Title: Development of a fast and robust 2D-3D Registration method for image-guided radiation therapy

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New radiation therapy methods, such as intensity-modulated radiation therapy and proton beam radiation therapy have been shown to have potential advantages over traditional three-dimensional conformal radiotherapy. These improvements have extended our ability to deliver highly conformal radiation dose to the prescribed treatment target. However, this has also increased the risk of tumor underdosage and the damage to the adjacent healthy tissue if the patient is not aligned with sufficient accuracy. Here we propose a 2D-3D bony anatomy-based registration method on linacs using 2D projective x-ray imaging (using electronic portal imaging devices (EPIDs))to yield accuracy comparable to 3D-3D registration using linac-based conebeam CT (CBCT). This has application to conventional x-ray radiotherapy and proton therapy.

The proposed 2D-3D registration method achieves 3D positioning by computing the best alignment of the 2D portal images with DRRs generated from a 3D CT dataset at incrementally different poses. Computationally expensive DRR calculation are performed in a graphics processing unit (GPU) rather than in a CPU. 2D-3D registration based on CPU based DRR computations can take on the order of hours, rendering it impractical for online clinical use. We present two 2D-3D registration strategies that could be implemented either on: 1) a single workstation equipped with a NVIDIA GeForce 8800 GPU and a DRR server software, which is networked to multiple standard EPID viewing stations via TCP/IP, hence minimizing hardware requirements, or 2) each viewing workstation containing the GPU and DRR software. A registration quality evaluator (RQE) is used to avoid local optima associated with 2D-3D registrations. RQE is an algorithm-based pattern classifier that identifies local optima trapping of an optimization, which can lead to incorrect patient positioning.

For the first strategy, i.e., the GPU on a server and a remote client PC connected through intranet, we achieved an accuracy of 1 mm and 1° for phantom and clinical imaging with the computation time <30 sec. For the second strategy, i.e., both the server and the client in a single workstation, the experiment showed the computation time <10 sec. The use of RQE eliminated any local optima trapping. RQE training yielded a sensitivity and a specificity of 0.9804 (0.8955-0.9995) and 0.9388 (0.8313-0.9872), respectively, at 95% confidence interval. Using test dataset from phantom imaging, the sensitivity and the specificity of RQE were 0.939 and 0.937, respectively.

Currently, CBCT generally has insufficient image quality for accurate deformable registration based on soft tissue, and 3D-3D registrations are largely driven by bony anatomy. Our 2D-3D bony anatomy-based registration provides accuracy comparable to 3D-3D registration using CBCT. The proposed proof-of-concept system offers a simple and inexpensive solution for those radiotherapy patients requiring precise 3D patient positioning based on bony anatomy without invasive fiducial markers that can be implemented for x-ray radiotherapy and proton therapy with projective imaging.