Multi-slice-to-volume registration for reducing targeting error during MRI-guided transrectal prostate biopsy

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Introduction

Context
- MRI-guided prostate biopsy workflow: Biopsy target points identified based on multi-parametric MRI review. Plan is warped to the intra-procedural configuration in the beginning of the procedure. [1]
- Intra-procedural motion of the prostate gland may dislocate the target points, leading to targeting errors.
- Registration of the planning image to intra-procedural scan showing the deformation can be used to reduce errors in needle placement.
- Most of the existing methods are impractical for routine clinical use because they require lengthy acquisition of volumetric images.

Purpose
- Evaluate a deformable image registration approach that relies on sparse MR imaging to recover motion and deformation of the prostate during MR-guided biopsy.

Registration method

Pre-processing
- Intensity inhomogeneity correction
- Sparse volume construction (Fig. 1.)

Registration

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<th>Stage 1</th>
<th>Stage 2</th>
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<tr>
<td>Sparse volume</td>
<td>Harmony image (rigid)</td>
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<tr>
<td>Compute metric (MMI) ROI: P+R+PB</td>
<td>Compute metric (MMI) ROI: P</td>
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<tr>
<td>metric value</td>
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<tr>
<td>Optimize metric (GD)</td>
<td>Optimize metric (L-BFGS-B)</td>
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<td>transformed moving image</td>
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<td>transformed parameters</td>
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<td>result transform</td>
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<tr>
<td>Moving image</td>
<td>moving image</td>
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<td>Prostate motion transform</td>
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Figure 2: Overview of the slice-to-volume registration algorithm. MMI: Matter Mutual Information; ROI: region of interest. P: prostate, R: rectum, PB: pubic bone; GD: gradient descent; L-BFGS-B: limited-memory Broyden–Fletcher–Goldfarb–Shannon optimizer with simple bounds.

Evaluation method and results

Imaging
- Clinical images of one patient, acquired by a Siemens Magnetom Verio 3T scanner.
- Target planning volume: axial T2w TSE sequence (320x320x320 voxels, 0.625x0.625x4.8mm voxel size)
- Intra-procedural slices: HASTE protocol (320x244 voxels, 0.94x0.94x3.6mm voxel size, 18 seconds acquisition time) and TrueFISP protocol (320x320 voxels, 1.25x1.25x3.6mm voxel size, 7 seconds acquisition time).

Evaluation
- Accuracy of the registration was qualitatively assessed by comparing the manually segmented prostate gland contours on the planning and slice images with and without registration.
- Robustness of the rigid registration step was evaluated by performing repeated registrations with the randomly perturbed initial transformation (±20mm translation and ±10° rotation).

Quantitative results
- Distance between the contours without registration: up to 3-4mm.
- With rigid registration: reduced to about 1-2mm.
- With additional non-rigid registration: reduced to about 1mm.
- In 95% of the experiments evaluating robustness, the registration result was within 0.4 mm translation and 0.5° rotation difference as compared to the non-perturbed result in case of the HASTE protocol, and within 1.8 mm and 2.5° difference with the TrueFISP.

Qualitative results

Figure 3: Prostate contours from the target planning volume overlaid on the axial intra-procedural slice. Left column: whole slice. Right column: prostate region magnified. Contour colors: Red: without registration. Orange: rigid registration. Green: deformable registration.

Conclusions
- The proposed registration technique may be able to estimate the prostate motion and deformation during MRI-guided prostate biopsy procedures by a quick multi-slice acquisition followed by a fully automatic computation step.
- Further testing on more patients is needed to confirm the results.

References