normalization of nucleus topology w.r.t. arbitrary deformations. Since unstressed cell nuclei tend to have a spherical shape, spherical mapping appears to be a natural choice for the shape normalization of cell nuclei. In contrast to some known mathematical schemes, e.g. conformal mappings, we present an approach for spherical mapping which relies on a consistent mechanical model of cell nuclei. Topology-preserving spherical mapping of the 3D geometry of the nucleus is obtained by inverting transformations performed on a finite element template mesh. The proposed method has been applied for the normalization of confocal laser scanning microscopy images of DAPI stained human fibroblast cell nuclei to enable the

localization of gene loci within the nucleus in terms of radial distances. The developed registration scheme can generally be applied for shape-normalizing mapping of objects which can consistently be deformed onto a sphere in the sense of a physically meaningful object deformation.

6144-178, Poster Session

Quantitative comparison of delineated structure shape in radiotherapy

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Targeted ionizing radiation has long been used to treat many forms of cancer. Healthy cells can recover from exposure preferentially to diseased ones, forming the biological basis for radiotherapy. However, healthy cells are destroyed during treatment and a balance must be struck between ensuring that all cancerous cells receive the prescribed dose and the radiotoxic side effects upon the surrounding healthy tissue.

There has been an influx of imaging and radiation targeting technology into radiotherapy over the past fifteen years so that radiation fields can now be accurately shaped to regions indicated by radiologists on treatment planning scans. Two well known problems at the very start of this system cause concern: inter and intra observer variability in planning scan delineations, and the motion of bodily organs relative to the bony landmarks used for patient alignment. To be able to properly address these problems, and hence accurately shape the margins of error used to account for them, an intuitive and quantitative system of describing this variability must be used.

This paper discusses a method of automatically creating correspondence points over similar non-polar delineation volumes so that their shape can be analysed as a set of independent one dimensional statistical problems. An intuitive and interactive display style is suggested.

A case study is presented to illustrate the method. A group of observers were asked to delineate a rectum on a series of time-of-treatment X-ray Volume Images over a patient's fractionation schedule. The inter-observer variability of each image was calculated using the above method and the significance of the organ motion over time evaluated.

6144-179, Poster Session

Sparse principal component analysis in medical shape modeling

K. V. Skoglund, M. B. Stegmann, Danmarks Tekniske Univ. (Denmark)

Principal component analysis (PCA) is a widely used tool in medical image analysis for data reduction, model building, and data understanding and exploration. While PCA is a holistic approach where each new variable is a linear combination of all original variables, sparse PCA (SPCA) aims at producing easily interpreted models through sparse loadings, i.e. each new variable is a linear combination of a subset of the original variables. One of the aims of using SPCA is the possible separation of the results into isolated and easily identifiable effects.

This article introduces SPCA for shape analysis in medicine. Results for three different data sets are given in relation to standard PCA and sparse PCA by simple thresholding of sufficiently small loadings. Focus is on a recent algorithm for computing sparse principal components, but a review of other approaches is supplied as well. The SPCA algorithm has been implemented using Matlab and is available for download.

The general behavior of the algorithm is investigated, and strengths and weaknesses are discussed. Experiments on the ability of SPCA to isolate subtle modes of variation, e.g. stemming from pathological processes, have been carried out. The original report on the SPCA algorithm argues that the ordering of modes is not an issue. We disagree on this point and propose several approaches to establish sensible orderings. A method that maximizes the total amount of explained variance is presented and investigated in detail.

6144-180, Poster Session

3D reconstruction of the coronary tree from two x-ray angiographic views

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In this paper, we develop a method for the reconstruction of 3D coronary artery based on two perspective projections acquired on a standard single plane angiographic system in the same systole. Our reconstruction is based on the model of generalized cylinders, which are generated by sweeping a two-dimensional cross section along an axis in three-dimensional space. We restrict the cross section to be circular and always perpendicular to the tangent of the axis. Firstly, the vascular centerlines of the X-ray angiography images on both projections are semiautomatically extracted by multiscale vessel tracking using Gabor filters, and the radius of the coronary are also acquired simultaneously. Secondly, the relative geometry of the two projections is determined by the gantry information and 2D matching is realized through the epipolar geometry and the consistency of the vessels. Thirdly, we determine the three-dimensional (3D) coordinates of the identified object points, to within a scale factor, from the image coordinates of the matched points and the calculated imaging system geometry. Finally, we link the consequent cross sections which are processed according to the radius and the direction information to obtain the 3D structure of the artery. The proposed 3D reconstruction method is validated on real data and is shown to perform robustly and accurately in the presence of noise.

6144-182, Poster Session

Creation of 3D craniofacial standards from CBCT images

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A low-dose three-dimensional Cone Beam Computed Tomography (CBCT) is introduced recently to clinical practice in dental medicine. 2-D Bolton Standards are used in head x-ray film to determine the deviation from the standard. With the advent of CBCT 3D imaging, we are proposing set of methods to extend 2D Bolton Standards into truly surface based 3D standards to analyze morphometric changes seen in craniofacial complex. To create 3D surface standards, we have implemented series of image processing and graphics steps. 1) Converting bi-plane 2D tracings into set of splines 2) Converting the 2D splines curves from bi-plane projection into 3D space curves 3) Creating labeled template of facial and skeletal shapes 4) Extraction of 3D facial and skeletal triangulated surfaces form 3D CBCT datasets 5) Fitting the patient 3D surfaces onto 3D space curves template and 6) Creating 3D surface Bolton standards. We have selected 5 male and female patients scanned with Hitachi MercuRay CBCT scanner providing high resolution and isotropic CT volume images, digitized Bolton Standards from age 3 to 18 years of lateral and frontal male, female and average tracings and converted to facial and skeletal 3D space curves. To validate this newer standard, we have created projections of 3D standard and compared them with existing gold standards. The landmark pair-wise matching resulted cumulative error distribution to mean of 0.04 mm and standard deviation of 0.06. This newer standard will help in assessing shape variations due to aging and provide reference to correct facial anomalies in dental medicine.

6144-183, Poster Session

Quantifying torso deformity in scoliosis

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Scoliosis affects the alignment of the spine and the shape of the torso. Most scoliosis patients and their families are more concerned about the effect of scoliosis on the torso than its effect on the spine. There is a need to develop robust techniques for quantifying torso deformity based on

full torso scans. In this paper, deformation indices obtained from orthogonal maps of full torso scans are used to quantify torso deformity in scoliosis. 'Orthogonal maps' are obtained by applying orthogonal transforms to 3D surface maps. (An 'orthogonal transform' maps a cylindrical coordinate system to a Cartesian coordinate

system.) The deformation index at a cross-section is a composite of the average derivatives of the edge lines at the cross-section and the shape context at the cross-section. The technique was tested on 200 deformed computer models of the human torso and ten actual models of scoliosis patients. It correctly detected the amount of deformation applied to the computer models all the time. Analysis of actual torso models show that the deformation index correlated with the component axial rotation and the overall cross-sectional shape distortion at the cross-section. The technique is robust, reliable, clinically-relevant, and captures more information than existing techniques for assessing torso shape.

In addition to quantifying deformity, the technique produces a visual representation of the entire torso in one view and is viable for use in a clinical environment for managing scoliosis.

6144-184, Poster Session

AIS TLS-ESPRIT feature selection for prostate tissue characterization

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In this paper, a new technique for prostate tissue characterization is developed. The proposed technique is based on spectral features extraction from Trans-Rectal Ultra-Sound (TRUS) images using the Total Least Square Estimation of Signal Parameters via Rotational Invariance Techniques (TLS-ESPRIT). Each image is segmented into Regions Of Interest (ROIs) by Gabor multi-resolution analysis, a crucial stage in which segmentation is achieved according to the frequency response of the image pixels. Pixels having the same response to the Gabor filter are assigned to the same region. Next, spectral features are constructed for each ROI using the TLS-ESPRIT. Classifier based feature selection is performed using the recently proposed Artificial Immune System (AIS) optimization technique. Using Support Vector Machine (SVM) classifier, our proposed system obtains a classification accuracy of 93.75%, with 100% sensitivity and 83.3% sensetivity.

6144-185, Poster Session

An adaptive image segmentation process for the classification of lung biopsy images

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The purpose of this study was to develop a computer-based second opinion diagnostic tool that could read microscope images of lung tissue and classify the tissue sample as normal or cancerous, and if cancerous, identify the type of cancer. In order to be useful, such a tool needs to be fast (providing it's classifications in minutes or seconds, rather than hours or days) as well as accurate.

The problem can be broken down into three areas: segmentation, feature extraction and measurement, and classification. We introduce a kernel-based extension of fuzzy c-means to provide a coarse initial segmentation, with heuristically-based mechanisms to improve this coarse segmentation. The segmented image is then processed to extract and quantify features (such as nucleus size, nucleocytoplasmic ratio, etc). Finally, the measured features are used by a Support Vector Machine (SVM) or Kernel-Partial Least Squares (K-PLS) to classify the tissue sample.

Results include the performance of this approach on a database of 85 images collected at the Moffitt Cancer Center and Research Institute. These images represent a wide variety of normal lung tissue samples, as well as multiple types of lung cancer.

6144-186, Poster Session

An automated fluorodeoxyglucose positron emission tomography image-analysis procedure for the Alzheimer disease diagnosis using statistical parametric mapping, interactive image display and a normal database

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Approving fluorodeoxyglucose positron emission tomography (FDG PET) for the diagnosis of Alzheimer's disease (AD) in some patients, the Centers for Medicare and Medicaid Services suggested the need to develop and test analysis techniques to optimize the diagnostic accuracy. We developed an automated computer package comparing an individual's FDG PET image to a group of normal volunteers.

The normal control group includes FDG-PET images from 82 cognitively normal subjects, 61.89 (std=5.67) years of age on average, who were characterized demographically, clinically, neuropsychologically, and by their apolipoprotein E genotype (known to be associated with a differential risk for AD). In addition, AD affected brain regions functionally defined based on a previous study (Alexander, et al, J. AmPsy., 2003) were also incorporated.

Our computer package permits the user to optionally select control subjects matching the individual patient for the gender, age, educational level etc. It is SPM99 based (http://www.fil.ion.ucl.ac.uk/spm/) with additional feature and fully streamlined. With one mouse click, the program runs automatically normalizing the individual patient image, setting up design matrix for comparing the single subject to a group of normal controls, performing the statistics, calculating the glucose reduction overlap index of the patient with the AD affected brain regions, and displaying the findings in references to the AD regions.

In conclusion, the package automatically contrasts a single patient to a normal subject database using sound statistical procedure. With further validation, this computer package could be a valuable tool assisting physicians in making their decisions and communicating the finding with patients and patient families.

6144-187, Poster Session

Lesion margin analysis for automated classification of cervical cancer lesions

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Digital colposcopy is an emerging technology, replacing the traditional colposcope for diagnosis of cervical lesions. Incorporating automated algorithms within a digital colposcopy system can improve the reliability and the diagnostic accuracy of cervical cancer. An automated computer-aided diagnosis (CAD) system can assess the three important cervical diagnostic cues: the color, the vascular patterns and the lesion margins with quantitative measures, similar to the way colposcopists use the Reid's index in traditional colposcopy. In this work we present a novel way to analyze and classify the global and the local features of one of the three major components in colposcopy diagnosis - the lesion margins. The margins of cervical lesion can be described as 'feathered,' 'geographic,' 'satellite,' 'regular or smooth' and 'margin-in-margin,' or they can be of mixed type. As margin characterization is a complex task, we use irregularity descriptors such as compactness indices and curvature descriptors. To address the complexity of the problem, the dependency of scale and the position of the lesion on the cervical image, our method use novel Fourier energy descriptors. The conceptually complex analysis of describing lesions as 'satellite' lesions or lesions with multiple margins is per-

formed using descriptors, where the distance, the position and the local statistical estimates of image intensity play important role. We trained this new algorithm to classify and diagnose the cervix, evaluating only the lesions. The accuracy of the results is assessed against a 'ground truth' scheme, using colposcopists' annotations and pathology results. We report the resulted accuracy of the classification method assessed against this scheme.

6144-188, Poster Session

Computer-aided diagnosis of splenic enlargement using wave pattern of spleen in abdominal CT images

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It is known that the spleen accompanied by liver cirrhosis is hypertrophied or enlarged. We have examined a wave pattern at the left boundary of spleen on the abdominal CT images having liver cirrhosis, and found that they are different from those on the images having a normal liver. It is noticed that the abdominal CT images of patient with liver cirrhosis shows strong bending in the wave pattern. In the case of normal liver, the images may also have a wave pattern, but its bends are not strong. Therefore, the total waving area of the spleen with liver cirrhosis is found to be greater than that of the spleen with a normal liver. Moreover, we found that the waves of the spleen from the image with liver cirrhosis have the higher degree of circularity compared to the normal liver case. Based on the two observations above, we propose an automatic method to diagnose splenic enlargement by using the wave pattern of the spleen in abdominal CT images. The proposed automatic method improves the diagnostic performance compared with the conventional process based on the size of spleen.

6144-189, Poster Session

Simulating nodules in chest radiographs with real nodules from multislice CT images

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To improve the detection of nodules in chest radiographs, large databases of chest radiographs with annotated, proven nodules are needed for both radiologists and computer-aided detection systems. The construction of such databases is a precise and time-consuming task. We present a novel technique to produce large amounts of chest x-rays with annotated nodules. We use real nodules segmented from CT images to generate realistic nodules in radiographs. An expert observer study has shown that the simulated nodules can not be distinguished from real nodules. This method has a large potential to aid the development of automated detection systems and as a teaching device for human observers.

6144-190, Poster Session

Hot spot detection, segmentation, and identification in PET images

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Positron Emission Tomography (PET) images provide functional or metabolic information from areas of high concentration of [18F]fluorodeoxyglucose (FDG) tracer, the "hot spots". These hot spots can be easily detected by the eye, but delineation and size determination required e.g. for diagnosis and staging of cancer is a tedious task that demands for automation. The approach for such an automated hot spot segmentation described in this paper comprises three steps: A region of interest detection by the watershed transform, a heart identification by an evaluation of scan lines, and the final segmentation of hot spot areas by a local threshold. The region of interest detection is the essential step, since it localizes the hot spot identification and the final segmentation. The heart identification is an example of how to differentiate between hot spots, and it is also a prerequisite for cardiac hot (or cold) spot quantification. The method is applicable to other techniques like SPECT.

6144-191, Poster Session

Improving computer-aided diagnosis of interstitial disease in chest radiographs by combining one-class and two-class classifiers

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In this paper we compare and combine two distinct pattern classification approaches to the automated detection of regions with interstitial abnormalities in frontal chest radiographs. We consider standard two-class classifiers and recently developed one-class classifiers. The one-class problem is to find the best model of the normal class and reject all objects that don't fit the model of normality. This one-class methodology was developed to deal with poorly balanced classes, and it uses only objects from a well-sampled class for training. This may be an advantageous approach in medical applications, where normal examples are easier to obtain than abnormal cases. We used receiver operating characteristic (ROC) analysis to evaluate classification performance by the different methods as a function of the number of abnormal cases available for training. Various two-class classifiers performed excellently in case that enough abnormal examples were available (area under ROC curve $A_z = 0.985$ for linear discriminant). The one-class approach gave worse result when used stand-alone ($A_z = 0.88$ for Gaussian data description) but the combination of both approaches, using a mean combining classifier resulted in better performance when only few abnormal samples were available (average $A_z = 0.94$ for the combination and $A_z = 0.91$ for the stand-alone linear discriminant for the same set-up). This indicates that computer-aided diagnosis schemes may benefit from using a combination of two-class and one-class approaches when relatively few abnormal samples are available.

6144-192, Poster Session

Computer aided lytic bone metastasis detection using regular CT images

J. Yao, S. D. O'Connor, R. M. Summers, National Institutes of Health

This paper presents a computer aided detection system to find lytic bone metastases in the spine. The CAD system is designed to run on regular chest and/or abdominal CT exams (5mm slice thickness) obtained during a patient's evaluation for other diseases. The system can therefore serve as a background procedure to detect bone metastases. The spine is first automatically extracted based on knowledge about spine anatomy, adaptive thresholding, morphological operation, rolling ball algorithm and region growing. The spinal cord is then traced from thoracic spine to lumbar spine using a dynamic graph search to set up a local spine coordinate system. A watershed algorithm is then applied to detect potential lytic bone lesions. A set of 26 quantitative features (density, shape and location) are computed for each detection. Support vector machines (SVM) are used as classifiers to determine if a detection is a true lesion. The SVM is trained using ground truth segmentation manually defined by experts. The CAD system was trained and tested on 70 patients with 212 lytic lesions. The data was randomly assigned to 43 training sets and 27 test sets. Initial results showed that in the training set the sensitivity was 79.1% (102/129) for all lesions and 84.9% (73/86) for lesions larger than 0.25 mm2, with 24.5 false positives per patient (0.2 per image). For the test set, the sensitivity was 71.1% (59/83) for all lesions and 76.7% (46/60) for lesions larger than 0.25 mm2, with 18.9 false positives per patient (0.15 per image).

6144-193, Poster Session

Hybrid committee classifiers for a computerized colonic polyp detection system

J. Li, J. Yao, National Institutes of Health; N. Petrick, U.S. Food and Drug Administration; R. M. Summers, National Institutes of Health; A. K. Hara, Mayo Clinic

We present a hybrid committee classifier for computer-aided detection (CAD) of colonic polyps in CT colonography (CTC). The classifier involved an ensemble of support vector machines (SVM) and neural networks (NN) for classification, a forward stepwise search algorithm for selecting a set of features used by the SVMs, a floating search algorithm for selecting features used by the NNs, and methodologies for learning from imbalanced data sets. Both prone (non-contrast) and supine (with intravenous contrast) CT colonography (CTC) were performed on 29 patients with 5 small (1-5mm), 12 medium (6-9mm), 15 large (10-19mm) polyps and 21 masses (20mm and above). These polyps produced 148 and 221 colonoscopically confirmed detections in prone scans and supine scans, respectively, multiple detections for one polyp might exist. A total of 102 different quantitative features were calculated for each polyp candidate. 3 features were selected for each of 7 different SVM classifiers which were then combined to form a committee of SVMs classifier. Similarly, features (numbers varied from 10-20) were selected for 11 NN classifiers which were again combined to form a NN committee classifier. Finally, a hybrid committee classifier was defined by combining the scores of both the SVM and NN committees. Five-fold cross validation with 100 bootstraps was applied to compare the three committee classifiers using free response receiving operation characteristic (FROC) curves, in terms of their partial area under the FROC curve (AUC). Our results showed that the hybrid committee classifier performed significantly better than others for prone data and was comparable to the SVM committee as the best classifier for supine data based on AUC.

6144-194, Poster Session

Measurement of colonic polyp size from virtual colonoscopy studies: Comparison of manual and automated methods

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Polyp size is an important feature descriptor for clinical classification and follow-up decision making in CT colonography. Currently, polyp size is measured from computed tomography (CT) studies manually as the single largest dimension of the polyp head, excluding the stalk if present, in either multi-planar reconstruction (MPR) or three-dimensional (3D) views. Manual measurements are subject to intra- and inter-reader variation, and can be time-consuming. Automated polyp segmentation and size measurement can reduce the variability and speed up the process. In this study, an automated polyp size measurement technique is developed. Using this technique, the polyp is segmented from the attached healthy tissue using a novel, model-based approach. The largest diameter of the segmented polyp is measured in axial, sagitttal and coronal MPR views. An expert radiologist identified 48 polyps from either supine or prone views of 52 cases of the Walter-Reed virtual colonoscopy database. Automated polyp size measurements were carried out and compared with the manual ones. For comparison, three different statistical methods were used: overall agreement using chance- corrected kappa indices; the mean absolute differences; and Bland-Altman limits of agreement. Manual and automated measurements show good agreement both in 2D and 3D views.

6144-195, Poster Session

Effect of quantisation on co-occurrence matrix based texture features: an example study in mammography

G. N. Lee, Gifu Univ. (Japan); M. J. Bottema, Flinders Univ. (Australia); H. Fujita, T. Hara, Gifu Univ. (Japan)

A co-occurrence matrix is the joint probability distribution that two pixels in an image separated by d units in the direction of θ and is one of the texture analysis methods favored by the medical image processing community. The size of a co-occurrence matrix depends on gray levels quantisation level Q. Hence, when dealing high depth resolution images, gray levels re-quantisation is routinely performed to reduce the size of the co-occurrence matrix. The gray levels re-quantisation may play a role in the display of spatial relationships in co-occurrence matrix but is usually dealt with lightly. In this paper, we use an example to study the effect of gray-level re-quantisation. in high depth resolution medical images. Digitized film-screen mammograms have a typical depth resolution of 4096 gray levels. In a study classifying masses on mammograms as benign or malignant, 260 texture features were measured on each 43 regions-of-interest (ROIs) containing malignant masses and 28 ROIs containing benign masses. Of the 260 texture features, 240 are texture features measured on co-occurrence matrices with parameters θ= 0, μ/2; d= 11, 15, 21, 25, 31; and Q= 50, 100, 400. A genetic algorithm was used to select a subset of features (out of 260) that has discriminative power. Top performing feature combinations selected were not restricted to a single value of Q. This indicates that instead of searching for a correct Q, it may be more appropriate to explore a range of Q values.

6144-196, Poster Session

Development of computerized method for detection of vertebral fractures on lateral chest radiographs

S. Kasai, F. Li, J. Shiraishi, Y. Nie, K. Doi, The Univ. of Chicago

Osteoporosis is one of major public health concerns in the world. Several clinical trials indicated clearly that pharmacologic therapy for osteoporosis is effective for people with vertebral fractures to prevent subsequent fractures. It is, therefore, important to diagnose vertebral fractures early. Although most vertebral fractures are asymptomatic, vertebral fractures can be often detected on lateral chest radiographs which may be taken for other purposes. However, investigators have reported that vertebral fractures which were visible on lateral chest radiographs were underdiagnosed or underreported. Therefore, the purpose of this study was to develop a computerized method for detection of vertebral fractures on lateral chest radiographs and to assist radiologists' image interpretation. Our computerized scheme is based on the detection of upper and lower edges of vertebrae on lateral chest images. The curved rectangular area which included a number of visible vertebrae was identified. This area was then straightened such that upper and lower edges of vertebrae would be oriented horizontally. In order to detect vertebral edges, line components were enhanced, and a multiple thresholding technique followed by image feature analysis was applied to the line enhanced image. Finally, vertebral heights determined from detected vertebral edges were used to characterize the shape of the vertebrae and to distinguish vertebral fractures from normal vertebrae. Our preliminary results indicated that all of severely fractured vertebrae in a small database were correctly detected by our computerized method.

6144-197, Poster Session

Automatic colonic polyp detection using multiobjective evolutionary technique

J. Li, A. Huang, J. Yao, I. Bitter, R. M. Summers, National Institutes of Health; P. J. Pickhardt, National Naval Medical Ctr. and Univ. of Wisconsin/Madison; J. R. Choi, Walter Reed Medical Ctr.

Colonic polyps appear like elliptical protrusions on the inner wall of the colon. Curvature based features for colonic polyp detection have been proved to be successful in several computer-aided diagnostic CT colonography (CTC) systems. Some simple thresholds are set for those features for creating initial polyp candidates, sophisticated classification scheme are then applied on these polyp candidates to reduce false positives. There are two objective functions, the number of missed polyps and false positive rate, need to be minimized when setting those thresholds. These two objectives conflict and it is usually not possible to optimize them both by a gradient search. In this paper, we utilized a multiobjective evolutionary method, Strength Pareto Evolutionary Algorithm (SPEA2), to optimize those thresholds. SPEA2 incorporates the concept of Pareto dominance and applies genetic techniques to evolve individual solutions to the Pareto front. The SPEA2 algorithm was applied to colon CT images from 27 patients each having a prone and a supine scan. There are 40 colonoscopically confirmed polyps resulting in 72 positive detections in CTC reading. The results obtained by SPEA2 were compared with that obtained by our old system. If we keep the sensitivity the same as that of our old system, the SPEA2 algorithm reduced false positive rate by 76.4% from average false positive 55.6 to 13.3 per data set. If the false positive rate is kept the same for both systems, SPEA2 increased the sensitivity by 13.1% from 53 to 61 among 72 viewable detections.

6144-198, Poster Session

False-positive elimination for computer-aided detection of pulmonary micronodules

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Computed Tomography (CT) is generally accepted as the most sensitive way for detecting pulmornary nodules. Its high contrast resolution allows the detection of small nodules and, thus, lung cancer at a very early stage. Due to the large amount of data it produces, however, automating the nodule detection process is viable. We propose a method for automating nodule detection from high resolution chest CT images.

Our method focuses on the detection of both calcified (high-contrast) and noncalcified (low-contrast) granulomatous nodules less than 5mm in size using a series of 3D filters. Pulmonary nodules can appear anywhere inside the lung, e.g., on lung walls, near vessels, or they may even be penetrated by vessels. Thus, we first present a 3D nonlinear filter to suppress vessels and noise. Although nodules usually have higher intensity values than surrounding regions, many malignant nodules are noncalcified and of low contrast. In order not to misclassify low contrast nodules, we also present a pair of 3D filters to further enhance nodule intensity values, which is a novel extension of variable N-Quoit filter.

The challenging problem for any nodule detection system is to keep low false-positive detection rate while maintaining high sensitivity. As with most automatic nodule detection methods, our method generates many false positive nodules. To address this, we develop a 3D filter for false positive elimination based on a deformable model. Each candidate nodule is tested with the deformable filter for its roundess and eliminated if the roundness measure is below a prespecified threshold.

Finally, we present promising results of our method. We applied our method to clinical chest CT datasets containing 57 nodules. The results were very promising with 100% (57 out of 57) sensitivity with only 3 false positive nodules.

6144-199, Poster Session

Confidence-based stratification of CAD recommendations with application to breast cancer detection

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We present a risk stratification methodology for predictions from computer-assisted detection (CAD) systems. For each case testing positive, the proposed technique assigns an individualized confidence measure as a function of the actual CAD output, the case-specific uncertainty of the prediction estimated from system's performance for similar cases and the value of the operating decision threshold. The study was performed using a mammographic database containing 1,337 regions of interest (ROIs) with known ground truth (681 with masses, 656 with normal parenchyma). Two types of decision models (1) a support vector machine with a radial basis function kernel (SVM) and (2) a back-propagation neural network (BPNN) were developed to detect masses based on 8 morphological features automatically extracted from each ROI. The study shows that as requirements on the minimum confidence value are being restricted, the positive predictive value (PPV) for qualifying cases steadily improves (from PPV=0.73 to PPV=0.97 for SVM, from PPV=0.67 to PPV=0.95 for BPNN). The proposed confidence metric was successfully applied for stratification of CAD recommendations into 3 categories of different expected reliability: HIGH (PPV=0.90), LOW (PPV=0.30) and MEDIUM (all remaining cases). Since radiologists often disregard accurate CAD cues, an individualized confidence measure should improve their ability to correctly process visual cues and thus reduce the interpretation error associated with the detection task. Keeping the clinically determined operating point satisfied, the proposed methodology draws more attention of CAD users to cases/regions of highest risk while helping them eliminate confidently cases with low risk.

6144-200, Poster Session

Centerline-based colon segmentation for CAD of CT colonography

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We developed a fast centerline-based segmentation (CBS) algorithm for the extraction of colon in computer-aided detection (CAD) for CT colonography (CTC). CBS calculates centerpoints along the thresholded components of abdominal air by use of axial, coronal, and sagittal scanlines, and connects these centerpoints iteratively in order to generate approximate centerlines through each thresholded component. The centerlines are then subjected to anatomic evaluation which reconnects the colon centerline over collapsed segments while eliminating centerlines in extracolonic components. For the application of CAD, a thick region encompassing the colonic wall is extracted by use of region-growing around the final centerline, and the CTC data are interpolated into isotropic resolution by use of shape-based interpolation. Polyps are detected by use of volumetric shape features, and false positives are reduced by a Bayesian neural network. The accuracy of CBS was evaluated by use of 38 CTC datasets representing various preparation conditions, and the detection performance of the CAD scheme was evaluated by use of 121 patients with 42 colonoscopy-confirmed polyps 5-25 mm. On average, CBS covered more than 96% of the colon with less than 1% extracolonic components, and it was approximately 80% faster than our previously developed knowledge-guided colon segmentation (KGS) algorithm. At a 93% by-polyp detection sensitivity for polyps >= 5-mm, a leave-one-patient-out evaluation of the CBS-based CAD scheme yielded 1.35 false-positive polyp detections per CTC volume.

6144-202, Poster Session

Local pulmonary structure classification for computer-aided nodule detection

C. Bahlmann, Siemens Corporate Research, Inc.; X. Li, Harvard Univ.; K. Okada, Siemens Corporate Research

In this paper, a new method of classifying the structure types, nodules, vessel, and junctions, in thoracic CT scans is proposed. This classification is important in the context of computer aided detection (CAD) of lung nodules. Our solution extends a previously proposed nodule segmentation algorithm, which is based on robustly fitting an anisotropic Gaussian-based intensity model to the data. Using the center and spread parameters of the fitted model, a 3D ellipsoidal manifold is computed, containing the bounding surface of the target structure. The number of high intensity clusters is automatically estimated by an EM algorithm-based data clustering solution incorporating directional statistics. The cluster number explicitly determines the type of pulmonary structures: nodule (0), vessel (2), junction (>3). The classification results provide an effective means of removing false positives caused by the vessels or junctions. This local procedure is more efficient than current state of the art and will help to improve the accuracy of computer-aided-diagnosis.

6144-203, Poster Session

Power spectral analysis of mammographic parenchymal patterns

H. Li, M. L. Giger, O. I. Olopade, The Univ. of Chicago

Mammographic parenchymal patterns have been shown to be associated with the risk of developing breast cancer. Two groups of women: gene-mutation carriers and low-risk women were included in this study. Power spectral analysis was performed within parenchymal regions of 172 digitized craniocaudal normal mammograms of the BRCA1/BRCA2 gene-mutation carriers and those of women at low-risk of developing breast cancer. The power law spectrum of the form, P(f)=B/f(beta) , was evaluated for the mammographic patterns. Receiver Operating Characteristic (ROC) analysis was used to assess the performance of exponent beta as a decision variable in the task of distinguishing between high and low-risk subjects. Power spectral analysis of mammograms demonstrated that mammographic parenchymal patterns have a power-law spectrum of the form, P(f)=B/f(beta) , where f is radial spatial frequency, with the average beta values of 2.92 and 2.47 for the gene-mutation carriers and for the low-risk women, respectively. Az values of 0.90 and 0.89 were achieved in distinguishing between the gene-mutation carriers and the low-risk women with the individual image beta value as the decision variable in the entire database and the age-matched group, respectively.

6144-204, Poster Session

Discrimination of malignant lymphomas and leukemia using Radon transform-based higher order spectra and textual features

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Mantle cell lymphoma (MCL) is a recently described entity, which is often misdiagnosed as chronic lymphocytic leukemia (CLL) or as follicular center cell lymphoma (FCC). Timely and accurate diagnosis of MCL is of extreme importance since it has a more aggressive clinical course than CLL or FCC. MCL is considered an intermediate grade lymphoma with a 3-5 year median survival rate. Earlier bio-medical imaging approaches to MCL discrimination are based on the Fourier shape descriptors. They achieve 74% detection accuracy with limited noise tolerance. This paper describes a new approach for the classification of malignant lymphomas and leukemia whose discrimination rate reaches 84% accuracy with robust noise performance. The proposed algorithm makes use of the Radon transform-based higher order spectra (HOS) to achieve scale invariance classification with high noise immunity. This, in turn, incorporates highly nonlinear shape and texture characteristics of MCL into the feature extraction procedure, thereby, allowing the use of much simpler classifiers. Morphological watersheds are used to extract cell boundaries in the given bone marrow or blood sample microscopic image. Two-dimensional (2-D) boundary of each extracted cell is reduced to a set of one-dimensional (1-D) functions via the Radon transform for computational efficiency. A triple product of Fourier coefficients, referred to as the (deterministic) bispectrum, is computed for each 1-D projection function. The Fourier phase is a shape-dependent function of the frequency and bispectra can extract this information invariant to translation, rotation, and scaling. The derived set is highly immune to symmetrically distributed background noise (e.g., white Gaussian, Laplacian, and uniform noise). A minimum Euclidean-distance classifier trained with the HOS features is used to discriminate the cell samples. Experiments show 100 % classification accuracy between malignant and normal cells. While this method classifies malignant and normal cells of the same class, it cannot discriminate between different types of lymphomas and leukemia. Texture features derived from gray-level co-occurrence matrix are used for this purpose, which improves the classification accuracy between leukemia and lymphoma cells to an average value of 85%.

6144-205, Poster Session

Computer-aided detection system of breast masses on ultrasound images

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It is difficult to detect tumors by mammography in dense breast cases. Therefore, mass screenings by using cross-sectional ultrasonography have started in some regions in Japan. We have developed a computer-aided detection (CAD) system for breast lesion on screening breat ultrasonogrms. Free-hand probe and whole breast scanning device (WBSD) were employed in this study. The WBSD has a mechanical system with an automatic moving probe. This CAD scheme consists of the following steps: 1) Image composition for virtual B- and C-mode images from 3 separated regions 2) Noise reduction using hysteresis smoothing algorithm, 3) Contrast enhancement by histogram equalization and gray-scale transformation, 4) Extraction of mammary gland based on density, 5) Region segmentation using watershed algorithm, 6) Region analysis based on shape and density features. The internal echo-levels of 40 tumors in our database tend to be free or very low. The sensitivity was 90% (36/40cases) at 0.18 (555/3048) false positive per image.

