Linear Object Registration: A Registration Algorithm using Points, Lines, and Planes

Matthew S. Holden, Gabor Fichtinger

Laboratory for Percutaneous Surgery, School of Computing, Queen's University, Kingston, Canada

PURPOSE: Image-guided interventions require medical images to be expressed in the same coordinate frame as physical anatomy. The process of determining the transformation between the image and anatomy coordinate frames is registration. Registration is typically performed using landmarks points with known correspondence and positions known or collected in both coordinate frames [1]. Unfortunately, many devices which must be registered do not have landmark points manufactured on them, so cannot be registered by typical methods; however, most devices have points, lines, or planes on them due to engineering constraints. We propose a registration algorithm which uses points, lines, and/or planes (which we call linear objects) and is guaranteed to converge to a solution close to the global optimum if a unique solution to the registration exists.

METHODS: The proposed algorithm uses the following pipeline: (1) find linear object correspondences between the two coordinate frames using distances to a set of reference points; (2) determine the least-squares centroid of the set of linear objects in each coordinate frame; (3) project the centroid onto each linear object in the coordinate system; (4) use the projected centroids and direction vectors to do traditional point-set registration; (5) use an iterative closest point algorithm to converge to the optimal solution. This algorithm was validated using simulated data and for practical phantom registrations (Fig. 1) where point-set registration results were used as ground-truth. It is implemented as a practical tool for phantom registration in the PLUS software library [2].

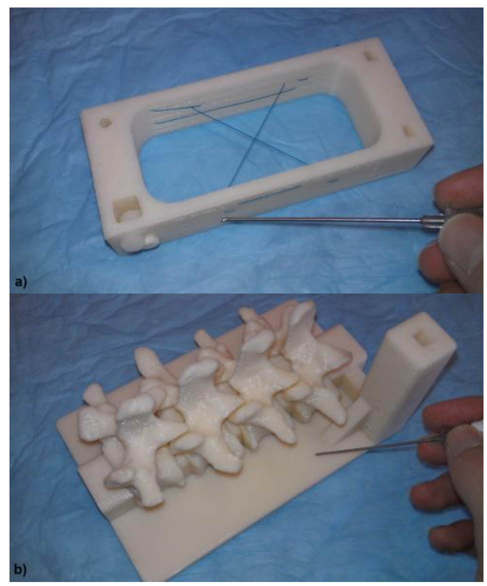

Fig. 1. The (a) ultrasound calibration phantom and (b) lumbar puncture phantom used for practical validation of the proposed registration algorithm.

RESULTS: The proposed algorithm performs sufficiently well in both simulated and real phantom registrations. With simulated data noise at 1.4mm (the root-mean-square noise associated with our tool tracking system) the algorithm exhibited average rotational error of 0.085° and translational error of 0.21mm, both of which are acceptable in practical scenarios. For real phantom registrations with an ultrasound calibration phantom and a lumbar puncture phantom, the average rotational deviation was 0.66° and the average translational deviation was 1.99mm.

CONCLUSION: The proposed algorithm provides an alternative method for phantom registration if landmark points are unavailable. The algorithm also has potential application to image registration problems, though its efficacy has not been tested for this. Current work involves improving the matching component of the algorithm and optimizing its implementation.

ACKNOWLEDGEMENT: This work was in part funded by Cancer Care Ontario through Applied Cancer Research Unit and Research Chair in Cancer Imaging grants.

[1] Horn, B. K. P., "Closed-form solution of absolute orientation using unit quaternions", Journal of the Optical Society of America, vol. 4, pp. 629-642, Apr. 1987.
[2] PLUS: Public Software Library for Ultrasound Imaging Research, http://www.plustoolkit.org/.