

SU-GG-I-115**Clinical Evaluation of Three Automatic Image Registration Algorithms From Two Commercial Systems**

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Purpose: Commercial image registration systems are often directly used in clinics to determine treatment setup for patients. It is imperative to assess the accuracy of these commercial systems because of their direct impact of radiation delivery. The purpose of this study is to investigate the accuracy of two commercially available image fusion systems implemented in our clinic.

Methods and Materials: A pelvic anthropomorphic phantom was CT-scanned and the pelvic bone, femoral heads, and sacrum were contoured. The phantom was setup in fifteen different positions and the corresponding MV-CBCTs were acquired with 8 MU for a 200 arc. Two commercially available image fusion systems (Syngo from Siemens and Mosaicq from Elekta) were used to automatically align the MV-CBCTs with the planning CT based on a maximizing mutual information (MMI) algorithm. Furthermore, a chamfer algorithm was evaluated for the Mosaicq system. Based on contours of bony structures, manual alignments in Syngo were conducted carefully by an experienced physicist and were used as the benchmark. **Results:** Compared to the manual alignments, the mean differences in lateral shifts from automatic registrations were 0.7 cm, 0.2 cm, and 0.2 cm for Syngo_{auto}, Mosaicq_{MMI}, and Mosaicq_{Chamfer}, respectively. The mean differences in longitudinal/vertical shifts were 0.5/0.3 cm, 0.0/0.0 cm, and 0.0/-0.1 cm, respectively. The standard deviations for measurements were 0.1 cm. **Conclusion:** The accuracy of automatic image registration varied from system to system. The Mosaicq system aligned datasets automatically within 2 mm accuracy for both algorithms. Larger deviations were observed in the Syngo system with automatic alignment, indicating that additional manual adjustments were necessary.

Conflict of Interest: A contributing author has grant support from Siemens Medical Solutions.

SU-GG-I-116**A Neural Network Based Registration Quality Evaluator for 2D-3D Image Registrations**J Wu¹ *, M Murphy¹, S Samant², (1) Virginia Commonwealth University, Richmond, VA, (2) University of Florida, Gainesville, FL

Purpose: To construct a registration quality evaluator (RQE) for 2D-3D registrations that can automatically identify unsuccessful registration solutions. **Method and Materials:** Two orthogonal kV x-ray projections of an anthropomorphic cranial phantom were acquired with the Elekta Synergy system. The training dataset for the RQE construction was generated by registering the two x-ray images simultaneously to the CT image of the same phantom 300 times. The registration optimized the normalized mutual information (NMI) between the two radiographs and their corresponding digitally reconstructed radiographs that were computed from the CT dataset. For each registration repetition, a random initial alignment was used. The average voxel deviations within the region-of-interest between the best known alignment and the registration solutions were computed. The registration solutions of the training dataset were categorized as "successful" and "unsuccessful" registrations by comparing the average voxel deviations with a user defined error threshold. For each registration solution, the symmetry and the distinctiveness that represent the local geometrical properties of the similarity measure function were computed. The supervised training was used to train a two-layer feed-forward neural network using above generated data. The network RQE was then used to evaluate registrations in a test data set. The confusion matrices and receiver operating characteristic (ROC) curves were used to evaluate the performance of the RQE. **Results:** RQE training yielded a sensitivity and a specificity of 0.944 and 0.971, respectively, for the training dataset. The sensitivity and the specificity were 0.955 and 1.00, respectively, for the test dataset. The ROC curves also confirmed the very good performance of the RQE. **Conclusion:** Our phantom study showed RQE had very good performance in identifying unacceptable results in 2D-3D registrations. As part of an automated patient positioning system, RQE can be combined with a 2D-3D registration algorithm to avoid local optima and improve robustness.

SU-GG-I-117**NURBS-Based Deformable Image Registration**T Jacobson¹ *, M Murphy², (1) Virginia Commonwealth University, Richmond, VA, (2) Virginia Commonwealth University, Richmond, VA

Purpose: The current trend of incorporating multi-modality and multi-instance imaging in treatment planning for external beam radiotherapy has highlighted the need for fast and accurate deformable image registration techniques. One current implementation of non-rigid registration uses uniform B-Splines to parametrically represent the displacement vector field (DVF). The piecewise B-spline segments are joined at "knots" that define the local region of support and influence for each segment. This approach has limited flexibility and can require a fairly large number of control points to describe local complexity in the DVF. The authors present the implementation of a more general functional representation of B-Splines, Non-Uniform Rational B-Splines (NURBS) as an alternative DVF model.

Method and Materials: To demonstrate the improved accuracy that NURBS can provide, we have made numerical fits to a one-dimensional scalar DVF in the shape of a Gaussian. We first fit the DVF with a uniform B-Spline to establish baseline accuracy. We then fit the Gaussian with a 1D NURBS model with the same number of control points but now with non-uniform knots and weighted control points. The metric of comparison of the two fitting routines is the sum of the squared differences between the curve fit and the target Gaussian. **Results:** For the same number of control points, the NURBS fit produced a sum of squared differences of .0019 compared to 1.625 for the uniform B-Spline fit. **Conclusion:** NURBS offer an attractive alternative to uniform B-Splines in modeling the DVF. They carry forward the mathematical compactness of B-Splines while simultaneously introducing new degrees of freedom. The additional free parameters gained from the generalization to NURBS curves offers increased local control as well as the ability to explicitly represent topological discontinuities.