6144-206, Poster Session

Highly-automated computer-aided diagnosis of neurological disorders using functional brain imaging

P. G. Spetsieris, Y. Ma, V. Dhawan, North Shore Univ. Hospital; J. R. Moeller, Columbia Univ. College of Physicians and Surgeons; D. Eidelberg, North Shore Univ. Hospital

We have implemented a highly automated analytical method for computer aided diagnosis (CAD) of neurological disorders using functional brain imaging that is based on the Scaled Subprofile Model (SSM). Accurate diagnosis of functional brain disorders such as Parkinson's disease is often difficult clinically, particularly in early stages. Using principal component analysis (PCA) in conjunction with SSM on brain images of patients and normals we can identify characteristic abnormal network covariance patterns which provide a subject dependent scalar score that not only discriminates a particular disease but also correlates with independent measures of disease severity. These patterns represent disease-specific brain networks that have been shown to be highly reproducible in distinct groups of patients. Topographic Profile Rating (TPR) is a reverse SSM computational algorithm to determine subject scores for new patients on a prospective basis. In our implementation, reference values

for a full range of patients and controls are automatically accessed for comparison. We also implemented an automated recalibration step to produce reference scores for images generated in a different imaging environment from that used in the initial network derivation. New subjects under the same setting can then be evaluated individually and a simple report is generated indicating the subject's classification. For scores near the normal limits, additional criteria are necessary to make a definitive diagnosis. With further refinement, automated TPR can be used to efficiently assess disease severity, monitor disease progression and evaluate treatment efficacy.

6144-207, Poster Session

Potential improvement of computerized mass detection on mammograms using a bilateral pairing technique

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We are developing a bilateral pairing technique to help reduce false positives identified by a single-view computer-aided detection (CAD) system. In this study, we compare the performance of the proposed bilateral CAD to the original single-view CAD. A database of 172 right/left breast pairs containing 205 biopsy-proven masses was used. Single-view CAD was run on each image using a lax selection threshold so that 5 objects per image were retained. The automated bilateral pairing algorithm identified all objects in a left breast mammogram matching a CAD detection in the corresponding right breast image and visa-versa. Bilateral pairing was based on geometrical correspondence between objects with a matching score derived from a paired right/left object feature set and a linear discriminant analysis classifier. Leave-one out resampling was used to train/test the technique. We compared the FROC performances of the original single-view CAD, the proposed bilateral technique and a modified CAD using manual pairing of bilateral structures. At a per-lesion detection sensitivity of 0.7, there were 3.80 FPs/image for the original CAD, 3.32 for the proposed technique, and 2.20 for the modified CAD using manual matching, a 12.6% and 42.1% reduction respectively. At an FP rate of 1.0 per image, the sensitivities for the original CAD, the proposed technique and the modified CAD using manual matching were 0.47, 0.51 and 0.60, respectively. Preliminary results show that CAD with bilateral pairing can improve upon single-view CAD by reducing FP-detections. Further studies are underway to both improve the automatic pairing technique and to determine whether or not the additional information available with bilateral matching is enough to justify its continued development.

6144-208, Poster Session

Mammographic CADx system using an image library with an intelligent agent: a pattern matching approach

S. B. Lo, Georgetown Univ. Medical Ctr.

In normal clinical practice, experienced radiologists often refer to their personal mental images of previous proven cases in making diagnoses and patient management decisions. In this study we hypothesize that a comprehensive clinical case library with intelligent agents can sort and render clinically similar cases and present clinically significant features, to assist the radiologist in interpreting mammograms. This computer library system is designed to integrate, search, and analyze clinical data that are analogous to the study case.

In this study, we used a deformable vector diagram as the primary framework for matching the mammographic masses. The vector diagram provides gradient and shape features of the mass. The deformable algorithm allows a flexible matching. The vector diagram was also incorporated with our newly developed delineation method using steepest changes of probability-based cost function. Thus it allows us to automatically extract the main body and significant part of border region for pattern matching using a weighted mutual information technique.

We have collected 86 mammograms. Of them, 46 contain a benign mass on each mammogram and the other 40 contain a malignant mass. Using the weighted mutual information technique on the vector diagram of the mass region, we found that the benign masses can be sorted into 6 groups except one case; the malignant masses can be sorted into 8 groups except two cases. For all 86 cases, the masses can be sorted into 13 groups except 3 cases. In addition, one group of benign masses and one group of malignant mass cases merged into one. Hence, the success sorting rate was 85.7% (12/14) in terms of group and was 84.9% (73/86) in terms of case, respectively.

6144-209, Poster Session

Regularized discriminate analysis for breast mass detection on full field digital mammograms

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

In computer-aided detection (CAD) applications, an important step is to design a classifier for the differentiation of the abnormal from the normal structures. We have previously developed a stepwise linear discriminant analysis (LDA) method with simplex optimization for this purpose. In this study, our goal was to investigate the performance of a regularized discriminant analysis (RDA) classifier in combination with a new feature selection method for classification of the masses and normal tissues detected on full field digital mammograms (FFDM). The new feature selection scheme combined a forward stepwise feature selection process and a backward stepwise feature elimination process to obtain the best feature subset. An RDA classifier and an LDA classifier in combination with the new feature selection method were compared to an LDA with stepwise feature selection. A data set of 114 patients containing 228 mammograms with 114 biopsy-proven masses was used. All cases had two mammographic views. The true locations of the masses were identified by experienced radiologists. To evaluate the performance of the classifiers, we randomly divided the data set into two equal-sized independent sets for training and testing. The Az values for the independent test set were 0.74, 0.78 and 0.80 for LDA with stepwise feature selection, LDA with the new feature selection method and RDA with the new feature selection method, respectively. The difference between the performance of stepwise LDA and that of LDA with the new feature selection method was statistically significant (p=0.0057). The performance of RDA with the new feature selection method was statistically better than that of LDA with either feature selection criterion (p=0.0098 and p=0.0002 for the new method and stepwise LDA, respectively). Our RDA classifier with a new feature selection scheme significantly improved the performance of classification. Further work is underway to optimize the feature selection and classification scheme and to evaluate if this approach can be generalized to other CAD classification tasks.

6144-210, Poster Session

Characterization of corresponding microcalcification clusters on temporal pairs of mammograms for interval change analysis - comparison of classifiers

L. M. Hadjiiski, D. Drouillard, H. Chan, B. Sahiner, M. A. Helvie, M. A. Roubidoux, C. Zhou, Univ. of Michigan

Our automated system consists of two stages: (1) automatic registration of corresponding clusters on temporal pairs of mammograms producing true (TP-TP) and false (TP-FP) pairs; and (2) characterization of temporal pairs of clusters as malignant and benign using a temporal classifier. In this study, we focussed on the design of the temporal classifier. Morphological and texture (RLS and GLDS) features are automatically extracted from the detected current and prior cluster locations. Additionally, difference morphological and RLS features are obtained. The automatically detected cluster locations on the temporal pairs may deviate from the optimal locations as selected by expert radiologists. This will introduce "noise" to the extracted features and make the classification task more

difficult. Linear discriminant analysis (LDA) and support vector machine (SVM) classifiers were trained to classify the true and false pairs. Leave-one-case-out resampling method was used for feature selection and classifier design. In this study, 175 serial mammogram pairs containing biopsy-proven microcalcification clusters were used. At the first stage of the system, 85% (149/175) of the TP-TP pairs were identified with 15 false matches within the 164 image pairs that had computer-detected clusters on the priors. At the second stage, an average of 7 features were selected (4 difference morphological, 1 difference RLS and 2 current GLDS). The LDA and SVM temporal classifiers achieved test Az of 0.83 and 0.82, respectively, for the classification of the 164 cluster temporal pairs as malignant or benign. In comparison, an MQSA radiologist achieved an Az of 0.72. Both the LDA and SVM classifiers were able to classify the automatically detected temporal pairs of microcalcification clusters with accuracy comparable to that of an experienced radiologist.

6144-211, Poster Session

Computer-aided detection of clustered microcalcifications on full-field digital mammograms: a two-view information fusion scheme for FP reduction

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

We are developing new techniques to improve the performance of our computer-aided detection (CAD) system for clustered microcalcifications on full-field digital mammograms (FFDMs) by using joint two-view information on craniocaudal (CC) and mediolateral-oblique (MLO) views. In this study, we evaluated the performance of an information fusion scheme in improving the detection accuracy of the CAD system. We compared the two-view fusion scheme using equal sensitivity levels for extracting the cluster candidates from the single-view system with that using two different sensitivity levels. We also compared three computerized methods for pairing of cluster candidates on the two mammographic views. A data set of 192 FFDM images was collected from 96 patients at the University of Michigan. All patients had two mammographic views. This data set contained 96 microcalcification clusters, of which 60 clusters were proven by biopsy to be malignant and 36 were proven to be benign. The true locations of these clusters were identified by an experienced radiologist. The areas under the receiver operating characteristic (ROC) curves for distinguishing TP pairs from other pairs were 0.76, 0.68, and 0.77 for the three pairing methods, respectively. At an image-based sensitivity of 75%, the FP rates were 0.41, 0.24 and 0.20 with the single view, two-view with equal sensitivity levels, and two-view with unequal sensitivity levels, respectively. A sensitivity of 85% could be achieved at FP rates of 0.65, 0.57 and 0.55 per image for the above three detection methods, respectively.

6144-212, Poster Session

Computerized lung nodule detection on screening CT scans: performance on juxta-pleural and internal nodules

B. Sahiner, L. M. Hadjiiski, H. Chan, C. Zhou, J. Wei, Univ. of Michigan

The purpose of this study was to evaluate object characteristics in the internal and juxta-pleural (JP) regions of a lung CT scan, and to develop different false-positive (FP) reduction classifiers for JP and internal objects. Our FP reduction technique utilized morphological, ellipsoid, and gradient features, as well as the scores of a newly-developed neural network trained on the eigenvalues of the Hessian matrix in a volume of interest containing the suspicious object. We designed an algorithm to automatically label the objects as internal or JP. Based on a training set of 75 CT scans containing 75 internal and 36 JP computer-detected nodules, two FP classifiers were trained separately for objects in the two types of lung regions. The system performance was evaluated on an independent test set of 27 low dose screening scans. The test cases had a median slice thickness of 1.25 mm (range: 1.25-2.5 mm) with an average of 227 slices per scan (range: 117-292). An experienced chest radiologist identified 64 solid nodules on the test cases (mean diameter: 5.3 mm, range: 3.0-12.9 mm) of which 33 were internal and 31 were JP. Our adaptive 3D prescreening algorithm detected 27 internal and 27 JP nodules. At 80% sensitivity, the average number of FPs was 3.9 and 9.7 in the internal and JP regions per case, respectively. Our results indicate that FPs in the JP region is more difficult to distinguish from true nodules. Further investigation of task-specific FP reduction techniques is needed.

6144-213, Poster Session

Detection of blue-white veil areas in dermoscopy images using machine learning techniques

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As a result of the advances in skin imaging technology and the development of suitable image processing techniques, during the last decade, there has been a significant increase of interest in the computer-aided diagnosis of skin cancer. Dermoscopy is a non-invasive skin imaging technique which permits visualization of features of pigmented melanocytic neoplasms that are not discernable by examination with the naked eye. One of the most discriminative features in dermoscopic diagnosis is the presence of blue-white veil areas (irregular, structureless areas of confluent blue pigmentation with an overlying white “ground-glass” film) which is mostly associated with invasive melanoma. In this paper, we present a machine learning approach to detection of blue-white veil areas in dermoscopy images. First, pixels in the training images that are representative of the two classes (veil and non-veil) are manually labeled by an expert dermatologist. Then, a number of color features, both relative and absolute, are extracted from these pixels. Finally, the feature data is fed to a decision tree induction algorithm (C4.5) and the induced rules are applied on the test images. The results demonstrate that the proposed method allows for reliable and fast detection of the blue-white veil areas in dermoscopy images.

6144-214, Poster Session

Reducing false-positive detections by combining two stage-1 computer-aided mass detection algorithms

M. P. Sampat, N. Bedard, P. Stokes, M. Markey, The Univ. of Texas at Austin

In this paper we present a strategy to reduce the number of false-positives in computer-aided mass detection by comparing the suspicious sites identified by two different “stage-1” detection algorithms. By “stage-1” we mean that each Computer-aided Detection (CADe) algorithm was designed to operate with high sensitivity, allowing for a large number of false positives. In this study, the first mass detection method used was Heath and Boywer’s algorithm based on the average fraction under the minimum filter (AFUM). The second mass detection method was a low-threshold bi-lateral subtraction algorithm. The two methods were applied separately to a set of images from the Digital Database for Screening Mammography (DDSM) to obtain two sets of mass candidates. The sets of mass candidates were combined by a logical “and” operation to eliminate regions of suspicion that were not independently identified by both techniques. It was shown that by combining the evidence from the AFUM filter method with that obtained from bi-lateral subtraction, the same sensitivity could be reached with less false-positives per image relative to using the AFUM filter alone.

6144-215, Poster Session

Combining texture features from MLO and CC views for mammographic CADx

S. Gupta, D. Zhang, M. P. Sampat, M. K. Markey, The Univ. of Texas at Austin

The purpose of this study was to investigate approaches for combining information from the MLO and CC mammographic views for Computer-aided Diagnosis (CADx) algorithms. Feature-level and classifier-output level combinations were explored. Linear discriminant analysis (LDA) with stepwise feature selection from a set of Haralick's texture features was used to develop classifiers for distinguishing between benign and malignant mammographic lesions. The effect of correlation between features from the two views on the performance of classifiers was investigated. The single view models included: (a) an LDA model with stepwise selection based on the MLO view only (MLO-Only) and (b) CC-Only LDA model. The feature-level combination models included: (a) LDA based on concatenation of feature sets selected independently from the two views (FEAT_CON), (b) LDA based on the concatenated feature sets along with the corresponding value of each feature from the opposite view (FEAT_COR_CON) if the correlation was below a threshold, (c) LDA based on the average of the MLO and CC feature values (FEAT_AVG). The classifier-output level combination models investigated included: (a) average of the outputs of the MLO-Only and CC-Only classifiers (OUTPUT_AVG), (b) maximum of the outputs of the MLO-Only and CC-Only classifiers (OUTPUT_MAX), (c) minimum of the outputs of the MLO-Only and CC-Only classifiers (OUTPUT_MIN), (d) a second level LDA classifier on the outputs of the MLO-Only and CC-Only classifiers (OUTPUT_LDA). The performance of the models was assessed and compared using the ROC methodology to determine if combination models performed better than the single-view models.

6144-216, Poster Session

The influence of CT dose and reconstruction parameters on automated detection of small pulmonary nodules

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The purpose of this study is to assess the influence of CT acquisition mAs and reconstruction algorithm on computer-aided detection (CAD) of small pulmonary nodules.

CT data was obtained for 19 subjects using a low dose, thin section imaging protocol on a helical multi-slice scanner. The standard of truth for the detection task was established by two thoracic radiologists. The selected data set contained 36 solid, non-calcified nodules (<13 mm diameter) and 5 nodules with ground glass attenuation. Twenty of the solid nodules were classified as micronodules with a diameter less than 4 mm. Software was used to simulate an even lower dose acquisition where tube current was reduced by 40% or more. The CT data for both tube current levels was reconstructed using three reconstruction filters corresponding to smooth, medium, and sharp. The reconstructed series were analyzed using two systems: (1) Siemens Nodule Enhanced Viewing (NEV) was used as a representative of commercial CAD systems, and a (2) UCLA research system designed to include detection of micronodules and ground glass attenuation.

The efficacy of both CAD systems in detecting pulmonary nodules was influenced by acquisition tube current and reconstruction algorithm. The CAD systems tested performed the best on images reconstructed with the smooth or medium reconstruction filter. The simulated lower mAs showed slightly reduced detection rates.

These results may have potential implications for the CT acquisition protocols as well as for the use of CAD systems for nodule detection.

6144-217, Poster Session

An efficient method for computing mathematical morphology for medical imaging

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Many medical imaging techniques use mathematical morphology (MM), with discs and spheres being the structuring elements (SE) of choice. Given the non-linear nature of the underlying comparison operations (min, max, AND, OR), MM optimization can be challenging. Many efficient methods have been proposed for various types of SE based on the ability to decompose the SE by way of separability or homotopy. Usually, these methods are only able to approximate disc and sphere SE rather than accomplish MM for the exact SE obtained by discretization of such shapes. We present a method that for efficiently computing MM for binary and gray scale image volumes using digitally convex and X-Y-Z symmetric flat SE, which includes discs and spheres. The computational cost is a function of the diameter of the SE and rather than its volume. Additional memory overhead, if any, is modest. We are able to compute MM on real medical image volumes with greatly reduced running times with increasing gains for larger SE. Our method is also robust to scale: it is applicable to ellipse and ellipsoid SE which may result from discretizing a disc or sphere on an anisotropic grid. In addition, it is easy to implement and can make use of existing image comparison operations. We present performance results on large medical chest CT datasets.

6144-218, Poster Session

A whole brain morphometric analysis of changes associated with pre-term birth

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Pre-term birth is strongly associated with subsequent neuropsychiatric impairment. To identify structural differences in preterm infants we have examined a dataset of magnetic resonance (MR) images containing 88 preterm infants and 19 term born controls. We have analysed these images by combining image registration, deformation based morphometry (DBM), multivariate statistics, and effect size maps (ESM). The methodology described has been performed directly on the MR intensity images rather than on segmented versions of the images. Differently from analysing the morphological differences given by the average volume change described by each sample group, we have analysed regional brain contraction and expansion of statistical extremes of preterm and term born infants. The results indicate that the multivariate approach makes clear the differences between the control and preterm samples, showing a leave-one-out classification accuracy of 94.74% and 95.45% respectively. In addition, exploring the most discriminant direction found by the statistical classifier we are able to identify not only common changes between preterm and term groups such as the volume loss within basal ganglia and thalami areas, but also highlight patterns of morphological group differences that are often not detectable.

6144-219, Poster Session

Feature-space exploration of pathology images using content-based database visualization

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The availability and easy exchange of pathology images raises the question for studies on large collections of datasets to find hidden regularities.

Considering the fact that the exploration of each single image of a large DB by a human expert is almost impossible, approaches for automated classification and image retrieval have been developed.

To support a more interactive analysis, we propose here an approach for the simultaneous exploration of both: the image and feature domain of large image sets.

The experimental dataset contains 80 histopathological images from meningioma WHO Grade I. The images show tissue of 20 different cases, each one belonging to one of four tumor subtypes, i.e. meningotheliomatous, fibroblastic, psammomatous and transitional. Dividing each image into sixteen subimages with 256x256 pixels, we derive a database containing 1280 images.

The visualization is based on combining Wavelet-based texture features with a method from the field of unsupervised machine learning, the Self organizing Map (SOM). The SOM is used for the projection of a high-dimensional feature space onto a two-dimensional grid, preserving the feature space topology.

The combination of wavelet-features and the SOM achieves a grouping of the images on the SOM corresponding to the classes, without incorporating any background information or class label. Thereby it provides a reliable interface for an interactive exploration even for a nontrivial clustered dataset like the considered one and visualizes the pathological categorization of the image domain.

6144-220, Poster Session

RANSAC-based EM algorithm for robust detection and segmentation of cylindrical fragments from calibrated C-arm images

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Automated identification, pose and size estimation of cylindrical fragments from registered C-arm images is highly desirable in various computer-assisted, fluoroscopy-based applications including long bone fracture reduction and intramedullary nailing, where the pose and size of bone fragment need to be accurately estimated for a better treatment. In this paper, a RANSAC-based EM algorithm for robust detection and segmentation of cylindrical fragments from calibrated C-arm images is presented. By detection, we mean that the axes and the radii of the principal fragments will be automatically determined. And by segmentation, we mean that the contour of the fragment projection onto each image plane will be automatically extracted. Benefited from the cylindrical shape of the fragments, we formulate the detection problem as an optimal process for fitting parameterized three-dimensional (3D) cylinder model to images. And this fitting process is solved by an iterative closest point (ICP) matching procedure. A RANSAC-based EM algorithm is proposed to find the optimal solution. The outer projection boundary of the estimated cylinder model is then fed to a region-based active contour model to robustly extract the contour of the fragment projection. The proposed algorithm has been successfully applied to real patient data with/without external objects, yielding promising results.

6144-221, Poster Session

Realtime automatic metal extraction of medical x-ray images for contrast improvement

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Our paper focuses on an approach for real-time metal extraction of x-ray images taken from modern x-ray machines like C-arms. Such machines are used for vessel diagnostics, surgical interventions, as well as cardiology, neurology and orthopedic examinations. They are very fast in taking images from different angles. For this reason, manual adjustment of contrast is infeasible and automatic adjustment algorithms have been applied to try to select the optimal radiation dose for contrast adjustment. Problems occur when metallic objects, e.g., a prosthesis or a screw, are in the absorption area of interest. In this case, the automatic adjustment mostly fails because the dark, metallic objects lead the algorithm to overdose the x-ray tube. This outshining effect results in overexposed images and bad contrast. To overcome this limitation, metallic objects have to be detected and extracted from images that are taken as input for the adjustment algorithm.

In our paper, we present a real-time solution for extracting metallic objects of x-ray images. We will explore the characteristic features of metallic objects in x-ray images and their distinction from bone fragments which form the basis to find a successful way for object segmentation and classification. Subsequently, we will present our edge based real-time approach for successful and fast automatic segmentation and classification of metallic objects. Finally, experimental results on the effectiveness and performance of our approach based on a vast amount of input image data sets will be presented.

6144-222, Poster Session

Histological characterization of DCE-MRI breast tumors with histological characterization of DCE-MRI breast tumors with dimensional data reduction

C. Varini, A. Degenhard, T. W. Nattkemper, Univ. Bielefeld (Germany)

Histological characterization of breast tumors is an important ingredient in successful treatment of this disease. A comparison of a breast lesion with different histologic types of tumors can in addition provide further clinical information on the nature of the lesion itself.

In this study we present an approach to the visual comparison of different histologic types of breast tumor making use of Locally Linear Embedding (LLE), an algorithm for the dimensional reduction of high-dimensional data.

The experimental data set contains the time-series of seven benign and seven malignant breast tumors of various histologic types that were manually labeled by an expert physician from a sequence of DCE-MRI volumes. The adopted DCE-MRI protocol involves the imaging of a region of interest once before and five times after the injection of a bolus contrast agent. As a result, a six-dimensional time-series of MR intensity values is associated with each voxel.

The set of all time-series from the 14 breast tumors constitutes a six-dimensional signal space where similar time-series exhibit locality. The analysis of this data set is conducted with the usage of LLE. This algorithm produces a low-dimensional embedding of high-dimensional data while preserving the local space topology. Therefore, similar time-series are mapped into neighboring data points in the LLE embedding.

The visualization of the embedding with customized colors characterizing the histologic types provides a convenient interface for the interactive comparison of various breast tumors.

6144-223, Poster Session

Characterization of pulmonary nodules features on computer tomography (CT) scans using wavelet coefficients and heatmaps

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Using CT images from the National Lung Screening Trial (NLST) of the National Cancer Institute (NCI), interpreted by radiologists at the Georgetown University, our goal was to investigate the feature extraction method using discrete wavelet transform (DWT) and to demonstrate their potential in distinguishing between benign and malignant nodule status. We analyzed multiple 2 mm thick slices of 40 subjects with benign nodules and 7 subjects with malignant nodules for a total of 112 and 78 slices, respectively. Data was analyzed in the region-of-interest (ROI) that included nodule and surrounding areas in three different windows. A linear

discriminant analysis (LDA) and joint statistics of wavelets coefficients was used for data analysis. In particular we examined discriminative power of the wavelet based features using Fisher LDA and the correlations between the pairs of coefficients. For visualization we used 3-D Heatmaps, originally developed in MATLAB(r) (MathWorks, Natick, MA) for gene expression array analysis, modified to display the magnitude of similarities between cases under analysis. The use of DWT in the image pre-processing modules resulted in a significant improvement in discrimination between benign and malignant nodules. The results show better classification accuracy of the DWT based features, as oppose to previously proposed classification features (p-values: 0.008, 0.022, and 0.039, depending on window size). The Heatmap provide useful data visualization for further investigation as it has the ability to identify cases that should be further explored to understand why some of the benign nodules looks alike malignant in the wavelet domain.

6144-224, Poster Session

A new anisotropic diffusion method with application to partial volume reduction

O. Salvado, D. L. Wilson, Case Western Reserve Univ.

Partial volume effect is a significant limitation in medical imaging that results in blurring when the boundary between two structures of interest falls in the middle of a voxel. A new anisotropic diffusion method allows one to create interpolated 3D images corrected for partial volume, without enhancement of noise.

After a zero-order interpolation, we apply a modified version of the anisotropic diffusion approach, wherein the diffusion coefficient becomes negative for high gradient values. As a result, the new scheme restores edges between regions that have been blurred by partial voluming but acts as normal anisotropic diffusion in flat regions subject to noise. We add constraints to stabilize the method and model partial volume; i.e., the sum of neighboring voxels must equal the signal in the original low resolution voxel and the signal in a voxel is kept within its neighbor's limits.

The method performed well on a variety of synthetic images as well as actual MRI scans. No noticeable artifact was induced during the sharpening of the edges. With the addition of the diffusion process, noise was much reduced in homogeneous regions. The method was applied to in vivo "thick" MRI carotid artery images for atherosclerosis detection and to ex vivo vessel images. There was a remarkable increase in the delineation of the lumen of the carotid artery, and improved tissue identification in the ex vivo samples.

6144-226, Poster Session

Metal artifacts reduction in CT images through Euler's elastica and curvature based sinogram inpainting

J. Gu, L. Zhang, Y. Xing, Tsinghua Univ. (China); G. Yu, Nuctech Co. Ltd. (China); Z. Chen, Tsinghua Univ. (China)

We present a sinogram inpainting approach for X-ray computed tomography (CT) to reduce metal artifacts. Metal artifacts arise in CT when rays traverse high attenuating objects such as metallic bodies and portions of projection become "missing". Hence, the unavailable data are either avoided (in iterative reconstruction) or interpolated (in filtered backprojection with data completion or restoration). In this paper, we propose a sinogram inpainting method based on Euler's elastica and curvature for metal artifacts reduction, in which the missing data are regarded as occlusion and can be inpainted inside the inpainting domain based on elastica interpolants. The method improves image quality by smoothly connecting occluded edges. Theoretical analysis and simulation results demonstrate that the metal artifacts due to photo starving can be effectively suppressed using this method. As compared to the filtered backprojection after linear interpolation, the sinogram inpainting-based reconstruction significantly reduces metallic artifacts and more accurately depicts of cross section structures, especially in the immediate neighborhood of the metallic objects.

6144-227, Poster Session

A new image calibration technique for colposcopic images

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Colposcopy is a primary diagnostic method used to detect cancer and precancerous lesions of the uterine cervix. During the examination, the metaplastic and abnormal tissues will turn different degrees of whiteness (acetowhitening effect) after applying 3%-5% acetic acid solution. Colposcopists evaluate color and density of the acetowhite tissue to access the severity of lesions for the purpose of diagnosis, telemedicine, and annotation. However, the color and illumination of the colposcopic images vary with the light sources, the instruments and camera settings, as well as the clinical environments. This makes assessment of the color information very challenging even for an expert. In terms of developing a Computer-Aided Diagnosis (CAD) system for Colposcopy, these variations affect the performance of the feature extraction algorithm for the acetowhite color. Non-uniform illumination from the light source is also an obstacle for detecting acetowhite regions, lesion margins and anatomic features. Therefore, in digital Colposcopy, it is critical to map the color appearance of the images taken with different colposcopes into one standard space with normalized illumination. This paper presents a novel image calibration technique for colposcopic images. First, a specially designed calibration unit is mounted on the Colposcope daily to acquire calibration data prior to performing patient examinations. The calibration routine is fast, automated, accurate and reliable. We then use our illumination correction algorithm and color calibration algorithm to calibrate the patient data. The presented technique has been applied in clinical studies.

6144-228, Poster Session

Improved MRSI with field inhomogeneity compensation

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MRSI is a method for assessing tissue function by obtaining information about the composition and spatial distribution of cellular metabolites. This distribution is characterized by a space-dependent spectrum function $q(x,f)$. The MR scanner produces the measurements of the form $\hat{p}(\mathbf{k},t)$, where $\mathbf{k}$ is the k-space variable.

Based on the measurements $\hat{p}(\mathbf{k},t)$, one has to solve the inverse problem in order to obtain q.

Due to long acquisition times, the measured data has limited k-space resolution (typically, 16x16), and simple Fourier inversion creates considerable voxel leakage. In the case of simple MR imaging, a constrained reconstruction method was proposed by Haacke, Liang and Izen. This method can naturally be extended to MRSI, as in SLIM/GSLIM algorithms, under the assumption that the regions of interest are known and are spectroscopically uniform (i.e., when the spectral and the spatial dimensions are independent).

One problem, however, arises because of the inhomogeneity of the main magnetic field B_0, as in typical clinical scanners. In combination with Fourier reconstruction, the inhomogeneity provokes heavy distortion of the metabolite peaks, known as the intra- and inter-voxel contamination of spectra. As a result, the performance of the algorithm is not satisfactory.

The two main reasons for the B_0 inhomogeneity are the imperfection of the field generated by the coils and the magnetic susceptibility effects near the tissue boundaries. First-order shimming can be applied to improve field homogeneity, however, only to a limited extent.

In this paper, we propose a new algorithm to find the spectra for the regions of interest with compensation for the B_0-inhomogeneity effects. We first measure the B_0 inhomogeneity map, which is then introduced in

the signal model. We also need a high-resolution MRI scan of the object, which is used to identify the regions that are considered spectroscopically uniform. The B_0 map and the MR image are the a priori data used by the algorithm to perform a least-square fit of the signal model with the MRSI measurements. The LS minimization is performed with a highly efficient algorithm that takes advantage of the block-diagonal structure of the underlying matrices.

The method is first demonstrated on synthetic 2-compartment data with artificial spectra. Next, we have tested it with a physical phantom, consisting of an inner bottle with Cre and NAA in doped water inside an outer bottle with corn oil. We use the AUTOSHIM-like technique to measure the B_0 inhomogeneity map. The algorithm clearly outperforms the standard approach (without B_0 inhomogeneity compensation); the spurious fat peaks for the inner compartment are completely suppressed.

6144-229, Poster Session

Wavelet-based multiscale level set curve evolution image denoising for MR imaging

J. Zhong, B. J. Dardzinski, J. Wansapura, Children's Hospital Medical Ctr.

For many MR imaging applications, due to the tradeoffs between the spatial resolution, scan time and SNR, the acquired image data usually suffers from low spatial resolution and low temporal resolution as well as poor signal-to-noise ratio (SNR). Numerous efforts have been devoted to developing image denoising techniques as the post-processing for noise reduction, but how to preserve image features when significantly reducing noise without generating artifacts is still challenging the state-of-the-art image denoising techniques. The nonlinear partial differential equation based level set methods have been widely applied for image denoising for their property of simultaneous noise reduction and edge preservation. But these techniques do not have a robust edge-stopping criterion, especially when noise level is high. As a result, they are not very efficient for denoising those images with low SNR and they cannot be used to improve the resolutions for MR imaging. In this paper, we used the improved algorithm of wavelet-based multiscale level set curve evolution for MR imaging to significantly reduce noise. The noisy image is first decomposed with the wavelet transform and the curve evolution is performed on wavelet coefficients at different scales. Since noise tends to decrease as the scale increases, the edge-stopping value is directly calculated from the wavelet coefficients rather than from an external force field by convolving the noisy image with a Gaussian filter. Thus the edge-stopping criterion is more robust than that on the raw noisy image domain. Experimental results demonstrated that this technique is very efficient for MR imaging.

6144-230, Poster Session

ICA domain filtering for reduction of scattered x-ray in cone-beam CT images

Y. Chen, Ritsumeikan Univ. (Japan); X. Han, Univ. of the Ryukyus (Japan)

Cone beam CT has a capability for the 3-dimentional imaging of large volumes with isotropic resolution. But the main limitation of cone beam CT is a larger amount of scattered x-ray. The scattered x-ray may enhance the noise in the reconstructed images. In this paper, we propose a new filtering based on independent component analysis (ICA) for reduction of scattered x-ray. In the proposed filtering, the image (projection) is first transformed to ICA domain and then the components of scattered x-ray are removed by a soft thresholding (Shrinkage). The proposed filter has been successfully applied to real x-ray image. Both Monte Carlo simulation results and experimental results show that the quality of the projection can be dramatically improved without any blurring in edge by the proposed filter.

6144-231, Poster Session

Charecterization of high-resolution MR images reconstructed by the GRAPPA parallel technique

S. Banerjee, S. Majumdar, Univ. of California/San Francisco and Univ. of California/Berkeley

This work implemented an auto-calibrating parallel imaging technique and applied it to in vivo magnetic resonance imaging (MRI) of trabecular bone micro-architecture. A Generalized Auto-calibrating Partially Parallel Acquisition (GRAPPA) based reconstruction technique using modified robust data fitting was developed. The MR data was acquired with an eight channel phased array receiver on three normal volunteers on a General Electric 3 Tesla scanner. Microstructures comprising the trabecular bone architecture are of the order of 100 microns and hence their depiction requires very high imaging resolution. This work examined the effects of GRAPPA based parallel imaging on signal and noise characteristics and effective spatial resolution in high resolution (HR) images, for the range of undersampling or reduction factors 2-4. Additionally quantitative analysis was performed to obtain structural measures of trabecular bone from the images. Image quality in terms of contrast and depiction of structures was maintained in parallel images for reduction factors up to 3. Comparison between regular and parallel images suggested similar spatial resolution for both. However differences in noise characteristics in parallel images compared to regular images affected the threshholding based quantification. This suggested that GRAPPA based parallel images might require different analysis techniques. In conclusion, the study showed the feasibility of using parallel imaging techniques in HR-MRI of trabecular bone,although quantification strategies will have to be further investigated. Reduction of acquisition time using parallel techniques can improve the clinical feasibility of MRI of trabecular bone for prognosis and staging of the skeletal disorder osteoporosis.

6144-232, Poster Session

Robust estimation of the noise variance from background MR data

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In image processing applications in which magnetic resonance (MR) images are involved, one of the most important parameters is the noise variance. Indeed, algorithms for segmentation, clustering, noise reduction etc, highly depend on the noise variance. In the literature, many methods are available for estimation of the noise variance. Two of the most popular methods employ the background data of magnitude MR images. However, till now, an in depth comparison of both methods has not been described. In this paper, both methods that estimate the noise variance from background MR data are thoroughly evaluated in terms of accuracy and precision using simulated as well as experimental MR data. Also, a rule of thumb is provided that helps the reader to select the proper method in a particular situation.

