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

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Introduction

Context

- MRI-guided prostate biopsy. [1]
- Biopsy targets are selected on a planning image (*target planning volume*) acquired at the beginning of the procedure.
- Intra-procedural patient motion dislocates the target points, leading to targeting errors.
- Image registration methods can be used to estimate and compensate the patient motion to reduce the targeting errors.
- Most of the existing methods are impractical for routine clinical use because they require lengthy acquisition of volumetric images.

Purpose

- Develop an automatic method for determining prostate motion from a few *intra-procedural MRI image slices*. The method should be fully automatic and the slice acquisitions should take only a few seconds.

Method

Pre-processing

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

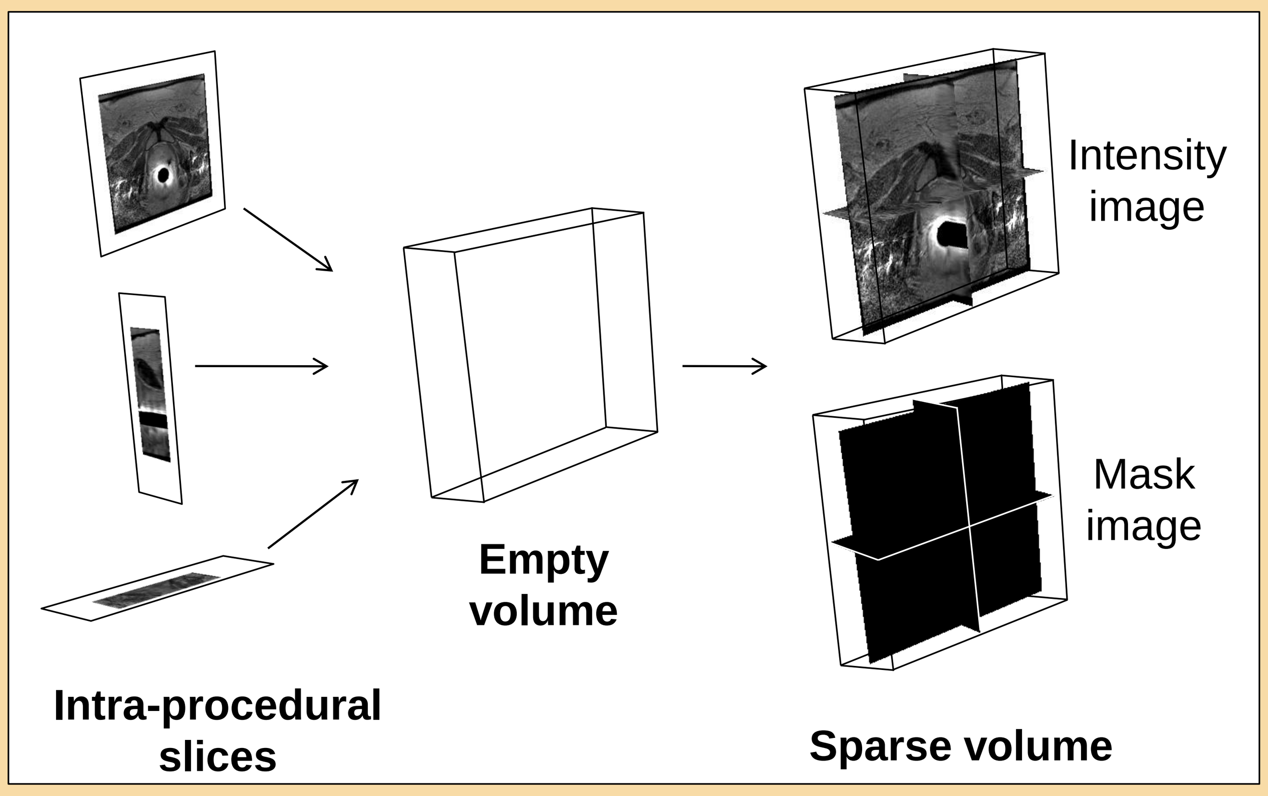

Figure 1: A sparse volume is created from a few intra-procedural slices

Registration

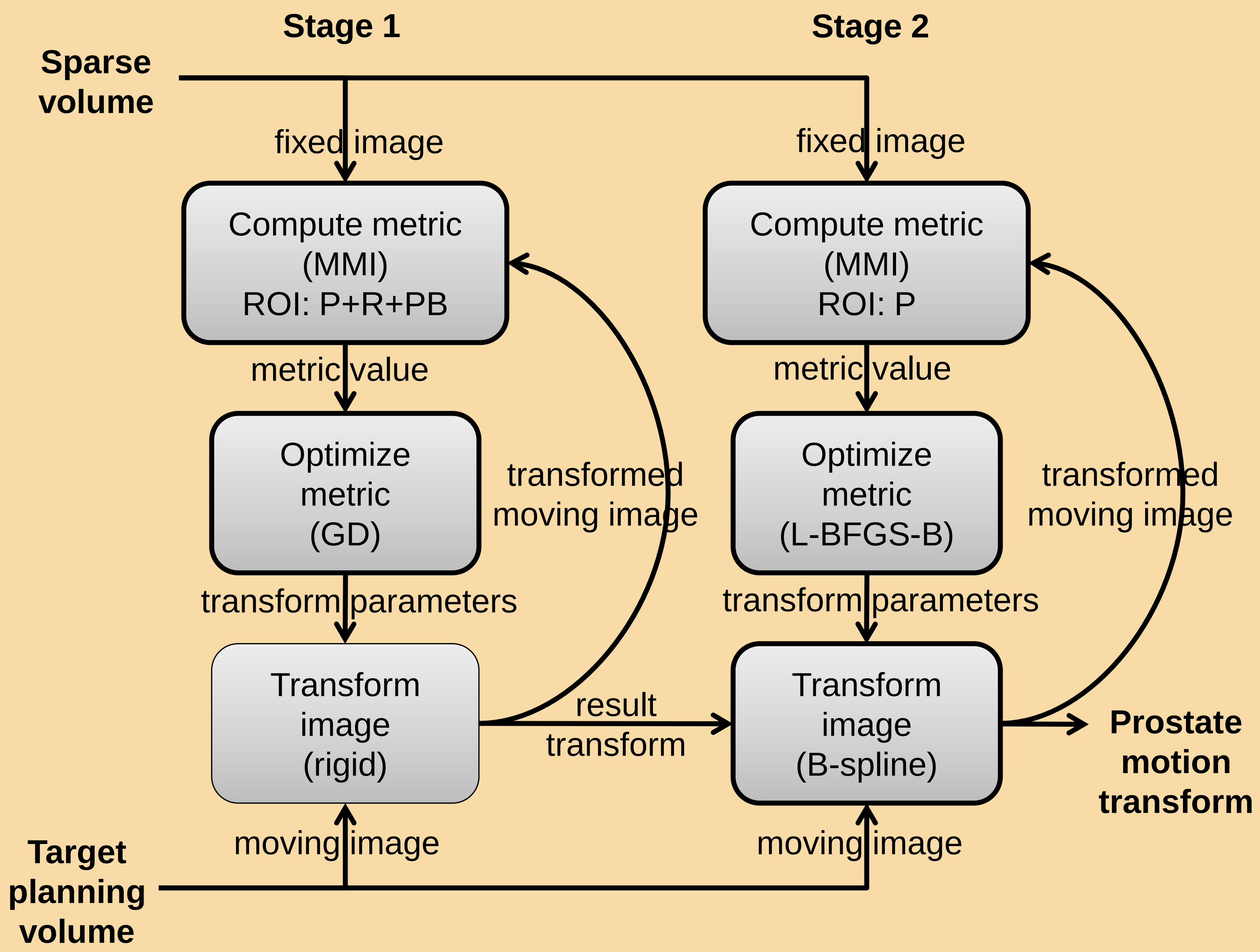

Figure 2: Overview of the slice-to-volume registration algorithm. *MMI*: Matter Mutual Information; *ROI*: region of interest. *P:* prostate, *R:* rectum, *PB:* pubic bone; *GD*: gradient descent; *L-BFGS-B:* limited-memory Broyden–Fletcher–Goldfarb–Shannon optimizer with simple bounds.