SU-GG-I-118**Adaptive Prostate Planning Based On Megavoltage Computed Tomography Images Enhanced by Nonlinear Diffusion Filtering**

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Megavoltage CT (MVCT) images are primarily used for setup verification in the helical tomotherapy system. Thus, the image quality is not designed to be comparable to that of kilovolt CT (KVCT) images which were used for treatment planning, due to the fact that the incident photons in MV beam were attenuated mainly by Compton scattering. It is hard to use the MVCT images for adaptive treatment planning because of the poor image quality. The current commercial system does not support deformable registration to account for deformable organ volume and shape changes. A coherence-enhanced diffusion filtering algorithm was used to improve the MVCT image contrast. This denoising technique first proposed by Meilckert and Scharr not only reduced the image noise, it also preserves edge locations and orientations at the same time. The processed MVCT image sets were thus registered through a deformable registration algorithm (demons algorithm) and the optimized transformation matrix was applied to the corresponding dose matrix in each fraction. The dose-volume histograms (DVH) of important organs like bladder and rectum were compared to the planning DVHs and a new plan can be used for the remaining fractions through the commercial Tomotherapy Planning System if dose limits for these important organs may be surpassed. Our preliminary results from one prostate cancer patient with 35 fractions show that the approach is feasible.

References:

Joachim Weikert and Hanno Scharr, A scheme for coherence-enhancing diffusion filtering with optimized rotation invariance, Journal of Visual Communication and Image Representation, Special Issue On Partial Differential Equations In Image Processing, Computer Vision, And Computer Graphics, pages 103-118, 2002

SU-GG-I-119**MRI-Guided Transrectal Robotic Prostate Biopsy Validation**H Xu¹, A Lasso¹, S Vikal¹, P Guion², A Krieger³, A Kaushal², L Whitcomb⁴, G Fichtinger^{1,4} *, (1) Queen's University, Kingston, ONT, CA, (2) National Institutes of Health, Bethesda, MD, (3) Sentinelle Medical Inc., Toronto, CA, (4) Johns Hopkins University, Baltimore, MD

PURPOSE: We report a quantitative evaluation of the clinical accuracy of an MRI-guided robotic transrectal prostate biopsy system that has been in

use for over five years at the U.S. National Cancer Institute. Through this retrospective study we also expect to gain insight to the nature and interplay of error factors in MRI-guided transrectal robotic prostate biopsy. **METHODS:** Pre- and post-insertion MR images show that while the whole group of relevant organs moves deformably, the prostate, rectum, and pubic bone shows little deformation according to Karnik et al. (SPIE Medical Imaging, vol. 7625, 2010.) Hence our validation framework entails two-stage rigid volume registration using mutual information between the pre- and post insertion images, using the Insight Toolkit. Global registration over the whole scene capture coupled gross prostate motion. Next, to account for residual decoupled prostate motion we re-register the global image with a region of interest including the prostate only. **RESULTS:** The two-stage registrations scheme was validated by 3D overlays of the segmented prostates and it was accurate up to 2 mm. A total of 82 biopsies from 21 patients were evaluated. The mean target displacement, needle placement error, and biopsy error was 5.9 mm, 2.3 mm, and 4 mm, respectively. This suggests that targets dislocate during the procedure, leading to often clinically significant biopsy errors, even in cases where needle placement in scanner coordinates may seem clinically acceptable. **CONCLUSION:** The mean anatomical biopsy error was 4 mm, which considering the minimal size of significant prostate cancer (about 4mm) is on the border of being clinically acceptable. Even considering imperfections in the registration framework (slice thickness, segmentation errors and assuming local rigidity) these findings indicate that compensation of target motion is necessary before inserting a biopsy needle.

SU-GG-I-120

Joint Simulation of Transmission X-Ray Imaging On GPU and Patient's Respiration On CPU

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Purpose: We previously proposed to compute the X-ray attenuation from polygons directly on the GPU, using OpenGL, to significantly increase performance without loss of accuracy. The method has been deployed into a training simulator for percutaneous transhepatic cholangiography. The simulations were however restricted to monochromatic X-rays using a point source. They now take into account both the geometrical blur and polychromatic X-rays. **Method and Materials:** To implement the Beer-Lambert law with a polychromatic beam, additional loops have been included in the simulation pipeline. It is split into rendering passes and uses frame buffer objects to store intermediate results. The source shape is modeled using a variable number of point sources and the incident beam is split into discrete energy channels. The respiration model is composed of ribs, spine, lungs, liver, diaphragm and the external skin. The organ motion simulation is based on anatomical and physiological studies: the model is monitored by two independent active components: the ribs with a kinematics law and the diaphragm tendon with an up and down translation. Other soft-tissue components are passively deformed using a 3D extension of the ChainMail algorithm. The respiration rate is also tunable to modify the respiratory profile. **Results:** We have extended the simulation pipeline to take into account focal spots that cause geometric unsharpness and polychromatic X-rays, and dynamic polygon meshes of a breathing patient can be used as input data. **Conclusions:** X-ray transmission images can be fully simulated on the GPU, by using the Beer-Lambert law with polychromatism and taking into account the shape of the source. The respiration of the patient can be modeled to produce dynamic meshes. This is a useful development to improve the level of realism in simulations, when it is needed to retain both speed and accuracy.

