Kinematic Model Based Sensor Fusion for Inertial Measurements Units in Injury Biomechanics

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Background

Accurate measurement of kinematics for human body segments is central to many investigations in biomechanics. The use of Inertial Measurement Units (IMUs) for this purpose is becoming increasingly effective in low acceleration regimes in part due to the incorporation of human body kinematic models in the sensor fusion process. However, for high energy impact scenarios in injury biomechanics, the required sample rates and measuring ranges are much larger than what is currently available in commercial IMU options with premade human-model-based fusion algorithms. Without sophisticated fusion algorithms that interface with impact IMUs, injury biomechanics research relies on camera-based motion capture systems (e.g., VICON motion capture system) and photo targets with high speed cameras to ensure reliable measurements of body segment position and orientation. The objective of the present research is to develop and validate a novel model-based sensor fusion algorithm for implementation with impact-rated IMUs (e.g., 3αω and 6αω configurations) to reduce the necessity of camera-based position and orientation measurements in injury biomechanics experiments.

Methodology

The scope of the present study focuses on full state estimation for anthropomorphic test device (ATD) upper limbs, but the methodology can be intuitively extended to the entire ATD. The algorithm takes in measurements from two 3αω mounted to the upper and lower arm segments, and one 6αω mounted to the ATD thoracic spine. From these measurements, the algorithm generates piecewise polynomial estimates for all the joint angles between ATD segments, as well as the six degrees of freedom of the ATD thoracic spine with respect to the inertial reference frame. These polynomials can be differentiated analytically to evaluate the full kinematic state of the ATD upper limb and thoracic spine assembly. The algorithm uses interior point optimization as a vehicle for maximal likelihood estimation, relying on a zero-mean gaussian noise model for the measurements and a kinematic model for the ATD upper limb/thoracic spine assembly to evaluate the likelihood of a given set of polynomial estimates.

Results and Discussion

At present, for measurements generated via simulation and augmented with gaussian noise, the algorithm estimate resulted in R^2 very close to one across all joint angles, joint angle velocities, and joint angle accelerations (R^2= .9999, .9999, and .9986, respectively). Physical experiments with a Hybrid III 50th percentile male arm will be used to validate the algorithm's position and orientation estimates against an industry standard camera-based system. Though physical testing is required to fully validate the methodology, the preliminary conclusion is that the algorithm and instrumentation scheme established in this research will suffice to replace camera-based motion capture for position and orientation measurements in high energy testing with various ATDs and ultimately with post mortem human subjects.