Multi-Modal Registration for Image-Guided Therapy

Tamara Williams

Artificial Intelligence Laboratory
Massachusetts Institue Of Technology
Cambridge, Massachusetts 02139

http://www.ai.mit.edu

The Problem: We have sought solutions to two key elements involved in the registration of ultrasound with CT/MR: feature extraction in ultrasound and accurate CT/MR registration.

Motivation: The development and refinement of medical imaging modalities, which aid in non-invasively studying the internal structures of the human body, is essential for complementing the human visual system. The future of minimally invasive therapy is highly dependent on our ability to precisely target and deliver therapy. To succeed, such therapy must have target-relative information. Conventionally, image-guided procedures undergo two separate steps - a pre-operative imaging step in which the target site is identified, and an intra-operative step in which realtime or near-realtime imaging is used to guide the procedure [1]. Pre-operative imaging is sufficient for image guided procedures in which organs are relatively immobile. However, a realtime, intra-operative imaging technique is necessary for image guidance in which organs shift with respect to time such as the pulsating heart and abdominal organs, which are constantly in motion due to respiration.

Previous Work: One of the main goals was to successfully detect edges in ultrasound images. Implementing the work of Kovesi [2], who proposed using phase-based methods versus traditional gradient-based methods for feature detection in "noisy" data, we were able to filter out most of the speckle noise and extract true edges in the provided ultrasound liver data as shown in Figure 1. Kovesi's work was explored because he constructed low level image measures that had a response independent of image illumination and/or contrast. In addition, he showed how congruency of the local phase over many scales can be used as an illumination and contrast invariant measure of feature significance of points in images.

A precise quantitative study of registration results is deemed necessary for most clinical applications. A sparse deformation field was calculated from manually chosen corresponding points. The elastic transformation was computed by interpolating the sparse deformation field over the entire volume using polynomials. Additional linear interpolation was applied to produce a dense deformation field the same size as the atlas image. We explored numerous variations on polynomial warping methods which included the following: variation of the number of corresponding points; variation of polynomial order; variation of the point set distribution; and error verification to measure sensitivity in our computed registration errors. Registration results of CT/MR using 132 corresponding points is provided in Figure 1. We found that the following parameters produced the most accurate registration results: a polynomial of order 2; 100 to 150 corresponding points; and points distributed along the outer region of the image.

Approach: We realized that the CT/MR and ultrasound registration problem could be attained through many carefully planned steps thus, we pursued a divide-and-conquer approach to our solution. Our proposal for achieving the registration of CT/MR and ultrasound included the following stages:

- Extract edges from ultrasound to isolate boundaries
- Determine an initial alignment between MR/CT and ultrasound
- Select a set of surface points from MR/CT, and use ICP to match the points to edges in ultrasound. This result provides an initial correspondence between the two data sets
- Use polynomial warps to refine the matching, taking the correspondence returned by ICP as the set of matched points
- Use the final result to warp the entire CT/MR image to ultrasound

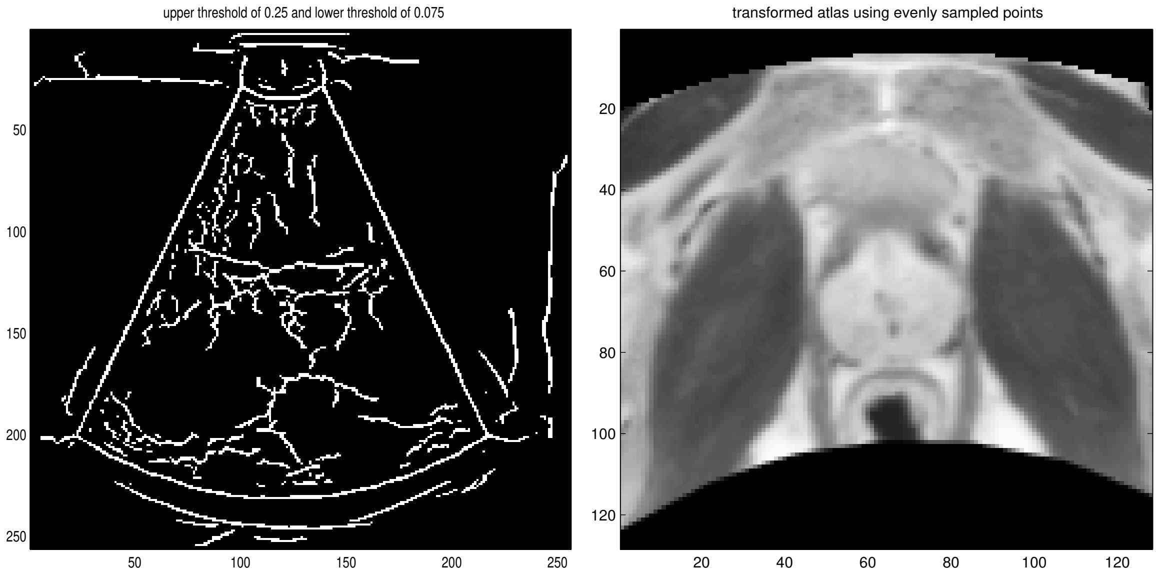

Figure 1: Ultrasound edges from phase congruency (left) and CT/MR registration results using 132 corresponding points (right)

Difficulty: The three main difficulties in this project involve: determining a reasonable compromise between edge detection and reduction of speckle noise in ultrasound; finding the transformation most suitable for the registration of the ultrasound edge points and CT/MR surface points; and extending the registration of CT/MR with ultrasound into realtime.

Impact: Accurate CT/MR and ultrasound registration will minimize cost, reduce the patients' exposure to ionizing radiation, and cause otherwise invasive procedures to become minimally invasive.

Future Work: In addition to exploring polynomial interpolators in the deformation field calculations, we would like to investigate the use of various spline functions. Ideally, we would like to compute registration errors that have a μ_{error} of no more than 2 voxels, which would be appropriate in surgical procedures. We will return to the problem of feature detection in ultrasound in anticipation that more prominent edges can be detected. We will investigate algorithms such as interpretation tree search, ICP, and Mixture Point Matching (MPM) to determine automatic correspondences to replace our current manual method. A segmentation algorithm for surface point extraction of CT/MR is necessary so that we can use ICP, for instance, to match the surface points to edge points in ultrasound. This will provide an initial correspondence between the two data sets. Our polynomial warping algorithm will then be used to refine the matching, taking the correspondence returned by ICP as the set of matching points. Finally, we will warp the entire CT/MR data set to the ultrasound for our registration results which will eventually be extended to real-time.

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References:

[1] F.A. Jolesz Image-guided procedures and the operating room of the future. *Radiology*, 204, 601-612, 1997.

[2] P. Kovesi. Image features from phase congruency. *Videre: Journal of Computer Vision Research*, 1(3), MIT, 1999.