Brachytherapy Seed and Applicator Localization via Iterative Forward Projection Matching Algorithm using Digital X-ray Projections

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Interstitial and intracavitary brachytherapy plays an essential role in management of several malignancies. However, the achievable accuracy of brachytherapy treatment for prostate and cervical cancer is limited due to the lack of intraoperative planning and adaptive replanning. A major problem in implementing TRUS-based intraoperative planning is an inability of TRUS to accurately localize individual seed poses (positions and orientations) relative to the prostate volume during or after the implantation. For the locally advanced cervical cancer patient, manual drawing of the source positions on orthogonal films can not localize the full 3D intracavitary brachytherapy (ICB) applicator geometry. A new iterative forward projection matching (IFPM) algorithm can explicitly localize each individual seed/applicator by iteratively matching computed projections of the post-implant patient with the measured projections. This thesis describes adaptation and implementation of a novel IFPM algorithm that addresses hitherto unsolved problems in localization of brachytherapy seeds and applicators. The prototype implementation of 3-parameter point-seed IFPM algorithm was experimentally validated using a set of a few cone-beam CT (CBCT) projections of both the phantom and post-implant patient's datasets. Geometric uncertainty due to gantry angle inaccuracy was incorporated. After this, IFPM algorithm was extended to 5-parameter elongated line-seed model which automatically reconstructs individual seed orientation as well as position. The accuracy of this algorithm was tested using both the synthetic-measured projections of clinically-realistic Model-6711 ^{125}I seed arrangements and measured projections of an in-house precision-machined prostate implant phantom that allows the orientations and locations of up to 100 seeds to be set to known values. The seed reconstruction error for simulation was less than 0.6 mm/3^{o}. For the physical phantom experiments, IFPM absolute accuracy for position, polar angle, and azimuthal angel were (0.78 ± 0.57) mm, $(5.8 \pm 4.8)^{o}$, and $(6.8 \pm 4.0)^{o}$, respectively. It avoids the need to match corresponding seeds in each projection and accommodates incomplete data, overlapping seed clusters, and highly-migrated seeds. IFPM was further generalized from 5-parameter to 6-parameter model which was needed to reconstruct 3D pose of arbitrary-shape applicators. The voxelized 3D model of the applicator was obtained from external complex combinatorial geometric modeling. It is then integrated into the forward projection matching method for computing the 2D projections of the 3D ICB applicators, iteratively. The applicator reconstruction error for simulation was about 0.5 mm/2^{o}. The residual 2D registration error (positional difference) between computed and actual measured applicator images was less than 1 mm for the intrauterine tandem and about 1.5 mm for the bilateral colpostats in each detector plane. By localizing the applicator's internal structure and the sources, the effect of intra and inter-applicator attenuation can be included in the resultant dose distribution and CBCT metal streaking artifact mitigation. The localization accuracy of better than 1 mm and 6^{o} has the potential to support more accurate Monte Carlo-based or 2D TG-43 dose calculations in clinical practice. It is hoped the clinical implementation of IFPM approach to localize elongated line-seed/applicator for intraoperative brachytherapy planning may have a positive impact on the treatment of prostate and cervical cancers.