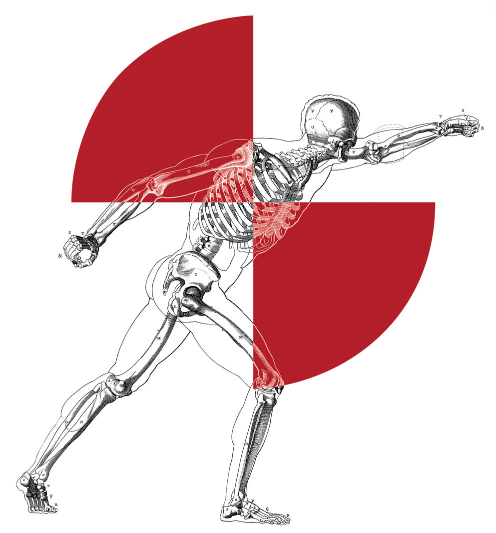

Kinematic Model Based Sensor Fusion for Inertial Measurement Units in Injury Biomechanics

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INTRODUCTION

- Measurements of whole-body position and orientation (pose) are important to injury biomechanics.
- Current practice uses optoelectronic stereophotogrammetric systems (OSS).
  - Problems: calibration and occlusion
- Drift-free inertial measurement unit (IMU) pose estimates are possible when kinematic models are used [1]
- Objective: Develop a Kinematic model based IMU sensor fusion algorithm for anthropomorphic test devices (ATDs) (i.e., crash test dummies)

Figure 1. OSS in ATD testing

METHODS: Instrumentation

- The algorithm interprets measurements from four IMUs mounted to the ATD
- Alternating placement ensures joint angle observability