Results

Images with simulated deformation

- Target planning volume: clinical image, T2w axial slices, endorectal probe, trans-rectal positioning device for needle insertion
- Intra-procedural slices: slices extracted from deformed target planning volume; deformation is caused by probe/prostate motion, computed by *Finite Element Modeling* (FEM) – Fig. 3. [2]
- *Target Reconstruction Error* (TRE) was computed on the whole prostate gland as the difference of the known simulated dislocation and the dislocation computed by the registration algorithm.
- Mean TRE is reduced to <1mm (Fig. 4.)
- Maximum TRE is reduced from 2.1–5.6mm to 0.9–3.2mm (stage 1, rigid only) and further to 0.6–0.9mm (stage 1+2, rigid and deformable) registration.

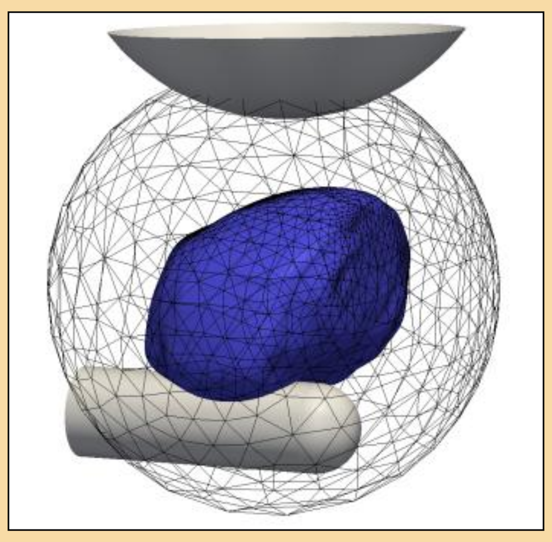

Figure 3: Objects used for computing the FEM-based simulated deformations

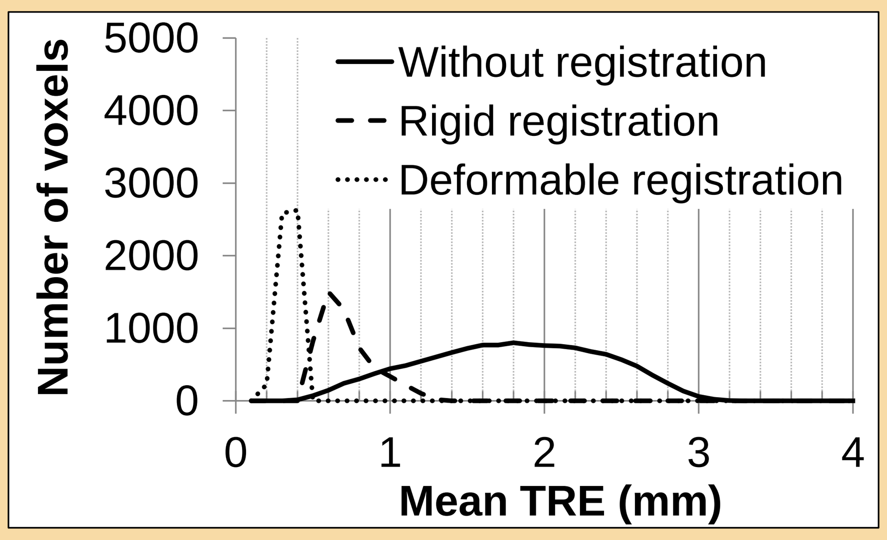

Figure 4: Mean TRE computed in the whole prostate gland using simulated deformations

Images with real deformation

- Images are acquired using the trans-rectal APT-MRI positioning device [3]
- Error is computed as 95% of the maximum Hausdorff distance between manually segmented prostate contours on 4 patient cases
- Initial error was 3.8±1.7mm, the registration method reduced it to 1.0±0.6mm.