6144-233, Poster Session

Improvement of image quality in MDCT by high-frequency sampling of x-, y- and z-direction

N. Yasuda, Y. Ishikawa, Y. Kodera, Nagoya Univ. (Japan)

The multi-detector row computed tomography (MDCT) has dramatically increased speed of scanning, and allows high-resolution imaging compared with the conventional single-detector row CT (SDCT). However, use of the MDCT was making use of three-dimensional (3D) volume scanning and four-dimensional (4D) scanning increase, and made radiation dose to patients increase simultaneously. In addition, in recent years, lung-

cancer screening CT (LSCT) is introduced, and low-dose scanning is required to increase the benefit/risk ratio. In this study, high-frequency volume data sampling (over-sampling) method of -, - and -direction was proposed as technique for reduction of noise in the MDCT and discussed about reduction of radiation dose and improvement of image quality. In this proposed method, volume data are obtained by over-sampling of -, - and -direction and image is obtained by averaging these data. In - and - direction, over-sampling is equivalent to obtaining projection data using large matrix size for same scan-field of view (scan-FOV), and in -direction, equivalent to using thin slice. Normally, when signal with which noise distribution differs are averaged -times, signal-to-noise ratio (SNR) will increases by factor of . In this method, each pixel value of the image is obtained from pixels by -times sampling for - and -direction, and -times sampling for -direction. In other words, SNR of the image increases - times. In this high-frequency data sampling method, it is possible to obtain high-quality image as compared with conventional image. Moreover, by applying to noisy image obtained with low-dose scanning, reduction of radiation dose to patients is possible.

6144-234, Poster Session

Platelets for denoising of SPECT images: phantom and patient study

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In this study the evaluation of a Platelet-based Maximum Penalized Likelihood Estimation (MPLE) for denoising SPECT images was performed and compared with other denoising methods such as Wavelets or Butterworth filteration. Platelet-based MPLE factorization as a multiscale decomposition approach has been already proposed for better edges and surfaces representation due to Poisson noise and inherent smoothness of this kind of images.

We applied this approach on both simulated and real SPECT images. For Nema phantom images, the measured noise levels before (Mb) and after (Ma) denoising with Platelet-based MPLE approach were Mb=2.1732, Ma=0.1399. In patient study for 32 cardiac SPECT images, the difference between noise level and SNR before and after the approach were (Mb=3.7607, SNRb=9.7762, Ma=0.7374, SNRa=41.0848) respectively. Thus the Coefficient Variance (C.V) of SNR values for denoised images with this algorithm as compared with Butterworth filter, (145/33%) was found. For 32 brain SPECT images the Coefficient Variance of SNR values, (196/17%) was obtained.

Our results showed that Platelet-based MPLE is a useful method for denoising SPECT images considering better homogenous image, improvements in SNR, better radioactive uptake in target organ and reduction of interfering activity from background radiation in compare with that of other conventional denoising methods.

6144-235, Poster Session

Automatic detection of specular reflections in uterine cervix images

G. Zimmerman, H. Greenspan, Tel Aviv Univ. (Israel)

Specular reflections (SR) strongly affect the appearance of images, and usually hinder computer vision algorithms. This is particularly the case with cervigrams, which are color images of the uterine cervix used for cervical cancer screening. Cervigrams are obtained with a specialized camera and a bright flash, which create multiple specular reflections in each image. This work is part of an on-going effort towards the creation of automated cervigram analysis schemes. Segmentation methodologies are being developed for the identification of several tissue types that differ in color and texture. The specular reflections are a major obstacle in the way of segmenting such images. There is a strong need for identification and special treatment of these potentially problematic regions.

The proposed method for SR identification in cervigrams utilizes intensity, saturation and gradient information and is achieved by a two-stage process. First, initial coarse regions that contain the reflections are defined by robust thresholds. This step helps to overcome the extreme imbalance between the number of specular and non-specular pixels in the entire image. Second, probabilistic modeling (mixture of Gaussians) is used to achieve a precise segmentation inside the initial regions. A simple yet effective scheme is proposed for filling-in the color information of the specularities. The color information from the surrounding pixels is smoothly propagated into the SR regions, resulting in a cervigram that looks specular-free. The efficiency of the method for cervix images is demonstrated, and evaluation by medical experts is carried out.

6144-237, Poster Session

An improved denoising algorithm based on multi-scale dyadic wavelet transform

Z. Qi, L. Zhang, Y. Xin, H. Gao, Tsinghua Univ. (China)

CT images are often degraded by random noise in the CT system and therefore it poses great difficulty for the following tasks, such as segmentation and identification. In this paper, an efficient denoising algorithm based on multi-scale dyadic wavelet transform is proposed to improve the quality of CT images. This algorithm mainly consists of three parts: (1) According to the inter-scale relationship of wavelet coefficient magnitude sum in the COI (cone of influence), wavelet coefficients at each scale are classified into two categories: edge-related and regular coefficients and irregular coefficients; (2) For edge-related and regular coefficients, only those located at the lowest decomposition level are denoised by wiener filtering, while no changes are made on coefficients located at other decomposition levels; and (3) For irregular coefficients, they are denoised at all decomposition levels by wiener filtering. This algorithm is performed on projection data, from which CT images are reconstructed. Experimental results demonstrate that it can effectively reduce the noise intensity while preserving the contrast and detail information and thus significantly improve the quality of CT images. The denoising results indicate that this algorithm can offer great help to the analysis work based on CT images.

6144-238, Poster Session

A weighted average algorithm for edge-preserving smoothing on MRI images

R. Jin, L. Zhang, B. Meng, E. Song, X. Xu, Huazhong Univ. of Science and Technology (China); C. Hung, Southern Polytech State Univ.

Medical images such as MRI images normally have smooth and round edges but existing general edge-preserving smoothing algorithms often result in coarse and sharp edges. A new image smoothing algorithm, based on a filter utilizing the weighted average of average pixel values in several neighborhood subregions is proposed to deal with the problem. Sharp subregions such as squares are avoid to be selected to make the edges being preserved for smooth and round. On smoothing process, each subregion is assigned a weight according to its homogeneousness which is evaluated by the variance of its pixel values. The weighted average of averages for all subregions is assigned to the center pixel being smoothed. The more homogeneous neighborhood has more influence on the center pixel so that the edges can be preserved well. But contributions from all neighborhoods also are taken into consideration especially when the homogeneousness are largely equal so that the result areas are more smooth. A evaluation of the algorithm on the simulated MRI images is carried out. Experiment results showed that the new algorithm can smooth the MRI images better while keeping the edges better comparing with the existing smoothing algorithms.

6144-239, Poster Session

Simulation of susceptibility-induced distortions in fMRI

N. Xu, Y. Li, C. B. Paschal, C. Gatenby, V. L. Morgan, D. R. Pickens III, B. M. Dawant, J. M. Fitzpatrick, Vanderbilt Univ.

It has been recently proposed that computer-simulated phantom images can be used to evaluate methods for fMRI preprocessing. It is widely recongnized that Gradient-Echo Echo Planar Imaging (EPI), the most often used technique for fMRI, is strongly affected by field inhomogeneities. Accurate and realistic phantom images for use by the fMRI community for software evaluation and training must incorporate these distortions and account for the effects on the distortions of head motion and respiration. A method to generate realistic distortions caused by field inhomogeneity for the generation of an fMRI phantom is presented in this paper. Changes in field inhomogeneity due to motion are studied by means of adding motions to the brain model and calculating the induced field map numerically rather than measuring it experimentally. A fast analytic version of an MR simulation is used to generate distorted EPI images based on the calculated field maps. The new generated fMRI phantoms can be used to evaluate processing algorithms for fMRI study more accurately. We can appreciate the importance of distortions for fMRI phantom generation by simulating a distortion-free image and adding distortions afterwards. Validations are performed by comparing the calculated field maps with measured ones. In addition, we show the similaries between a simulated fMRI phantom and real EPI image from our MR scanner.

6144-240, Poster Session

Retinal image enhancement based on the human visual system

B. Raman, K. Belkacem-Boussaid, G. Zamora, Kestrel Corp.; Y. Srinivasan, Texas Tech Univ.; S. Bursell, Harvard Medical School

Improving the quality of gray level images continues to be a challenging task, and the challenge increases for color images due to the interaction of multiple parameters within a scene. Each color plane or wavelength constitutes an image by itself, and its quality depends on many parameters such as absorption, reflectance or scattering of the object with the lighting source. Non-uniformity of the lighting, optics, electronics of the camera, and even the environment of the object are sources of degradation in the image. Therefore, segmentation and interpretation of the image may become very difficult if its quality is not enhanced. The main goal of the present work is to demonstrate an image processing algorithm that is inspired on the Human Visual System (HVS). HVS concepts have been widely used in gray level image enhancement and here we show how they can be successfully extended to color images. The resulting Multi-Scale Spatial Decomposition (MSSD) is employed to enhance the quality of color images. Of particular interest for medical imaging is the enhancement of retinal images whose quality is extremely sensitive to imaging artifacts. We show that our MSSD algorithm improves the readability and gradeability of retinal images and quantify such improvements using both subjective and objective metrics of image quality.

6144-241, Poster Session

Prior-information-driven multiple contrast projection of

S. Rajagopalan, R. A. Robb, Mayo Clinic

Despite the improvements in MR imaging, the optimization of fast imaging techniques for display of T2 contrast has not yet been accomplished. Existing methods that make use of prior-information (feature-recognizing MRI, constrained reconstruction techniques, dynamic imaging etc) are sub-optimal. In this paper, we present a fast, robust method to enhance the T2 related contrast in an MRI image acquired at, but not restricted to, "just-enough-to-highlight-T2" repetition time so as to produce a computed mosaic of the same image at different repetition (TR) and echo (TE) times. This leads to substantial reduction in scan time and simultaneous provision of multiple snapshots of the same image at different TR and TE time settings. The enhanced mapping is performed using a feature-guided, non-linear equalization technique based on prior knowledge. The proposed methodology could be synergistically cascaded with other fast imaging techniques to further improve the acquisition rate. The clinical applications of the proposed contrast enhancement technique include: a pre-scan application in which projected images assist in prescribing a subsequent image acquisition; a real-time application in which images are acquired quickly with a short TR from which projected images at long TR are produced in near real-time; and post processing applications where enhanced images are produced to assist in diagnosis.

6144-242, Poster Session

Implications of MR contrast standardization on image computing

S. Rajagopalan, R. A. Robb, Mayo Clinic

The process of transforming the non-linear magnetic field perturbations induced by radiowaves into linear reconstructions based on Radon and Fourier transforms has resulted in MR acquisitions in which intensities do not have a fixed meaning, not even within the same protocol, for the same body region, for images obtained on the same scanner, for the same patient, on the same day. This makes robust image interpretation and processing extremely challenging. The status quo of fine tuning an image processing algorithm with the ever-varying MRI intensity space could best be summarized as a "random search through the parameter space". This investigation demonstrates the implications of standardizing the contrast across multiple tissue types on the robustness and efficiency of image processing algorithms. Contrast standardization is performed using a prior-knowledge driven feature-guided, fast, non-linear equalization technique. Without loss of generality, skull stripping and brain tissue segmentation are considered in this investigation. Results show that the iterative image processing algorithms converge faster with minimal parameter tweaking and the abstractions are significantly better in the contrast standardized space than in the native stochastic space.

6144-243, Poster Session

Contrast enhancement of soft tissues in computed tomography images

R. Lerman, D. S. Raicu, J. D. Furst, DePaul Univ.

Even though soft tissues are of primary interest to radiologists, they are represented using only 12.5% of the total number of gray levels in a typical DICOM format of a Computed Tomography (CT) scan. This poor distribution of gray levels reduces the overall contrast and the texture differences between individual organs, and poses a serious visualization problem since radiologists need clear visual representations of organs to produce proper diagnoses. In order to enhance the contrast within the soft tissues, the gray levels can be redistributed both linearly and non-linearly using the gray level frequencies of the original CT scan. We propose a new non-linear approach for contrast enhancement of soft tissues in CT images using both clipped binning and non-linear binning based on a k-means clustering algorithm. The optimal number of bins, in particular number of gray levels, is chosen automatically using entropy and average distance between the histogram of the original gray level distribution and the contrast enhancement function's curve. The contrast enhancement results were obtained and evaluated using 141 CT images of the chest and abdomen from two normal CT studies.

6144-244, Poster Session

Adaptive conductance filtering for spatially varying noise in PET images

D. R. Padfield, R. M. Manjeshwar, GE Global Research

PET images that have been reconstructed with unregularized algorithms are commonly smoothed with linear Gaussian filters to control noise. Since these filters are spatially invariant, they degrade feature contrast in the image, compromising lesion detectability. Edge-preserving smoothing filters can differentially preserve edges and features while smoothing noise. These filters assume spatially uniform noise models. However, the noise in PET images is spatially variant, approximately following a Poisson behavior. Therefore, different regions of a PET image need smoothing by different amounts. In this work, we introduce an adaptive filter designed specifically to overcome this problem. In this algorithm, the diffusion is varied according to a local estimate of the noise using the grayscale image opening to weight the conductance parameter. The algorithm is thus tailored to the task of PET image smoothing, adapting itself to varying noise while preserving significant features in the image. This filter was compared with Gaussian smoothing and a representative anisotropic diffusion method using three quantitative task-relevant metrics calculated on simulated PET images with lesions in the lung and liver. The contrast gain and noise ratio metrics were used to measure the ability to do accurate quantitation; the Channelized Hotelling Observer lesion detectability index was used to quantify lesion detectability. The adaptive filter improved the signal-to-noise ratio by more than 45% and lesion detectability by more than 55% over the Gaussian filter while producing "natural" looking images and consistent image quality across different anatomical regions.

6144-245, Poster Session

Denoising diffusion tensor images: preprocessing for automated detection of subtle diffusion tensor abnormalities between populations

T. M. Lee, Univ. of California/Los Angeles

Quantitative techniques such as diffusion tensor imaging (DTI) are finding increasing clinical applications in psychiatric conditions. Many disease states such as depression show subtle changes in diffusion tensor indices, which can only be detected by comparison of population cohorts. An accurate statistical comparison to detect population-based differences requires high quality image data. Further, it is important to reduce noise in the acquired diffusion weighted images to perform accurate fiber tracking. In order to obtain acceptable SNR values for DTI images, a large number of averages are required. For whole brain coverage with isotropic and high-resolution imaging, this leads to unacceptable scan times. In order to obtain high SNR images with smaller number of averages, we propose to combine the strengths of two recently developed methodologies for denoising: total variation and wavelet. Our algorithm, which uses translational invariant BayesShrink wavelet thresholding with total variation regularization, successfully removes image noise and Pseudo-Gibbs phenomena while preserving both texture and edges. We compare our results with other denoising methods proposed for DTI images based on visual and quantitative metrics.

6144-246, Poster Session

A voxel-based partial volume correction in nuclear medicine

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In brain imaging using SPECT or PET, accurate detection and analysis of small region of interest (ROI) are primarily limited by the partial volume effect (PVE). PVE is mainly due to finite spatial resolution of the imaging system, and it causes the loss of signal especially in the region smaller than about 2-3 times the FWHM in the system. Correction for PVE (PVC) is important for better quantitation. Many PVC methods have been previously proposed. The region-based PVC methods assume uniform activity within each ROI. A simple region-based PVC method, developed by Rousset et al (JNM, 1998), models PVE through a simple linear combination of weighted mean activity from different ROIs. Using the anatomical information from a co-registered anatomical image (e.g. MRI), and estimated mean activity within each ROI from the observed image, the true activity can then be obtained by solving the linear equation. Rousset's method is popular due to its simple operation, and effectiveness in uniform PVC. In this study, we investigate a voxel-based PVC approach by modifying Rousset's uniform region-based method to account for non-uniform distribution within each ROI. The modified PVC approach was implemented using a simulated imaging model, 2D digital phantoms and perfect co-registered MRIs. The results of the modified PVC method show better regional recovery from PVE as compared to those of Rousset's method, in particular, in a smaller ROI. For future work, we will consider more physical effects including scatter, 3D objects in the imaging model.

6144-247, Poster Session

Detectability improvement of early sign of acute stroke on brain CT images using an adaptive partial smoothing filter

Y. Lee, Niigata Univ. (Japan); N. Takahashi, Niigata Univ. (Japan) and Sendai City Hospital (Japan); D. Tsai, Niigata Univ. (Japan)

Detection of early infarct signs on non-enhanced CT is mandatory in patients with acute ischemic stroke. However, its detection is considerably difficult. We present a method for improving the detectability of early infarct signs of acute ischemic stroke. This approach is considered as the first step for computer-aided diagnosis in acute ischemic stroke. Loss of the gray-white matter interface at the lentiform nucleus or the insular ribbon has been an important early infarct sign, which affects decisions on thrombolytic therapy. However, its detection is difficult, since early infarct sign is subtle hypoattenuation. In order to improve the detectability of early infarct signs, an image processing being able to reduce local noise with edges preserved is desirable. To cope with this issue, we devised an adaptive partial smoothing filter (APSF). Because the APSF can markedly improve the visibility of the normal gray-white matter interface, the detection of conspicuity of loss of gray-white matter interface due to hypoattenuation could be increased. The APSF is a specifically designed filter used to perform local smoothing using a variable filter size determined by the distribution of pixel values of edges in the region of interest. By adjusting 3 major parameters that exist in the APSF, an optimal condition for image enhancement can be obtained. In order to demonstrate the effectiveness of the APSF, computer-simulated images were used for quantitative evaluation. The APSF was applied to five clinical CT scans in hyperacute stroke patients. Our preliminary results showed that the detectability of early infarct signs is much improved.

6144-248, Poster Session

A novel contrast equalization method for chest radiograph

M. Zhang, X. Mou, Xi'an Jiaotong Univ. (China)

This paper proposed a novel contrast equalization algorithm for display or print ready processing of x-ray chest radiograph based on a multi-scale decomposition and reconstruction architecture. Firstly, using this architecture, the original image is decomposed into multi-scale components. At this stage, three methods are used. The first two methods are based on Gauss convolution filters and the third is based on mean curvature motion equation, which is one of nonlinear partial differential equation(PDE) models. Secondly the components at different scale are weighted using a set of controlled equalization coefficients and then inte-

grated into the display or print ready image to ensure the improvement of the visibility of weakly contrasting details and the contrast between tissues in different area. Preliminary experiments on clinical images in deed testify the superiority of our algorithm. This algorithm can effectively improve contrast of low-contrast-region, increase the detail visibility of the rendered image to CRT or film as the image latitude has adequate broad.

6144-249, Poster Session

On interpolation of sparsely sampled sinograms

T. Aach, RWTH Aachen (Germany); S. Schroeder, Georg-August-Univ. Göttingen (Germany); I. Stuke, Univ. zu Lübeck (Germany)

Certain situations, for instance in flat-panel cone beam CT, permit that only a relatively low number of projections are acquired. The reconstruction quality of the volume to be imaged is then compromised by streaking artifacts. To avoid these degradations, additional projections are interpolated between the genuinely acquired ones. Since straightforward linear, non-adaptive interpolation generally results in loss of sharpness, techniques were developed which adapt to, e.g., local orientation within the sinogram. So far, such directional interpolation algorithms consider only single local orientations. Especially in x-ray imaging, however, different non-opaque orientated structures may be superimposed. We therefore show how such multiply-oriented structures can be detected, estimated, and included in the interpolation process. Furthermore, genuine sinograms meet certain conditions regarding their moments as well as regarding their spectra. Moments of 2D sinograms depend on the projection angle in the form of sinosoids, while the Fourier spectrum of the sinogram takes the form of a 'bow tie'. The consistency of the interpolated data with these conditions may therefore be viewed as additional measures of the interpolation quality. For linear interpolation, we analyze how well the interpolated data comply with these constraints. We also show how the moment constraint can be integrated into the interpolation process.

6144-250, Poster Session

Adaptive multichannel contrast enhancement of mammograms based on human visual system

K. A. Gandhi, H. Roehrig, M. K. Sundareshan, J. Fan, E. A. Krupinski, The Univ. of Arizona

Human observers are an integral part of most imaging systems. However, majority of the existing methods of image contrast enhancement focus mainly on the properties of the image being processed without any consideration of the observer characteristics. It has been shown that the Human Visual System (HVS) can be approximately represented by a multichannel system containing a number of parallel channels, each selective to a limited range of frequencies. The HVS can be modeled using octave bandwidth spatial filters. In this paper, we present an adaptive algorithm that tailors the enhancement required based on the local features in the multi-channel representation of the image and the contrast sensitivity function of the HVS. Applying thresholds based on local statistics, features in the band-pass images are extracted. The amount of contrast enhancement is then determined by a ratio of local contrast to the normal contrast threshold at that frequency. The proposed method is adaptive, non-linear and is noise-resistant in the sense that it prevents noise amplification. Experimental results using mammograms show increased enhancement which can benefit clinical applications.

6144-251, Poster Session

A new post-processing method of applying independent component analysis to fMRI data

X. Wu, L. Yao, Z. Long, Beijing Normal Univ. (China); K. Chen, Banner Good Samaritan Medical Ctr.

Independent component analysis (ICA) method can be used to separate fMRI data into some task-related independent components, including one consistently task-related (CTR) and several transiently task-related (TTR) components. However, the weights, with which the CTR and TTRs contribute to the final task component, are often unknown, but are important for finding its relevant spatial activation area. Here we propose a new ICA post-processing method alternative to combine not only these CTR and TTRs which sometimes are judged in a subjective manner, but also others in an effort to identify a comprehended and summed spatial pattern that is responsible for the behavior under investigation. This proposed procedure has been successfully used in principal component analysis (PCA) based scaled subprofile modeling (SSM). Adopting this newly proposed approach, we essentially refer the ICA exploratory findings to a hypothesized temporal brain response pattern (reference function). Basically, we will use linear regression method to seek the relationship between the reference function and time courses of multi components generated from the ICA procedure. The linear regression coefficients are then used as relative weights in generating the final summed spatial pattern. Moreover, this approach allows a researcher to use T-test to statistically infer the importance of each independent component in its contribution to the final pattern and consequently the contribution to the cognitive process. Experiment result also shows that the spatial activation of the final task component becomes more accurate.

6144-252, Poster Session

Integrating and classifying parametric features from fMRI data for brain function characterization

Y. M. Wang, C. Zhou, Univ. of Illinois at Urbana-Champaign

Recent advances in functional magnetic resonance imaging (fMRI) provide an unparalleled opportunity for measuring and characterizing brain function in humans. However, the typically small signal change is very noisy and susceptible to various artifacts, such as those caused by scanner drift, head motion, and cardio-respiratory effects. This paper presents an integrated and exploratory approach to characterize brain function from fMRI data by providing techniques for both functional segregation and integration without any prior knowledge of the experimental paradigm. We demonstrate that principal component analysis (PCA) can be used for temporal shape modeling and shape feature extraction, shedding lights from a different perspective for the application of PCA in fMRI analysis. Appropriate feature screening is also performed to eliminate the parameters corresponding to data noise or artifacts. The extracted and screened shape parameters are revealed to be effective and efficient representations of the true fMRI time series. We then propose a novel strategy which classifies the fMRI data into distinct activation regions based on the selected temporal shape features. Furthermore, we propose to infer functional connectivity of the identified patterns by the distance measures in this parametric shape feature space. Validation for accuracy, sensitivity, and efficiency of the method and comparison with existing fMRI analysis techniques are performed using both simulated and real fMRI data. Future directions of this work include generalizing the proposed strategies to independent component analysis (ICA), automating the feature selection process, and applying the method to analysis of more complicated cognitive fMRI data.

6144-253, Poster Session

Enhanced techniques for asymmetry quantification in brain imagery

X. Liu, C. Imielinska, Columbia Univ.; J. Rosiene, Eastern Connecticut State Univ.; M. E. Sughrue, A. L. D'Ambrosio, Columbia Univ.

Introduction: Utilization of inherent left-right symmetry in the brain is used to statistically enhance the differences in otherwise symmetric regions of the brain. The detection of slight variations left to right in brain imagery is complicated by normal differences in the anatomical structures. We propose a methodology for utilization of the apparent bi-lateral symmetry in brain imagery through the application of non-parametric statistical tests

operating on the pairs of samples and non-parametric statistical tests on local averages.

Methods: In radiological brain images, to measure differences in bi-fold mirror symmetry the axis of symmetry must be estimated and the image "self-registered" to this axis. After detection and registration of the image to the axis of symmetry, the data can be checked for significant differences in the image in regions collocated relative to the given axis of symmetry. This approach define the essence of the relative difference map (RDM) method that quantifies and highlights asymmetric areas in both brain hemispheres.

Results: We illustrate below the technique on medically relevant examples. Computation of relative asymmetric regions is used for quantification of perfusion-weighted images, and pre-segmentation of brain tumors from structural magnetic resonance imaging. In the results, the relative or original values are shown on superimposed on the detected area of asymmetry.

Conclusions: We present a generic method to compute axis of symmetry and quantification of asymmetry in brain imagery. There are various clinical applications that make use of brain imagery where quantification of asymmetry provides potential computer-assisted assessment and diagnostic tool.

6144-254, Poster Session

Analysis of the topological properties of the proximal femur on a regional scale: evaluation of multi-detector CT-scans for the assessment of biomechanical strength using local Minkowski functionals in 3D

H. F. Boehm, Ludwig-Maximilians-Univ. München (Germany); T. M. Link, Univ. of California/San Francisco; R. A. Monetti, Max-Planck-Institut für extraterrestrische Physik (Germany); V. Kuhn, Medizinische Univ. Innsbruck (Austria); F. Eckstein, Paracelsus Medizinische Privatuniversität (Austria); M. Reiser, Ludwig-Maximilians-Univ. München (Germany); C. W. Raeth, Max-Planck-Institut für extraterrestrische Physik (Germany)

In our recent studies on the analysis of bone texture in the context of Osteoporosis, we could already demonstrate the great potential of the topological evaluation of bone architecture based on the Minkowski Functionals (MF) in 2D and 3D for the prediction of the mechanical strength of cubic bone specimens depicted by high resolution MRI.

Other than before, we now assess the mechanical characteristics of whole hip bone specimens imaged by multi-detector computed tomography. Due to the specific properties of the imaging modality and the bone tissue in the proximal femur, this requires to introduce a new analysis method.

The internal architecture of the hip is functionally highly specialized to withstand the complex pattern of external and internal forces associated with human gait. Since the direction, connectivity and distribution of the trabeculae changes considerably within narrow spatial limits it seems most reasonable to evaluate the femoral bone structure on a local scale.

The Minkowski functionals are a set of morphological descriptors for the topological characterization of binarized, multi-dimensional, convex objects with respect to shape, structure, and the connectivity of their components. The MF are usually used as global descriptors and may react very sensitively to minor structural variations which presents a major limitation in a number of applications.

The objective of this work is to assess the mechanical competence of whole hip bone specimens using parameters based on the MF. We introduce an algorithm that considers the local topological aspects of the bone architecture of the proximal femur allowing to identify regions within the bone that contribute more to the overall mechanical strength than others.

6144-255, Poster Session

Automatic textural feature selection on echocardiographic images

I. P. Ponce, R. Valdes-Cristerna, Univ. Autonoma Metropolitana (Mexico)

The quality of the information content in echographic images is often reduced by the present of dropout, speckle, movement artifacts, and far field attenuation, although ultrasound is suitable to assessing the dynamic aspects of heart. The goal of this work is to find a set of texture features that optimally characterize the cardiac chambers from the echocardiographic images, and using this selected features to classify the image to enhance the segmentation. In this work 77 texture characteristics, were extracted from echographic images and border map images, where an optimal set of them were selected by an algorithm based on separability criterion, classification rate criterion, and sequential forward algorithm. As a result the optimal set of texture characteristics found is: [Echo, Homogeneity of the co-ocurrence matrix at 90°, Central moment 22 and Central moment 22 in border map] with 76.4% of classification rate.

6144-256, Poster Session

Investigation of temporal radiographic texture analysis for the detection of periprosthetic osteolysis

J. R. Wilkie, M. L. Giger, The Univ. of Chicago; C. A. Engh, Sr., R. H. Hopper, Jr., Anderson Orthopaedic Research Institute; J. M. Martell, The Univ. of Chicago

Periprosthetic osteolysis is a disease caused by the body's response to submicron polyethylene debris particles from the hip implant in total hip replacement (THR) patients. It leads to resorption of bone surrounding the implant and deterioration of the bone's trabecular texture, but this is difficult to detect until the later stages of disease progression. Radiographic texture analysis methods have shown promise in detecting this disease at an earlier stage; however, changes in texture over time may be more important than absolute texture measures. In this research, we investigated temporal radiographic texture analysis (tRTA) methods as possible aids in the detection of osteolysis. A database of 48 THR cases with images available from four different follow-up time intervals was used. ROIs were selected within the osteolytic region of the most recent follow-up image (or comparable region for normal cases) and visually matched on all previous images. Texture features were calculated from the ROIs and then trend analysis was performed using a simple linear regression method, an LDA method and a BANN method. The performance of these three methods was evaluated by ROC analysis. Maximum AUC values of 0.68, 0.78, and 0.88 for the task of distinguishing between osteolysis and normal cases were achieved for the respective tRTA features. These performances were superior to those of our prior stationary, non-temporal texture analysis. The results suggest that tRTA may have the potential to help detect osteolysis at an earlier, more treatable stage.

6144-258, Poster Session

Exploiting 3D volume texture model for automatic detection of diffuse lung disease from multislice computed tomography

Z. Yao, M. Zhu, Institute of Electronics (China)

The automatic detection and classification of abnormal lung opacities in High Resolution Computed Tomography (HRCT) is a necessary stage in the construction of a Computer Aided Diagnosis (CAD) system against diffuse lung disease. Former works interpret lung patterns from thin-chipped HRCT images as 2D (axial) textures. Such methods have trouble when discriminating some anomalous pattern (e.g. nodules) from normal lung texture caused by vessels and bronchi. In this work we propose a novel 3D

volume texture model to extract texture features from multi-slice HRCT volume images. We extend 3D texture model from 2D Julesz ensemble theory [1] and define the 3D volume texture ensemble Ω(h) as a set of volume data share identical statistics h. The texture modeling is posed as an inverse problem: Given a set of images sampled from an unknown ensemble Ω(h*), we search for the statistics h* that define the ensemble. We prove that histograms of the response from 3D filter banks compose an efficient set of statistics h, therefore 3D Gabor-filter banks are exploited to extract volume texture features. To perform abnormality detection, we firstly segment the multi-slice HRCT lung images into many cubes with similar inner texture pattern and then apply the 3D Gabor filter banks to extract features from each cube. Finally, the K-nearest neighbor algorithm is used to classify cubes with normal and abnormal textures. Through simulation, we find that our method can successfully separate many textures indiscriminable by 2D methods. Experimental results with real HRCT data demonstrate that our method yield better detection performance (ROC) than other 2D texture based abnormality detection methods

6144-259, Poster Session

Fourier-domain based datacentric performance ranking of competing medical image processing algorithms

S. Rajagopalan, R. A. Robb, Mayo Clinic

To accomplish a given computational task, a number of algorithmic and heuristic approaches can be employed to act upon the ever-varying input data. Depending upon the assumptions made regarding the data, the algorithm and the task, the end result from each of these approaches could be different. Currently, there does not exist an automatic, robust, precise, simple, and algorithm-independent measure to rate the accuracy of a multiplicity of algorithms to accomplish a given task on the given data. Lack of such a measure severely restricts the integration of "datacentric" computational tools. This paper proposes a Fourier-domain based method to robustly assess and rank the accuracy of a multiplicity of abstractions vis-a-vis the original data. The method is scalable across dimensions and data types and is blind to the task associated with the generation of the competing to-be-rated abstractions.

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6145-01, Session 1

The iSite concept: a convergence of medicine, engineering, and science

P. J. Chang, Univ. of Pittsburgh Medical Ctr.

No abstract available

6145-02, Session 1

MoniQA: a general approach to monitor quality assurance

T. J. Deprez, J. Jacobs, G. Marchal, H. Bosmans, Univ. Ziekenhuizen Leuven (Belgium)

MoniQA ("Monitor Quality Assurance" software) is a new, non-commercial, independent quality assurance software application developed in our medical physics team. It is a complete java TM -based modular environment for the evaluation of radiological viewing devices and it thus fits in the global quality assurance network of our (filmless) radiology department. The purpose of the software tool is to guide the medical physicist through an acceptance protocol and the radiologist through a constancy check protocol by presentation of the necessary test patterns and by automated data storage. Data are then sent to a central management system for further analysis. At the moment 39 patterns have been implemented, which can be grouped in schemes to implement protocols (AAPM, DIN and EUREF). Some test patterns are dynamically created and 'drawn' on the viewing device with randomize parameters as our new pattern for constancy testing, which provides a drastic reduction of the overall quality control time investment and improvement of data reliability. The software is installed on 35 diagnostic stations (70 monitors) in a filmless radiology department. Learning time was very limited. A constancy check - with the new pattern that assesses luminance decrease, resolution problems and geometric distortion- takes only 2 minutes and 28 seconds per monitor. The modular approach of the software allows the evaluation of new or emerging test patterns. We will report on the software and usability: practicality of the constancy check tests in our hospital and on the results from acceptance tests of viewing stations for digital mammography.

6145-03, Session 1

A method for reduction of eye fatigue by optimizing the ambient light conditions in medical imaging reading rooms

A. S. Chawla, E. Samei, Duke Univ.

Ambient lighting in soft-copy reading rooms are currently kept at low values to preserve contrast rendition in the dark regions of a medical image. This is especially important for reading rooms which employ CRTs with typically high diffuse reflection coefficients, R_d , highly reflecting the ambient lighting. Low illuminance levels, however, create inadequate viewing conditions and can also cause eye-strain as can be most commonly experienced when viewing bright televisions in a dark room. This eye-strain may be attributed to notable variations in luminance adaptation state of the reader's eyes when moving the gaze intermittently between the brighter display and darker surrounding surfaces. This paper presents a methodology to optimize the lighting conditions of reading rooms to reduce visual fatigue by minimizing this variation by exploiting the improved properties of LCDs with lower diffuse reflection coefficients and higher luminance ratio as compared to CRTs. First, a computational model was developed to determine a global luminance adaptation value, L_{adp}, when viewing a medical image on display. The model is based on the diameter of the pupil size which depends on the luminance of the observed object. Second, this value was compared with the luminance reflected off surrounding surfaces, L_s , under various conditions of room illuminance, E, different values of diffuse reflection coefficients of surrounding surfaces, R_s, and calibration settings of a typical LCD. The results suggest that for typical luminance settings of current LCDs, it is possible to raise ambient illumination to minimize differences in eye adaptation, potentially reducing visual fatigue while also complying with the TG18 specifications for controlled contrast rendition, provided that the ratio R_s/R_d is greater than 60.