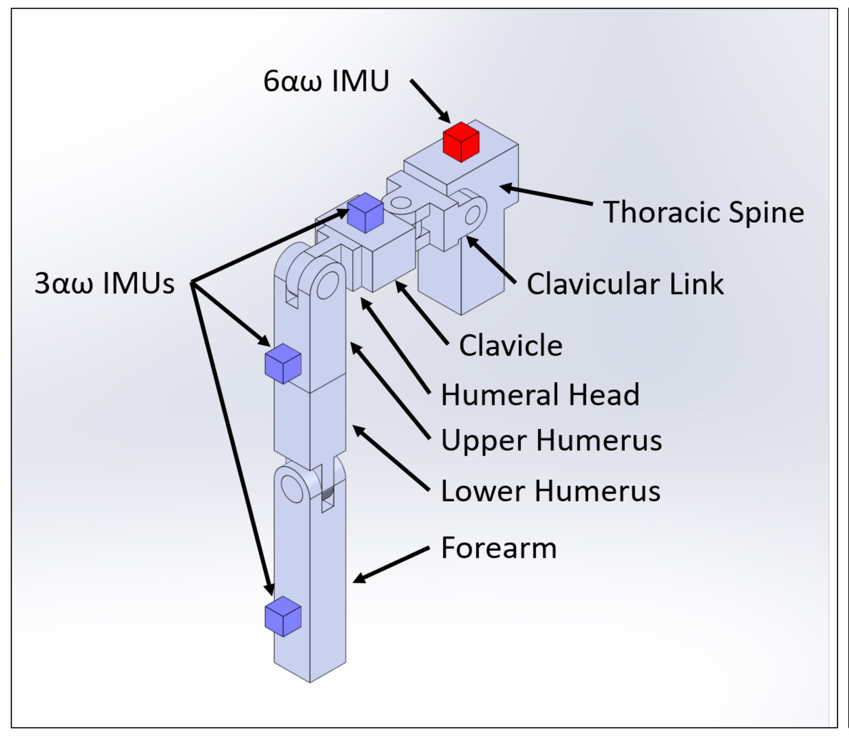


Figure 2. Link names and IMU types

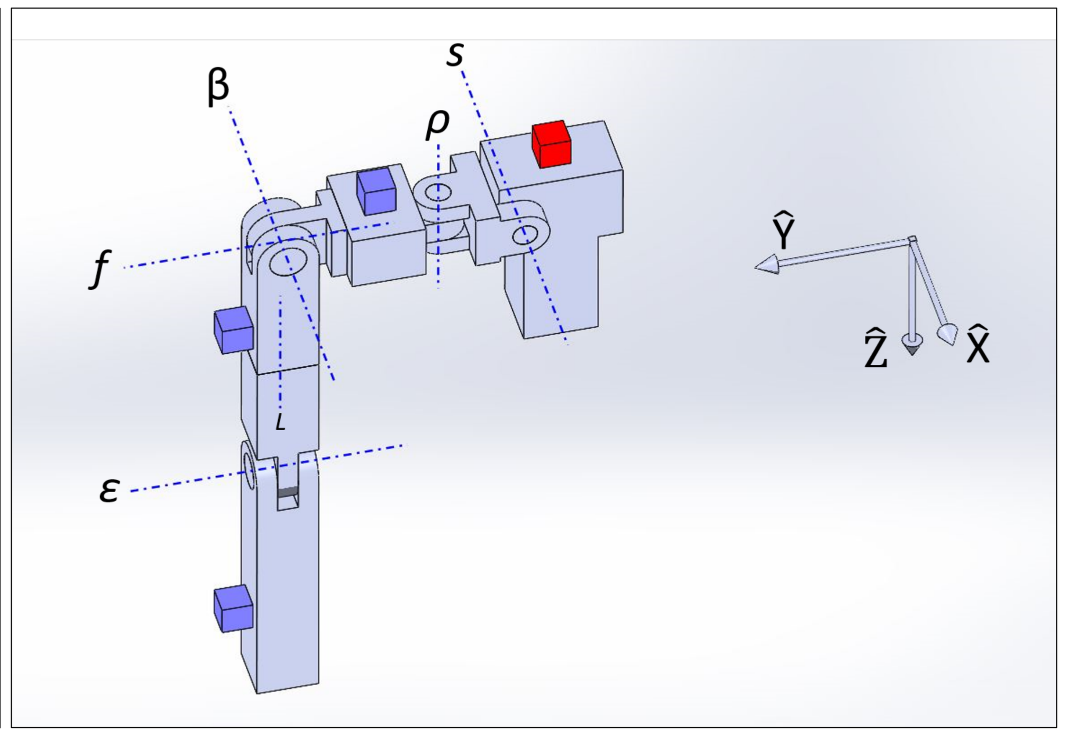
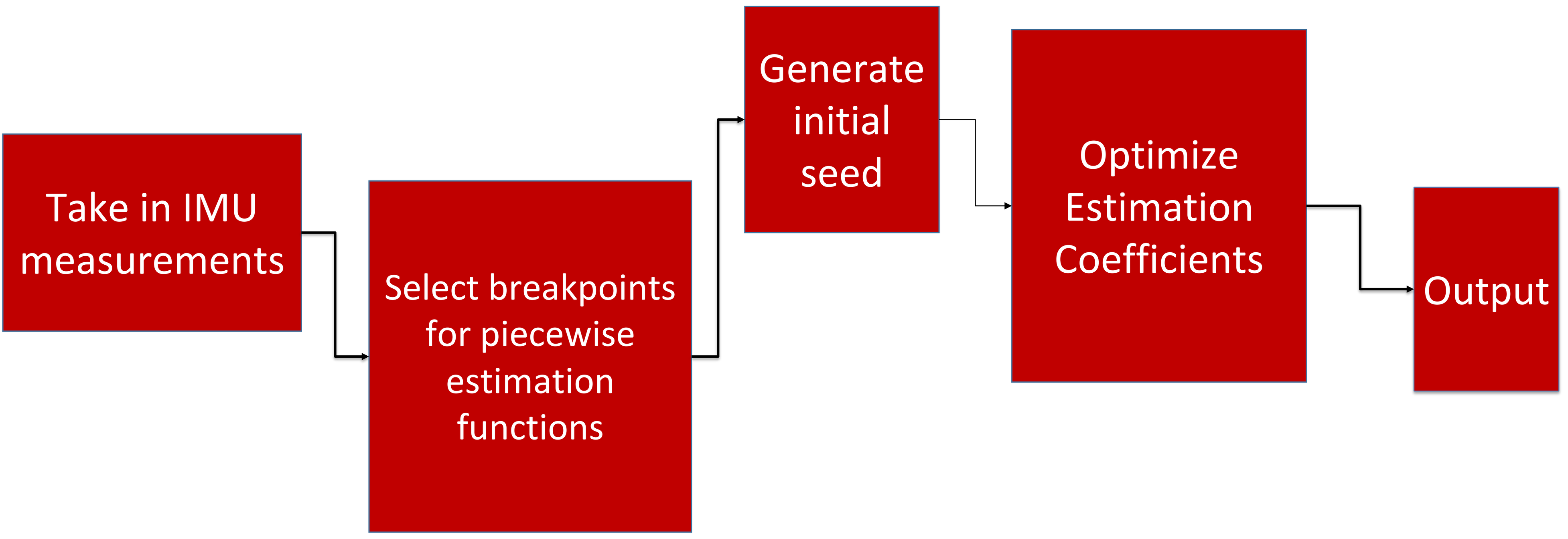


