3D-2D Registration for Interventional Guidance

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The Problem: We work toward a method for the automatic registation of pre-operative CT and/or MR with intra-operative 2D x-ray images (e.g. from biplane fluoroscopy). Specifically, we investigate an intensity-based approach to rigid 3D-2D coregistration, whereby alignment is achieved by optimizing a similarity measure that is evaluated on the joint intensities of the x-ray data and of digitally-reconstructed radiographs (DRR) generated from the volumetric data. The effort is now aimed at producing a demonstration system that will function on plastic pelvis models.

Motivation: There are a number of therapies to which we might find application for the fusion of preoperatively-processed CT and/or MR with intraoperatively-acquired fluoroscopy. Currently there are many types of surgeries that require superior guidance which, by current methods, require complicated measurement and reference schemes, use of fiducials, or near-continuous use of fluoroscopy (which not infrequently results in radiation-related injuries such as hair loss).

Examples of therapies suited to improvement by MR-fluoroscopy registration, involve access to soft tissue targets, such as tumors, by their relation to bony structures nearby. In these cases, MR can define preoperatively and in 3D, the relationship of the soft tissue to bony structures with confidence, and the fluoroscopy can give accurate information about the state of the bony structures (and, by inference, the soft tissue) during a procedure. Specific examples of prodedures are Pallidotomy, brain tumor resections, and spinal disc decompressions.

Therapies that could be improved by CT-fluoroscopy registration are those that involve access to structures which can be visualized by x-ray with the addition of contrast agents, but whose geometeries are ambiguous in radiographically-projected images. A specific example is transcatheter procedures in which a catheter is navigated through complicated vascular structures in the head to correct flow problems and vascular abnormalities. Another example is "re-orienting osteotomies" whereby one's ability to walk can be improved by making cuts in the pelvis around the acetabular cups.

Previous Work: We have previous experience with 3D-3D registration of medical images, as well as 2D-3D registration of video images, using the method of "Alignment by Maximization of Mutual Information". [1, 2] While other groups have approached 2D-3D, rigid registration problem from a variety of directions (Pizer et al. at the University of North Carolina, Duncan et al. at Yale, and Penney et al. [3]), we feel that there is ample remaining opportunity.

Approach: We investigate a number of similarity measures which have been applied in other multi-modal registration contexts. The similarity measures are judged empirically by probing the space of transformations between the coordinate frames of an MR or CT volume and biplanar DRRs produced from a corresponding CT volume. This method allows us to know the "ground truth" of the registration, which could be established by proven methods for rigid, 3D-3D, CT-MR alignment.[1] This evaluation of measures for accuracy and robustness will be used as a starting point for further application-specific algorithm development.

Futhermore, we propose a method of DRR production called *voxel-projection* which drastically reduces processing time relative to standard *ray-casting* methods. We hypothesize that its speed may enable 3D-2D registration methods which rely on evaluation of a similarity measure over the entirety of a DRR and model radiograph to account for structural or variational features (for instance, *pattern intensity* [3]).

Based on similarity measure chacteristics observed in our probing experiments, and using the *voxel-projection* method, we adapt the *uphill-simplex* optimization algorithm to implement an intensity-based MR-fluoroscopy rigid registatration engine. We also consider a parallelized version of the registration algorithm presented in [3].

Difficulty: The inner loop of any intensity-based registration algorithm of this kind will involve the production of DRRs from a volumetric image. As even optimized methods for full DRR production have running times on the order of seconds for medical images of typical size, the efficiency of the optimization scheme is important to making the algorithm serviceably fast. Some degree of parallelization or sparse evaluation of DRRs may be needed for this reason.

Impact: The computational efficiency of *voxel-projection* makes it a useful tool for the investigation of similarity measures in this 3D-2D context. The quality of DRRs produced by *voxel-projection* is close to that of those produced by *ray-casting*, but the speed of projection is increased by more that an order of magnitude, as shown in Figures 1 and 2.

Comparisons of similarity measures on a limited dataset suggest that *pattern intensity* is well-suited to this type of 3D-2D registration.

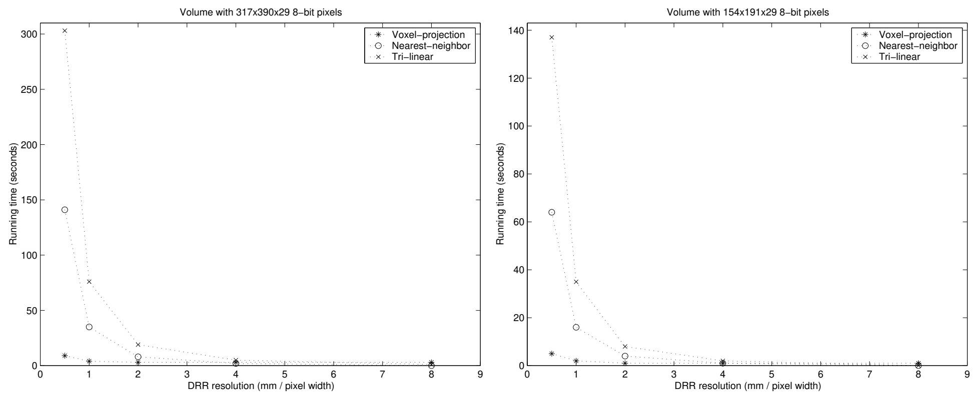

Figure 1: Comparison of the running times of voxel-projection and ray-casting (using trilinear and nearest-neighbor interpolation to derive inter-voxel MR intensities) over a series of DRR sizes, given in terms of DRR pixel resolution.

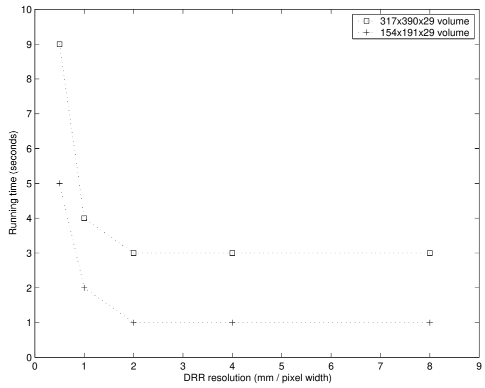

Figure 2: Voxel-projection run-times for different volume sizes.

Research Support: This research is supported by the National Science Foundation Engineering Research Center contract #8810-274 administered through Johns Hopkins University.

References:

[1] P. Viola and W. Wells. Alignment by Maximization of Mutual Information. *International Journal of Computer Vision.* 1997;24:137–154.

[2] W. Wells, P. Viola, H. Atsumi, S. Nakajima and R. Kikinis. Multi-modal Volume Registration by Maximization of Mutual Information. *Medical Image Analysis.* 1996;1:35–52.

[3] Graeme P Penney and Jurgen Weese and John A Little and Paul Desmedt and Derek LG Hill and David J Hakes. A comparison of similarity measures for use in 2D-3D medical image registration. *Image Sciences Institute*, PO Box 8550, AZU-E.01.334, NL-3508 GA Utrecht, the Netherlands.