6145-04, Session 1

Interpretation time required for chest direct radiography with and without dual-energy subtraction

K. M. Siddiqui, VA Maryland Health Care System; P. A. Vandermeer, Univ. of Maryland Medical System; W. W. Boonn, Univ. of Pennsylvania; A. E. Musk, N. M. Safdar, Univ. of Maryland Medical System; R. Moffitt, VA Maryland Health Care System; T. R. Fleiter, C. S. White, R. D. Pugatch, Univ. of Maryland Medical System; B. I. Reiner, E. Siegel, VA Maryland Health Care System

The purpose of this study was to determine whether the addition of 2 views associated with the dual-energy subtraction (DES) technique resulted in a significant change in interpretation times in chest radiography. The study included 139 patients referred for computed tomography (CT) imaging of the chest. Each patient also underwent chest radiography with a direct digital receptor (DR) system (which produced a conventional posterior/anterior [PA] and lateral pair of images) and an additional image acquired at a lower energy to yield both a calcium-subtracted and a calcium-enhanced image. Five experienced radiologists interpreted the images in 2 sessions (first the PA and lateral digital radiographs and later the complete DES chest study, which included a total of 4 images). The time required for interpretation was recorded electronically for each type of study. The mean time required for interpretation of the 2-view DR study was significantly different from that for the 4-image DES study (148 s and 112 s, respectively; $P = 0.02$). As expected, each time was significantly less than the mean time required for CT interpretation (263 s; $P < 0.0001$). However, the results included the unexpected finding that less time was required for interpretation of the 4-image DES study than for the more conventional 2-image study. Preliminary assessments of reports by participants suggest that the DES studies provided more detail and could be read with a higher level of confidence, diminishing search time without compromising quality.

6145-05, Session 2

Network-based reading system for lung cancer screening CT

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This research aims to support chest CT (computed tomography) medical checkups to decrease the death rate by lung cancer. We developed a remote cooperative reading system for lung cancer screening over the Internet, a secure transmitting function, and a cooperative reading environment. We carried out an experimental trial over the JGN (Japan Gigabit Network).

6145-06, Session 2

CMAS: a rich media annotation system for medical imaging

I. Lin, H. Chao, Hewlett Packard Co.

A system called (CMAS, collaborative medical annotation system) was developed to annotate medical records, such as medical images or procedure videos, with rich media. With the advancement in medical imaging, medical procedure and image guided surgery, it becomes more important to accurately capture as much diagnostic information as possible and integrate it as part of the medical record. This technology also allows the opinions of remote distributed specialists to be incorporated within the context of the course of the medical care.

The key technology in the CMAS system is the authoring environment that intuitively captures physical annotation of displayed digital images/video while recording the synchronized audio. Physical annotation can be as simple as a laser pointer spot to full-motion overlaid video from HP's Active Shadows algorithm (http://www.hpl.hp.com/research/isl/activeshadows/). The resulting medical record not only captures facts and measurements of the patient diagnostic result through time, but also the development of the diagnostic medical opinion, explained through presence of the doctor and the movement of a marking device.

We will demonstrate the system by annotating 1) CT images by a doctor pointing out its abnormalities, and 2) a medical procedure video, e.g. interventional surgery, colonoscopy, dermatology exam, etc.

This annotation from CMAS can be provided as metadata or a link to metadata in a secure authorized database. The system allows multiple annotations from different sources and at different time points, while maintaining a historical context and consistent referencing of the images and video.

6145-07, Session 2

Defining and evaluating custom 2D, 3D, and advanced imaging digital display protocols

W. W. Boonn, Univ. of Pennsylvania; K. M. Siddiqui, Veterans Affairs Medical Ctr.; P. Vandermeer, Univ. of Maryland Medical System; J. Whipple, S. Severance, Veterans Affairs Medical Ctr.; N. Safdar, Univ. of Maryland Medical System; B. I. Reiner, E. L. Siegel, Veterans Affairs Medical Ctr.

Digital display protocols (DDPs) promise to reduce the radiologist's workload by automatically "hanging" images in the desired order and configuration at the moment the study is accessed. However, wide variabilities in the ways in which images are acquired, as well as poorly defined and elaborated DDPs, can actually increase the workload and, in some cases, create the opportunity for misidentification or misreads. Building on previous work showing that properly implemented DDPs can improve productivity, this exhibit will outline a systematic process for defining and evaluating DDPs in a heterogeneous environment of 2- and 3D images with advanced image processing applications. Information about initial reader testing will be included with sample DDP formats, as well as information on how this approach can be customized in the practice setting. Special challenges of creating and customizing protocols in the 3D interpretation environment will be addressed.

6145-08, Session 2

On-demand rendering of an oblique slice through 3D volumetric data using JPEG2000 client-server framework

R. L. Joshi, Eastman Kodak Co.

In medical imaging, the popularity of image capture modalities such as multislice CT and MRI is resulting in an exponential increase in the amount of volumetric data that needs to be archived and transmitted. At the same time, the increased data is taxing the interpretation capabilities of radiologists. One of the workflow strategies recommended for radiologists to overcome the data overload is the use of volumetric navigation. This allows the radiologist to seek a series of oblique slices through the data. However, it might be inconvenient for a radiologist to wait until all the slices are transferred from the PACS server to a client, such as a diagnostic workstation.

To overcome this problem, we propose a client-server architecture based on JPEG2000 and the JPEG2000 Interactive Protocol (JPIP) for rendering oblique slices through 3-D volumetric data stored remotely at a server. The client uses the JPIP protocol for obtaining JPEG2000 compressed data from the server on an as needed basis. In JPEG2000, the image pixels are wavelet-transformed and the wavelet coefficients are grouped into precincts. Based on the positioning of the oblique slice, compressed data from only certain precincts is needed to render the slice. The client communicates this information to the server so that the server can transmit only relevant compressed data. We also discuss the use of caching on the client side for further reduction in bandwidth requirements. Finally, we present simulation results to quantify the bandwidth savings for rendering a series of oblique slices.

6145-09, Session 3

PACS in surgery: developments towards a surgical DICOM

H. Lemke, Technische Univ. Berlin (Germany)

No abstract available

6145-10, Session 3

Structured recording of intraoperative surgical workflows

T. Neumuth, N. Durstewitz, M. Fischer, G. Strauss, A. Dietz, Univ. Leipzig (Germany); P. Jannin, Univ. de Rennes I (France); K. R. Cleary, Georgetown Univ.; H. Lemke, O. Burgert, Univ. Leipzig (Germany)

The formalized description of surgical procedures offers the possibility to analyze and evaluate surgical procedures in detail. Establishing systems which support the surgical workflow in operating rooms requires a multistaged development process beginning with the description of surgical workflows. To obtain reliable data for carrying out research on workflows of surgical interventions, it is important to find a way to describe and analyze the steps that comprise a surgical procedure.

This approach describes data structures and technologies for workflow data acquisition and processing. A workflow editor has been developed to support the recording person in dealing with the complex relations and concurrencies during the recording of a surgical intervention. The key concerns are how to handle the flood of data under clinical conditions and how to provide a methodical processing of the information. The result of the editor-based recording process is a structured description of the intervention in XML format, which is used for automatic generation of 2D-visualisation and storage in a workflow database. The editor was used to record data in different surgical disciplines. The proposed strategy allows easy data collection of very fine grained intraoperative surgical workflows. It can be easily adapted to different surgical disciplines by changing the underlying ontology.

6145-11, Session 3

Workflow in interventional radiology: nerve blocks and facet blocks

D. R. Siddoway, K. R. Cleary, Georgetown Univ.; O. Burgert, T. Neumuth, Univ. Leipzig (Germany); V. Watson, Georgetown Univ.

Workflow management has the potential to dramatically improve the efficiency and clinical outcomes of medical procedures. In this study, we

recorded the workflow for nerve block and facet block procedures in the interventional radiology suite at Georgetown University Hospital in Washington, DC, USA. We employed a custom client / server software architecture developed by the Innovation Center for Computer Assisted Surgery (ICCAS) at the University of Leipzig, Germany. This software runs in an internet browser, and allows the user to record the actions taken by the physician during a procedure. The data recorded during the procedure is stored as an XML document, which can then be further processed. We have successfully gathered data on a number of cases using a tablet PC, and these preliminary results show the feasibility of using this software in an interventional radiology setting. We are rapidly accruing additional cases and when more data has been collected we will analyze the workflow of these procedures to look for inefficiencies and potential improvements.

6145-12, Session 3

An ultrasound image-guided surgical workflow model

B. Guo, Univ. of Southern California; H. Lemke, Technische Univ. Berlin (Germany); B. J. Liu, H. K. Huang, E. G. Grant, Univ. of Southern California

In order to find out the inefficient and redundant processes, scattered data in clinical systems, and to improve the overall quality of Ultrasound Image-Guided surgical procedures to the patient, we have implemented and evaluated an ultrasound (US) image-guided surgical workflow (IG SWF) model based on the current baseline workflow within the Imaging Department of an outpatient facility. This paper describes the methodology for development and implementation of a US IG SWF model. First, we identified six major components in the SWF modeling: real-world workflow data collection, modeling, presentation of the SWF model, analysis, implementation, and validation and evaluation. With these components, a workflow study was first performed on a specific image-guided US surgical procedure. The US IG Liver Biopsy procedure in the Ultrasound procedure room at an outpatient facility was chosen as the first workflow study observation. Based on the workflow, twenty-four workflow steps including readying the patient, preparing tools, and performing the procedure, were identified and researched. Finally, a new US IG SWF model was developed and implemented successfully at HCCII, USC specifically for the US image-guided liver biopsy procedure. The inefficient and redundant processes were addressed and a better understanding was obtained on how the operational processes can be performed efficiently in the future.

6145-13, Session 4

Medical compliance

P. Kevill, Applied Micro Circuits Corp.

Government regulations from the Health Insurance Portability and Accountability Act (HIPAA) have drastically changed storage requirements in the medical industry causing an incredible surge in the demand for new, affordable network storage infrastructures.

Compliant data has three characteristics that are driving the significant demand, (1) data must be retained for longer periods of time, (2) it must be readily accessible, and (3) it must be capable of being accessed by a number of sources.

The compliance issue is at the heart of the new rules and needs in the medical field. The easiest way to think about these issues is to understand that the technologies used in the last century are being phased out (film, paper, etc.) at our government's insistence. Everything is to be stored electronically by mid 2007, from MRIs to medical charts.

With the overwhelming amount of files to be digitized, reliable storage, high read speeds, and capacity in the Terabytes is required to provide anytime access to all patient records anywhere, anytime.

The goal is to use the Internet to get medical records into the hands of doctors who need it anywhere in the world a patient may be. However, storage now becomes an issue for hospitals and other medical institutions. Compression is not allowed under HIPAA, so all data must be kept at its original size, as predictions about the compression software are an uneven concern when discussing worldwide implications.

SATA technology can simplify this significantly because disk-based technology offers all the benefits ideal for building scalable storage solutions including low cost per MB, high speed for archival and retrieval; reliability for maintaining fail-safe libraries; and hot swap features.

6145-14, Session 4

Peer-to-peer architecture for multidepartmental distributed PACS

A. Rosset, O. M. Ratib, J. Heuberger, Univ. Hospital of Geneva (Switzerland)

We have elected to explore peer-to-peer technology as an alternative to centralized PACS architecture for the increasing requirements for wide access to images inside and outside a radiology. The goal being to allow users across the enterprise to access any study anytime without the need for prefetching or routing of images from central archive. Images can be accessed between different workstations and local storage nodes.

We implemented "bonjour" a new remote file access technology developed by Apple allowing applications to share data and files remotely with optimized data access and data transfer. Our Open-source image display platform called OsiriX was adapted to allow sharing of local DICOM images through direct access of each local SQL database to be accessible from any other OsiriX workstation over the network. A server version of Osirix Core Data database also allows to access distributed archives servers in the same way.

The infrastructure implemented allows fast and efficient access to any image anywhere anytime independently from the actual physical location of the data. It also allows benefiting from the performance of distributed low-cost and high capacity storage servers that can provide efficient caching of PACS data that was found to be 10 to 20 x faster that accessing the same date from the central PACS archive. It is particularly suitable for large hospitals and academic environments where clinical conferences, interdisciplinary discussions and successive sessions of image processing are often part of complex workflow or patient management and decision making.

6145-16, Session 4

A demanding Web-based PACS supported by web services technology

C. M. Costa, J. L. Oliveira, A. M. Silva, Univ. de Aveiro (Portugal); V. G. Ribeiro, J. Ribeiro, Ctr. Hospitalar de Vila Nova de Gaia (Portugal)

In the last decade, the commerce-driven World Wide Web (WWW) pushed practically all PACS suppliers to develop client applications where clinical practitioners can send or receive images using conventional personal computers and Web browsers. However, the use of these software packages has been restricted to Intranets. Paradigmatically, one of the most important advantages of digital image systems is to allow widespread sharing and remote access of medical data between healthcare institutions. This paper will analyse the traditional PACS drawbacks that contribute to their reduced usage in the Internet and describe the development, deployment and results of a Web-enabled PACS. We propose a PACS solution based on web services technology that supports a customized DICOM encoding syntax and compression scheme in a critical Cardiology medical image scenario. The wide and secure users' access, associated to the availability of all historical patient data in a unique Web interface is a very important achievement to practitioners and to patients. Currently we have permanently available 15000 procedures at a "single mouse click". Good trade-off between compression ratio and diagnostic quality, low network traffic load, backup facilities and data portability are other achievements of this proposal. The above PACS characteristics make

it particularly important in telemedicine communication scenarios with low network bandwidth and/or reduced communications budget. Moreover, the Himage development was the core element that allows us to implement a fully digital Echocardiography Laboratory.

6145-17, Session 4

A design methodology for fault-tolerance in a DICOM-compliant data storage grid

J. R. Documet, Z. Zhou, B. J. Liu, N. King, H. K. Huang, Univ. of Southern California

With the increasing demand of PAC systems, more and more examinations are acquired by medical institutions which results in an enormous amount of image data and metadata information that needs to be archived and retrievable especially during recovery from disasters. Last year we presented a Data Storage Grid (DSG) architecture based on the five-layer architecture design for Grid technology that provides a 99.999% up time. The proposed solution was implemented as a testbed with a set of three federated PACS and it was developed using the Globus 3.2 Toolkit. A grid architecture built on Globus middleware achieves reliability and availability through the distribution of hardware components and services. However, a DICOM-compliant DSG requires a Metadata Catalog to make DICOM header information available to the DSG clients. For this reason, this paper describes the continued development of the DSG utilizing DICOM and IHE standards and the strategy for providing grid Fault-Tolerance and also the development of a fault-tolerant Metadata Catalog for a DICOM complaint data grid environment.

6145-18, Session 4

Medical image compression using cubic spline interpolation for low bit-rate telemedicine applications

S. Chen, Shu-Te Univ. (Taiwan); T. Truong, I-Shou Univ. (Taiwan)

In this paper, a new medical image compression algorithm using cubic spline interpolation (CSI) is presented for telemedicine applications. The CSI is developed in order to subsample image data with minimal distortion and to achieve compression. It has been shown in literatures that the CSI can be combined with the JPEG/JPEG2000 algorithms to develop a modified JPEG/JPEG2000 codec, which obtains a higher compression ratio and a better quality of reconstructed image than the standard JPEG/JPEG2000. Hence this paper further makes use of the modified JPEG/JPEG2000 codec to medical image compression. Experimental results show that the proposed scheme can increase 50~70% compression ratio of original JPEG/JPEG2000 medical data compression system with similar visual quality. This system can reduce the loading of telecommunication networks and is quite suitable for low bit-rate telemedicine applications.

6145-19, Session 5

The retrieval process in the SAFRS (Système d'Aide à la Formation des Radiologues-Sénologues) system with the case-based reasoning approach

S. Demigha, Univ. Paris 1 Panthéon Sorbonne (France)

The paper presents the retrieval process in the SAFRS (Système d'Aide à la Formation des Radiologues-Sénologues i.e. system supporting the training of radiologists-senologists) system with the case-based reasoning (CBR) approach (the CBR approach is adopted to represent the experience of expert radiologists-senologists as cases) and modelized with the MAP concept. Retrieval process relies on a procedure of case-based reasoning for retrieval of similar cases formalized using a MAP, a re-use methodology named: the retrieval MAP. The model of the MAP is an intentional representation system. It is based on concepts of intention and strategy. The concept of intention (or a goal) aims to capture the objective to be achieved. A strategy is the manner to achieve an intention.

The retrieval process with the MAP is a multi-step/multi-algorithm process, which permits to retrieve similar cases in various modes and strategies. It is achieved according to 3 complex strategies: global strategy (or global retrieval strategy), elementary strategy (or elementary retrieval strategy) and mixed strategy (or the mixed retrieval strategy). We start this work by introducing the architecture and working principles of the system, we describe briefly the case representation model, we describe in details the retrieval process model. Finally, the paper ends with our conclusions and future plans.

6145-20, Session 5

Atlas of protein expression: image capture, analysis and design of terabyte image database

J. Wu, G. Maslen, A. Warford, J. Xie, G. Griffin, S. Crowther, J. McCafferty, Wellcome Trust Sanger Institute (United Kingdom)

The activity of genes in health and disease are manifested through the proteins which they encode. Ultimately, proteins drive functional processes in cells and tissues and so by measuring individual protein levels, studying modifications and discovering their sites of action we will understand better their function. It is possible to visualise the location of proteins of interest in tissue sections using labelled antibodies which bind to the target protein. This procedure, known as immunohistochemistry (IHC), provides valuable information on the cellular and sub-cellular distribution of proteins in tissue.

The project, atlas of protein expression, aims to create a quality, information rich database of protein expression profiles, which is accessible to the world-wide research community. For the long term archival value of the data, the accompanying validated antibody and protein clones will potentially have great research, diagnostic and possibly therapeutic potential.

To achieve this we had introduced a number of novel technologies, e.g. express recombinant proteins, select antibodies, stain proteins present in tissue section, and tissue microarray image analysis. These are currently being optimised, automated and integrated into a multi-disciplinary production process. We had also created infrastructure for multi-terabyte scale image capture, established an image analysis capability for initial screening and quantisation.

6145-21, Session 5

Relevance feedback for shape-based pathology in spine x-ray image retrieval

X. Xu, Brigham Young Univ.; S. K. Antani, National Library of Medicine; D. Lee, Brigham Young Univ.; L. R. Long, G. R. Thoma, National Library of Medicine

Relevance feedback (RF) has become an active research area in Content-based Image Retrieval (CBIR). RF attempts to bridge the gap between low-level image features and high-level human visual perception by analyzing and employing user feedback in an effort to refine the retrieval results to better reflect the individual user's preference. Need for overcoming this gap is more evident in medical image retrieval due to commonly found characteristics in medical images, viz., (1) images belonging to different pathological categories exhibit subtle differences, and (2) subjective nature of images often elicit different opinions, even among experts. The National Library of Medicine maintains a collection of digitized spine X-rays from the second National Health and Nutrition Examination Survey (NHANES II). A pathology found to be frequently exhibited in these images is the Anterior Osteophyte (AO), which is of interest to researchers in bone morphometry and osteoarthritis. Since this pathology is exhibited as deviation in shape, we have proposed the use of partial shape matching (PSM) methods for pathology-specific spinal X-ray image retrieval. Shape matching tends to suffer from the variability in the

pathology expressed by the vertebral shape. This paper describes a novel weight-updating approach to RF. The algorithm was tested and evaluated on a subset of data selected from the image collection. The ground truth was established using Macnab's classification to determine pathology type and a grading system developed by us to express the pathology severity. Experimental results show over 20% overall improvement on retrieving the correct pathological category.

6145-22, Session 5

BIRAM: a content-based image retrieval framework for medical images

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In the medical field, digital images are becoming more and more important for diagnostics and therapy of the patients. At the same time the development of new technologies has increased the amount of image data produced in a hospital. This creates a demand for access methods that offer more than text-based queries for retrieval of the information. The Content Based Image Retrieval (CBIR) systems allow the retrieval of images by the use of intrinsic characteristics of the image using a similarity criterion. In this paper is proposed a framework for the retrieval of medical images that allows the use of several algorithms for the search for similarity of medical images. The framework also enables the search for textual information from an associated medical report and DICOM header information. The proposed system can be used for support of clinical decision making and is intended to be integrated with an open source picture, archiving and communication systems (PACS). The BIRAM has the following advantages: (i) Can receive several types of algorithms for image similarity search; (ii) Allows the codification of the report according to a medical dictionary, improving the indexing of the information and retrieval; (iii) The algorithms can be selectively applied to images with the appropriated characteristics, for instance, only in magnetic resonance images. The framework was implemented in Java language using a MS Access database. The proposed framework can still be improved, by the use of regions of interest (ROI), indexing with slim-trees and integration with a PACS Server.

6145-54, Session 5

Automated dual-energy x-ray absorptiometry (DEXA) bone densitometry reporting solution for Hologic(r) scanners

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PURPOSE: DEXA bone densitometry is an established standard for measuring bone mineral density (BMD). Despite availability of various report generating software from the manufacturers, generation of reports remains a very time consuming process for those who use a speech-recognition dictation system. This is due to the typical tabular report format the commercial report generating software utilizes, which does not translate properly to text-only radiology information systems (RIS). The aim of this project was to develop a process that would automate much of DEXA bone densitometry reporting and generate reports suitable for text-only RIS.

BACKGROUND: Though DICOM Structured Reporting (DICOM SR) is becoming available from some imaging equipment, its incorporation into radiology information, dictation, and speech recognition systems lags behind. Though there are proposed DICOM and Integrating the Healthcare Enterprise (IHE) solutions, these have not yet found wide adoption. In the interim, the reports generated by imaging and other equipment are frequently transcribed by the radiologist into information systems so as to make the results of patient studies available to healthcare providers. This transcription process is error-prone and slow compared with what could be achieved if an electronic interface were available.

METHODS: The initial report is generated using Hologic(r)'s report generating software with a modified template. This report is subsequently reformatted using customized software and is then transferred over to voice recognition dictation system.

RESULTS: The automation process eliminates the factor of human error in data entry and decreases report generation time from typical 2 to 3 minutes per report to less than 10 seconds per report. With an average of 7 reports per day, the physician can spend 61 to 91 hours a year alone on report generation for this one examination type. Automation of the reporting procedure can reduce this to approximately 5 hours.

CONCLUSION: An automated DEXA bone densitometry report generation solution, developed for Hologic(r) scanners, increases productivity by reducing report generating time and reducing data entry error. The principles used in developing this software could potentially be used for translation between other systems that generate reports and speech recognition or structured reporting systems until DICOM and IHE solutions are more widely available.

6145-24, Session 6

An ontology supporting daily practice requirements of radiologists-senologists with the standard BI-RADS

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This paper presents concepts and relationships allowing the development of an ontology which supports daily practice requirements of radiologists-senologists with the standard BI-RADS (Breast Imaging Reporting and Data System). This ontology aims to describe radiologic-senologic knowledge which is shared between the community of technicians, practitioners, gynecologists, radiologists, surgeons and anatomo-pathologists. It represents an unifying scope for reducing and eliminating ambiguities and conceptual and terminological confusions and insures the understanding by the concerned community. It allows communication and dialogue between members of the community even if they are working on different contexts with different requirements and point of views. This ontology allowed us to obtain the domain conceptual model of radiology-senology. Details concerning the development of the ontology and the generalization of the conceptual scheme which leads to the design of the conceptual model are de-scribed.

6145-25, Session 6

Building an IT Healthcare Enterprise by taking the standards to the limits and sometimes beyond that

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Background: The regional management of "Vastra Gotalandsregionen, VGR"made a descion to start a project to make 17 x-ray department in the region to become as one "virtually" digital department, meeting the needs and demands from the patients. The project were called "DRW" Distributed Radiology Workflow. The aim of the project was to prepare a health infrastructure for the region, starting with radiology.

Main Mission: The project tries to achieve an IT Healthcare Enterprise based on the IHE approach. The producers of the healthcare information stored in the central archive are forced to follow the information model, created by the region, based on the worldwide standards data models DICOM and HL7. The DICOM Object hereby created by the producers is then stored as DICOM objects in the central archive, accessible with a DICOM-Viewer.

This viewer makes it possible for the Healthcare-environment to access all patient information stored. This could create a good transparency against the radiology information and open the possibilities for other specialities to access the information easily. Healthcare professional needs to collaborate accurately and better than today, the information sharing between professions is fundamental to determine the right treatment/ diagnosis for the patient.

To ensure that radiological information can participate in a sophisticated healthcare workflow we have developed an XML-framework based on XDS to ensure that we have a good integration of DICOM objects into web-based applications. DICOM- objects other than images for example waveforms and text are stored as SR-objects to more efficiently meet the IHE integration profiles.

6145-26, Session 6

A unified approach for the adequate visualization of structured medical reports

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DICOM Structured Reporting (SR) allows to exchange structured data and coded information in a standardized way. Although SR documents cannot be viewed directly, the DICOM standard does not specify how an application should render them. As a consequence, the interoperability of SR documents which are intended to be displayed to a medical user is restricted to those structures that are known to the visualizing application. In order to avoid this limitation, we have developed a unified process for the adequate visualization of arbitrary structured medical reports. The basic idea of this new approach is to map well-known sub-structures of the document tree (e. g. templates) to appropriate display components. For this purpose, the generic processing part is strictly separated from an extensible knowledge base which includes a machine readable description of the template structures and display components. During our work we found out that the template detection is a crucial part of the whole visualization process. On the one hand, the existing template identification method in the DICOM standard covers only a limited number of cases. On the other hand, the complexity and dynamic structure of SR templates make the detection difficult or even impossible in certain cases. Therefore, we propose to enhance this identification method and revise the corresponding part of the standard. In conclusion, we hope that the presented approach will assist vendors in developing general purpose reporting workstations and thereby promote the use of DICOM Structured Reporting.

6145-27, Session 6

IHE cross-enterprise document sharing for imaging: design challenges

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Integrating the Healthcare Enterprise (IHE) has recently published a new integration profile for sharing documents between multiple enterprises. The Cross-Enterprise Document Sharing Integration Profile (XDS) lays the basic framework for deploying regional and national Electronic Health Record (EHR). This profile proposes an architecture based on a central Registry that holds metadata information describing published Documents that reside in one or multiple Documents Repositories.

As medical images constitute important information of the patient health record, it is logical to extend the XDS Integration Profile to include images. However, including images in the EHR presents many challenges. The complete image set is very large; it is useful for radiologists and other specialists such as surgeons and orthopedists. The imaging report, on the other hand, is widely needed and its broad accessibility is vital for achieving optimal patient care. Moreover, a subset of relevant images may also be of wide interest along with the report.

Therefore, IHE recently published a new integration profile for sharing images and imaging reports between multiple enterprises. This new profile, the Cross-Enterprise Document Sharing for Imaging (XDS-I), is based in the XDS architecture.

The XDS-I integration solution that is published as part of the IHE Technical Framework is the result of an extensive investigation effort of several design solutions. This paper presents and discusses the design challenges and the rationales behind the design decisions of the IHE XDS-I Integration Profile, for a better understanding and appreciation of the final published solution.

6145-28, Session 6

Three-dimensional lossless digital signature embedding for the integrity of volumetric images

Z. Zhou, H. K. Huang, B. J. Liu, Univ. of Southern California

Our previous study presented a lossless digital signature embedding (LDSE) method for assuring the integrity of 2D medical images in network transit or during archival. With the advent of multi-detector CT scanners and volume acquisition technologies, a PACS exam can now potentially generate hundreds, even thousands, of images. To perform the 2D LDSE method on each individual image in the volume would be extremely time consuming and inefficient. For this reason, a novel 3D LDSE method has been investigated for 3D image volumes. The method begins with generating a single digital signature (DS) of the entire volume. Embedding of the DS is performed first by identifying a bit stream from the image volume based on the correlation of 3D pixel values. The bit stream is compressed using lossless compression methods and the DS is concatenated with the compressed bit stream. This concatenated bit stream is then embedded within the image volume. During the verification process, the embedded bit stream is extracted and utilized to recover the original bit stream and the original DS. The original bit stream can be used to restore the image volume which in turn can be used in the verification of the DS. In addition, to 3D LDSE embedding methodology for image volumes, a new procedure is developed to address clinical workflow for 3D image volumes. Experimental results demonstrated that the 3D LDSE method can assure the integrity of 3D image volume efficiently and effectively; and a 3D clinical image workflow procedure was demonstrated.

6145-29, Session 6

A DICOM-RT ePR radiation therapy information system for managing brain tumor patients

B. J. Liu, M. Y. Law, H. K. Huang, C. Zee, L. W. Chan, Univ. of Southern California

The need for comprehensive clinical image data and relevant information in image-guided Radiation Therapy (RT) is becoming steadily apparent. However, the disparate and complex data is scattered throughout the RT department compromising an efficient clinical workflow since the data crucial for a clinical decision may be time-consuming to retrieve, temporarily missing, or even lost. In the past, the research focus of an RT department has primarily been developing new protocols and devices to improve treatment process and outcomes of cancer patients with minimal effort dedicated to integration of imaging and information systems. Our research, tightly-coupling radiology and RT information systems and the DICOM standard, represents a new frontier for medical informatics research that has never been previously considered. We propose to test our hypothesis using a brain tumor case model that an integrated DICOM-RT based electronic patient record (ePR) system can improve clinical workflow efficiency for treatment and management of patients. This DICOM-RT based ePR system integrated with clinical images and RT data can impact the RT department in a similar fashion as PACS (Picture Archival and Communication System) has already successfully done for Radiology. As a first step, the specific treatment case of patients with brain tumors treated by the Cyberknife and Gamma Knife RT systems will be the initial proof of concept for the research design, implementation, evaluation, and clinical relevance.

6145-23, Poster Session

Content-based medical image retrieval in picture archiving and communication systems

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Traditionally, Picture Archiving and Communication Systems (PACS) use textual-based retrieval, which have their limitations. General-purposed content-based image retrieval (CBIR) systems often do not perform well

in medical images and are not integrated with PACS and Radiology Information System (RIS). In this presentation we propose a CBIR system that is integrated with PACS and RIS, so that given a user-supplied query image, similar images are returned from PACS and corresponding reports can also be obtained from RIS. We also employ ACR index for radiological diagnosis to reduce the search space and to provide meaningful result. We use HRCT lung images as the data. A key image is selected for each series, and after a radiologist delineates the pathology bearing region, local texture features as well as ACR indexes and series UID are stored in a CBIR server. Series UID can be used to retrieve images from PACS and to obtain corresponding reports from RIS. The system is a useful learning tool for radiology education and can provide valuable reference for radiologists when a new case comes.

6145-42, Poster Session

The impact of lossless image compression to radiographs

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The increasing number of digital imaging modalities results in data volumes of several Tera Bytes per year that must be transferred and archived in a common-sized hospital. Hence, data compression is an important issue for picture archiving and communication systems (PACS). The effect of lossy image compression is frequently analyzed with respect to images from a certain modality supporting a certain diagnosis. However, novel compression schemes have been developed recently allowing efficient but lossless compression. In this study, we compare the lossless compression schemes embedded in the tagged image file format (TIFF), graphics interchange format (GIF), and joint photographic experts group (JPEG 2000 II) with the Borrows-Wheeler Compression Algorithm (BWCA) with respect to image content and origin. Repeated measures ANOVA was based on 1.200 images in total. Statistically significant effects ($p < 0{,}0001$) of compression scheme, image content, and image origin were found. Best mean compression factor of 3.5 (2.272 bpp) is obtained applying BTW to secondarily digitized radiographs of the head, while the lowest factor of 1,05 (7.587 bpp) resulted from the TIFF packbits algorithm applied to pelvis images captured digitally. Over all, the BWCA is slightly but significantly more effective than JPEG 2000. Both compression schemes reduce the required bits per pixel (bpp) below 3. Also, secondarily digitized images are more compressible than the directly digital ones. Interestingly, JPEG outperforms BWCA for directly digital images regardless of image content, while BWCA performs better than JPEG on secondarily digitized radiographs. In conclusion, efficient lossless image compression schemes are available for PACS.

6145-43, Poster Session

Development of mobile emergency patient information and imaging communication system for emergency diagnosis based on CDMA-1X EVDO

K. H. Yang, W. Kang, B. M. Jang, J. I. Kim, D. H. Han, H. Jung, S. Yoo, H. Yoo, H. Kim, Yonsei Univ. (South Korea)

The high bit rate wireless mobile service using CDMA-1X EVDO is now popular in Korea. Also mobile device is increasingly being used as the conventional communication mechanism. In this paper, we developed the web based mobile system that communicates emergency patient information and patient image using CDMA-1X EVDO for prompt emergency diagnosis. This system allows a fast access to emergency patient information management database system storing both emergency medical images and patient medical information inside hospital anytime and anywhere for moving outside the hospital. Especially, images were compressed into JPEG2000 format and transmitted from mobile web PACS system inside hospital to radiological specialist using Pocket PC located outside the hospital. All of those images were progressively transmitted to Pocket PC and displayed on the web browser of Pocket PC. Also radiological specialists located outside the hospital can enquiry specific emergency patient information for more exact emergency diagnosis. It may be a useful system when radiological specialist is located outside hospital.

6145-44, Poster Session

Applying XDS for sharing CDA-based medical records

J. I. Kim, B. M. Jang, D. H. Han, K. H. Yang, W. Kang, H. Jung, H. Kim, Yonsei Univ. (South Korea)

Many countries have set the long-term objective of establishing an Electronic Health Records (EHRs). And different IT Strategies note that integration between EHRs systems has a high priority. Because of the EHRs systems are based on different information models and different technology platforms. One of the key integration problems in the realization of the EHRs for the patients' continuity of care is the inability to share patient records across enterprise. Integrating the Healthcare Enterprise (IHE) committee has defined the detailed implementations of existing standards such as DICOM, HL7, in a publicly available document called the IHE technical framework (IHE-TF). Cross-enterprise document sharing (XDS), one of IHE technical frameworks, is describing how to apply the standards into the information systems for sharing of medical documents among hospitals. The paper aims to make CDA schema based on HL7, it is selected a discharge abstract that is common one of medical records used in hospitals, and to apply implementation strategies of XDS, it transmit this CDA schema.

