Estimating subject-specific parameters for modeling hand joints

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In both biomedical and graphics applications, quantifying skeletal motion requires a kinematic model describing the joint location and axis directions. In this talk, we present techniques we have recently developed for determining parameters of three types of anatomic joints. In particular, it is important but difficult to obtain high-quality parameter estimates for the joints of the human hand. Due to the small scale of hand segments, mis-location of joint centers by even 1 cm leads to unacceptable errors in the joint angle measurement. In addition, the axis directions of hand joints are not aligned with standard anatomical planes [1], and each individual has subject-specific axis directions. The errors in axis location and direction from standard estimation techniques result in noticeable differences in reconstructed hand shape and the grasp contact points of the fingers.

Our methods address these challenges arising from the small range of motion and complex anatomy of hand joints. These methods have been previously published to the biomechanics community, but they may also be used for subject-specific hand models in animation or virtual reality applications.

Geometric joint models. Parameters for a spherical joint and a single-axis hinge joint are fit using geometry-based optimization approaches. Previous methods for these joints work well for near-ideal joint movement with large ranges of motion. However, the small range of motion and noise in real hand data result in poor estimates (over 1 cm position error and over 30° direction error) due to plane singularities of the existing techniques.

For a spherical joint, measured data points are fit to concentric spheres. Our solution [2] relocates the plane singularity of the standard least squares solution to a point singularity associated with zero-radii spheres, a case which is not encountered in practice. The constrained least-squares formulation provides a repeatable solution with a direct global optimization that is not subject to local minima and does not require manually-tuned parameters typical in iterative techniques.

For a hinge joint, the data points are fit to circular paths in parallel planes. Our solution [3] avoids the singularity from minimizing only planar errors by additionally penalizing the paths' radial errors. This reflects the joint constraints more accurately, and the dominant rotation axis can be determined even in the presence of secondary motion.

Anatomy-based model. The carpo-metacarpal (CMC) "saddle joint" is difficult to model because the two axes are non-orthogonal (skew) nor intersect at a common point (separated). The complex model for separated skew axes has a high-dimensional parameter space, and a purely geometric cost function of distance errors is extremely flat in this space. Our anatomy-based technique [4] uses a reduced parameter space representing equivalent solution families and incorporates anatomical constraints to bias the search. Our resulting subject-specific models were consistent with clinical anatomical descriptions of the CMC, and our evaluation of 48 human hands contributes range of motion measurements for un-impaired thumbs.

Our talk will present the spherical joint estimation as the primary example to highlight the importance of choosing an appropriate optimization function. We will also briefly describe our insights into the cost function choices for fitting the hinge joint and the saddle joint models.

References

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