Title: A Novel System and Image Processing for Improving 3D Ultrasound-guided Interventional Cancer Procedures

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Structured Abstract:

Minimally invasive interventional techniques are increasingly being adopted for diagnostic and therapeutic cancer procedures, such as biopsy and ablation. These image-guided procedures offer alternatives to conventional open surgical practices and have been shown to decrease patient recovery times and complications while improving patient quality-of-life. Unfortunately, the accuracy of these procedures have prevented adoption as the first-line option (as observed with prostate and liver cancer procedures), which has been associated with variability in needle applicator targeting accuracy under conventional 2D ultrasound (US) imaging. The overarching goal of this work is to improve cancer diagnosis and therapy by improving the placement of applicators via the incorporation of 3DUS. Specifically, by automating image processing steps in 3DUS/MR prostate biopsy and developing a novel 3DUS system for liver ablation, improved multi-modal imaging and spatial context may lead to higher prostate cancer detection rates and reduced local liver cancer recurrence.

A real-time 2D to 3DUS prostate registration algorithm was developed to perform motion compensation during prostate biopsy procedures. After evaluation on phantom and patient images, the algorithm was implemented on a 3DUS system and resulted in a median registration error of 2.0 [1.3, 2.5] mm and a mean computation time of 22±3 ms using a modified workflow on prospective patient images (n=18). Clinical workflow was further improved by developing a generalizable automatic prostate segmentation algorithm using deep-learning on a clinically diverse 3D transrectal US dataset. When evaluated on an unseen dataset of 20 3DUS images, a median Dice coefficient of 94.3 [93.1, 95.2]% was observed with a <0.70 s computation time. A novel system consisting of a three-motor mechanical mover held by a counterbalanced tracking system was manufactured to incorporate 3DUS in liver ablation procedures. This system was evaluated for mechanical error, image reconstruction error, clinical feasibility with a volunteer scan, and targeted applicator placement accuracy with a mock end-to-end phantom procedure. The mock procedure resulted in a mean targeting accuracy of 4.27±2.47 mm for targets up to a depth of 106 mm and 32 mm from the centre of the 3D image. In addition to the system, a semi-automated 3D applicator segmentation algorithm was developed; it was trained using a set of phantom images and a user study evaluated the algorithm on 16 unseen patient 3DUS images. The median tip and trajectory errors across four users were 5.1 [2.2, 5.9] mm and 4.5 [2.4, 5.2]° with a computation time ≤0.31 s.

This work focused on the need to improve prostate and liver cancer procedures using methods to incorporate 3DUS into centres with preexisting US systems. Improving workflows that incorporate 3DUS could offer an inexpensive alternative for improving the diagnostic and therapeutic accuracy of minimally invasive cancer procedures.