6145-45, Poster Session

The application of multilayer tree structure in DICOM

M. Pan, Shanghai Jiao Tong Univ. (China); Z. Yao, Ruijin Hospital (China)

In order to enhance the sharing of DICOM, we have proposed to introduce XML into DICOM data dictionary and file (SPIE2005 5748-57), which can extend the readability and the expansibility of DICOM files. In our research, we will improve the data structure of DICOM on the basis of the idea we proposed. We change the one-dimension array into the multilayer tree structure and change the original DICOM dictionary which consists of numerical code into the structured data dictionary according to the technique of XML. All of the elements are in the special modules. The idea of modulization promotes the searching efficiency and reduces the data redundancy. Data conversion replaces DICOM numerical code with character string tag containing explicit meaning. These information are also formed as multilayer tree structure according to their modules and they are kept as this structure in storage, transmission and display. After being added and translated, the private data (such as diagnose report) will be linked directly as a new child-node to the root-node so that the information are available without any special data dictionary. In this way, we can extend the capacity of data elements, integrate data from different sources and enlarge the scope of data sharing in DICOM.

6145-46, Poster Session

Development of patient collation system by kinetic analysis in chest dynamic radiogram with flat panel detector

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The purpose of this study was to develop the automatic patient collation system by the kinetic analysis in the dynamic radiogram examination. The two sets of dynamic chest radiographs (1344x1344matrix, 12bit, 3fps, 10sec) of eight healthy volunteers (22~54 year, male) during respiration were obtained by using a modified FPD system (CXDI-40G, CANON Co.,

Ltd., Tokyo, Japan). The dynamic radiographs were converted into the color static image by the new algorithm that we had been developed. This algorithm (kinetic map algorithm) is a technique for making kinetic information visible. The optical flow of the local area that was kinetic information was detected from all images, they were colored to RGB color by the direction classification, and density was calculated by the intensity transformation. The static image made by our technique was defined as the "kinetic map". From the result of a prior experiment that used I.I., uniqueness and reproducibility were discovered as a character of the kinetic map made from the same person. The similarity of same person's map was statistics significant high ($P<0.01$). After the Afain transformation for the adjustment of the position and the morphological change by time, ANN and the distinction analysis equation constructed by I.I. data set judged the correlation coefficient, the Euclid distance, and the Mahalanobis distance. The distinction performance of 120 patterns that were a combination of two maps in eight volunteers obtained 100% as sensitivity and specificity. Our system that has superior patient collation performance in the dynamic radiogram examination is effective to the risk management in PACS.

6145-47, Poster Session

Operation monitoring and security management in RIS-integrated PACS

J. Zhang, X. Chen, J. Jin, J. Sun, Y. Yang, C. Liang, Shanghai Institute of Technical Physics (China); H. K. Huang, Univ. of Southern California

RIS-integrated PACS (RIS-PACS) is a large system consisting of many components. Chances of any of these components fail at a given period of time are high. When it happens, immediate attention and service were required to resume PACS normal operation. Also, the HIPAA requires security services being implemented in healthcare information systems, and DIOCM Sup95 defines a mechanism to collect the Auditing Trail Messages generated by applications to facilitate detection of improper creation, access, modification and deletion of Protected Health Information. For this reason, we present an HIPAA compliant automatic monitoring system (HC-AMS) with a novel architecture to monitor RIS-PACS operation. The HC-AMS consists of two parts: monitoring agents running in each PACS/RIS component and a Monitor Server running in a Web server. Monitoring agents connect to all services in each PACS component. The Monitor Server monitors each agent tracking the status and data flows of individual component, and verifies image data and reports being used in accordance with the healthcare provider's data security requirements. We have installed the HC-AMS in an existing RIS-PACS in a 800 bed hospital. The PACS manager using Web browser can monitor the entire RIS-PACS operation from anywhere.

6145-48, Poster Session

Interactive radiological education file system integrated with PACS

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Radiological images, more specifically CT and MRI, are prevailing throughout most clinical practice and being important tools for better understanding of normal and abnormal cross-sectional anatomy. Since PACS has been introduced and implemented in 2000, a lot of radiological images are filed for the medical education. Easy and convenient on-line accessibility of PACS integrated with RIS or HIS makes those medical images more flexible to follow up during daily practice and to be materialized for building educational files. One of the most advantage of this interactive education file system is its versatility simply because of this system is integrated with PACS. We will present our interactive radiological education file system integrated with PACS. The contents of this exhibition will contain; 1) the concept of our education file system, 2) the methods of follow-up cases and building-up files, 3) the diversity of educational materials integrated with PACS, 4) the user interface in reviewing files interactively, 5) future perspectives of interactive radiological education file system in conjunction with a variety of other medical education system or computer aided diagnosis, and 6) the design of system architecture.

6145-49, Poster Session

Sharing medical images: a proposal of a reference image database

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Due to increasing number of digital images used in medical diagnosis, the image processing and analysis are becoming essential for many tasks in Medicine. Reliable evaluation of medical image processing methods is of major importance for routine applications and essential for unfolding the potential benefits. One of the great obstacles within the field of medical image processing is the lack of reference image datasets freely available for groups and/or individual users, in order to evaluate their new methods and applications. In order to improve this situation, this work presents the development of a framework to make available a free, online, multipurpose and multimodality medical image database for software and algorithm evaluation. The project is implemented as a distributed architecture for medical image database including a publishing workflow, authoring tools, and role-based access control. Our effort aims to offer a testbed and a set of resources including software, links to scientific papers, gold standards, reference and post-processed images, enabling the medical image processing community (scientists, physicians, students and industrials) to be more aware of evaluation issues. The proposed approach has been used as an electronic teaching system in Radiology as well.

6145-50, Poster Session

Automatic orientation correction for radiographs

H. Luo, J. Luo, Eastman Kodak Co.

In picture archiving and communications systems (PACS), images need to be displayed in

standardized ways for radiologists' interpretations. However, for most radiographs acquired by digitized films, computer radiography (CR), or digital radiography (DR), the image orientation is undetermined because of the variation of examination conditions and patient situations. To address this problem, an automatic orientation correction method is presented. It first detects the most indicative region for orientation in a radiograph, and then extracts a set of low-level visual features sensitive to rotation from the region. Based on these features, a trained classifier is employed to recognize the correct orientation of the radiographs for each body part and projection.

A large-scale experiment has been conducted on more than 10,000 radiographs covering a large variety of body parts and projections to validate the method. The overall performance is very promising, with the success rate of orientation correction reaching 95%. A workflow study on the method also demonstrates a significant improvement in efficiency for image display.

6145-51, Poster Session

Implementation of a fault-tolerant PACS over a grid architecture

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This paper describes the experience in the implementation of a fault-tolerant Picture Archiving and Communication System (PACS) over a data grid architecture. The system is centered on a DICOM image server with distributed storage and failover capability. Our grid infrastructure integrates, over long distance links (> 400 km), the two main public Hospitals in Sao Paulo and one University Hospital in Rio de Janeiro, Brazil. The architecture of the PACS image server can be divided into two functional modules: i) DICOM protocol handler; ii) Distributed storage of image data. The fault-tolerance capability is achieved by injecting redundancy into the modules. The DICOM protocol handler comprises a series of server processes hosted by different machines and a load-balancer node which distributes requests among the servers. The load balancer includes a backup node which is triggered in case of failure, thus assuring high availability. Distributed storage is managed by the Storage Resource Broker (SRB) developed at the University of California. Replication of image data in the three sites allows the PACS server to retrieve an image even when only a single site is available. The system features also include a Web-based interface and a Java DICOM image viewer. Security is assured by a role based authentication system. Presently, the DICOM image server has been deployed into the grid environment and is under evaluation to improve its performance, availability and security characteristics. The developed system is mostly based on open-source software components, thus providing a low cost solution for a fault-tolerant PACS architecture.

6145-52, Poster Session

Integration of lossless digital signature embedding (LDSE) and patient tracking logs with HIPAA compliant auditing system (HCAS)

Z. Zhou, B. J. Liu, H. K. Huang, B. Guo, J. Documet, N. King, Univ. of Southern California

The deadline of HIPAA Security Rules mandate has passed on February 2005; therefore being HIPAA compliant becomes extremely critical to healthcare providers. HIPAA mandates healthcare providers to protect the privacy and integrity of the health data and have the ability to demonstrate examples of mechanisms that can be used to accomplish this task. It is also required that a healthcare institution must be able to provide audit trails on image data access on demand for a specific patient. We have conducted research in several areas related to image data security assurance, including a HIPAA compliant auditing system (HCAS), lossless digital signature embedding (LDSE) methods, and a patient tracking system, in order to satisfy these requirements. Last year, we presented the development of the HCAS for auditing image data access activities in a PACS. The HCAS collects audit log data from the PACS components and stores the data in a centralized database, which is utilized for generating the audit trails. The LDSE method was developed for assuring medical image integrity, while the patient tracking system was developed to create a security zone in the clinical environment. These methods are all related to the integrity and privacy requirements within HIPAA Security Rules. In this paper, we present further integration of the HCAS with the logs collected from the various methods described previously. This system integration provides additional information of image data access in PACS for the HCAS and enables the HCAS to demonstrate how image integrity and privacy is protected in PACS.

6145-53, Poster Session

Rib shape recognition in lung x-ray images for intelligent assistance

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The purpose of this research is to develop a method for recognizing shapes of ribs in chest X-rays, which can be utilized as intelligent assistance to diagnosis to decrease false positives (FPs) due to ribs in chest CAD and automatically generate a schema in report.

(1) Rib Shape Model: Shapes of ribs are manually extracted from several CR images to create a rib shape model using Point Distribution Model (PDM), in which shapes of anterior/posterior ribs are represented as sets of coordinates and an arbitrary shape of a rib is expressed only with principle components that have a high contribution ratio to shape variation.

(2) Rib Shape Recognition Processing: Shapes of ribs in a chest X-ray image are identified as follows:

(a) Identify the lung field. (b) Find an allowable range of weights of principle components in the shape model within which the model aligns to an edge of the lung field (a). (c) Create several shape model images by applying different weights of principle components. (d) Apply a six-direction Gabor filter to the X-ray image and each one of the shape model images to create an image containing only rib elements. (e) From images created in (d), search for a shape model image that shows the highest correlation coefficient with the X-ray image.

We created a rib shape model using 110 training images, of which nine principle components accounted for more than 90% of contribution rate. These principle components were classifiable into two: those representing individual differences in rib characteristics (e.g. barrel-shaped or cone-shaped thoracic cage) and those representing differences in exposure conditions (e.g. size, front/back/left/right inclination, inclination toward right-forward or left-forward). We applied the rib shape model to 100 test images while changing weights of principle components. We were able to identify positions of ribs and anatomical rib numbers with an average margin of error being no more than two fifths of a rib and a half of a rib in case of anterior ribs.

6145-30, Session 7

A tracking and verification system implemented in a clinical environment for partial HIPAA compliance

B. Guo, J. R. Documet, B. J. Liu, N. King, R. Shrestha, K. Wang, H. K. Huang, Univ. of Southern California

In order to streamline the patient workflow, protect against erroneous examinations and create a security zone to prevent and audit unauthorized access to patient healthcare data under the HIPAA mandate, we have designed, developed, and implemented a novel system for tracking and verifying patients and staff in a clinical environment by integrating wireless tracking and facial biometrics technology. This paper describes the methodology for design, development and implementation of a Location Tracking and Verification System (LTVS) that has distinct benefits for the Imaging Department at the Healthcare Consultation Center II (HCCII), an outpatient imaging facility located on the USC Health Science Campus. First, a workflow study was performed to observe the physical locations of patients and clinical staff as well as procedure rooms and reading area within the Imaging Department at HCCII. Based on this workflow and user needs, a Graphical User Interface (GUI) was developed integrating both real-time locating system and the facial biometrics embedded within the application which allows users to extract precise real-time location and identity verification information. The system was implemented in key areas of HCCII where identity verification was necessary according to the workflow study. Finally, the LTVS was implemented within the clinical environment of HCCII and initial results and experiences will be discussed including overall clinical workflow efficiency improvements within

the Imaging Department. In conclusion, the LTVS serves as a potential solution for improving the overall clinical workflow efficiency of an Imaging Department as well as management of policies and procedures in a clinical environment in order to partially fulfill HIPAA requirements for data security.

6145-31, Session 7

Implementation and integration experiences of a tracking and verification system in a clinical imaging environment

B. J. Liu, J. Lee, K. Ma, V. Nguyen, J. R. Documet, B. Guo, Univ. of Southern California

HIPAA Security Standards mandate health institutions to protect health information against unauthorized use or disclosure. However, in a clinical environment, the challenge of protecting access to clinical information is made even more difficult when it is a fully digital environment with multiple access points throughout the department. In addition, it is also important that patients are both identified as well as tracked in order to prevent mis-identification prior to examination and abnormally long wait times. By implementing a tracking and verification system, clinical facilities can effectively monitor workflow and heighten information security in today's growing demand towards digital imaging informatics. This paper presents the implementation and integration experiences encountered during the development a Location Tracking and Verification System (LTVS) and its implementation in a clinical environment. LTVS is the integration of facial biometrics with wireless tracking to locate and verify patients and staff within a clinical environment. Integration and implementation challenges fall into three areas: 1) Implementing and refining a wireless tracking system tailored to the needs of clinical management, 2) Acquiring and verifying real-time face images in a clinical environment, and 3) Integration of both systems as well as integration with existing clinical information systems (e.g. RIS, PACS). An initial prototype LTVS has been implemented and evaluated within the HCC2 (Healthcare Consultation Center 2) Outpatient Facility, USC which currently has a fully digital imaging department environment with integrated HIS/RIS/PACS/ VR. Results of the evaluation as well as the experiences of the three main challenges are discussed and presented.

6145-32, Session 7

Grid-based medical image workflow and archiving for research and enterprise PACS applications

S. G. Erberich, M. Dixit, V. Chen, A. Chervenak, M. D. Nelson, C. Kesselmann, Univ. of Southern California

PACS provides a consistent model to communicate and to store images with recent additions to fault tolerance and disaster reliability. However PACS still lacks fine granulated user based authentication and authorization, flexible data distribution, and semantic associations between images and their embedded information. These are critical components for future Enterprise operations in dynamic medical research and health care environments. Here we introduce a flexible Grid based model of a PACS in order to add these methods and to describe its implementation in the Child Oncology Group (COG) Grid. The combination of existing standards for medical images, DICOM, and the abstraction to files and meta catalog information in the Grid domain provides new flexibility to the traditional PACS design. We conclude that Grid technology demonstrates a reliable and efficient distributed informatics infrastructure which is well applicable to medical informatics as described in this work. Grid technology will provide new opportunities for PACS deployment and subsequently new medical image applications.

6145-33, Session 7

Hierarchical storage of large volume of multidetctor CT data using distributed servers

O. M. Ratib, A. Rosset, J. Heuberger, Univ. Hospital of Geneva (Switzerland)

Multidector scanners and hybrid multimodality scanners have the ability to generate large number of high-resolution images resulting in very large data sets. In most cases, these datasets are generated for the sole purpose of generating secondary processed images and 3D rendered images as well as oblique and curved multiplanar reformatted images. It is therefore not essential to archive the original images after they have been processed. We have developed an architecture of distributed archive servers for temporary storage of large image datasets for 3D rendering and image processing without the need for long term storage in PACS archive. With the relatively low cost of storage devices it is possible to configure these servers to hold several months or even years of data, long enough for allowing subsequent re-processing if required by specific clinical situations. We tested the latest generation of RAID servers provided by Apple computers with a capacity of 5 TBytes. We implemented a peer-to-peer data access software based on our Open-Source image management software called OsiriX, allowing remote workstations to directly access DICOM image files located on the server through a new technology called "bonjour". This architecture offers a seamless integration of multiple servers and workstations without the need for central database or complex workflow management tools. It allows efficient access to image data from multiple workstation for image analysis and visualization without the need for image data transfer. It provides a convenient alternative to centralized PACS architecture while avoiding complex and time-consuming data transfer and storage.

6145-34, Session 7

Tele diagnostic by web

S. Sugiyama, Gifu Univ. (Japan)

Because of the development of multimedia technologies like Web and Internet, it now becomes possible to think about Tele Medicine and Diagnostic from a distant place for people who do not have a medical assistance or suggestions from a doctor or a nurse around. And also it can make possible to add some kind of intelligence onto it, which makes possible to have some kind of a medical assistance or suggestions from a computer system.

For doing this, here considers about a basic system of "Tele Diagnostic for a remote place" where it dose not have a doctor and a medical assistance or suggestions for an aged person or a feeling ill person. For implementing the system, JAVA, VRML, HTML, and CORTONA are used. For adding intelligence, Back Propagation Neural Networks (BPNN) is used.

By this study, here introduces the system that has the following basic mechanisms;

1. By putting physical data like temperature or blood pressure, the system shows a diagnostic assistance by TEXT and the bad place of body can be shown graphically if there is any.
2. The system can be put onto Web, so that anybody can have this assistance at any place as shown below ubiquitously.

6145-35, Session 8

Computer-aided diagnosis workstation and data base system for chest diagnosis based on multihelical CT images

H. Satoh, Oyama National College (Japan); N. Niki, The Univ. of Tokushima (Japan)

Mass screening based on 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 and a coronary artery calcification screening algorithm that automatically detects suspected coronary artery calcification. We also have developed electronic medical recording system and prototype internet system for the community health in two or more regions by using the Virtual Private Network router. This electronic medical recording system and prototype internet system were developed so as not to loosen the communication among staffs of hospital. Based on these diagnostic assistance methods, we have now developed a new computer-aided workstation and database that can display suspected lesions three-dimensionally in a short time. This paper describes basic studies that have been conducted to evaluate this new system.

6145-36, Session 8

Carpal bone analysis in bone age assessment

A. Zhang, A. Gertych, B. J. Liu, Univ. of Southern California; S. Kurkowska-Pospiech, Politechnika Slaska (Poland); H. K. Huang, Univ. of Southern California

A computer-aided-diagnosis (CAD) method has been previously developed in our Laboratory based on features extracted from regions of interest (ROI) in phalanges in a digital hand atlas. Due to various factors, including, the diversity of size, shape and orientation of carpal bones, nonuniformity of soft tissue, low contrast between the bony structure and soft tissue, the automatic identification and segmentation of bone boundaries is an extremely challenging task. Past research work on carpal bone segmentation has been done utilizing dynamic thresholding. However, due to the discrepancy of carpal bones developments and the limitation of segmentation algorithms, carpal bone ROI have not been taken into consideration in the bone age assessment procedure. In this paper, we present a method for fully automatic carpal bone segmentation and feature analysis in hand X-ray radiograph. The purpose of this paper is to develop automatically segment the carpal bones by anisotropic diffusion and Canny edge detection techniques. By adding their respective features extracted from carpal bones ROI to the phalangeal ROI feature space, the accuracy of bone age assessment can be improved especially when the image processing in the phalangeal ROI fails in younger children.

6145-37, Session 8

Using irreversible compression in digital radiology: a preliminary study of the opinions of radiologists

E. Seeram, British Columbia Institute of Technology (Canada)

The large volumes of digital images produced by digital imaging modalities in Radiology have provided the motivation for the development of picture archiving and communication systems (PACS) in an effort to provide an organized mechanism for digital image management. The development of more sophisticated methods of digital image acquisition (Multidetector CT and Digital Mammography, for example), as well as the implementation of PACS and Teleradiology systems in a health care environment, have created challenges in the area of image compression with respect to storing and transmitting digital images.

Image compression can be reversible (lossless) or irreversible (lossy). While in the former, there is no loss of information, the latter presents concerns since there is a loss of information. This loss of information from diagnostic medical images is of primary concern not only to radiologists, but also to patients and their physicians. In 1997, Goldberg pointed out that "there is growing evidence that lossy compression can be applied without significantly affecting the diagnostic content of images... there is growing consensus in the radiologic community that some forms of lossy compression are acceptable".

The purpose of this study was to explore the opinions of expert radiologists, and related professional organizations on the use of irreversible compression in routine practice.

The opinions of notable radiologists in the US and Canada are varied indicating no consensus of opinion on the use of irreversible compression in primary diagnosis, however, they are generally positive on the notion of the image storage and transmission advantages. Almost all radiologists are concerned with the litigation potential of an incorrect diagnosis based on irreversible compressed images.

The survey of several radiology professional and related organizations reveals that no professional practice standards exist for the use of irreversible compression. Currently, the only standard for image compression is stated in the ACR's Technical Standards for Teleradiology and Digital Image Management.

6145-38, Session 8

A mouse imaging collaboration environment

J. Szymanski, Case Western Reserve Univ.; C. Flask, Univ. Hospitals of Cleveland; D. L. Wilson, G. Zhang, D. Johnson, Case Western Reserve Univ.

With the ever-increasing complexity of science and engineering, many important research problems are being addressed by collaborative, multidisciplinary teams. We propose a web-based collaborative environment for small animal imaging research, called MICE (Mouse Imaging Collaboration Environment). MICE provides an effective and user-friendly tool for managing and sharing of the terabytes of high-resolution and high-dimension images generated at small animal imaging core facilities. We present the design and implementation of a beta-version baseline-MICE. The baseline-MICE provides an integrated solution from image acquisition to end-user access and long-term data storage at the UH/Case Small Animal Imaging Resource Center. As images are acquired from scanners, they are pushed to the MICE server which automatically stores them in a directory structure according to their DICOM metadata. The directory structure reflects imaging modality, principle investigators, animal models, scanning dates and study details. Registered end-users access these imaging data through an authenticated web-interface. Visualization is achieved by public-domain plug-ins such as ImageJ through client's web-browser while data down-loading is achieved through ftp. MICE also provides a security infrastructure that manages user access privileges such as read, write, and the right to modify the access privileges. Establishing the initial image directory structure and letting the project leader manage data access through a web-interface represent Phase I implementation. In Phase II, features for uploading image analysis scripts and results back to the MICE server will be implemented, as well as mechanisms facilitating asynchronous and synchronous discussion, annotation, and analysis.

6145-39, Session 8

Impact of volumetric ultrasound on PACS

S. C. Horii, A. Goldszal, R. O. Redfern, B. Coleman, J. Langer, D. Morton, S. Rowling, W. W. Boonn, C. Iyoob, Univ. of Pennsylvania

Current ultrasound equipment is capable of storing a number of frames and sending these to a PACS as a DICOM Multiframe object. Such "cine loops" are becoming increasingly used clinically both to demonstrate motion in imaged anatomy and to provide a way to image most, or all, of an anatomic structure. This has proven useful when the physician interpreting an examination does so at a time remote from when the study was done. The multiple frames captured on a scan through an anatomic structure is often referred to as volumetric ultrasound and the viewing of it is similar to "stack view" with computed tomographic images. The increased use of this technique, however, has an impact on PACS both in storage capacity needed and network traffic. This paper will review typical changes in examination sizes as volumetric imaging is added and will discuss the impact this has had on the authors' PACS, network, workstations, and radiologist workflow.

6145-40, Session 8

The impact of dose reduction for subtraction CT angiography of the head and neck using a low dose simulator

P. A. Vandermeer, Univ. of Maryland Medical System and VA Maryland Health Care System; W. W. Boonn, Univ. of Pennsylvania; K. M. Siddiqui, VA Maryland Health Care System; N. M. Safdar, Univ. of Maryland Medical System; N. S. Amiridze, VA Maryland Health Care System; R. Shekhar, Univ. of Maryland Medical System; E. L. Siegel, VA Maryland Health Care System

This study was designed to determine whether unenhanced computed tomography (CT) imaging of the head and neck obtained as a subtraction "mask" for CT angiography (CTA) can be acquired using an ultra-low dose technique and to assess the effect of such technique on the perceived quality of images. CTA imaging of the head and neck was performed without and with contrast per our clinical CTA subtraction protocol, utilizing a 16-channel CT scanner at a standard dose of 100 mAs and 120 kVp. The unenhanced scan served as a subtraction "mask." Noise was introduced to simulate various lower dose levels (20, 40, 60, and 80 mAs), generating 4 additional subtraction "mask" series. The non-contrast-enhanced image was subtracted from the transformed contrast-enhanced image. Three radiologists reviewed the studies and were asked to identify the subtraction dataset that was created with the lower dose dataset. Images were viewed on a 3D workstation with volume-rendered and maximum intensity projection (MIP) visualizations. Preliminary subjective ratings and discrimination tests using the MIP and volume-rendered images suggested no significant differences in perceived image quality; nor were the radiologists able to determine which study was performed with the simulated lower dose subtraction images, even for images obtained at 20 mAs. Our initial data suggest that an unenhanced CT of the head and neck can be obtained at a small fraction of the dose currently utilized (20%) in most centers, without a deleterious impact on MIP or 3D image interpretation.

6145-41, Session 9

The top ten things you need to know about radiologists: what radiologists do and how they think they do it

S. C. Horii, Univ. of Pennsylvania

No abstract available

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6146-01, Session 1

Can radiologists recognize that a computer has identified cancers that they have overlooked?

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Purpose: For computer-aided detection (CADe) to be effective, the computer must be able to identify cancers that a radiologist misses clinically and the radiologist must be able to recognize that a cancer was missed when he or she reviews the computer output. There are several papers indicating CADe can detected clinically missed cancers. The purpose of this study is to examine whether radiologists can use the CADe output effectively to detect more cancers.

Method and Materials: Three-hundred mammographic cases, which included current and previous exams were collected: 65 cases containing a missed cancer that was recognized in retrospect and 235 were normal cases. These were analyzed by a commercial CAD system. An observer study with 3 MQSA-qualified radiologists was conducted using a sequential reading method. That is, the radiologist viewed the mammograms and scored the case. Then they reviewed the CADe output and rescored the case.

Results: The computer had a sensitivity of 54% with an average of 0.59 false detections per image. For all cancers (n=69), the radiologists had a sensitivity of 71% with no aid and 75% with aid. In cases where the computer detected the cancer in only one view (n=23), the radiologists had a sensitivity of 78% unaided and increased to 84% aided. In cases where the computer detected the cancer in both views (n=13), the radiologists had a sensitivity of 77% unaided and 85% aided. Conclusions: Radiologist do not always recognize a cancer even though it is correctly identified by the computer.

6146-02, Session 1

Actual versus intended use of CAD systems in the clinical environment

D. Gur, D. Chough, C. Cohen, J. H. Sumkin, G. Abrams, M. A. Ganott, L. Wallace, R. Shah, B. Zheng, Univ. of Pittsburgh

Although computer-aided detection (CAD) is assumed to be used as a second-reader, namely the radiologist is expected to first interpret images before viewing the CAD-cued results, it is not clear whether radiologists in a busy clinical environment follow this guideline. In this study, we "shadowed" ten radiologists in reading and interpreting total 635 mammography examinations. The observation results indicated that in detecting micro-calcification clusters only a few radiologists actually used a magnifying glass to scan carefully all images. Areas in which no CAD cues were identified for micro-calcifications were largely ignored. The vast majority of radiologists used CAD cues for micro-calcifications as a pre-screening tool. In less than 15% of cases in which CAD cues for micro-calcifications clusters were marked, the radiologists actually scanned the complete set of images for possible additional micro-calcifications. Most of the more careful searches were performed by only three radiologists who voluntarily admitted they knew they were an exception in regards to their reading style and admitted they believed they were also slower. The CAD-cued masses were largely ignored by the majority of the radiologists. Several radiologists actually looked at additional prior mammograms for possible changes in a notable fraction of cases that were cued for mass. The study found that there was a large difference in the use of CAD for detection of micro-calcifications and masses. The majority of radiologists relied on CAD results to identify micro-calcifications; while largely ignoring or discarding CAD-cued masses. In addition, radiologists did not always use CAD as a second-reader. This issue should be carefully considered in designing CAD systems as well as when conducting observer performance studies to evaluate the impact of CAD on actual radiologists' performance.

6146-04, Session 1

A method for assessing the uncertainty in feature selection tasks

Y. Jiang, The Univ. of Chicago

Feature selection is a common task in the development of computer-aided diagnosis techniques and other areas of research where there is a need to identify discriminative variables that can be used to separate two classes, e.g., individuals with a certain type of disease and those without. Features-selection results based on a small sample are not reliable if they are not reproducible in replicated experiments. However, when unlimited large samples are not available, it is often difficult to assess sample size with respect to the reliability of the results of feature selection. We propose a method that could be used for assessing the uncertainty in the results of feature selection. We use the area under the ROC curve, Az, as the figure of merit for selecting features. For a set of features, we compute a joint probability distribution function for observing the set of maximum-likelihood Az values conditional on an arbitrary set of truth Az values. This multivariate distribution function is a function of the sample size and a function of the set of observed maximum-likelihood Az values. We propose to use this multivariate distribution function as a measure of the uncertainty in the feature-selection results, which is, in effect, a measure of sample size with respect the feature-selection task. Simulation results for independent variables will be discussed.

6146-05, Session 1

Comparative performance analysis for computer-aided lung nodule detection and segmentation on ultra-low-dose vs. standard dose CT

R. Wiemker, Philips Research Labs. (Germany); P. Rogalla, Humboldt Univ. (Germany); R. Opfer, Philips Research Labs. (Germany); A. Ekin, Philips Research Labs. (Netherlands); T. Bülow, Philips Research Labs. (Germany); E. Hein, V. Romano, Humboldt Univ. (Germany)

The performance of computer aided lung nodule detection (CAD) and computer aided nodule volumetry is compared between standard-dose (70-100 mAs) and ultra-low-dose CT images (5-10 mAs). A direct quantitative performance comparison was possible, since for each patient both an ultra-low-dose and a standard-dose CT scan were acquired within the same examination session. The data sets were recorded with a multi-slice CT scanner at the Charité university hospital Berlin with 1 mm slice thickness.

Our computer aided nodule detection and segmentation algorithms were deployed on both ultra-low-dose and standard-dose CT data without any dose-specific fine-tuning or preprocessing. As a reference standard 266 nodules from 20 patients were visually identified, each nodule both in ultra-low-dose and standard-dose data sets.

The CAD performance was analyzed by virtue of multiple FROC curves for different lower thresholds of the nodule diameter. For nodules with a volume-equivalent diameter of equal or larger than 4 mm (174 nodules pairs), we observed a detection rate of 86% at a median false positive rate of 4 per patient in standard-dose images, and 81% detection rate in ultra-low-dose images, also at 4 FPs per patient (or alternatively, 81% detection rate with only 1 FP in standard-dose).

Moreover, we observed a correlation > 90% between the volume-equivalent nodule diameter as automatically measured on ultra-low-dose versus on standard-dose images, indicating that ultra-low-dose CT is also feasible for growth-rate assessment in follow-up examinations.

The comparable performance of lung nodule CAD in ultra-low-dose and standard-dose images is of particular interest with respect to lung cancer screening of asymptomatic patients.

6146-47, Session 1

Mass detection in mammographic ROIs using Watson filters

S. Singh, Duke Univ.; A. H. Baydush, Wake Forest Univ.; B. P. Harrawood, J. Y. Lo, Duke Univ.

Human vision models have been shown to capture the response of the visual system and their incorporation into the classification stage of a Computer Aided Detection system could improve performance. This study seeks to improve the performance of an automated breast mass detection system by using the Watson model over a Laguerre Gauss Channelized Hotelling Observer (LG-CHO). The LG-CHO and the Watson filter model were trained and tested on a 512x512 ROI database acquired from the Digital Database of Screening Mammography consisting of 800 total ROIs; 200 of which were malignant, 200 were benign and 400 were normal. Half of the ROIs were used to train the weights for ten LG-CHO templates that were later used during the testing stage. For the Watson filter model, the training cases were used to optimize 2 filter parameters empirically to yield the best ROC AUC performance. This set of filter parameters was then used to test on the remaining cases. The training AUC for the LG-CHO and the Watson filter was 0.901 ± 0.015 and 0.9175 ± 0.013 respectively. The testing AUC for the LG-CHO and Watson filter was 0.885 ± 0.017 and 0.883 ± 0.017. The two-tailed p-value for testing was 0.815, which is not a significant difference, thus implying it does not over-train. The p-value for training was 0.025 - thus supporting our hypothesis that the Watson filter model trains better than the LG-CHO without over-training; suggesting the potential for better performance of this model for breast mass detection.

6146-06, Session 2

Recent developments and outstanding problems for the field of diagnostic technology assessment

R. F. Wagner, U.S. Food and Drug Administration

This will be a review of issues related to study design, experimental measurements, and statistical analysis of studies for the assessment of diagnostic imaging, and computerized and computer-assisted diagnostic technologies. Many important theoretical and practical issues have emerged from studies carried out in research laboratories during the technology development phase, studies for FDA review during the pre-market phase, and studies by The American College of Radiology Imaging Network (ACRIN) at the post-market phase. There are still outstanding practical problems to be solved related to the most meaningful and efficient ways for radiologists to provide their “patient management” report within a scheme that can also be used to measure the entire receiver operating characteristic (ROC) curve. Recent years have witnessed a generalization of the ROC approach to embrace multiple random effects, such as patient and reader variability, and complex issues related to lesion localization and imperfect “gold standards.” The emergence of statistical learning machines to fuse multiple imaging features, or multiple diagnostic or prognostic biomarkers, requires yet another level of complexity of the analysis. A selection of such topics of contemporary interest to this audience will be discussed.

6146-07, Session 2

Potential use of a large-screen display for interpreting radiographic images

E. A. Krupinski, W. Berger, H. Roehrig, The Univ. of Arizona; S. Dalal, D. Stanton, Philips Electronics North America

Radiology has readily made the transition to the digital reading room. One commodity left behind when moving to digital displays however is display real estate. Even with multiple monitors radiologists cannot display numerous images as they did on a film alternator. We evaluated a large-screen rear-projection display (Philips Electronics) for potential use in radiology. Resolution was 1920 x 1080 with a 44-inch diagonal size and it was a color display. For comparison we used the IBM 9 Mpixel color display (22-inch diagonal) set to a comparable resolution and maximum luminance. Diagnostic accuracy with a series of bone images with subtle fractures and six observers was comparable ($F = 0.3170$, $p = 0.5743$) to traditional computer monitor. Viewing time, however, was significantly shorter ($t = 6.723$, $p < 0.0001$) with the large display for both normal and fracture images. On average, readers sat significantly closer ($t = 5.578$, $p = 0.0026$) to the small display than the large display. Four of the 6 radiologists preferred the smaller display, judging it to yield a sharper image. Half of the readers thought the black level was better with the large display and half with the small display. Most of the radiologists thought the large-screen display has potential for use in conferencing situations or those in which multiple viewers need to see images simultaneously.