Figure 3. Joint angles and inertial coordinate system

METHODS: Algorithm Overview



METHODS: Breakpoint Selection

- The algorithm iteratively fits piecewise 3rd order polynomials to the angular acceleration and specific force measurements, adding new break points in every iteration based on the quality of fit within each panel

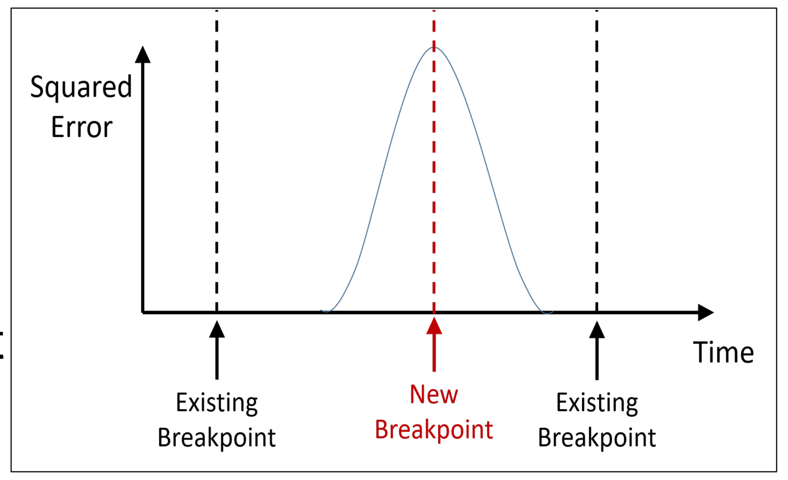


Figure 4. Break Point Placement

$$wSE_j = \sum_{i=1}^{m} \frac{\left(Y_{ij} - \hat{Y}_{ij}\right)^2}{Var_i}$$

$$bp_{new} = \frac{\sum_{j=1}^{n} wSE_j t_j}{\sum_{j=1}^{n} wSE_j}$$

- Algorithm starts with one panel
- New break points are placed at the first moment of the weighted squared error distribution in time within panels with unacceptable error

METHODS: Optimization

- Objective Function

$$Cost = \sum \frac{\left(Measurement_{obs} - Measurement_{est}\right)^2}{NoiseVariance}$$

  - Minimizing this cost maximizes the posterior likelihood
- Constraints
  - Continuity and twice differentiability of polynomials at breakpoints

METHODS: Simulation

- The algorithm was tested in simulation using a rigid body model in Simulink Simscape (MATLAB).
- Simulated arm flailing from torso acceleration
- The sensor noise variances and sample rates were set to mimic real experiments.

