Assessment of registration accuracy between Magnetic Resonance Imaging and three dimensional Trans-Rectal Ultrasound Imaging of prostate cancer

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Introduction: Prostate cancer (PCa) is the third most common cancer in the world and becomes more prevalent with age. A total of 186,320 new prostate cancer cases and 28,660 deaths from cancer are projected to occur in the United States in 2008 [1,2]. Definitive diagnosis of PCa requires a biopsy, and transrectal ultrasound (TRUS) is often used to guide biopsy needle placement. However, TRUS guided biopsies often underestimate or fail to detect the presence of PCa [5,6], likely due to inadequate sampling of the prostate resulting from poor visualization of PCa with ultrasound (US). Approximately 10-25% of patients whose first TRUS biopsies were negative are later diagnosed with cancer. This sub-optimal detection performance can be attributed to the underestimation of the Gleason score, a measure of the cancer progression or can be attributed to the low quality images produced by US resulting in poor visualization of the PCa. Magnetic Resonance Imaging (MRI) has been shown to be extremely sensitive and specific for the detection of prostate cancer [3]. However, biopsy under MRI guidance is very difficult to achieve. If MRI images could be registered in real time to 3D TRUS images, the MRI images could be used to guide the biopsy, potentially reducing the rate of false negative biopsies guided by TRUS alone. The goal of this project is to characterize the registration accuracy between 2D T2-weighted (T2-w) MRI and 3D TRUS images.

Methods: A polyvinyl alcohol (PVA) prostate phantom (PP) was constructed from the mold of the actual prostate, including part of the entry/exit section of the urethra and 10 implanted polystyrene beads (diameter 1 to 2.5 mm) were implanted to act as fiducial markers. This PP was embedded in a second PVA phantom designed to simulate the pelvic area. MRI of the PP was performed on a 3T MRI with a combined pelvic surface-coil array [GE Healthcare, Waukesha, WI. USA] and endorectal prostate coil (e-coil) [MRInnervu, Medrad, Pittsburgh, PA. USA]. A series of 2D axial T2-weighted MRI images from the prostate phantom were obtained using a fast spin echo (FSE) sequence (TR: 6050 ms, TE: 163 ms, FOV 14 cm, 2.20 mm thick slices, 384x256 matrix). US of the PP was performed with the Philips HDI 3500 and probe model C9-5 (5-9 MHz). Axial US images were obtained using a standard clinical protocol for the human prostate. The marker position coordinates and the entry/exit points of the urethra on the US and MRI images were manually determined four separate times, to allow estimation of the MRI and US fiducial localization error (FLE, defined as the standard deviation in the repeated measurement of marker position).[4] 3D US and MRI volumes were segmented manually to create a boundary of the prostate in each modality. The boundary points are normalized to minimize error when aligning the points. A subset of the embedded fiducial markers was selected and an iterative closest point (ICP) algorithm [7] was used to match the same point in different volumes and measure the position of fiducial markers. The target registration error (TRE) was defined as the distance between corresponding marker positions in the registered MRI and US images, and was calculated for the fiducial markers not used for registration. [4,5]