6146-08, Session 2

Impact of defective pixels in AMLCDs on the perception of medical images

T. R. L. Kimpe, Y. Sneyders, Barco N.V. (Belgium)

With LCD displays, each pixel has its own individual transistor that controls the transmittance of that pixel. Occasionally, these individual transistors will short or alternatively malfunction, resulting in a defective pixel always showing the same brightness (typically black or white). With ever increasing resolution of displays the number of defect pixels per display increases accordingly. State of the art processes are capable of producing displays with no more than one faulty transistor out of 3 million. A five Mega Pixel medical LCD panel contains 15 million individual subpixels (3 subpixels per pixel), each having an individual transistor. This means that a five Mega Pixel display on average will have 5 failing pixels.

This paper investigates the visibility of defective pixels and analyzes the impact of defective pixels on the perception of medical images. Both a psychovisual test and JND simulations were done to study the effect of defective pixels on medical images. Our results indicate that defective LCD pixels can mask subtle features in medical images in an unexpectedly broad area around the defect and therefore may reduce the quality of diagnosis for specific high-demanding areas such as mammography. As a second contribution an innovative solution is proposed. A specialized image processing algorithm can make defective pixels completely invisible and moreover can also recover the information of the defect so that the radiologist perceives the medical image correctly.

6146-09, Session 2

Assessment of the influence of display veiling glare on observer and model performance

E. A. Krupinski, The Univ. of Arizona; J. Lubin, Sarnoff Corp.; H. Roehrig, The Univ. of Arizona; J. P. Johnson, J. Nafziger, Siemens Corporate Research

We evaluated human observer and model (JNDmetrix) performance to assess whether the veiling glare of a digital display influences performance in softcopy interpretation of mammographic images. 160 mammographic images, half with a single mass, were processed to simulate four levels of veiling glare: none, comparable to a typical cathode ray tube (CRT) display, double a CRT and quadruple a CRT. Six observers were shown the

images in a randomized presentation order on a liquid crystal display (LCD) that had relatively no veiling glare. The JNDmetrix human visual system model also analyzed the images. Receiver Operating Characteristic techniques showd that performance declined with increasing veiling glare ($F = 6.884$, $p = 0.0035$). Quadruple veiling glare yielded significantly lower performance than the lower veiling glare levels. The JNDmetrix model did not predict a reduction in performance with changes in veiling glare, and correlation with the human observer data was modest (0.588). Display veiling glare may influence observer performance, but only at very high levels. The human visual system model correlated only modestly with human performance, perhaps because the version used only accounts for lesion detection and not false positives.

6146-10, Session 3

Optimization of an ROC hypersurface constructed only from an observer's within-class sensitivities

D. C. Edwards, C. E. Metz, The Univ. of Chicago

We have shown in previous work that an ideal observer in a classification task with N classes achieves the optimal receiver operating characteristic (ROC) hypersurface in a Neyman-Pearson sense. That is, the hypersurface obtained by taking one of the ideal observer's misclassification probabilities as a function of the other N^2-N-1 misclassification probabilities is never above the corresponding hypersurface obtained by any other observer. Due to the inherent complexity of evaluating observer performance in an N-class classification task with N>2, some researchers have suggested a generally incomplete but more tractable evaluation in terms of a hypersurface plotting only the N "sensitivities" (the probabilities of correctly classifying observations in the various classes). An N-class observer generally has up to N^2-N-1 degrees of freedom, so a given sensitivity will still vary when the other N-1 are held fixed; a well-defined hypersurface can be constructed by considering only the maximum possible value of one sensitivity for each achievable value of the other N-1. We show that optimal performance in terms of this generally incomplete performance descriptor, in a Neyman-Pearson sense, is still achieved by the N-class ideal observer. That is, the hypersurface obtained by taking the maximal value of one of the ideal observer's correct classification probabilities as a function of the other N-1 is never below the corresponding hypersurface obtained by any other observer.

6146-11, Session 3

Optimal observer framework and categorization observer framework for three-class ROC analysis

X. He, E. C. Frey, Johns Hopkins Univ.

ROC analysis has been an important tool for system evaluation and optimization in medical imaging. Despite its success in evaluating binary classification tasks, ROC analysis does not provide a direct way for evaluating performance on classification tasks that involve more than two diagnostic alternatives. We have previously developed a three-class ROC analysis method that provides a practical way to evaluate 3-class task performance. Based on 2-class ROC analysis and the proposed three-class ROC analysis method, this work proposes two frameworks, the optimal observer framework and the categorization observer framework, for three-class ROC analysis. The optimal observer framework seeks three-class decision rules and decision variables based on a formal decision strategy; it provides a ROC surface for system comparison on the basis of optimal performance with respect to this strategy. A categorization procedure is the generalization to 3-D of a 2-alternative forced choice procedure and is an important concept in the categorization observer framework. The categorization observer framework seeks three-class decision rules, decision variables and ROC surface such that task performance as measured by volume under the ROC surface (VUS) and the percent correct on the categorization procedure are equal. We then show that how our previously-proposed three-class ROC method fits into both frameworks.

6146-12, Session 3

Performance analysis of 3-class classifiers: properties of the 3D ROC surface and the normalized volume under the surface

B. Sahiner, H. Chan, L. M. Hadjiiski, Univ. of Michigan

Many computer-aided diagnostic problems involve three-class classification (e.g., abnormal (malignant), normal, and benign classes). A general analysis of the performance of a 3-class classifier results in a complex six-dimensional (6D) ROC space for which no simple solution is available at present. A practical paradigm for performance analysis and a figure of merit (FOM) are yet to be developed. The area Az under the ROC curve plays an important role in the evaluation of two-class classifiers. An analogous FOM for three-class classification is highly desirable. We have been investigating conditions for reducing the 6D ROC space to 3D by constraining the utilities of some of the decisions in the classification task. The 3D ROC space can be formulated as the true-positive fraction (TPF) as a function of the two types of false-positive fractions (FPFs). We have previously proposed an FOM, referred to as the normalized volume under the surface (NVUS), in the 3D ROC space. In this study, we investigate the properties of the NVUS for a maximum-likelihood classifier under the condition that the three class distributions in the feature space are multivariate normal with equal covariance matrices. Under this condition, it can be shown that the probability density functions (pdfs) of the decision variables follow a bivariate log-normal distribution. By considering these pdfs, we can derive analytical expressions for the TPF in terms of the FPFs, and for the NVUS. We have compared the NVUS value obtained by using the analytical pdfs to that obtained from a Monte Carlo simulation study in which the 3D ROC surface was generated by empirical "optimal" classification of case samples in the multi-dimensional feature space following the assumed distributions. The analytical NVUS value was found to be in good agreement with that obtained from the Monte Carlo simulation study. Our results indicate that the NVUS exhibits many of the intuitive properties that a proper FOM should satisfy and may be used as a performance index under the conditions that we imposed on the utilities.

6146-13, Session 3

Exploring FROC paradigm: initial experience with clinical applications

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Design of receiver-operating characteristic (ROC)-based paradigm and data analysis methods that capture and adequately address the complexity of clinical decision-making will facilitate the development and evaluation of new image acquisition, reconstruction and processing techniques. We compare the JAFROC (Jackknife free-response ROC) to traditional ROC paradigm and analysis in two image evaluation studies. The first study is aimed at comparing the diagnostic quality of myocardial perfusion SPECT (MPS) images obtained with different quantitative image reconstruction and compensation methods in an ongoing clinical trial. The observer assesses status of each of the three main vascular territories for each patient. This experimental set-up uses standardized locations of vascular territories on myocardial polar plot images, and a fixed number of three rating scores per patient. We compare results from the newly available JAFROC versus the traditional ROC analysis technique previously applied in similar studies, using a set of data from an on-going clinical trial. The second study is designed to address advantages of "free response" features of JAFROC paradigm in a breast lesion detection task. We developed tools allowing the acquisition of FROC-type rating data and use them on a set of 52 simulated scintimammography images. Four observers participated in a small preliminary study. Rating data is then analyzed using traditional ROC and JAFROC techniques. Comparison of two analysis methodologies reveals generally consistent behavior, corresponding to theoretical predictions.

6146-14, Session 3

LROC assessment of nonlinear filtering methods in Ga-67 SPECT imaging

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In emission tomography, iterative reconstruction is usually followed by a linear smoothing filter to make such images more appropriate for visual inspection and diagnosis by a physician.

The purpose of this study is to investigate which possible advantages a non-linear, edge-preserving filter could have on lesion detection in Ga-67 SPECT imaging. Image quality can be defined based on the task that has to be performed on the image. This study used LROC observer studies based on a dataset created by CPU-intensive Gate Monte Carlo simulations of a voxelized digital phantom. The filters considered in this study were a linear Gaussian filter, a bilateral filter (which is a non-iterative method using both a geometric closeness and a pixel similarity function), the Perona-Malik anisotropic diffusion filter and the Catté filtering scheme (which is a regularized version of the latter).

The 3D MCAT software phantom was used to simulate the distribution of Ga-67 citrate in the abdomen. Tumor-present cases had a 1-cm diameter tumor randomly placed near the edges of the anatomical boundaries of the kidneys, bone, liver and spleen. Our data set was generated out of a single noisy background simulation using the bootstrap method, to significantly reduce the simulation time and to allow for a larger observer data set. Lesions were simulated separately and added to the background afterwards. These were then reconstructed with an iterative approach, using a sufficiently large number of MLEM iterations to establish convergence.

No significant improvement was found for using edge-preserving filtering techniques over standard linear Gaussian filtering.

6146-15, Session 4

Incorporating detection tasks into the quantitative assessment of image quality

E. M. Scalzetti, W. Huda, K. M. Ogden, M. Khan, M. L. Roskopf, D. Ogden, Upstate Medical Univ./SUNY

In this study, we compared a traditional assessment of CT images with a task dependent metric of image quality. We used chest CT examinations obtained with a standard protocol for subjects participating in a lung cancer-screening project. Images were selected for patients whose weight ranged from ~40 kg to ~130 kg. Radiologists subjectively ranked these images using a five fold ranking scheme that ranged from 1 (poor) to 5 (excellent). Three subtle diagnostic tasks were identified: (1) sub-centimeter nodule of ground-glass opacity in the upper lobe of the left lung; (2) lymph node of soft tissue density in the pre-carinal region of the mediastinum; (3) rounded low attenuation lesion in the periphery of the right hepatic lobe (1.5 cm diameter). Radiologists were asked to estimate the probability of detecting each type of lesion in the appropriate CT section. Traditional and task dependent measures of image quality were plotted as a function of patient weight. The subjective (non task dependent) assessment of image quality showed the expected decrease with increasing patient size. For all three detection tasks investigated, there were no clear trends in the task-dependent assessment of image quality with varying patient size. An additional finding was a wide variation in task-dependent scores between different readers.

6146-16, Session 4

Tanner and Birdsall revisited: d' and efficiency

A. E. Burgess, Brigham and Women's Hospital

Observer performance can be described using efficiency and d' measures. Tanner and Birdsall (J. Acoust. Soc.Am.,30,pp 922-928,1958) provided definitions and developed examples using band-limited white noise. They used efficiency as the fundamental measure, defined as the ratio of signal energies required by the ideal and observer under test to perform a given task at a selected accuracy. Detectability, d', was a derived measure. This approach can be generalized for correlated noise to give a definition of d' as the SNR required by the ideal observer to perform a given task at a selected accuracy. Similarly, the generalized efficiency calculation can be based on squared signal amplitude ratios. It is important to note that the method of calculating d' is task-dependent. Analysis of several tasks will be described. Human SKE results will be reviewed, demonstrating non-linearities in d' versus signal amplitude. This implies that efficiency calculated using squared d' ratios at a given signal amplitude will not equal efficiency calculated using energy (or squared amplitude) ratios at a given d' value. Problems in performance analysis will be discussed as a prelude to the subsequent presentation (6146-18) on experimental design and methods. Misinterpretation and/or misapplication can lead to incorrect conclusions and confusion. For example, the calculation of d' from percentage of correct responses in a forced-choice experiment depends on details of experimental design. The calculation of d' using the inverse error function is only valid for 2AFC experiments with no uncertainty about signal parameters.

6146-17, Session 4

Effect of dose reduction on the detection of mammographic lesions based on mathematical observer models

A. S. Chawla, R. S. Saunders, Jr., E. Samei, Duke Univ.

The purpose of this study was to determine the effect of dose reduction on the detectability of breast lesions in mammograms. First, simulation techniques were used to insert simulated masses and microcalcifications into raw digital mammograms. Dose reduction was achieved by adding corresponding simulated noise into clinically-acquired "original" mammograms. Mammograms with three dose levels corresponding to 1/2, 1/4 and 1/8 th of the original clinically-relevant exposure levels were simulated. The images were then processed with standard image processing techniques and appropriately windowed and leveled and finally analyzed by two mathematical observer models, namely the Non-prewhitening Matched Filter with Eye Filter (NPWE) and the Laguerre-Gauss Channelized Hotelling Observer (LG-CHO). Performance was measured in terms of ROC curves under Signal Known Exactly but Variable Tasks (SKEV) paradigm and detectability indices, d' , under the 2-AFC paradigm. NPWE observer did not indicate significant differences in detectability of lesions with any reduction of dose. However, higher detectability was indicated for masses than for microcalcifications. d' was in the 2-3 range for masses and in the 0.8-0.9 range for microcalcifications. LG-CHO indicated negligible differences in the detectability of masses but a significant decrease in detectability of microcalcifications when the dose was reduced by 1/2. Significant differences in the detectability of both the masses and microcalcifications were indicated by LG-CHO when the dose levels were reduced by 1/4 or 1/8th of the original dose level. d' was in the 2-3 range for masses and in the 1-1.5 range for microcalcifications.

6146-18, Session 4

Observer experiments: design and methods

A. E. Burgess, Brigham and Women's Hospital

The focus of this presentation is on experiments using simulated or hybrid images rather than ROC experiments with clinical images. Design of observer performance experiments should be based on the question of interest. Unfortunately, poor design can lead to "strange" results and incorrect conclusions. This, in turn, leads to confusion in the literature. The purpose of this paper is to review important experimental design considerations. A number of items will be discussed. (1) Selection of the type of experiment (2AFC/MAFC), and the amount of signal parameter uncertainty, which affect design and analysis difficulty. (2) Selection of images, numbers and properties will affect the accuracy of observer performance estimates. (3) Selection of signals, sizes and shapes, which should be reasonable representations of those found in medical images. It is not difficult to find artificial signals that give low human efficiency. Two ex-

amples are signals with very small pixel counts and large Gaussians which have small edge gradients. (4) Display considerations are very important. Presentation of clinical images can provide some guidance here. Poor display design can lead to artificially low human performance relative to observer models - which have direct access to signal parameters and image data. Every attempt should be made to effectively provide the same information to human observers and avoid effects that will degrade human performance. Items include background image size, monitor luminance, spatial variation in luminance, lookup tables, and observer cueing about signal properties.

6146-19, Session 4

Evaluation of MR parallel reconstructions: detection and perceptual difference studies

Y. Jiang, D. L. Wilson, Case Western Reserve Univ.

Parallel imaging using multiple coils and sub-sampled k-space data is a promising fast MR image acquisition technique. We used detection studies and perceptual difference models on image data with 1/4 sampling to evaluate three different reconstruction methods: a regularization method developed by Leslie Ying and Zhipei Liang at UIUC, a revised regularization method developed in our lab, and an iterative method. We also included images obtained from a full complement of k-space data as "gold standard" images. Detection studies were performed using a simulated dark tumor added on MR images of bovine liver. We found that human detection depended strongly on the reconstruction methods used, with the revised regularization and UIUC methods achieving better performance than the iterative method. We also evaluated images using detection by a Channlized Hotelling Observer model and by Perceptual Difference Model (PDM) scores. Both predicted the same trends as observed from human detection. We are encouraged that PDM gives trends similar to that for detection studies. Its ease of use and applicability to a variety of MR imaging situations make it attractive for evaluating image quality in a variety of MR studies.

6146-20, Session 4

Using perceptual difference model to improve GRAPPA reconstruction in MRI

D. Huo, D. L. Wilson, Case Western Reserve Univ.

GRAPPA is a popular reconstruction technique in parallel imaging. In GRAPPA, a least-squares technique is used to solve the over-determined equations and get the "fitting" coefficients for the reconstruction. We developed the Robust GRAPPA method whereby robust estimation techniques are used to estimate the coefficients with discounting of k-space data outliers. One implementation, Slow Robust GRAPPA used iteratively re-weighted techniques, and it was compared to an ad hoc Fast Robust GRAPPA implementation. We evaluated these new algorithms using the Perceptual Difference Model (PDM). PDM has already been successfully applied to a variety of MR applications. We systematically investigated independent variables including algorithm, outer reduction factor, total reduction factor, outlier ratio, and noise across multiple image datasets, giving 9000 images. We conclude that Fast Robust GRAPPA method gives results very similar to Slow Robust GRAPPA and that both give significant improvements as compared to standard GRAPPA. PDM is very helpful in designing and optimizing the MR reconstruction algorithms.

6146-32, Poster Session

Does mammographic practice affect film reading style: breast screening vs. symptomatic radiologists?

H. J. Scott, A. G. Gale, Loughborough Univ. (United Kingdom)

In the UK there are two groups of radiologists who routinely read mammographic cases: symptomatic and screening radiologists. We examined the performance of these two film-reading populations, Breast Screening Radiologists and Symptomatic Radiologists, to evaluate if there were group differences in their 'style' of reading the same set of cases.

Specifically we looked at each group's sensitivity and specificity measures. In addition we investigated if there were any individual group differences apparent in the cases which they found challenging and what (if any) were the characteristics (in terms of features and classifications) of those cases. Data from 25 Breast Screening Radiologists and a group of 25 Symptomatic Radiologists were compared over a number of years (360 cases). Results are presented which demonstrate that whilst the two groups demonstrate overall similarities in performance (cancer detection skills) there exist subtle underlying differences which we attribute to the differences in their everyday experience of the types of cases that they read. In conclusion we argue that these differences are related to the volume and type of cases which UK screening Radiologists read in order to maintain skill level.

6146-33, Poster Session

A proposal of the diagnosis-dynamic characteristic (DDC) model describing the relation between search time and confidence levels and an application for ROC curve generation from a dichotomous judgment

T. Matsumoto, N. Fukuda, A. Furukawa, National Institute of Radiological Sciences (Japan); K. Suwa, Nippon Dental Univ. (Japan); S. Wada, Niigata Univ. (Japan); M. Matsumoto, Diichi Hospital (Japan); S. Sone, JA Azumi General Hospital (Japan)

Purpose : The purpose is to propose a model named the diagnosis-dynamic characteristic model (DDC) and to demonstrate that the ROC curves could be generated based on the DDC model without confidence levels.

Method: When physicians inspect an image, they make up a certain degree of confidence that the image are abnormal; p(t), or normal; n(t)[n(t)=1-p(t)]. After infinite time of the inspection, they reach the equilibrium levels of the confidence of $p^*=p(\infty)$ and $n^*=n(\infty)$. There are psychological conflicts between the decisions of normal and abnormal. We assume that the decision of "normal" is distracted by the decision of "abnormal" by a factor of $k(1 + ap)$, and in an inverse direction by a factor of $k(1 + bn)$, where $k (> 0)$ is a parameter that relates with image quality and skill of the physicians, and a and b are unknown constants. After the infinite time of inspection, the conflict reaches the equilibrium, which satisfies the equation, $k(1 + ap^*)n^* = k(1 + bn^*)p^*$. Here we define a parameter c, which is $2p^*/[p^*(1 - p^*)]$. We also assume that changes in the confidence level with the time (dp/dt) is proportional to $[k(1+ap)n –k(1+bn)p]$, i.e. $k[-cp2 + (c - 2)p + 1]$. Solving the differential equation, we derived the equation; t(p) depending with the parameters; k, c, S. S (0~1) is the value arbitrary selected and related with probability of "abnormal" before the image inspection ($S = p(0)$).

Results: Image reading studies were executed for CT images. The ROC curves generated by the DDC model sufficiently fitted to those by the traditional methods.

New or breakthrough work to be presented: A proposal of DDC model and ROC curve generation from a dichotomous judgment by applying the model was theoretically and experimentally investigate for the first time.

Conclusions: ROC curves can be generated by measuring time for making diagnosis without the subjective scores of diagnostic confidence and applying the DDC model.

6146-35, Poster Session

Observer performance detecting signals in globally non-stationary oriented noise

Y. Zhang, C. K. Abbey, M. P. Eckstein, Univ. of California/Santa Barbara

Most of the studies on signal detection task have used backgrounds that are or assumed to be statistical stationary. Fewer studies have addressed how humans detect signals in non-stationary backgrounds. In particular, it is unknown whether humans can adapt their strategy to different local statistical properties in non-stationary backgrounds.

We compared human performance detecting a signal embedded in statistically non-stationary noise and in statistically stationary noise. The images were designed so that performance of model observers assumed statistically stationary, making no use of differences in local statistics, would be constant across both conditions. In contrast, performance of an adaptive region of interest prewhitening matched filter (PWROI) that uses local statistics is about 140% higher with the non-stationary backgrounds than the stationary ones. Human performance was 33% higher in the non-stationary backgrounds. We conclude that humans can adapt their strategy to the local statistical properties of non-stationary backgrounds (although suboptimally compared to the adaptive-PWROI model observer) and that model observers that derive their templates based on stationary assumptions might be inadequate to predict human performance in some non-stationary backgrounds.

6146-36, Poster Session

An applicability research on JND model

T. Luo, X. Mou, Xi'an Jiaotong Univ. (China)

In medical radiation department, physician makes his diagnosis by surveying the images represented to CRT or film. Due to the inherent characteristic of radiograph, the pathology features always exhibit in the form of small size image signal with low contrast and noisy staining. To investigate the detectivity of human vision on these will help to solve the problem in what condition just-noticeable differences can be detected, and then to choose proper x-ray tube voltage and current to make x-ray exposure. In this work, a software of improved 4-forced choice experiment is developed. This experiment is performed to test observer performance in more than 600 groups respectively. By ROC analyzing, an exact range of some image parameters is detected to satisfy the Rose model. Some results are obtained as follows: when observer can detect JND with 50% TPF, the minimum contrast is approximately 1%, while background intensity is 20% of the maximum intensity and the value of k in Rose model approximately varies from 2 to 3 as target area changing. The minimum contrast decreases when the background intensity is above 20%.

6146-37, Poster Session

How does mass lesion detection vary with lesion size, display window width, and radiation exposure in computed radiography?

K. M. Ogden, W. Huda, V. Garg, M. Khan, M. A. Reichel, M. L. Roskopf, Upstate Medical Univ./SUNY

We studied mass lesion detection using a computed radiography imaging system in the absence of any anatomical (structured) noise. Parameters investigated were the lesion size, display window width, and radiation exposure. Uniform CR exposures were obtained at air kerma at the receptor between 1 microGy and 10 microGy. We added simulated Gaussian lesion with sizes ranging from 1 to 5.5 mm. A 4 Alternate Forced Choice (4-AFC) method was used to determine the lesion intensity needed to achieve 92% accuracy (I92%) for window display widths that were varied by up to a factor of eight. Measured contrast detail slopes were -0.80 at 1 microGy, and -0.64 at 10 microGy. Increasing the radiation exposure by a factor of ten improved detection of 1 mm size lesions by a factor of 2.4 and 5.5 mm lesions by a factor of 1.9. Decreasing display contrast by a factor of four reduced lesion visibility by ~25% for exposures > 5 mGy, and by ~10% for exposures of 1 mGy. Reductions in lesion visibility with lower display contrast were similar for all lesion sizes. We conclude that detection performance generally improves when the radiation dose and/or display contrast are increased. At the lowest radiation doses investigated (1 microGy), display contrast is less important than at doses above 5 microGy.

6146-38, Poster Session

First validation of a new phantom for global quality control in digital mammography

H. T. Bosmans, K. Nijs, Katholieke Univ. Leuven (Belgium); K. C. Young, The Royal Surrey County Hospital NHS Trust (United Kingdom); F. Rogge, Katholieke Univ. Leuven (Belgium); P. Moran, M. L. Chevalier, Univ. Complutense de Madrid (Spain); M. Borowski, Klinikum Braunschweig GmbH (Germany); A. Taibi, Univ. degli Studi di Ferrara (Italy); J. J. Cook, The Royal Surrey County Hospital NHS Trust (United Kingdom); G. Marchal, Katholieke Univ. Leuven (Belgium)

In the frame of an EC funded project, a scheme for a new phantom has been proposed that consists of a smaller contrast-detail part than the CDMAM phantom and that contains other items for other parts of an acceptance protocol for digital mammography. A first prototype of the "DIGIMAM" has been produced and was compared to the CDMAM phantom.

The results with the new phantom were very similar to results obtained with the CDMAM phantom: readers scored different from each other and there was an overlap in the scores for the different systems. A system with a poor score in CDMAM had also the worst score for DIGIMAM. Reading time was significantly reduced however. In order to reduce the subjectivity of the readings, computerized reading will be developed. In a second version of the phantom, we propose to add more disks of the same size and contrast in each square to improve the statistical power of each reading.

6146-39, Poster Session

Characterization of a new generation of computed radiography system based on line scanning and phosphor needles

O. Dragusin, F. Rogge, H. Pauwels, G. Marchal, H. T. Bosmans, Katholieke Univ. Leuven (Belgium)

A new generation CR system that is based on phosphor needles and that uses a digitizer with line scan technology was compared to a clinically used CR system. Purely technical and more clinically related tests were run on both systems. This included the calculation of the DQE, signal to noise and contrast to noise ratios from Aluminum inserts, contrast detail analysis with the CDRAD phantom and the use of anthropomorphic phantoms (wrist, chest and skull) with scoring by a radiologist. X-ray exposures with various dose levels and 50kV, 70kV and 125kV were acquired. For detector doses above 3μGy, all noise related measurements showed the superiority of the new technology. The MTF confirmed the improvement in sharpness: between 1 and 3 lp/mm increases ranged from 20 to 50%. Further work should be devoted to the determination of the required dose levels in the plate for the different radiological applications.

6146-40, Poster Session

Potential for lower absorbed dose in digital mammography: a JAFROC experiment using dose-reduced clinical hybrid images

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Purpose: To determine how image quality linked to tumor detection is affected by reducing the absorbed dose to 50% and 30% of standard levels, i.e. an average glandular dose of 1.3 mGy for a standard breast according to European guidelines.

Materials and Method: Five irregular-shaped malignant tumor masses were simulated. One to three of these masses were inserted at various positions into 40 out of 90 normal, unprocessed images acquired from the screening department using a Siemens Mammomat Novation unit. All 90 images were then dose-reduced by adding simulated quantum noise to represent images acquired at 50% and 30% of the original dose, resulting in 270 images, which were subsequently processed for final display. Four radiologists and four physicists participated in a free-response receiver operating characteristics (FROC) study, in which they marked the positions of the masses and the degree of suspicion. The analysis of the results was carried out using the jackknife FROC (JAFROC) method together with analysis of variance (ANOVA).

Results: Considering the 100%, 50% and 30% dose levels examined, the mean JAFROC figure of merit (FOM) for the radiologists was 0.73, 0.70 and 0.68, respectively, and 0.55, 0.62 and 0.61 for the physicists. ANOVA revealed a p-value of 0.26 for the radiologists, and 0.11 for the physicists, respectively, indicating no statistically significant difference between any two pairs of scores.

Conclusion: For the masses used in this experiment, there was no significant change in detection by increasing quantum noise, indicating a potential for dose reduction.

6146-41, Poster Session

Development and implementation of a user friendly and automated environment for the creation of databases of digital mammograms with simulated microcalcifications

F. Zanca, J. Jacobs, C. Van Ongeval, Univ. Ziekenhuizen Leuven (Belgium); A. G. Carton, Univ. of Pennsylvania; T. J. Deprez, G. Marchal, H. Bosmans, Univ. Ziekenhuizen Leuven (Belgium)

Databases of selected raw patient images could be used for quality assurance purposes of image processing and subsequent viewing conditions. Images with full documentation of the clinical problem are for many purposes most useful. In earlier work, we had shown that our simulated microcalcifications can not be discerned from real microcalcifications. Therefore, we have developed software tools for (1) the set-up of databases with (raw) images that include simulated microcalcifications, and for (2) maximally automated processing of reading scores concerning the detected fraction of these artefacts. In digital images of microcalcifications, segmentation and feature extraction had been performed in our team and templates of microcalcifications like they would be observed in ideally sharp detectors (MTF = 1) were defined. Based on technical specifications of new detectors and for a given energy spectrum, templates can then be recalculated. User-friendly and automated software tools are now developed to paste clusters of such templates in clinical mammograms in user-specified locations and with a full log file. Clusters with microcalcifications were successfully inserted in raw images of the DM1000 (Agfa) and the modular approach is prepared for the file format of other systems we have ready access to (Siemens Novation, CR systems of Agfa). Major tasks included the selection of input images, the handling of the raw data file formats and the implementation of viewing tools for scoring the images by simple mouse clicks. The databases will be used soon to compare 2 viewing modalities for digital mammography and to compare emerging image processing algorithms.

6146-42, Poster Session

A comparison of 2D and 3D evaluation methods for pulmonary embolism detection in CT images

A. P. Kiraly, C. L. Novak, Siemens Corporate Research; D. P. Naidich, I. Vlahos, J. P. Ko, G. T. Brusca-Augello, New York Univ.

Contrast-enhanced high-resolution computed tomographic (CT) images of the lungs permit diagnosis of pulmonary embolism (PE). We evaluated a novel 3D technique for detecting PE, which consists of visualizing the pulmonary vasculature with shading corresponding to intraluminal density, and compared it with traditional 2D axial interpretation.

Three readers independently marked 10 cases using the 3D method, and a separate interpretation was performed at a later date using only source axial images. An experienced thoracic radiologist adjudicated all marks, classifying clots according to location and confidence. The mean sensitivity and false positive (FP) rates were determined; statistical significance was calculated with the two-tailed t-test.

There were a total of 8 positive examinations with 69 validated emboli. 44 (64%) of the clots were segmental while 12 (17%) proved subsegmental. Using the traditional 2D method for examination, readers detected a mean of 45 PE for 66% sensitivity. Using the 3D method, readers detected a mean of 35 PE (50% sensitivity). Combining both methods, readers detected a mean of 51 PE (74% sensitivity), significantly higher than either single method ($p<0.001$). Considered by arterial level, significant improvement was observed for detection of segmental and subsegmental clots ($p<0.001$) when comparing combined reading with either single method. The mean FP per patient was 0.23 for both 2D and 3D readings and 0.4 for combined reading.

3D visualization of pulmonary arteries allowed readers to detect a significant number of additional emboli not detected during 2D axial interpretations and thus may lead to a more accurate diagnosis of PE.

6146-44, Poster Session

An optimized decision-fusion algorithm for classification of heterogeneous breast cancer data

J. L. Jesneck, L. W. Nolte, J. Y. Lo, Duke Univ.

Modern medical technology is making an increasingly large amount of data available for breast cancer detection and diagnosis, such as digital mammography, ultrasound, genomic, and proteomic tests. Despite this sudden abundance of information, current breast cancer computer-aided diagnosis programs tend to use only one type of data, usually digitized mammogram films. Combining disparate data types together is a difficult problem. Towards this aim, we have developed a novel decision-fusion classification technique that combines features from disparate sources. Our technique can be optimized for arbitrary performance metrics by using a genetic algorithm to search for a set of feature thresholds that maximizes the desired metric. This offers a significant advantage over classification techniques designed to minimize mean squared error, such as a linear discriminant (LDA). We evaluated our decision-fusion algorithm and an LDA on two breast cancer data sets consisting of heterogeneous data, an easily linearly separable BI-RADS data set and a much more challenging breast microcalcification data set. For evaluation we used bootstrap subsampling and k-fold cross validation of two different clinically relevant performance metrics: the area under the ROC curve (AUC), and the normalized partial area under the ROC curve (pAUC). In both data sets and both performance metrics, the decision-fusion classifier significantly outperformed the LDA. For the BI-RADS data set, the LDA reached AUC = 0.90±0.005 and pAUC = 0.51±0.01 at 500 samples, while the decision-fusion classifier peaked at 100 samples with AUC = 0.95±0.02 and pAUC

= 0.76±0.07. For the calcification data set, the LDA achieved a maximum of AUC = 0.67±0.03 and pAUC = 0.13±0.033 at 500 samples. The decision-fusion classifier had a peak at 100 samples with AUC = 0.96±0.02 and pAUC = 0.76±0.1.

6146-45, Poster Session

Comparison of sensitivity and reading time for the use of CAD as concurrent and second reader

F. Beyer, Westfälische Wilhelms-Univ. Münster (Germany); L. Zierott, K. U. Juergens, E. M. Fallenberg, Univ. Hospital Munster (Germany); J. Stoeckel, Siemens Medical Solutions; W. L. Heindel, D. Wormanns, Westfälische Wilhelms-Univ. Münster (Germany)

Purpose: To compare sensitivity and reading time when using CAD as second reader resp. concurrent reader.

Materials and Methods: Fifty chest MDCT scans due to clinical indication were analysed independently by four radiologists two times: First with CAD as concurrent reader (display of CAD results simultaneously to the primary reading by the radiologist); then after more than one week with CAD as second reader (CAD results were shown after completion of a reading session without CAD). A prototype version of Siemens LungCAD (Siemens,Malvern,USA) was used. Sensitivities and reading times for detecting nodules ≥4mm of concurrent reading, reading without CAD and second reading were recorded. In a consensus conference false positive findings were eliminated. Student's T-Test was used to compare sensitivities and reading times.

Results: 108 true positive nodules were found. Mean sensitivity was .68 for reading without CAD, .68 for concurrent reading and .75 for second reading. Differences of sensitivities were significant between concurrent and second reading (p<.001) resp. reading without CAD and second reading (p=.001). Mean reading time for concurrent reading was significant shorter (274s) compared to reading without CAD (294s;p=.04) and second reading (337s;p<.001).

New work to be presented: To our knowledge this is the first study that compares sensitivities and reading times between use of CAD as concurrent resp. second reader.

Conclusion: CAD can either be used to speed up reading of chest CT cases for pulmonary nodules without loss of sensitivity as concurrent reader - OR (and not AND) to increase sensitivity and reading time as second reader.