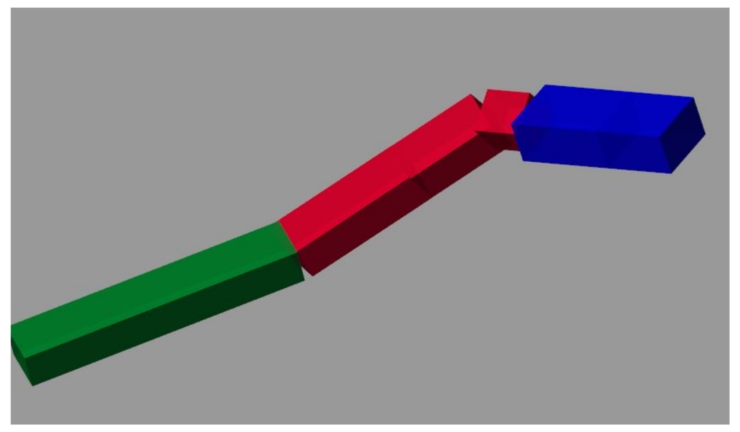


Figure 5. Simscape animation

RESULTS

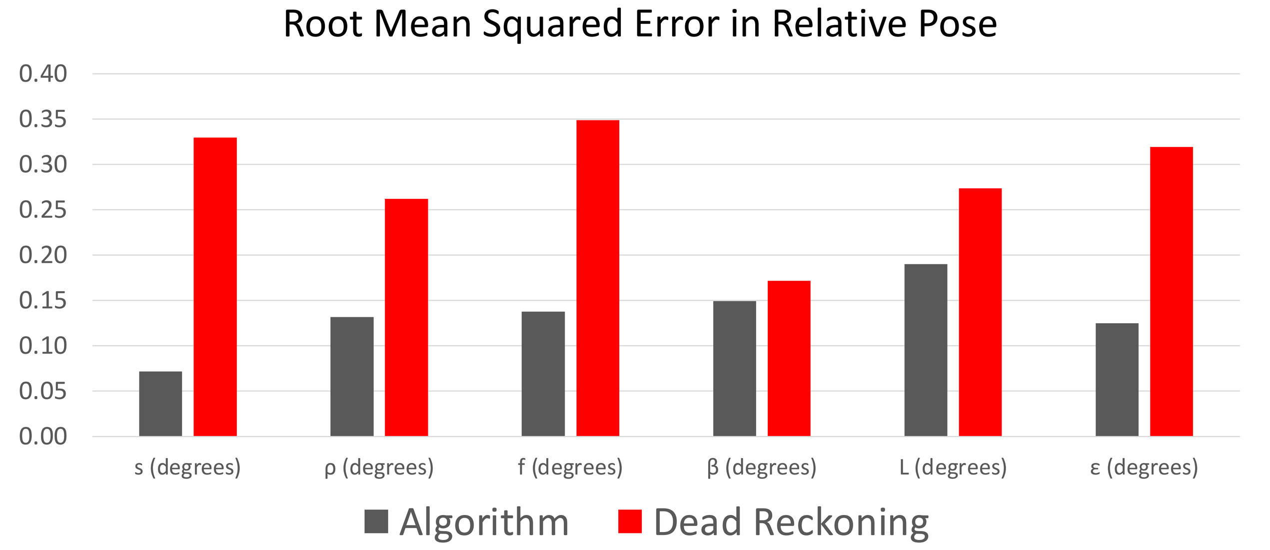


Figure 6. Relative Pose RMSE

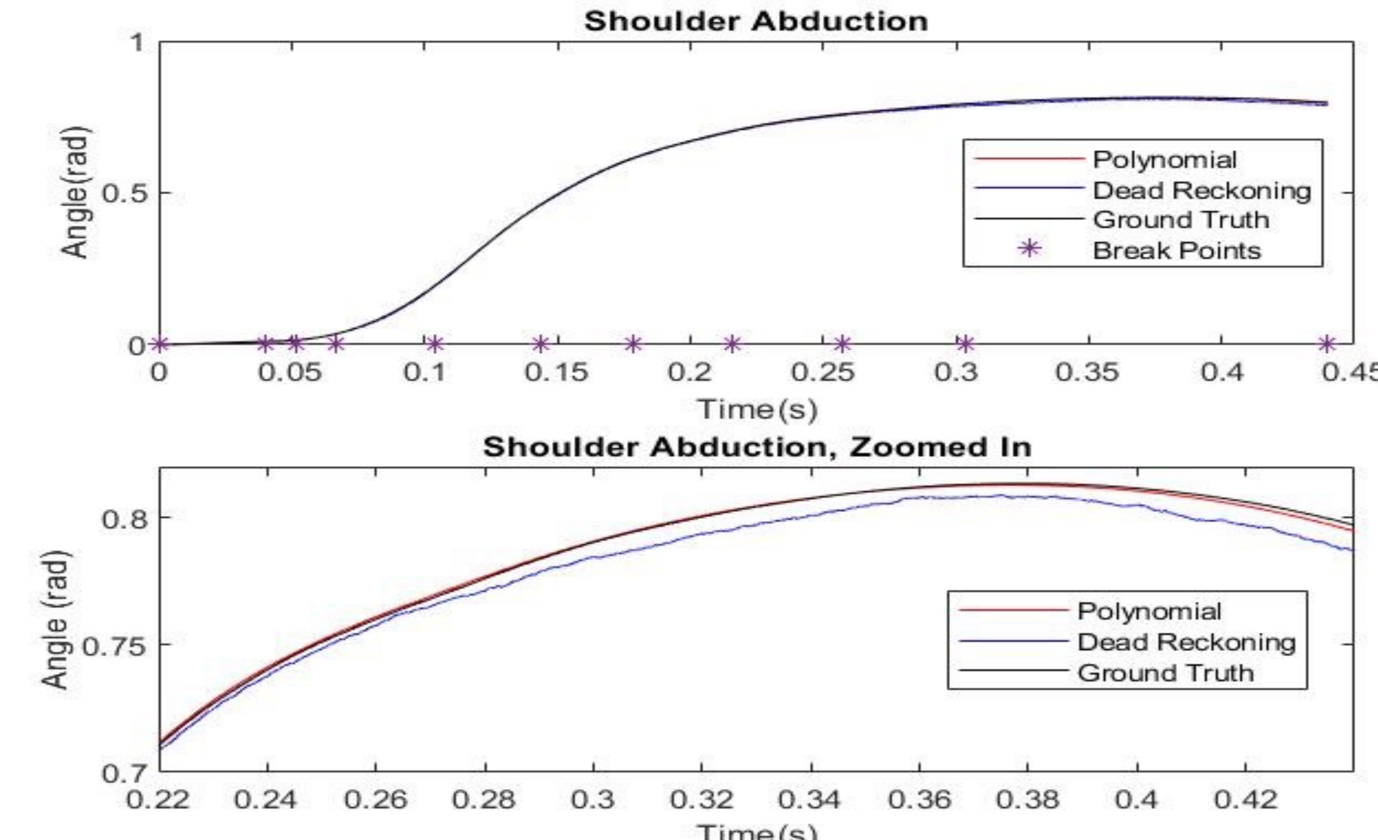


Figure 7. Example Performance

DISCUSSION

- The algorithm only provides an advantage for relative pose measurement
- Errors in position were uncorrelated to time, indicating little to no drift in relative pose for longer experiments
- The algorithm depends on a zero mean gaussian noise model for the IMU Measurements and a highly accurate kinematic model
- Though the simulation tests seem promising, no conclusions may be drawn as to the efficacy of this method as a replacement for OSSs