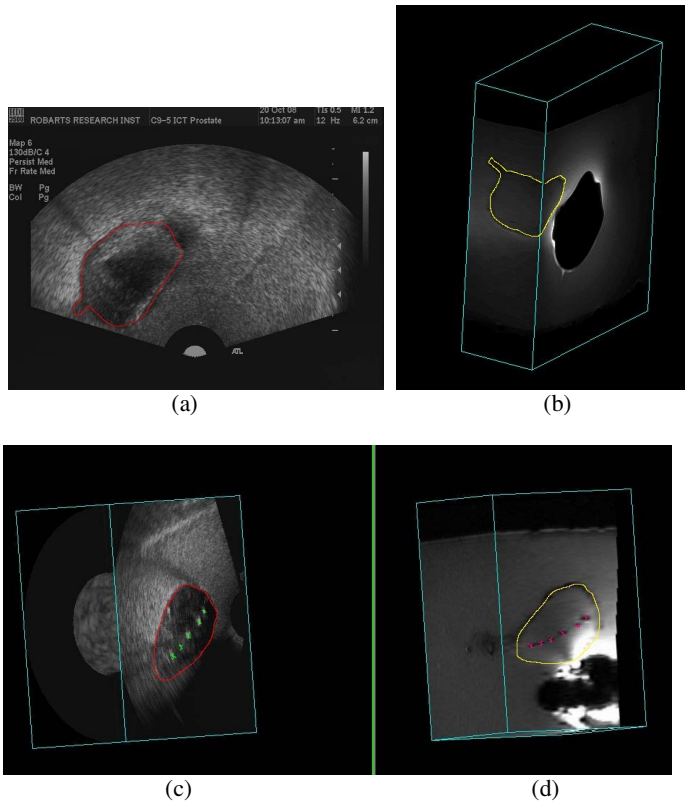

Figure 1: (a) 2D US image of prostate phantom with urethra. Red line indicates manually segmented prostate surface. (b) 2D T2 weighted MRI image of prostate phantom with urethra. Yellow line indicates manually segmented prostate boundary. (c) 3D reconstruction of the 2D-US prostate phantom images. Red indicates the segmented surface of the prostate phantom. Green "x" indicates the manually identified marker positions (d) 3D reconstruction of the 2D-T2 weighted prostate phantom images. Yellow indicates the segmented surface of the prostate phantom. Pink "x" indicates the manually identified marker positions

Results: Figure 1(a) and (b) show a 2D TRUS and 2D T2-w MR images of the sagital prostate with the urethra before registration. Figures 1(c) and 1(d) show fiducial marker positions located in US and MRI volumes respectively. The FLE was 0.6 mm for MRI and 0.3 mm for US without the urethra. Including the urethra the FLE value for MRI was 0.6 mm and for US 0.8 mm, and the TRE was found to be 1.1 ± 0.1 mm. Neither FLE nor TRE was found to vary significantly with marker position. Figure 2 shows the fusion of the MRI and US in one single 3D prostate volume of both images sets.

Discussion: The FLE for both MRI and US was considerably smaller than the TRE, suggesting that the error in registration is due primarily to the registration algorithm. The TRE is sufficiently small to suggest that MRI and TRUS images of the phantom were registered with sufficient accuracy to allow image guidance of prostate phantom biopsies with fused MRI and US data. However, this registration was done without deforming the prostate phantom. Since deformation of the prostate is likely to occur during TRUS guided biopsy, these in vitro results represent a best case. These measurements will be repeated with realistic deformation of the prostate phantom.

References: [1] Hedvig Hricak, et al. Radiology 2007; v. 243: 28-53. [2] Ahmedin Jenel, et al. CA Cancer J Clinic 2008; v. 58: 7-96. [3] B. Nicolas Bloch et al. Radiolgy 2007; v. 245: 176-185. [4] J. M. Fitzpatrick et al. IEEE 2001; v. 20: 917-927. [5] Djavan B, et al. Euro Urology 2000; v. 38(2): 218-224. [6] Park SJ, et al. Int. J Urology 2003; v. 10: 68-71. [7] Paul J. Besl et al. IEEE 1992; v. 14: 239-256.

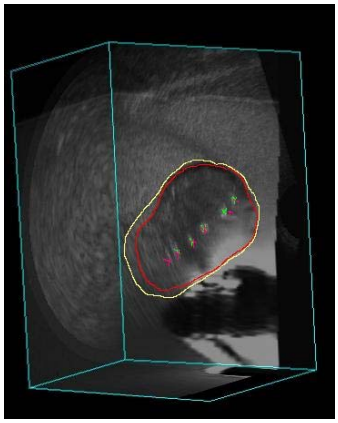

Figure 2: Fused US (red line) and MRI (yellow line) volumes after registration along with the surface contours and marker positions (pink (MRI) and green (US) crosses).