A 3D METHOD FOR SEGMENTING AND REGISTERING CARPAL BONES FROM CT VOLUME IMAGES

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INTRODUCTION

The purpose of this study was to measure the accuracy of a new method to extract three-dimensional *in vivo* carpal kinematics from CT volume images. Recent advancements in three-dimensional imaging have offered the opportunity to examine *in vivo* carpal kinematics accurately and without invasive procedures. Our previous method requires manual segmentation of the CT volume for each wrist posture, which is labor intensive (Crisco et al. 1999). Our new method requires the manual segmentation of only one scan. Here, we report the kinematic accuracy of this new method in measuring 3D motion of ten bones of the wrist.

Our algorithm works in two stages. In the first stage, each CT volume image is automatically segmented by a tissue classifier that estimates each voxel's distance to the nearest boundary between tissues. The distance to a boundary between cortical bone and other tissues defines where the cortical bone surface lies within the CT data. This estimate accounts for the blurring or partial-volume effects inherent to CT imaging. In the second stage, a 3D polyhedral model of each wrist bone, reconstructed from the manually segmented neutral posture, is matched to the tissue-classified volume images to obtain the new bone position and orientation. For each vertex in the polyhedral model, its distance to a bone boundary is looked up in the tissue-classified CT volume. The bone position is then adjusted iteratively to minimize these distances.

MATERIALS AND METHODS

Specimen Preparation: We used one cadaveric specimen in four different positions to investigate the accuracy of this method. The cadaveric specimen was separated into two components: the hand, composed of the eight carpal bones, and the forearm, composed of the distal third of the radius and ulna. The skin and other soft tissues were removed, and then each component was encased in a plastic resin, to prevent relative motion between any bones. Seven radiopaque ceramic spheres of various high tolerance diameters (6.35 to 19.05 ± 0.002 mm) were then rigidly fixed to each component (Figure 1).

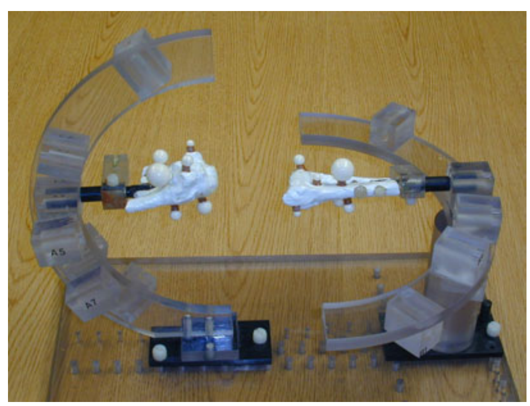

Figure 1: Cadaver positioning jig— hand and forearm components with affixed spheres

Image Acquisition: This specimen was placed in four different positions, and axially scanned using a GE Highspeed

Advantage CT (GE Medical Systems, Milwaukee, WI). Volume images were obtained with the voxel dimensions of 0.3125 X 0.3125 X 1 mm^3. Cortical bone contours from one single volume image were manually extracted using Analyze™ software (Mayo Foundation, Rochester, MN).

Data Analysis: For each component, "gold standard" rotation and translation transformations were obtained using the sphere centroids. All seven spheres were used in the rigid body calculation by a method of least squares. Rotation and translation transformations were converted to helical axis of motion (HAM) variables. The kinematic error of the algorithm was defined as the differences in the HAM variables from the "gold standard" sphere values.

RESULTS AND DISCUSSION

Mean distance between all possible pairs of sphere centroids over the four scan positions was 0.52mm (S.D. 0.31mm, range 1.33mm). As a result of the small variation in intersphere distances, the specimen components were assumed to move as rigid bodies, allowing for direct comparison of sphere and bone motion. When comparing the registration algorithm with the "gold standard", the mean carpal bone rotational error was less than 0.5º for all bones (Figure 2). Mean bone translational error was less than 2.0mm, except for the pisiform and trapezoid (Figure 2).

The advantage of this algorithm is that it does not require the manual segmentation of each individual scan. The limitation is that manual segmentation must still be performed on one scan. The error analysis described evaluates the kinematic accuracy of the algorithm and all aspects of the scanning and image processing. As expected, the accuracy was better for larger bones and worse for smaller and more spherical bones. Our method dramatically reduces the user interaction time, while maintaining the accuracy and stability of the manual approach. The method would also be applicable to bones of other joints.

REFERENCES

Crisco, J.J., McGovern, R.D., and Wolfe, S. W. (1999). *J Orthop Res*, 17(1), 96-100.

ACKNOWLEDGMENTS

Funded in part by NIH AR44005 and NSF CCR-0093238.

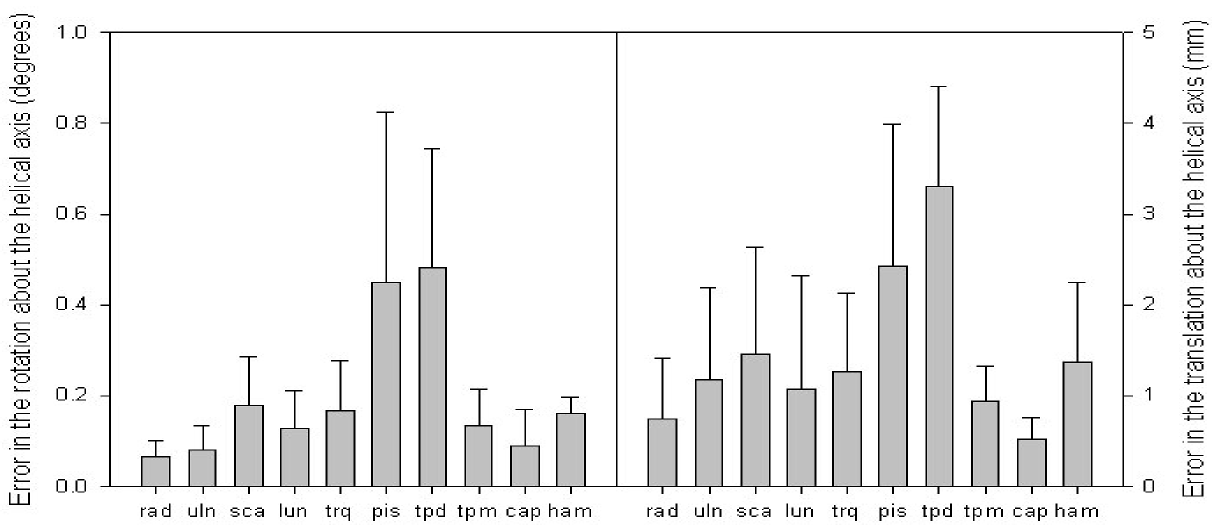

Figure 2: Mean (+ one S.D.) errors in HAM rotation and translation for the radius, ulna and the eight carpal bones