CONCLUSIONS

- Simulations show the algorithm and instrumentation scheme are superior to dead reconning for estimation of the kinematic state of an ATD upper limb and thoracic spine assembly
- Future work must compare the performance of this method to OSS measurements using physical experiments in order to conclude on its value as a replacement for OSSs in ATD testing

ONGOING WORK

- Physical pendulum testing

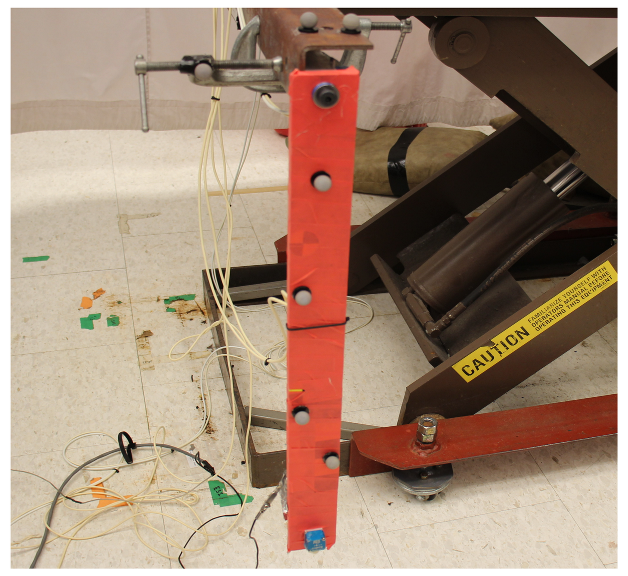


Figure 8. Single Pendulum

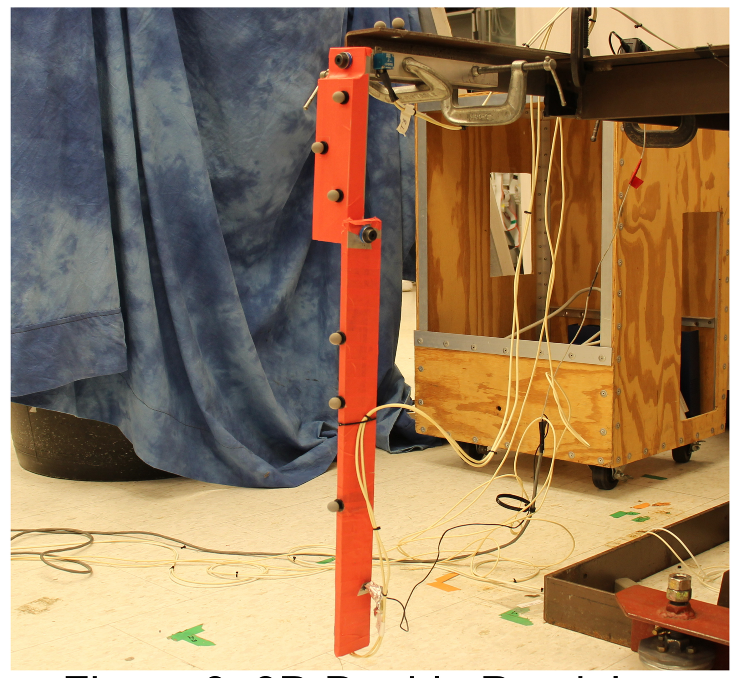


Figure 9. 3D Double Pendulum

- Physical ATD upper limb testing

REFERENCES CITED

[1] Kok, M., Eckhoff, K., Weygers, I., & Seel, T. (2021). Observability of the relative motion from inertial data in kinematic chains. ArXiv, abs/2102.02675.

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