6146-46, Poster Session

Potential effect of CAD systems on the detection of actionable nodules in chest CT scans during routine reporting

D. Wormanns, F. Beyer, Westfälische Wilhelms-Univ. Münster (Germany); A. Butzbach, Median Technologies (France); L. Zierott, Univ. Hospital Munster (Germany); W. Heindel, Westfälische Wilhelms-Univ. Münster (Germany)

Purpose: To determine impact of two CAD systems for detection of actionable nodules (>4mm) on the interpretation of chest CT scans during routine reporting.

\Material and methods: Fifty consecutive MDCT scans with corresponding reports in the radiology information system (RIS) were selected from clinical routine. The two recent prototype CAD systems Siemens LungCAD and MEDIAN CAD-Lung were independently applied to the scans: Two radiologists independently reviewed the CAD results and accepted resp. rejected CAD's findings. Patients were classified into group 1 if at least one actionable nodule was detected -the remainder into group 2. The effect of CAD on routine reporting was simulated as set union of the findings of routine and CAD reporting thus applying CAD as second reader. McNemar's test was used to compare classifications.

Results: RIS report classified 18 cases into group 1 and 32 cases into group 2. Application of a CAD system as second reader added 11 (LungCAD) resp. 14 (CAD-Lung) cases to group 1. Both CAD systems agreed in 45 of 50 cases; in four cases CAD-Lung and in one case LungCAD reclassified a case into group 1 while the other CAD system missed the finding. Sensitivity difference between CAD systems was not significant (p=.37).

New work to be presented: To our knowledge this is the first study that evaluates the potential effect of CAD systems on the detection of actionable nodules in chest CT scans during routine reporting

Conclusion: In our study use of CAD as second reader in routine reporting nearly doubled percentage of patients with actionable nodules.

6146-48, Poster Session

Explanation of the improvement mechanism of diagnostic performance with CAD system in interpreting CT images

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Purpose: The purpose is to make clear the mechanism that a person (physician or radiological technologist) effectively identify abnormal findings in CT images of lung cancer screening by using with CAD system.

Method: Estimation of 2X2 decision matrix between a person and a CAD: We suppose the next scene to be it. At first, a person judges whether abnormal findings per one patient per one CT image are present (1) or absent (0) without CAD results. The second, a person judges whether abnormal findings are present (1) or absent (0) with CAD results. We expresses the correlation between diagnoses by a person and CAD system for abnormal cases and for normal cases by following formula using phi correlation coefficient:ϕ*(cd-ab)/*(a+c)(b+d)(b+c)(a+d). a,b,c,d: 2X2 decision matrix parameters.

If TPR1=(a+c)/n, TPR2=(b+c)/n and TPR3=(a+b+c)/n for abnormal cases, TPR3=TPR1+TPR2 - TPR1_TRR2 - ϕ*TPR1(1-TPR1)TPR2(1-TPR2).

Therefore, a=n (TPR3 - TPR1)*b=n (TPR3 - TPR2)*c=n (TPR1 + TPR2 - TPR3)*d=n (1.0 - TPR3).

Experimental data applied the theory: The 43 students interpreted the same CT images [no training]. A second interpretation was performed after they had been instructed on how to interpret CT images [training], and third was assisted by a virtual CAD [training + CAD].

Results: The mechanism that makes up for a good point of a person and a CAD was deciphered for each person, each case of CT image, and "no training + CAD" or " training + CAD".

New or breakthrough work to be presented: The improvement mechanism of diagnostic performance with CAD in interpreting CT images was theoretically and experimentally investigated for the first time

Conclusions: We proposed a method guessing the decision matrix (2X2) between a person and a CAD decided the" presence" or "absence" of abnormal findings and explained the improvement mechanism of diagnostic performance with CAD system.

6146-49, Poster Session

Presentation of CAD findings to the radiologist: influence of the CAD marker type on radiologist's sensitivity and specificity in detection of lung nodules at chest CT

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Purpose: The user interface of CAD systems can influence the radiologist's

performance in detection of lung nodules at chest CT. Very striking CAD markers might distract radiologist's attention from other parts of the image. This study was aimed to analyze the influence of different CAD markers on radiologist's performance.

Material and methods: Ten radiologists reviewed 150 chest CT images. One CAD marker was present on every image; five different CAD markers (1: thick square, 2: thin circle, 3: small arrow, 4: subtle dot, 5: very subtle color change) were used at 30 images each. At 100 images one nodule was visible: the CAD marker pointed to the lesion in 50 cases and pointed to a false positive CAD finding in 50 cases. The remaining 50 images did not contain any nodule but a CAD marker pointing to a false positive finding. The radiologists had to decide for each image if a nodule is present and to click on the nodule. Sensitivity and specificity of nodule detection were calculated for every type of CAD marker.

Results: Mean sensitivities of all readers were 59%, 62%, 64%, 65% and 64% for marker type 1 to 5 (in the order from very striking to very subtle), specificity was 50%, 51%, 64%, 45% and 67%, respectively. In cases with incorrectly placed CAD markers of different types 41%, 58%, 59%, 49% and 54% of all nodules were correctly identified.

New work to be presented: To the knowledge of the authors this is the first study to explore the effect of different CAD markers on the radiologist's performance.

Conclusion: A small arrow was found to be the best of the tested methods for presenting CAD results to the radiologist.

6146-51, Poster Session

Automatic image quality assessment for cervical imagery

J. Gu, W. Li, STI Medical Systems

Uterine cervical cancer is the second most common cancer among women worldwide. However, its death rate can be dramatically reduced by appropriate treatment, if early detection is available. We are developing a Computer-Aided-Diagnosis (CAD) system to facilitate colposcopic examinations for cervical cancer screening and diagnosis. Unfortunately, the effort to develop fully automated cervical cancer diagnostic algorithms is hindered by the paucity of high quality, standardized imaging data. The limited quality of cervical imagery can be attributed to several factors, including: incorrect instrumental settings or positioning, glint (specular reflection), blur due to poor focus, and physical contaminants. Glint eliminates the color information in affected pixels and can therefore introduce artifacts in feature extraction algorithms. Instrumental settings that result in an inadequate dynamic range or overly constrained region of interest can reduce or eliminate pixel information and thus make image analysis algorithms unreliable. Poor focus causes image blur with a consequent loss of texture information. In addition, a variety of physical contaminants, such as blood or mucus can obscure the desired scene and reduce or eliminate diagnostic information from affected areas. Thus, automated feedback should be provided to the colposcopist as a means to promote corrective actions. The current practice for colposcopic examinations employs a visual inspection of the cervix by a colposcopist. However, in addition to the problems outlined above, this is both time consuming and error prone due to human subjectivity. In this paper, we describe automated image quality assessment techniques, which include region of interest detection and assessment, contrast dynamic range assessment, blur detection, and contaminant detection. We have tested these algorithms using clinical colposcopic imagery, and plan to implement these algorithms in a CAD system designed to simplify high quality data acquisition. Moreover, these algorithms may also be suitable for image quality assessment in telemedicine applications.

6146-52, Poster Session

A study on the performance evaluation of computer-aided diagnosis for detecting pulmonary nodules for the various CT reconstruction

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Purpose: To evaluate the robust performance of computer-aided diagnosis system detecting pulmonary nodules for the various CT image qualities of the low dose CT cancer screening.

Method and Materials: 41chest CT examination cases with 41 lung nodules consisting mainly GGO were used* from a lung cancer screening program. All the CT examinations were performed using a Multi -slice CT Asteion 4 scanner (Toshiba Medical Systems Co. Ltd, Japan). Helical CT image data were obtained using a detector row width of 5mm, 0.75-second rotation time, and 30mA. After the examination, CT image reconstructions with 21 kinds of condition for every examination were performed using 7 reconstruction kernels with three kinds of CT image thickness. The 7 reconstruction kernels consisted of three types of standard or smoothed kernel, and four types of high resolution kernel. The reconstruction image thicknesses were 5mm, 8mm and 10mm. Nodule detection using a computer-aided diagnosis system (Fujitsu Ltd, Japan) were performed. The mean size of the 41 nodules was 0.73cm∓0.17 (SD) (range 0.3-1.05cm in diameter). Detectable performance of our CAD system was evaluated.

Results: In the total of 41 nodules, our CAD system identified 28 to 32 nodules in the image thickness of 8mm for 7 reconstruction kernels, yielding a a true-positive rate(TPR: sensitivity)) of 73% to 78%. In the image thickness of 5mm CAD system indicated 32 to 35 nodules, yielding a TPR 78% to 85%. In the image thickness of 10mm TPR was distributed from 46% to 71%. Some kernel indicated relatively high sensitivity with high false positive rate (FPR), other kernel indicated high sensitivity with relatively low FPR, and some kernels indicated low sensitivity with low FPR.

Conclusion: Multi-conditions reconstructed image database of lung cancer screening was convenient to demonstrat a dependency characteristics of a CAD system detecting pulmonary nodule by multi-slice low-dose CT.

6146-21, Session 5

Human observer models for detection of lung nodules in tomosynthetic images

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Two-alternative forced choice experiments were carried out by human observers for the detection of lung nodules in anatomical backgrounds for tomosynthetic reconstructions. The anatomical backgrounds consisted of 46 subimages obtained from tomosynthetic reconstructions of a plastinated dog lung with anatomical complexity similar to that of a human. The channelized Hotelling observer using Laguerre-Gauss channels with internal noise and the non-prewhitening eye (NPWE) filter were picked to match the human observer performance for the projection data as training. The data from the tomosynthetic angles 3, 6 and 9 degrees were used for testing the predictive nature of the models. Both models tracked human performance in a a rank-order sense as the tomosynthetic angle changed with the NPWE giving somewhat more accurate results. The parameters in both models were also chosen to maximize the detectability of the nodules as an approximation of the ideal linear observer. Given the small number of images used per tomosynthetic angle and the highly nonstationary and asymmetric nature of the backgrounds and nodules, the NPWE model provided a better estimate of the ideal linear observer than the channelized Hotelling observer. Our results show that human observer models can capture the type of improvements in image quality brought about by tomosynthesis in images with complex anatomical

structures. We will explore the dependence of detectability on the size of the nodules, the variability in the detectability estimates given the small number of images and what subsets of the data can be used as a training set to predict the rest.

6146-22, Session 5

The efficiency of reading around learned backgrounds

M. P. Eckstein, Univ. of California/Santa Barbara

Models have been used to predict human performance detecting signals in computer generated noise and real structured backgrounds. Most metrics of medical image quality typically treat all components of the background as noise. This includes task based model observers (non-prewhitening matched filter with an eye filter, Hotelling and Channelized Hotelling) as well as Fourier metrics of medical image quality such as Generalized Noise Equivalent Quanta (GNEQ). However, many investigators have correctly pointed out (e.g., Harold Kundel) that physicians often can discount signal-looking structures that are part of the normal anatomic background. This process has been referred to as "reading around the background or noise". The purpose of this paper is to develop an experimental framework to systematically study the ability of human observers to read around learned backgrounds and compare their ability to that of an optimal ideal observer. We measured human localization performance of one of 12 Gaussian targets of differing standard deviation, contrast and polarity (signal known statistically, SKS) appearing anywhere within test-image. A background was generated with 30 randomly placed Gaussians with randomly chosen contrasts and sizes. On each trial the background was shifted vertically and horizontally by a random displacement (with wrap-around). A new sample of Gaussian white noise was added to the test image on each trial. Human performance was compared to standard model observers that treat the background as noise (a non-prewhitening matched filter with an eye filter, a Hotelling) and an ideal observer that has perfect knowledge of the background. Human performance exceeded that of the Hotelling and NPWE models, but was far inferior to that of the ideal observer. Our results demonstrate that for some types of images human signal localization performance is consistent with use of knowledge about the backgrounds to discount signal-looking structures that belong to the background. In such scenarios model observers that treat backgrounds as noise (NPWE, Hotelling, Channelized Hotelling) are incomplete models of human visual detection.

6146-23, Session 5

Observer efficiency in boundary discrimination tasks related to assessment of breast lesions with ultrasound

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The statistical efficiency of human observers in diagnostic tasks is an important measure of how effectively task relevant information in the image is being utilized. Most efficiency studies have investigated efficiency in terms of contrast or size effects. In many cases, malignant lesions will have similar contrast to normal or benign objects, but can be distinguished by properties of their boundary. We investigate this issue in the framework of malignant/benign discrimination tasks for the breast with ultrasound. In order to identify effects in terms of specific features and to control for other effects such as aberration or specular reflections, we simulate the formation of beam-formed radio-frequency (RF) data. We consider three tasks related to lesion boundaries including boundary eccentricity, boundary sharpness, and detection of boundary spiculations. We also consider standard detection and contrast discrimination tasks. We find that human observers exhibit surprisingly low efficiency with respect to the ideal observer acting on RF data in boundary discrimination tasks (0.08%-3.3%), and that efficiency of human observers is substantially increased by improving the resolution of the images through Wiener-filtering RF frame data. We also find a limitation in efficiency is the computation of an envelope image from the RF data recorded by the transducer. Smith-Wagner approximations to the ideal observer acting on the envelope images indicate that humans may be substantially more efficient (10%-75%) with respect to the envelope ideal observers. Our work suggests that significant diagnostic information may be lost in standard envelope processing in the formation of ultrasonic images.

6146-24, Session 5

Performance of a channelized-ideal observer using Laguerre-Gauss channels for detecting a Gaussian signal at a known location in different lumpy backgrounds

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A channelized-ideal observer (CIO), which reduces the dimensionality of the integral that needs to be calculated for the ideal observer, was introduced in the past. The ultimate goal of the CIO is to approximate the performance of the ideal observer in detection tasks. In this work, a CIO using Laguerre-Gauss channels is employed for detecting a Gaussian signal at a known location in the lumpy background. The mean number of lumps in the lumpy background as well as the width parameter of channels is varied to see the impact of image statistics on the performance of this CIO and a channelized-Hotelling observer (CHO) using the same channels. A Markov-chain Monte Carlo method is used to determine the performance of the CIO using different numbers of LG channels. Results show that the gap between the performances of the CIO and the CHO becomes larger when the mean number of lumps in the lumpy background decreases. The results also indicate that the performance of the CIO approaches that of the ideal observer more closely as the mean number of lumps decreases. Thus LG channels may be efficient for the CIO to approximate the performance of the ideal observer in tasks using highly non-Gaussian lumpy backgrounds.

6146-25, Session 5

Human efficiency for detecting Gaussian signals in non-Gaussian distributed lumpy backgrounds using different display characteristics and scaling methods

S. Park, B. D. Gallas, A. Badano, N. Petrick, K. J. Myers, U.S. Food and Drug Administration

A psychophysical study for finding a Gaussian signal at a known location in a non-Gaussian distributed lumpy background showed that human efficiency is less than 3% while the ideal observer achieves 0.95 in the area under the receiver operating characteristic curve. In this work, another study is done with changes that substantially improve upon the prior study design. First, a DICOM-calibrated monitor is used in this study for human-observer performance, whereas an uncalibrated LCD monitor was used in the prior study. Second, two scaling methods to display image values are employed to see how scaling affects human performance for the same task. Third, a different, random order of image pairs is chosen for each observer to reduce correlations in human performance that may have been caused by a fixed ordering of image pairs.

The study results show that human efficiency relative to the ideal observer is less than 5% at the same performance level of the ideal observer as above. Our variance analysis indicates that neither scaling nor display makes a significant difference in human performance in these studies. Therefore, we conclude that using highly non-Gaussian distributed lumpy backgrounds in the tasks may have been the major source of low human efficiency.

6146-26, Session 6

Variability in the interpretation of mammograms: Do similar decisions entail similar visual sampling strategies?

C. Mello-Thoms, Univ. of Pittsburgh

Inter- and intra-observer variability of radiologists reading mammograms has been shown to be associated with a significant percentage of missed breast cancers. Eye position tracking has shown that most cancers that are not reported do in fact attract the radiologists' visual attention, often for as long as cancers that are reported. Hence, detection is not the main problem for most radiologists; rather, image interpretation is the underlying reason why detected findings go unreported. According with models of image perception, the decision to report or to dismiss a perceived finding is made based upon not only on the conspicuity of the local elements but also on the selection of certain areas of the background parenchyma, which the radiologist uses to compare the finding against and thus determine its uniqueness. This sampling of the background corresponds to a visual search strategy. Nonetheless, several studies have shown that the final pattern observed in visual search is particular for each observer, and that even when the same observer searches the same image the pattern is likely to be different the second time around. This has led to the assumption that visual search is random. In this study we will compare the visual sampling strategy of experienced mammographers as they search a case set of mammograms looking for benign and malignant masses. We will determine whether similar decisions, that is, decisions to report the same findings, entail the sampling of the same areas of the background, regardless of in which order these areas were sampled.

6146-27, Session 6

Lesion detection using an a-contrario detector in simulated digital mammograms

B. Grosjean, S. L. Muller, H. Souchay, GE Healthcare (France)

Burgess (Lesion detection in digital mammograms, SPIE 2001) showed that lesion detectability does have a non-trivial behaviour with textured mammographic backgrounds: the threshold detectability occurs when the log contrast is linearly related to the log size with positive slope. Grosjean et al. (A-contrario detection of simulated opacities in power-law filtered noise images, MIPS 2005) validated the a-contrario detector as an acceptable observer for detection on such backgrounds. In this study, we quantitatively simulated projected breast images containing lesions with a variety of sizes and thicknesses, for a 56mm thick, 50/50 glandular breast and with a textured background generated by the power-law filtered noise model of Burgess. The acquisition parameters used in the simulation correspond to the optimal techniques provided by a digital mammography system for that specific breast (Shramchenko et al., Optimized Exposure Control in Digital Mammography, SPIE 2004). Images have then been automatically scored by the a-contrario detector in order to find, for each acquisition condition, the minimum thickness of the lesion needed to reach the detection threshold.

Taking into account the Fourier spectrum properties of the breast texture and using the a-contrario observer as a new metric for the detection task, we found the same detection slopes as described by Burgess. With our quantitative simulation, which includes a realistic image chain of a digital mammography system, and with the implementation of a novel detection process, we found that for the considered lesion sizes, lesions are easier to detect on textures with a high value of power-law exponent.

6146-28, Session 6

Lesion removal and lesion addition algorithms in lung volumetric data sets for perception studies

M. T. Madsen, K. S. Berbaum, A. Ellingson, B. H. Thompson, B. Mullan, The Univ. of Iowa

Image perception studies of medical images provide important information about how radiologists interpret images and insights for reducing reading errors. In the past, perception studies have been difficult to perform using clinical imaging studies because of the problems associated with obtaining images demonstrating proven abnormalities and appropriate normal control images. We developed and evaluated interactive software that allows the seamless removal of abnormal areas from CT lung image sets. We have also developed interactive software for capturing lung lesions in a database where they can be added to lung CT studies. The efficacy of the software to remove abnormal areas of lung CT studies was evaluated psychophysically by having radiologists select the one altered image from a display of four. The software for adding lesions was evaluated by having radiologists classify displayed CT slices with lesions as real or artificial scaled to 3 levels of confidence. The results of these experiments demonstrated that the radiologist had difficulty in distinguishing the raw clinical images from those that had been altered. We conclude that this software can be used to create experimental normal control and "proven" lesion data sets for volumetric CT of the lung fields. We also note that this software can be easily adapted to work with other tissue besides lung and that it can be adapted to other digital imaging modalities.

6146-29, Session 6

Mammographic texture synthesis using genetic programming and clustered lumpy background

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In this work we investigated the digital synthesis of images, which mimic real textures observed in mammograms. Such images could be produced in an unlimited number with tunable statistical properties in order to study human performance and model observer performance in perception experiments.

We used the previously developed clustered lumpy background (CLB) technique and optimized its parameters with a genetic algorithm (GA). In order to maximize the realism of the textures, we combined the GA objective approach with psychophysical experiments involving the judgments of radiologists. 36 statistical features were computed and averaged, over 1000 real mammograms regions of interest. The same features were measured for the synthetic textures, and the Mahalanobis distance was used to quantify the similarity of the features between real and synthetic textures. The similarity (in terms of Mahalanobis distance) was used as GA fitness function for evolving the free CLB parameters. In the psychophysical approach, experienced radiologists were asked to qualify the realism of synthetic images by considering typical structures that are expected to be found on real mammograms: glandular and fatty areas, and fiber crossings.

Results show that CLB images found by optimization through GA are significantly closer to real mammograms than previously published images. Moreover, the psychophysical experiments confirm that all the above-mentioned structures are reproduced well on the generated images. This means that we can generate an arbitrary large database of textures mimicking mammograms with traceable statistical properties.

6146-30, Session 6

Perceptually-limited modality-adaptive medical image watermarking

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Increasingly widespread communication of medical images across multiple user systems raises concerns for image security, for which digital image watermarking offers one solution. While digital image watermarking methods have been widely studied, much less attention has been paid to their application in medical imaging situations, due partially to specula-

tions on loss in viewer performance due to degradation of image information. Such concerns are addressed if the amount of information lost due to watermarking can be kept at minimal levels and certainly well below visual perception thresholds. This paper describes a method for applying watermarks to medical images on a locally varying basis, so as to ensure that the visual impact of changes in pixel values is minimal. The method uses an adaptive approach based on 8x8 blocks of pixels, and takes into account the imaging modality and local image contents according to common perceptual information models, when determining the amount of watermark payload information to be encoded. It is assumed that a light payload is possible, and some typical examples of watermarks that might be used (e.g. patient identifiers and examination details) are provided to substantiate this position. Experimental results for a range of typical X-ray, CT and MR images are presented, and the performance of the method across a range of different choices of parameters is analysed. This would be useful in situations where images are manipulated on and transferred between many different independent image storage systems (including PACS), which would not allow the integrity of the image data to be assured.

6146-31, Session 6

Optimum ambient lighting conditions for the viewing of softcopy radiological images

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Purpose: The aim of the work is to determine the optimum ambient lighting conditions for viewing softcopy radiological images on LCD.

Materials and Methods: The study measured the diagnostic performance of observers viewing images on liquid crystal display (LCD) monitor under different ambient lighting conditions: 480, 100, 40, 25 and 7lux. An ROC analysis was performed along with quantification of false positives and false negatives as measures of diagnostic performance. A set of 30 postero-anterior wrist images was used, 15 of which had fractures present. These were evaluated by 79 American Board of Radiology certified Radiologists.

Results: The observers performed better at 40 and 25lux compared with 480 and 100 lux. At 7lux, the observers' performance was generally similar to that at 480 and 100lux.

Conclusion: Using the previously recommended ambient lighting levels of 100lux resulted in no improvement over typical office lighting of 480lux. Lower ambient lighting levels ranging from 40-25lux improves diagnostic performance over higher levels. Lowering ambient lighting to 7lux (almost complete darkness apart from the light emanating from the monitor) reduces diagnostic performance to a level equal to that of typical office lighting. It is clearly important to control ambient lighting to ensure that diagnostic performance is maximized.

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6147-01, Session 1

Evaluation of image compression for computer-aided diagnosis of breast tumors in 3D sonography

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Medical imaging examinations form the basis for physicians diagnosing diseases, as evidenced by the increasing use of digital medical images for picture archiving and communications systems (PACS). However, with enlarged medical image databases and rapid advances in storage and transmission technologies, PACS requires image compression to accelerate the image transmission rate and conserve disk space in order to reduce implementation costs. JPEG and JPEG2000 have been accepted as legal formats for the digital imaging and communications in medicine (DICOM). The high compression ratio is felt to be useful for medical imagery. Therefore, this study evaluates the compression ratios of JPEG and JPEG2000 standards for computer-aided diagnosis (CAD) of breast tumors in 3-D medical ultrasound images. The 3-D ultrasound (US) data sets with various compression ratios are compressed by using the two efficacious image compression standards. The reconstructed data sets are then diagnosed by a proposed CAD system. The diagnostic accuracy is measured based on receiver operating characteristic (ROC) analysis. ROC curves can be used to compare the diagnostic performance of two or more reconstructed images. Analysis results ensure a comparison of the compression ratios with JPEG and JPEG2000 for 3-D US images. Results of this study provide the possible bit rates using JPEG and JPEG2000 for 3-D breast US images.

6147-02, Session 1

Advanced volume rendering algorithm for ultrasound real-time 3D: integrating pre-integration into shear-image order algorithm

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3D ultrasound imaging has been gaining widespread clinical use as a visualization tool to allow clinicians to obtain unique views in real time, which is not available with traditional 2D ultrasound imaging. Unlike CT and MRI, visualization of 3D ultrasound data is challenging due to the noisy and fuzzy nature of ultrasound data and a large amount of computation required for real-time imaging. The shear-warp algorithm has been traditionally used for rendering the ultrasound data for its effectiveness at low computing cost. However, this low computing cost does come at the price of reduced image quality due to (a) the presence of final warp interpolation, which smoothes finer details, (b) sampling only at discrete slice locations, which introduces aliasing and staircase artifacts, and (c) zooming only during the warping phase, which leads to considerable blurring artifacts at zoom factors greater than 2. Two rendering methods, shear-image-order [1] and pre-integrated volume rendering [2], independent of each other, have been proposed to overcome the above limitations of shear-warp for other clinical (e.g., CT) and non-medical applications of 3D.

For real-time 3D ultrasound, we merged pre-integration and shear-image-order algorithms for improving the image quality and overcoming the limitations of the shear-warp algorithm while still maintaining the computational advantage. In this paper, we will discuss three (shear-warp, shear-image-order, and pre-integrated) volume-rendering algorithms along with our merged algorithm. We will present the results of subjective quality evaluation with synthetic and clinical phantom data sets. We will analyze the advantages and disadvantages of each of these algorithms and also present how an advanced DSP processor can be used to support each of these algorithms in real time.

[1] Y. Wu, V. Bhatia, H. Lauer, and L. Seiler, "Shear-image order ray casting volume rendering," Proceedings of the 2003 Symposium on Interactive 3D Graphics, April 2003, pp. 153-168.

[2] J. P. Schulze, M. Kraus, U. Lang and T. Ertl, "Integrating pre-integration into the shear-warp algorithm," Proceedings of the Third International Workshop on Volume Graphics, Tokyo, July 2003, pp. 109-118.

6147-03, Session 1

Real-time transrectal 3D ultrasound using synthetic aperture

J. Yen, N. M. Daher, C. Seo, Univ. of Southern California

Abstract - In previous work, we investigated 3-D synthetic aperture imaging with 2-D array designs for real-time rectilinear volumetric imaging of targets near the transducer such as the breast and carotid artery. Here we present results for cylindrical 3-D imaging for 3-D transrectal ultrasound (TRUS). The main benefit of this design is the interconnect where an expensive multilayer flex circuit is no longer required. The interconnect uses a row-column addressing scheme to enable different groups of elements. Over multiple transmissions, this design is capable of synthesizing a 256 x 256 = 65,536 element fully sampled 2-D cylindrical array if desired. In receive, the echoes from individual elements along a row are recorded by the system receive channels. For faster volume acquisition time, we present a design where all elements of the 2-D array transmit simultaneously, and signals are recorded one row at a time. For a depth of 6 cm, a volume rate of 50 volumes/s can be achieved. We have performed computer simulations of a 10 MHz 256 x 256 synthetic 2-D array to determine the radiation pattern. For an F/2 aperture, the on-axis case (x,y,z) = (0,0,20) mm showed a narrow beam down to -45 dB. In the azimuth direction, on-axis lateral beamwidths at -6, -20, and -40 dB were 0.47 mm , 0.81 mm, and 2.54 mm, respectively. As a tradeoff, elevational beamwidths were wider with on-axis beamwidths of 0.52 mm, 1.23 mm, and 3.21 mm for the same corresponding dB levels.

6147-04, Session 1

High resolution 3D prostate ultrasound imaging

Y. Li, J. A. Hossack, Univ. of Virginia

A new dedicated, high resolution, 3D capable transducer has been designed and built. This transducer operates at up to 14 MHz and possesses resolution approximately 200 microns laterally and 100 microns axially. The high frequency and long aperture (39.2mm) enable possibly the highest prostate ultrasound imaging resolution yet achieved. The transducer is configured as an 'I-Beam' transducer [1] with tracking arrays mounted integrally on the tip so as to facilitate efficient, accurate and rapid acquisition of 3D prostate volumes so that the volumetric extent and location of individual suspected cancers may be identified. Garra et al. [2] had proposed a cancer classification approach based on the size (shape) of the cancer as estimated from the elastographic (strain) images. It is well known that the benign cancers manifest different shapes from those of the malignant cancers. Hence, estimating the shape and size of cancers based on 3D volume (tomography) imaging holds a key to increasing the sensitivity and the specificity of prostate cancer detection using elastographic (elasticity imaging) techniques.

This transducer comprises 192, 8-14MHz elements on a 0.2 mm pitch for Imaging and two pairs of 32 elements, also on a 0.2 mm pitch, for Tracking in 3D space. We have previously demonstrated that the volume reconstruction accuracy of an I-Beam transducer was better than 5 % in the reconstructed dimension - i.e. the elevational dimension with respect to the central 'Imaging' array. The transducer also possesses the facility to inflate a water filled sheath over the transducer so as to enable a 'Synthetic Digital Rectal Examination'. Initial phantom results with the new transducer are presented describing the ability of the transducer to both detect small, deep elastic inhomogeneities and to reconstruct volumes. We plan to conduct human studies in the near future once our techniques are optimized and patient studies institutional permission is received.

6147-05, Session 1

Breast tumor angiogenesis analysis using 3D power Doppler ultrasound

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Angiogenesis is the process that correlates to tumor growth, invasion, and metastasis. Breast cancer angiogenesis has been the most extensively studied and now serves as a paradigm for understanding the biology of angiogenesis and its effects on tumor outcome and patient prognosis. Most studies on characterization of angiogenesis focus on pixel/voxel counts more than morphological analysis. Nevertheless, in cancer, the blood flow is greatly affected by the morphological changes, such as the number of vessels, branching pattern, length, and diameter. This paper presents a computer-aided diagnostic (CAD) system that can quantify vascular morphology using 3-D power Doppler ultrasound (US) on breast tumors. We propose a scheme to extract the morphological information from angiography and to relate them to tumor diagnosis outcome. At first, a 3-D thinning algorithm helps narrow down the vessels into their skeletons. The measurements of vascular morphology significantly rely on the traversing of the vascular trees produced from skeletons. Our study of 3-D assessment of vascular morphological features regards vessel count, length, bifurcation, and diameter of vessels. Investigations into 221 solid breast tumors including 110 benign and 111 malignant cases, the p values using the Student's t-test for all features were less than 0.05 indicating that the proposed features were deemed statistically significant. Our scheme focuses on the vascular architecture without involving the technique of tumor segmentation. The results show that the proposed method is feasible, and have a good agreement with the diagnosis of the pathologists.

6147-06, Session 1

Multiview 3D reconstruction with volumetric registration in a freehand ultrasound imaging system

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Abstract - In this paper, we describe a new freehand ultrasound imaging system for reconstructing 3D objects from 2D slices. An important contribution of the proposed system is its ability to reconstruct from multiple standard views. The multi-view reconstruction procedure results in significant reduction in reconstruction error. The system uses object-based 3D volumetric registration, allowing for arbitrary rigid object movements in inter-view acquisition. Furthermore, a new segmentation procedure that combines level set methods with gradient vector flow is used for automatically segmenting 2D echocardiographic images, in which high level of speckle noise, weak boundaries and boundary gaps are common. The new segmentation approach is expected to be robust to these artifacts. The segmentation algorithm robustness is assessed by comparison to manual segmentation.

The proposed system has been validated on simulated data and a physical, 3D ultrasound calibration phantom. Quantitative experimental results demonstrate the effectiveness of the new 3D reconstruction system, and a significant reduction in the mean-squared error via the registered multiview reconstruction method. We are currently also testing and validating the system on reconstructions of the left ventricle. We will report our findings on multi-view reconstruction of the left ventricle in the full paper.

6147-07, Session 1

Boundary detection in 3D ultrasound reconstruction using nearest neighbor map

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Ultrasound imaging is a noninvasive technique well-suited for detecting abnormalities like cysts, lesions and blood clot. In order to use 3D ultrasound to visualize the size and shape of such abnormalities, effective boundary detection methods are needed. A robust boundary detection technique using a nearest neighbor map (NNM) applicable to multi-object cases has been developed. The algorithm contains three modules: pre-processor, main processor and boundary constructor. The pre-processor detects the object(s), obtains geometrical as well as statistical information, whereas the main processor uses that information to perform the final processing of the image. The first two modules perform image normalization, thresholding, filtering using median, wavelet, Wiener and morphological filters, estimation and boundary detection of object(s) using NNM, calculation of object size and their location. The boundary constructor module implements an active contour model that uses information from previous modules to obtain seed-point(s). The proposed algorithm is found to offer high boundary detection accuracy of 98.9% for single scan plane (SSP) and 96.2% for multiple scan plane (MSP) images. The algorithm has been compared with Stick's algorithm and Gibbs Joint Probability Function based algorithm and was found to offer lower execution time with higher accuracy than either of them. SSP simulated ultrasound images, SSP real ultrasound images, MSP phantom images and MSP simulated ultrasound images were processed. The proposed algorithm provides an area estimate of the target object(s), which along with position information of the ultrasound transducer can be used to calculate the object volume(s) for 3D visualization of object(s).

6147-08, Session 2

Automatic time gain compensation and dynamic range control in ultrasound imaging systems

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For efficient and accurate diagnosis of ultrasound images, the time gain compensation (TGC) and dynamic range (DR) control of the ultrasound echo signal are important. TGC is for compensating the attenuation of the ultrasound echo signal along the depth, and DR is used to control the image contrast. In recent ultrasound systems, these two factors are automatically set by the system and/or manually adjusted by an operator to obtain a desired image on the screen. In this paper, we propose an algorithm to find the optimized values of TGC and DR automatically. Since the attenuation of US echo signal can be approximated as an exponential curve and a US image is obtained after log compression of the echo signal, the image attenuation can be modeled as a linear line. Therefore, for TGC optimization, we determine a linear image attenuation function using the least squares fit technique. Then, based the slope of determined attenuation line, we compensate the intensity along the depth. For DR optimization, we first measure the two characteristics, edge contrast and background roughness, of US images according to the change of DR. Then, we propose a novel cost function, which has the minimum value for the optimized DR producing an image with high edge contrast and low background roughness. Experimental results show that the proposed algorithm automatically set the values of TGC and DR so that the subjective quality of the corresponding US image is good enough for efficient and accurate diagnosis.