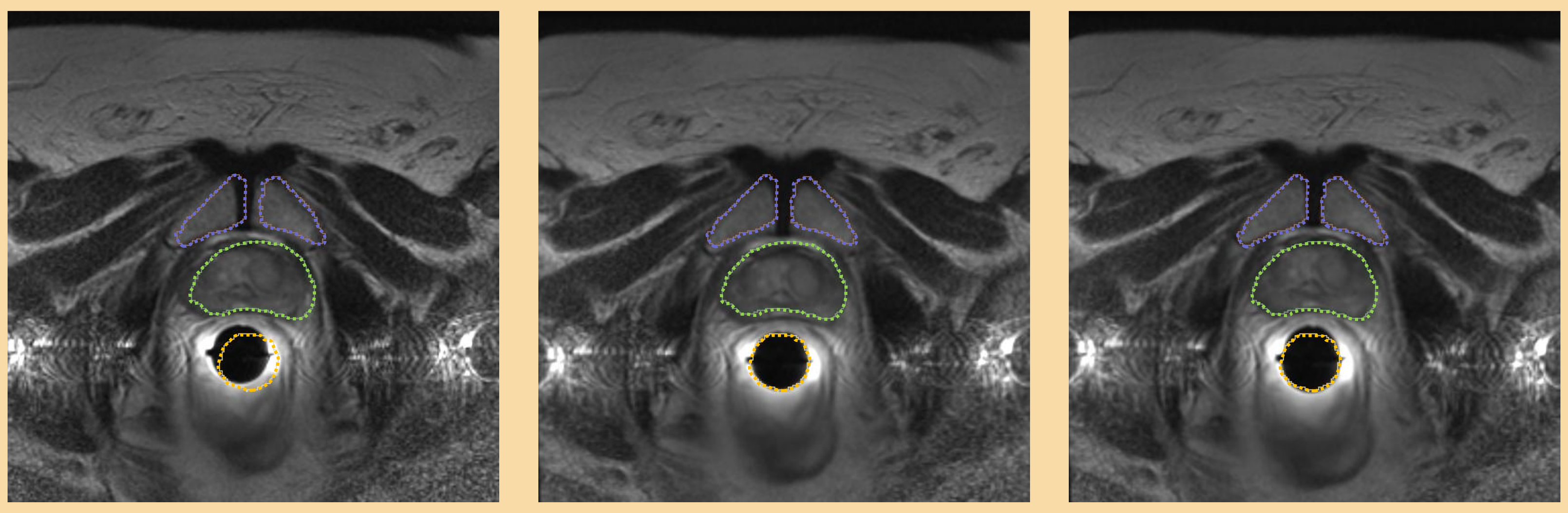

Figure 5: Example of the patient motion compensation on clinical images with real deformation

Conclusions

- Multi-slice-to-volume registration can considerably decrease the targeting error caused by patient motion.
- Rigid registration decreased the targeting error, and deformable registration reduced the error even further.
- Final error is less than about 1mm.

References

[1] Tempany, C.; Straus, S.; Hata, N. & Haker, S. (2008), 'MR-guided prostate interventions.', J Magn Reson Imaging 27(2), pp. 356–367.

[2] Lasso, A.; Avni, S. & Fichtinger, G. (2010), 'Targeting Error Simulator for Image-guided Prostate Needle Placement', in 'EMBC2010 - 32nd Annual International Conference of the IEEE Engineering in Medicine and Biology Society', Buenos Aires, Argentina, pp. 5424–5427.

[2] Krieger, A.; Susil, R. C.; Menard, C.; Coleman, J. A.; Fichtinger, G.; Atalar, E. & Whitcomb, L. L. (2005), 'Design of a novel MRI compatible manipulator for image guided prostate interventions', IEEE Transactions on Biomedical Engineering 52(2), pp. 306–313.