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Cone beam tomosynthesis as a new imaging modality for patient setup

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Abstract:

Purpose: The research question raised in the thesis is the feasibility of digital tomosynthesis (DTS) for accurate image guided patient positioning versus competing image based approaches such as cone-beam computed tomography (CBCT) or portal images. DTS is an alternative solution when setup time, gantry-couch clearance and imaging dose using CBCT are a concern. This thesis work demonstrates the feasibility of using DTS for patient setup and characterizes the DTS data acquisition, reconstruction and registration parameters. By comparing tomosynthesis to full-angle cone-beam tomography and portal images, three different setup cases are discussed.

Methods: The work was carried out in three parts (I, II, and III). Reconstruction of DTS images was performed using Feldkamp-David-Kress algorithm (part I & II) and Shift-and–add algorithm (part III) . Methods of registration of DTS images to the reference (planning CT or CBCT) data were developed and customized for each site (prostate, breast).

Part I: The air-tissue interface of the anterior endorectal-balloon used for immobilization of the prostate was extracted from the DTS and CBCT images. Comparison of the air-tissue interface extracted from the DTS images to that extracted from CBCT images provided the deviation of localized air-tissue interface using the two types of images. The deviation identified was due to distortions introduced by the tomosynthesis technique and was used as a measure of accuracy to evaluate interface localization from DTS images as a function of scan angle.

Part II: The registration of DTS images to planning CTs was done using an automatic algorithm, which was developed to overcome specific challenges of localization and registration of clips implanted in the breast. The automatic method consisted of auto-segmentation (intensity based thresholding with *a priori* knowledge about clip size and location to distinguish clips from bony features) and auto-registration of the segmented clip clusters (to efficiently remove false positives/negatives).

Part III: The shift-and-add algorithm was used for DTS volume reconstructions while automated cross-correlation matches were performed within Varian DTS software. Triangulation on two short DTS arcs separated by various angular spread was done to improve 3D registration accuracy. Software performance was evaluated based on registration accuracy; investigated parameters included arc lengths, arc orientations, angular separation between two arcs, reconstruction slice spacing and number of arcs.

Results: Part I: Decreasing the DTS scan angle reduces the ability to identify the air-tissue interface. Scans of 60^{o} or larger were able to localize an air-tissue interface with accuracy on the order of 1mm.

Part II: The developed algorithm is robust against false positives and false negatives and provides a registration accuracy of better than 2.3 mm for 60^{o} DTS and 3.3 mm for 40^{o} DTS.

Part III: Varian DTS software provided registration accuracy of 2 mm when the reconstruction arc length was > 5^{o} for clips with HU ≥ 1000. The optimal arc separation was ≥ 20^{o} and optimal arc length was 10^{o}.

Conclusions: Although the acquisition time for DTS is shortened by a factor of four compared to conventional cone-beam imaging, the spatial resolution is degraded due to the limited number of projections used. We found that in a limited class of cases DTS allows to accurately locate the clinical feature for image registration. This offers the option to replace cone-beam imaging with tomosynthsis that is superior to portal images since it reduces the overlay from different anatomical regions thus improves registration accuracy by a factor two. In conclusion, the contributions achieved by this thesis work are the establishment of a safe protocol and determination of optimal parameters for using DTS. This allows for the implementation of DTS for accurate patient setup in clinical settings.