6147-09, Session 2

An iterative, wavelet-based deconvolution algorithm for the restoration of ultrasound images in an EM framework

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The quality of medical ultrasound images is limited by inherent poor resolution due to the finite temporal bandwidth of the acoustic pulse and the non-negligible width of the system point-spread function. One of the major difficulties in designing a practical and effective restoration algorithm is to develop a model for the tissue reflectivity that can adequately capture significant image features without being computationally prohibitive. The reflectivities of biological tissues do not exhibit the piecewise smooth char-

acteristics of natural images considered in the standard image processing literature; while the macroscopic variations in echogenicity are indeed piecewise smooth, the presence of sub-wavelength scatterers adds a pseudo-random component at the microscopic level. This observation leads us to propose modelling the tissue reflectivity as the product of a piecewise smooth echogenicity map and a unit-variance random field. The chief advantage of such an explicit representation is that it allows us to exploit representations for piecewise smooth functions (such as wavelet bases) in modelling variations in echogenicity without neglecting the microscopic pseudo-random detail. As an example of how this multiplicative model may be exploited, we propose an expectation-maximisation (EM) restoration algorithm that alternates between inverse filtering (to estimate the tissue reflectivity) and logarithmic wavelet denoising (to estimate the echogenicity map). We provide simulation and in vitro results to demonstrate that our proposed algorithm yields solutions that enjoy higher resolution, better contrast and greater fidelity to the tissue reflectivity compared with the current state-of-the-art in ultrasound image restoration.

6147-11, Session 2

The sonic window: second generation results

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Medical Ultrasound Imaging is widely used clinically because of its relatively low cost, portability, lack of ionizing radiation, and real-time nature. However, even with these advantages ultrasound has failed to permeate the broad array of clinical applications where its use could be of value. A prime example of this untapped potential is the routine use of ultrasound to guide intravenous access. In this particular application existing systems lack the required portability, low cost, and ease-of-use required for widespread acceptance.

Our team has been working for a number of years to develop an extremely low-cost, pocket-sized, and intuitive ultrasound imaging system that we refer to as the "Sonic Window." We have previously described the first generation Sonic Window prototype that was a bench-top device using a 1024 element, fully populated array operating at a center frequency of 3.3 MHz. Through a high degree of custom front-end integration combined with multiplexing down to a 2 channel PC based digitizer this system acquired a full set of RF data over a course of 512 transmit events. While initial results were encouraging, this system exhibited limitations resulting from low SNR, relatively coarse array sampling, and relatively slow data acquisition.

We have recently begun assembling a second-generation Sonic Window system. This system uses a 3600 element fully sampled array operating at 5.0 MHz with a 300 micron element pitch. This system extends the integration of the first generation system to include front-end protection, pre-amplification, a programmable bandpass filter, four sample and holds, and four A/D converters for all 3600 channels in a set of custom integrated circuits with a combined area smaller than the 1.8 x 1.8 cm footprint of the transducer array. We present initial results from this front-end and present benchmark results from a software beamformer implemented on the Analog Devices BF-561 DSP. We discuss our immediate plans for further integration and testing. This second prototype represents a major reduction in size and forms the foundation of a fully functional, fully integrated, pocket sized prototype.

6147-12, Session 2

Efficient array beamformer using spatial filtering for ultrasound B-mode imaging

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We propose an efficient array beamformer using spatial matched filtering. In the proposed method, ultrasound waves are transmitted from an array subaperture with fixed transmit focus as in conventional array imaging. At receive, radio frequency (RF) echo signals from each receive channel are passed through a spatial matched filter that is constructed based on the system transmit-receive spatial impulse response. The filtered echo signals are then summed. The filter remaps and spatially registers the acoustic energy from each element so that the pulse-echo impulse response of the summed output is focused with acceptably low side lobes.

Analytical beam pattern analysis and simulation results using a linear array show that the proposed spatial matched filtering method can provide more improved spatial resolution and contrast-to-noise ratio (CNR) compared with conventional dynamic receive focusing (DRF) method by implementing two-way dynamically focused beam pattern throughout the field.

We tested the predictions experimentally using an f/1.5, 8-ring annular array with 10 MHz center frequency focused geometrically at 45 mm. The -6 dB beam width measured with spatial filtering and DRF were measured to be 0.13 mm and 16.64 mm, respectively, at a depth of 25 mm.

Spatial filtering was applied to the design of high frequency arrays for small animal imaging where delay and sum beamforming is problematic. Predictions of beam properties at 70 MHz will be presented.

6147-13, Session 2

Recursive delay calculation unit for parametric beamformer

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This paper suggests a recursive approach for parametric delay calculations for a beamformer. The suggested calculation procedure is capable of calculating the delays for any image line defined by an origin and arbitrary direction. It involves only multiply-and-accumulate operations (MAC) making it suitable for hardware implementation. One delay-calculation unit (DCU) needs 6 parameters and all operations can be implemented using fixed-point arithmetics. An N-channel system needs N+1 DCUs per line - one for the distance from the transmit origin to the image point and N for the distances from the image point to each of the receivers.

Each DCU recursively calculates the square of the distance between a transducer element and a point on the beamformed line. Then it finds the approximate square root using Newton's method. The latter operation involves a multiplication with the reciprocal of the distance, which again is calculated using Newton's method. The distance and its reciprocal calculated for point i are used as an initial guess in the Newton's equations for point i+1. Both calculations converge in a single iteration. The basic algorithm involves 5 multiplications, 3 additions, 2 subtractions and 2 shift operations.

The method has been tested using floating-point and fixed-point arithmetics. The precision of the delay calculation using floating point is on the order of 10^{-11} samples. Using fixed-point calculations with 36-bit precision gives an error in the delay calculations on the order of 10^{-2} samples, at a sampling frequency of fs = 40 MHz.

6147-14, Session 2

Breaking the resolution limit: an exciting experimental result

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For more than a century it has believed that the resolving power of an imaging system is limited by the wavelength, λ, that can be propagated according to the "Diffraction Limit" (DL), which excludes the possibility of achieving subwavelength resolution. This implies that in order to achieve high resolution, very short wavelengths need to be propagated. However, as λ decreases the wave experiences an increasing attenuation, which ultimately reduces the maximum imaging depth, this being the major limitation of current ultrasonic and microwave imaging systems.

Recent progress in microscopy has shown that by exploiting the super-oscillatory properties of evanescent fields, resolution several orders of magnitude smaller than the wavelength can be achieved so leading to Near-field Scanning Optical Microscopy. Based on a similar argument, this paper investigates the possibility of obtaining super resolution in the far-field (here far-field refers to a distance greater than λ), which would

enable high resolution imaging at relatively large depth. The theoretical principles which result in the DL are reviewed and a new strategy to overcome it is proposed. An advanced imaging algorithm for linear and two-dimensional array probing systems is presented and its capability of resolving targets as close as λ/3 is demonstrated experimentally, the targets being at several wavelength distance from the array. The results show that the method is superior to conventional techniques such as Synthetic Aperture Focusing, Synthetic Phased Arrays and Time Reversal.

6147-36, Session 2

Beamforming and hardware design for a multichannel front-end integrated circuit for real-time 3D catheter-based ultrasonic imaging

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We present the design of a multichannel front-end integrated circuit (IC) for a catheter-based 3D ultrasound imaging system. The IC is designed to be flip-chip bonded to a 16x16-element capacitive micromachined ultrasound transducer (CMUT) array. We consider CMUT arrays with center frequencies of 3 MHz to 7 MHz and with 250-um and 150-um pitches. The IC is designed to interface to an FPGA-based data acquisition system with 16 channels of analog-to-digital converters (ADCs).

Given a fixed number of transducer array elements and dedicated receive channels, beamforming is one of the primary considerations for the front-end IC design. We evaluated simulations of a number of beamforming strategies. The strategy chosen based on these simulations uses the 32 elements along the diagonals of the 2D array for receive, and the remaining 224 elements for transmit. To form focused and steerable transmit beams with the 224 transmitting elements delay information is serially loaded into a series of registers on the IC. Each register controls the timing of a pulser circuit. We use 32x32 beam lines to form a single 90_90 image frame. Each beam requires two transmissions to acquire echo signals from the 32 receive elements using only 16 ADC channels. For an imaging depth of 30 mm, the maximum frame rate is 12 frames per second. Compared with classic phased array (CPA) imaging, the point spread function (PSF) is only slightly degraded and the image signal-to-noise ratio is just 10 dB worse. Compared with the classic synthetic aperture (CSA) imaging used in our initial implementation of a front-end IC, the SNR is 38 dB better and the effects of the grating lobes imposed by CSA are eliminated.

6147-15, Session 3

Remote consulting based on ultrasound digital immages and dynamic ultrasound sequences

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Telematic ultrasound diagnostics is a relatively new tool in providing health care to patients in remote, islolated communities. Our project facility, «The Virtual Polyclinic - A Specialists' Consulting Network for the Islands», is located on the island of Cres in the Adriatic Sea in Croatia and has been extending telemedical services to the archipelago population since 2000. Telemedicine applications include consulting services by specialists at the University Clinical Hospital Center Rebro in Zagreb and at «Magdalena», a leading cardiology clinic in Croatia. After several years of experience with static high resolution ultrasound digital immages for the consulting diagnostics purposes, we now also use dynamic ultrasound sequences in a project with the Department of Emmergency Gastroenterology at Rebro in Zagreb. The aim of the ongoing project is to compare the advantages and shortcomings in transmitting static ultrasound digital immages and live sequences of ultrasound examination in remote diagnostics. Ultrasound examination is a dynamic process in which the diagnostic accuracy is highly dependent on the dynamic moment of an ultrasound probe and signal. Our first results indicate that in diffuse parenchymal organ pathology the progression and the follow up of a disease is better presented to a remote consulting specialist by dynamic ultrasound sequences. However, the changes that involve only one part of a parenchymal organ can be suitably presented by static ultrasound digital immages alone. Furthermore, we need less time for digital immaging and such tele-consultations overall are more economical. Our previous telemedicine research and practice proved that we can greatly improve the level of medical care in remote healthcare facilities and cut healthcare costs considerably. Early experience in the ongoing project points to a conclusion that we can further optimize remote diagnostics benefits by a right choice of telematic application thus reaching a correct diagnosis and starting an applicable therapy even faster. Nevertheless, a successful implementation of such diagnostics methods may require further improvements in telemedical systems.

6147-16, Session 3

Quantitative ultrasound imaging of healthy and reconstruted cleft lips: a feasibility study

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The feasibility was investigated of quantitative echographic imaging of the various tissues in healthy lip and in reconstructed cleft lip and estimating the size and the echo level of these tissues.

Three healthy subjects and two patients with reconstructed cleft lips were examined. Echographic images were made with commercial medical ultrasound equipment, using a linear array transducer (7-11 MHz bandwidth) and non-contact gel coupling. Tissue dimensions were measured by means of calipers. Echolevels were calibrated and corrected for beam characteristics, gel path and tissue attenuation by using a tissue mimicking phantom.

At central position, mean thickness (and standard deviation) of lip parenchyma, m. orbicularis oris and glandular layer was 4.0 (sd 0.1) mm, 2.3 (sd 0.7) mm, 2.2 (sd 0.7) mm, respectively, in healthy lip at rest. Mean (sd) echolevel of muscle and glandular tissue with respect to echo level of lip parenchyma was in relaxed condition: - 44 (sd 4) dB and - 23 (sd 7) dB. Echolevel of parenchyma was - 20 (sd 6) dB relative to phantom echo level obtained in the focus of the transducer. Color mode echo images were calculated after adaptive filtering of the images which show the tissues in separate colors and highlight the details of reconstructed cleft lip. It is concluded that quantitative assessment of thickness and echo level of various lip tissues is feasible after proper calibration of the echographic equipment. Diagnostic potentials for non-invasive evaluation of the quality of cleft lip reconstruction are promising.

6147-17, Session 3

Integrated system for ultrasonic, photoacoustic and elasticity imaging

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No abstract available

6147-18, Session 3

Ultrasonic imaging with time-reversed ultrasound

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The Time-Reversal Mirror (TRM) is an emerging technology that focuses ultrasonic signals back to their origins/scatterers. It is based on time-reversal invariance inherent in wave propagation, and is a simple and ingenious way to use measured signals to recreate origins (e.g., tumors) that generate/scatter ultrasonic waves. We make use of the principle of TRM to de-

velop an image-reconstruction method for ultrasonic breast imaging. The new method uses full waveforms of recorded ultrasonic data and the principle of TRM for image reconstruction on computers. We present preliminary imaging results of in-vivo ultrasonic breast data that were collected using a clinical prototype scanner with ring transducer array. The imaging results demonstrate that the TRM-based imaging method in combination with the ultrasonic scanner having ring transducer array has the potential to produce high-quality and high-resolution breast images.

6147-19, Session 3

Detection of brachytherapy seeds using ultrasound radio frequency signals

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This paper proposed a novel ultrasonic imaging approach for detecting brachytherapy seeds. Accurate and fast seed localization plays a key role in computing dosimetry for prostate brachytherapy. However, currently used B-mode transrectal ultrasound (TRUS) does not adequately visualize implanted seeds, because the diameter of the seed is quite small and visualization is hampered by speckle noise and angulation of the specular reflection of the seeds. Based on the fact that much more ultrasound wave energy is reflected from metal seeds than from other scatterers in tissue, we developed a new seed detection method directly using ultrasound radio frequency (RF) signals (the raw high frequency echoes before the formation of B-mode TRUS images). It monitors the average power (a version of 2-norm) of the RF signals to measure the reflected wave energy. Each RF scan line is subdivided into a sequence of short segments with the same length and spacing. The average power of each segment is computed by the Fourier based spectra or parametric spectral analysis approaches. In the new method, the logarithmic compression is not applied to the raw RF data, and the average power is proportional to the sum of the square of the signal amplitude. Therefore, it produces significantly higher contrast than conventional B-mode TRUS. Furthermore, the average power algorithm can be implemented very efficiently since no numerical optimization is required. Phantom and ex-vivo experiments show that the average power technique successfully detects implanted brachytherapy seeds, and produces superior results compared with B-mode TRUS imaging.

6147-20, Session 3

Investigation of foreign objects in soft-tissue by a PE-CMOS ultrasound system: a preliminary comparative study

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Radiographs are commonly used to search for foreign matters: some is radiopaque, other is radiolucent. When it is visible, the usually method of retrieval is to place localizing needles near the wound, take a radiograph, and then triangulate from the needles to the site of the foreign matter. What is usually not done is direct observation using a fluoroscope - in part because of the radiation exposure that occurs; in part because many of the foreign objects cast no shadow.

In this study, we used a projection ultrasound system (Acoustocam made by Imperium Inc.) to investigate the potential of finding foreign objections in the soft-tissue. The system consists of an unfocused transducer, compound acoustic lens, and a CMOS based two-dimensional ultrasound sensor array.

As an initial in vitro study, we inserted some foreign objects into a slab of pork in a water tank to prevent bubbles. The pork is composed of skin, fat, and muscle. The foreign objects used were wood sticks, plastic sticks, glasses, and aluminum samples. Each object was inserted from skin to the fat tissue layer and penetrated into the muscle layer.

The images of the pork were taken by the Acoustocam, a B-scan ultrasound system, a conventional x-ray, and a computerized radiography X-ray (CR) system. We found that the aluminum and glass objects can be seen in the X-ray images. However the wood and plastic sticks are not clearly observable. The B-scan ultrasound images show wood sticks, plastic sticks and glasses inside the pork. Due to the speckle, small objects were not clearly visible. In addition, one of the thin aluminum samples can also be seen on the B-scan ultrasound images. The Acoustocam images show the fold fibro structures of fat and muscle tissues as well as all the foreign objects except the thinnest aluminum sample.

6147-21, Session 3

Image stitching for three-pass whole breast ultrasound

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Early detection through screening is the best defense against morbidity and mortality from breast cancers. Mammography is the most used screening tool for detecting early breast cancer because it can easily obtain the view of whole breast. However, because the ultrasound images are cross-sectional images, not projection images like mammography, and the ultrasound probe does not fully cover the breast width, it is not a convenient screening tool when adjunct with screening mammography. The physician needs a lot of examination time to perform the breast screening. Recently, some whole breast ultrasound scanning machines are developed. The examination could be performed by an experienced technician. Because the probe width still does not fully cover the breast width, several scanning passes are required to obtain the whole breast image. The physician still cannot have a full view of breast. In this paper, an image stitching technique is proposed to stitch multi-pass images into a full-view image. The produced full-view image can reveal the breast anatomy and assists physicians to reduce extra manual adjustment.

6147-22, Session 4

A scalable beamforming architecture for real-time 3D ultrasonic imaging using nonuniform sampling

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Real-time acquisition of 3D volumes is an emerging trend in medical imaging. True real-time 3D ultrasonic imaging is particularly valuable for echocardiography and trauma imaging as well as an intra-operative imaging technique for surgical navigation. Since the frame rate of ultrasonic imaging is fundamentally limited by the speed of sound, many schemes of forming multiple receive beams with a single transmit event have been proposed. With the advent of parallel receive beamforming, several architectures to form multiple (4-8) scan lines at a time have been suggested. Most of these architectures employ uniform sampling and input memory banks to store the samples acquired from all the channels. Some recent developments like crossed electrode array, coded excitation, and synthetic aperture imaging facilitate forming an entire 2D plane with a single transmit event. These techniques are speeding up frame rate to eventually accomplish true real-time 3D ultrasonic imaging. We present an FPGA-based scalable architecture capable of forming a complete scan plane in the time it usually takes to form a single scan line. Our current implementation supports 32 input channels per FPGA and up to 200 dynamically focused beam outputs. The desired focusing delay resolution is achieved using a hybrid scheme, with a combination of nonuniform sampling of the analog channels and linear interpolation for nonsparse delays within a user-specified minimum sampling interval. Overall, our pipelined architecture is capable of processing the input RF data in an online fashion, thereby reducing the input storage requirements and potentially providing better image quality.

6147-23, Session 4

Three-dimensional segmentation of the heart muscle using image statistics

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Segmentation of the heart muscle in 3D echocardiographic images provides a tool for visualization of cardiac anatomy and assessment of heart function, and serves as an important pre-processing step for cardiac strain imaging. By incorporating spatial and temporal information of 3D ultrasound image sequences (4D), a fully automated method using image statistics was developed to perform 3D segmentation of the heart muscle. 3D rf-data were acquired with a Philips SONOS 7500 live 3D ultrasound system, and an X4 matrix array transducer (2-4 MHz). Left ventricle images of three healthy children were taken in transthoracial short/long axis view. As a first step, image statistics of blood and heart muscle were investigated. Next, based on these statistics, an adaptive mean squares filter was applied to the image. Window size was related to speckle size (5x2 speckles). The degree of adaptive filtering was automatically steered by the local homogeneity of tissue. As a result, discrimination of heart muscle and blood was optimized, while sharpness of edges was preserved. After this processing stage, homomorphic filtering and automatic thresholding were performed to obtain the inner borders of the heart muscle. Finally, a deformable contour algorithm was used to yield a closed contour of the left ventricular cavity in each elevational plane. Each contour was optimized using contours of the surrounding planes (spatial and temporal) as limiting condition to ensure spatial and temporal continuity.

Better segmentation of the ventricle was obtained using 4D information than using information of each plane separately.

6147-24, Session 4

Cardiac current mapping using the acousto-electric effect

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Conventional methods for diagnosing electrophysiological lack either spatial resolution (e.g. ECG) or are very time consuming (intra-cardiac catheter electrode mapping.)

We present a method, based on the acousto-electric effect (AEE), for potentially mapping the current distribution of the heart rapidly with high spatial resolution. The AEE is a pressure-induced conductivity modulation, where focused ultrasound can be used as spatially localized pressure source. If an ultrasound beam is focused between a pair of electrodes in a homogeneous conductive medium, the voltage recorded by the electrodes will be a product of the pressure modulated conductivity and the local current density. As the current density at the ultrasound focus changes with time, as it would in the heart, the amplitude of the voltage will change proportionally.

Preliminary experiments demonstrate the feasibility of this method. A 540 kHz ultrasound transducer is focused between two tin electrodes lying parallel to the beam axis. These electrodes inject current into a 0.9% saline solution. A pair of insulated stainless steel electrodes exposed at the tip is used to record the voltage signal. To simulate a cardiac current, a low frequency current waveform is injected into the sample. The transducer is pulsed at different delays after waveform initiation. Delays are chosen such that the low frequency waveform is adequately sampled. In this manner an ECG waveform has been successfully reconstructed from the ultrasound modulated voltage traces. In-vitro experiments using an excised heart are planned.

6147-25, Session 4

Towards real-time endocardial boundary detection from intracardiac echocardiographic images: a comparative study

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In this paper a novel method is proposed for live endocardial boundary identification. The goal is to achieve an optimal solution to the problem of real-time automatic detection and tracking of endocardial border in ultrasonic image sequences acquired through IntraCardiac Echocardiography (ICE). Border identification of 2D ultrasonic images, which normally consists of a number of stages namely preprocessing, segmentation, detection and visualization of the border, is a cumbersome task. ICE's potential in guidance of minimally invasive interventions requires online boundary detection of its inherently less speckled images. Numerous studies have addressed this issue in echographic images by proposing various methods applicable at each stage. With this repository of methods available, a comparative study is performed on single-image segmentation approaches. An algorithm based on order-statistics operators is proposed to achieve fast border delineation in a sequence of images. This method can outperform other approaches in terms of time and robustness, and does not require user interaction.

6147-26, Session 4

Novel spatiotemporal voxel interpolation with multibeat fusion for 3D echocardiography with irregular data distribution

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We developed a novel multi-beat image fusion technique using a special spatiotemporal interpolation for sparse, irregularly sampled data (ISI). It is applied to irregularly distributed 3D cardiac ultrasound data acquired with a fast rotating ultrasound (FRU) transducer. ISI is based on Normalized Convolution with Gaussian kernels tuned to irregular beam data spacing over cardiac phase (p), and beam rotation (θ) and elevation angles (ϕ).

Methods: images are acquired with the FRU transducer developed in our laboratory, a linear array rotating mechanically at very high speed (240-480rpm). High-quality 2D images are acquired at ~100 frames/s over 5-10 seconds. ECG is recorded simultaneously. Images are irregularly distributed over p and θ, because rotation is not synchronized to heartrate. ISI was compared quantitatively to spatiotemporal nearest neighbor interpolation (STNI) on synthetic (distance function) data of a pulsating ellipsoid for 32 angles (θ) and 37 phases (p). ISI was also tested qualitatively on 20 in-vivo cardiac image sets and compared to classical temporal binning with trilinear voxel interpolation, at resolutions of 128*128*400 for 16 phases.

Results: From the synthetic data simulations, ISI showed absolute distance errors (mean±SD) of 1.23 ± 1.52mm; considerably lower than for STNI (3.45 ± 3.03mm). For in-vivo images, ISI voxel sets showed reduced motion artifacts, suppression of noise and interpolation artifacts and better delineation of endocardium.

Conclusions: ISI improves the quality of 3D+T images acquired with a fast rotating transducer in simulated and in-vivo data. It may also be useful for similar spatiotemporal irregularly distributed data, e.g. freehand 3D echocardiography.

6147-27, Session 4

Development of a high frame rate ultrasonic system for cardiac imaging in small animals

L. Sun, J. M. Cannata, Univ. of Southern California; J. Johnson, Capistrano Labs., Inc.; J. Yen, Univ. of Southern California; C. C. Feng, Capistrano Labs., Inc.; K. K. Shung, Univ. of Southern California

Ultrasound imaging is a well established technology for echocardiography on humans. For cardiac imaging in small animals whose hearts beat at a rate higher than 200 beats per minute, the spatial and temporal resolutions of current clinical ultrasonic scanners are far from ideal and simply inadequate for such applications.

In this research, a real-time high frequency ultrasound imaging system was developed with a frame rate higher than 100Hz for cardiac applications in small animals. The device designed and fabricated has a mechanical sector scanner using magnetic drive mechanism to reduce moving parts and ensure long life. A single element transducer was specially designed and constructed with very light weight of about 0.5 gram to achieve a frame rate of at least 100Hz, sweeping through an arc at the end of a pendulum for imaging the heart of small animals at a frequency from 30 to 50 MHz. The imaging electronics consist of a low noise pulser/receiver, a high-speed data acquisition board, and fast scan conversion and signal processing algorithms for large amount of data processing and real time display. In vivo results on mouse and mouse embryo showed that real time ultrasound imaging at higher frame rate (100 fps) could demonstrate more detailed depiction of cardiac functions with a spatial resolution of around 50 micrometers, which allows researchers to fully examine and monitor small animal cardiac functions.

6147-28, Poster Session

Fully sampled, 3600 element, two dimensional transducer array for low cost C-scan imaging

M. D. Eames, S. Zhou, J. A. Hossack, Univ. of Virginia

We have been investigating techniques for fabricating high channel count, fully sampled 2D arrays for several years with the objective of applying the technology to low cost C-Scan imaging. Our previous array possessed 32 x 32 (1024) elements and had a relatively low center frequency (3 MHz). We have modified our design in a number of fundamental ways to now yield a 60 x 60 (3600) element 5 MHz 2D array. The transducer is formed on a FR-4 glass reinforced plastic substrate with metalized through holes. This approach enables the 'signal' connection to each of all 3600 elements. The ground return is formed using a continuous gold plated polyester sheet that is bonded across the top of all elements. We present a combination of finite element simulations and experimentally measured results for both impedance and pulse-echo waveforms. Systematic testing of all 3600 elements has not been possible yet but based on our test of approximately 5% of the elements we are achieving approximately 98+% working elements - excluding 'edge' elements where the live element yield is slightly lower. In operation in the prototype scanner, electrical connection to each element is provided by sandwiching the transducer board with exposed matrix of metal pads to a 'fanout' circuit via a compressed Z-axis conductive polymer sheet.

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6147-29, Poster Session

Ultrasound image deconvolution in symmetrical mirror wavelet bases

W. Yeoh, C. Zhang, M. Chen, M. Yan, Nanyang Technological Univ. (Singapore)

This paper presents a new wavelet based deconvolution method for medical ultrasound imaging. It is known that observed radio frequency ultrasound images are degraded representations of tissue structures due to the two-dimensional (2-D) convolution of the biological tissues with the ultrasonic 2-D point spread function (PSF). And resultant images are further contaminated by additive noise.

In image processing, wavelets have been well known for its excellent performance in image denoising and compression. Its property of sparse signal representation enables noise reduction and image compression to be achieved with a simple threshold operation. Wavelet deconvolution consists of an inversion of the observed image with the 2-D PSF and followed by denoising in the wavelet basis.

Since the ultrasonic 2-D PSF is typically a band-limited frequency response, there will be almost null in the out-of-band frequencies. Inverting the observed ultrasound image with the 2-D PSF in presence of the additive noise amplifies the noise and causes it to become color in the neighborhood of these frequencies. Under this condition, the noise covariance will not be diagonal and the existing dyadic wavelet decomposition cannot concentrate the noise energy into few coefficients. This degrades the effectiveness of the thresholding operator in removing the noise.

In view of this, we design a new orthogonal symmetrical mirror wavelet basis that provides the required frequency resolution. Denoising is then accomplished by modeling the tissue structures with generalized Gaussian density function and under Bayesian philosophy. The deconvolved images are shaper and more appealing for human visualization.

6147-30, Poster Session

Plane wave fast color flow mode imaging: parameter study

I. Bolic, Danmarks Tekniske Univ. (Denmark); J. Udesen, Danmarks Tekniske Univ. (Denmark) and B-K Medical A/S (Denmark); F. Gran, J. A. Jensen, Danmarks Tekniske Univ. (Denmark)

The main purpose of Color Doppler ultrasound systems is to show an image of the blood velocity, in real time, in order to diagnose cardiovascular diseases. However, conventional ultrasound color flow mode (CFM) imaging has a low frame rate (<20 Hz). The new method, "Plane wave fast color flow mode imaging method" (PWM) is a method with a significantly higher frame rate (~1000 Hz) than conventional ultrasound CFM imaging, which could be beneficial in e.g. cardiac imaging, in larger blood vessels CFM imaging or in 3-D blood velocity estimation. The PWM is based on using a plane wave excitation with temporal encoding, the data are beamformed along the direction of the flow, and velocity is found by cross correlation. The PWM has previously been used for blood velocity estimation and it has shown some promising results (Udesen et.al. 2005).

This paper presents an experimental investigation of PWM using "Directional Velocity Estimation" (Jensen 2003). A parameter study is performed to investigate the reliability of the PWM for different beam to flow angles and its robustness. The center of the tube, with radius of 6 mm, was placed at a depth of 52 mm and 1000 pulse-echo acquisitions were made, for different beam to flow angles, namely 45 deg., 60 deg. and 75 deg. The peak velocity in the center of the tube was 0.3 m/s. The velocity profile is estimated with a best mean standard deviation relative to peak velocity of 1.73 % for 45 deg. angle, 1.57 % for 60 deg. angle and 1.72 % for 75 deg. angle.

6147-31, Poster Session

Comparison of fusion techniques for spatial compounding, with application to 3D breast ultrasound imaging

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Standard spatial compounding, via averaging acquisitions from different angles, has proved to be an efficient technique for speckle pattern reduc-

tion in ultrasound B-mode images. However, the resulting images may be blurred due to the averaging of point spread functions and the misalignment of the different views. These blurring artefacts result in a loss of important anatomical features that may be critical for medical diagnosis.

In this paper, we evaluate some spatial compounding techniques, focusing on how to combine the different acquisitions. The evaluated methods are: weighed averaging, wavelet coefficient fusion and multiview deconvolution. To some extent, these techniques take into account the limitations of spatial compounding, by proposing alternative fusion methods that can reduce speckle artefacts while preserving standard spatial resolution and anatomical features.

We experimented these compounding methods with synthetic images to show that these advanced techniques could outperform traditional averaging. In particular, multiview deconvolution techniques performed best, showing improvement in respect to averaging (6.81 dB) for realistic levels of speckle noise and spatial degradation. Wavelet fusion technique ranked second (2.25 dB), and weighted average third (0.70 dB). On the other hand, weighted averaging was the least time consuming, followed by wavelet fusion (x2) and multiview deconvolution (x5). Wavelet fusion offered an interesting trade-off between performance and computational cost.

Experiments on 3D breast ultrasound imaging, showed consistent results with those obtained on synthetic images. Tissue was linearly scanned with a 2D probe in different directions, and volumes were compounded using the aforementioned techniques. This resulted in a high-resolution volume, with better tissue delineation and less speckle patterning.

6147-32, Poster Session

Coded excitation with sigma delta sampling for medical ultrasound imaging

Y. M. Yoo, Univ. of Washington; J. Cao, L. M. Koh, Nanyang Technological Univ. (Singapore); Y. Kim, Univ. of Washington

We have developed a new coded excitation technique where sigma delta sampling and corresponding single-bit pre-compression are utilized to reduce dynamic focusing artifacts and hardware complexity. This sigma delta sampling based coded excitation (SDS-CE) method could lead to the integration of the transmitter and receiver circuitries into a single chip as well as improving the signal-to-noise-ratio (SNR) and penetration. We have obtained a 10.03 dB SNR improvement with the proposed SDS-CE method compared to the conventional pulse-echo excitation method at the same voltage level (i.e., ±10 V). To obtain a comparable SNR and penetration depth, the necessary voltage level for the SDS-CE is one fourth of that for the conventional pulse-echo excitation method. The dynamic focusing artifacts are effectively removed since the SDS-CE method utilizes pre-compression (i.e., pulse compression before beamforming). These preliminary results indicate that the proposed method can improve the SNR and penetration. Alternatively, it can lower the required voltage level in the transmit pulser without dynamic focusing artifacts. To evaluate the hardware complexity in the proposed method, the number of gates was estimated based on the 0.35-μm CMOS fabrication process with 3.5 V. The proposed SDS-CE method can save 78.8% and 56.3% gates compared to the conventional coded excitation methods based on pre- and post-compression, respectively.

6147-33, Poster Session

Freehand ultrasound calibration using the unscented Kalman filter

M. H. Moghari, Queens Univ. (Canada); T. K. Chen, Queen's Univ. (Canada); P. Abolmaesumi, Queens Univ. (Canada)

This paper presents the preliminary results of a novel free-hand ultrasound calibration algorithm which is based on a sequential least squares method, known as the Unscented Kalman Filter (UKF). This work has significant advantages over the prior art, where the block least squares techniques have been employed to perform the ultrasound probe calibration. The advantage of using the sequential least squares techniques over the block least squares ones is that in addition to calculating the calibration parameters, the sequential methods also provide us with the variance of the calculated parameters which could be used as a confidence measure for the calibration process. The variance evaluation enables us to stop the calibration procedure once the desired calibration confidence interval is met or informs us to collect more sample points to improve the calibration accuracy.

There are different types of sequential least squares estimators introduced in the literature such as the Kalman Filter (KF), Unscented Kalman Filter (UKF), etc. The KF algorithm is used for the linear systems which are corrupted by the Gaussian noise. On the other hand, the UKF algorithm is employed when a system corrupted by the Gaussian noise is nonlinear. Our new calibration technique takes advantage of the UKF algorithm since the ultrasound probe calibration (a 2-D to 3-D registration problem) is a nonlinear operation in terms of the calibration parameters. We also assume that the collected sample points are stimulated by the Gaussian noise.

6147-34, Poster Session

Functional and morphological ultrasonic biomicroscopy for tissue engineers

S. Mallidi, S. R. Aglyamov, A. Karpiouk, S. Park, S. Y. Emelianov, The Univ. of Texas at Austin

No abstract available.

6147-35, Poster Session

Tissue imaging utilizing the ultrasonic vibration potential

S. Wang, C. Nguyen, S. Li, G. J. Diebold, Brown Univ.

The ultrasonic vibration potential refers to the generation of voltages in colloids or ionic solutions by ultrasound. We show that the vibration potential can be used for imaging by directing a burst of ultrasound into a body and recording the current production between a pair of parallel plates placed in contact with the body. The signal can be recorded in the time domain by detecting at what point the vibration potential is generated following irradiation of the body with a short burst of ultrasound. Alternately, the signal can be recorded in the frequency domain by slowly sweeping the frequency of a quasi-continuous ultrasound beam and recording the magnitude and phase of the current between the two plates. The salient feature of vibration potential imaging is its high contrast for whole blood, which is both colloidal and ionic, relative to most tissue. We present recent experiments with colloidal phantoms.

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