SU-GG-I-121

JDQE: A User-Friendly ImageJ Plugin for DQE Calculation

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Purpose: The detective quantum efficiency (DQE) is useful for physical characterization of digital x-ray detectors. ImageJ is an open source application for image manipulation and processing. We developed JDQE, a user-friendly ImageJ plugin to perform MTF, NPS and DQE calculations. **Method and Materials:** We developed the original code in Matlab and successfully used it to characterize several digital sensors. We used MATLAB Builder JA to produce Java classes which contain the encrypted MATLAB code and the Java classes that wrap the MATLAB functionality. This provides an interface between the Matlab functions and ImageJ. JDQE

requires Windows 2000 or higher, Java SDK 1.6 or Java SE Runtime version 6 and ImageJ version 1.41o or higher and the Matlab Compiler Runtime (MCR). JDQE features MTF calculation from edge images. Several methods for extracting a one-dimensional NPS from a two-dimensional NPS are provided, including the method specified by IEC 62210-1 and 62210-1-2. For DQE calculation, the user can select one of the standard beam qualities specified in IEC 61267 and 62210-1-2 and enter the air kerma, or enter fluence values manually. JDQE produces plots of the MTF, NPS and DQE and all the results can be exported to text files. We validated JDQE using data from several x-ray sensors, including a 5 x 5 cm CMOS mammography detector (Hamamtsu Corp). We compared the results to those produced by the original Matlab code and to results reported in the literature for similar sensors. **Results:** Results from JDQE match those of the Matlab code and are in broad agreement with results reported in the literature for similar sensors. **Conclusion:** JDQE successfully computes the MTF, NPS and DQE under a variety of beam conditions and using several standard techniques, including the methodology specified by the IEC.

SU-GG-I-122

An Automated Scoring Method to Quantitatively Evaluate Imaging Artifacts in 4D-CT Images

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Purpose: To develop an automated scoring method based on normalized cross correlation to evaluate imaging artifacts due to respiratory motion in four-dimensional-computed tomography (4D-CT) images. **Method and Materials:** Imaging artifacts in 4D CT have been extensively documented in the literature. Manual analysis of the magnitude of the artifacts is subjective and time consuming and there has no automated methods been reported for the objective quantification of the artifacts. We have developed an automated method to score the 4D-CT images based on the calculation of the normalized cross-correlation coefficients (NCC) between adjacent image slices at couch transitions (edge slices). We used three scoring criteria to evaluate the imaging artifacts: the minimum of the NCC (score #1), the average NCC (score #2), and the mean of the difference between the NCC of edge slices and the mean NCC of the edge slices with their respective neighboring slices within the same couch position (score #3). Our method was tested using a commercially available 4D motion phantom and subsequently applied to the 4D-CT scans of 30 lung cancer patients. **Results:** Our method is able to detect imaging artifacts in the reconstructed respiratory phases of the 4D-CT scans that are verified visually. In particular, score #1 correlates well with the maximum magnitudes of two types of artifacts that were measured manually by an unbiased observer. In contrast, scores #2 and #3 showed no correlations. **Conclusions:** Our automated scoring method based on normalized cross correlation is suitable to quantitatively evaluate imaging artifacts. Score #1 appears to be the most reliable measure to quantify artifacts and has been verified visually. Used in conjunction with score #1, score #2 can be an indicator of the overall goodness of the image quality while score #3 indicates the 'badness' of edge slices as compared with their respective neighboring slices.

SU-GG-I-123

Volumetric Reduction of the Corpus Callosum in Alzheimer's Disease

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Purpose: This study investigated correlations between regional corpus callosum (CC) atrophy and cognitive measurements in AD subjects at mild disease stages with volumetry. Our aims were to replicate ROI-based findings of reduced volumes of the CC in AD patients relative to mild cognitive impairment (MCI) and to investigate, on a voxel-by-voxel basis, the presence of significant correlations between CC atrophy and cognitive test scores in AD subjects. **Method and Materials:** We used the VBM and cross-sectional ROI-based volumetry approach to conduct a detailed assessment of CC volumetric reductions in a probable AD patients (n=40) in comparison to MCI (n=40) and subjective memory impairment (SMI) (n=12) matched for age. **Results:** The volumetric reduction of the posterior portion of the CC body, which inter-connects cortical regions that are also early affected in AD (mean area at mid intersection, AD=510.7mm², MCI=515.6mm², SMI=603.9mm², relative%ratio: AD=0.27, MCI=0.3, SMI=0.4) such as the superior temporal lobes, is also consistent with results of previous ROI-based morphometric MRI studies. Significant CC atrophy was detected in the anterior-superior portion of the splenium, the isthmus,