

Optimization vs Unscented Filtering for Measuring Walking Motion using IMUs

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Summary

This study applied optimization and unscented Kalman filter methods to an 18-DOF lower body model to convert synthetic inertial measurement unit (IMU) data into corresponding joint angles. Tracking errors produced by both methods were compared using overground and treadmill walking data. The optimization method was more accurate and robust, although it required more computation time.

Introduction

IMUs could provide an attractive alternative to video motion capture systems for measuring walking in a non-laboratory setting. The two most common methods for converting IMU data into corresponding joint angle data are optimization and unscented Kalman filtering. While optimization methods are more flexible, unscented filtering methods are generally faster computationally. This study compares these two methods using noisy synthetic IMU data generated from actual video motion capture walking data.

Methods

Experimental video motion capture and IMU data were collected from a single subject who performed overground and treadmill walking trials. For an initial static trial, three reflective markers were placed on each IMU consistent with IMU local coordinate systems. OpenSim model scaling [1,2] was performed to scale a generic 3D OpenSim model [3] and attach dynamic markers and IMUs to the pelvis (6 DOFs) and lower body segments (6 DOFs per leg). Next, OpenSim inverse kinematics was performed to calculate pelvis and lower body joint angles as well as corresponding synthetic IMU measurements. Finally, synthetic noise was added to the synthetic IMU data to emulate actual IMU data.

For one overground and one treadmill walking trial, pelvis and lower body joint angles were recovered from the noisy synthetic IMU data using a nonlinear least squares optimization method and a standard unscented filter method, both implemented in Matlab. For each time frame, the optimization method adjusted the kinematic model's joint positions, velocities, and accelerations to minimize errors between model and synthetic IMU data (including integrated IMU orientations, velocities, and positions) and between model and integrated joint positions and velocities. All numerical integration was performed using an implicit method.

Results and Discussion

Overall, the optimization method was more accurate and robust than was the unscented filter method. While the unscented filter was only slightly less accurate for 4 seconds

of overground walking (Fig. 1), it completely diverged for 30 seconds of treadmill walking. In contrast, the optimization method tracked the correct joint positions well for the duration of the treadmill walking trial (average RMS errors of < 2 mm for translations and < 1 deg for rotations for last 3 seconds). Thus, the optimization method could entrain the kinematic model to the natural system dynamics, while the unscented filter method could not. The main drawback of the optimization method was increased computational cost, though no effort was made to improve it.

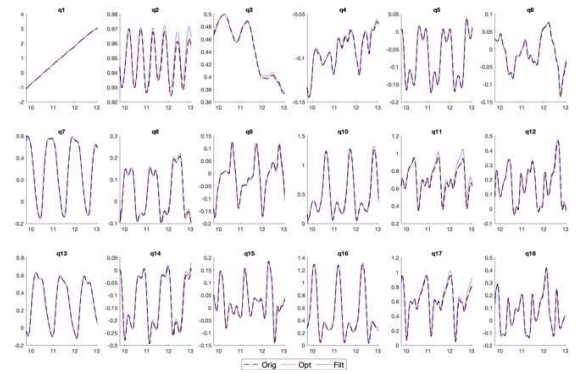


Figure 1: Optimization vs. filtering for overground walking.

Both methods required parameter tuning to achieve the best tracking of the original joint angles. The optimization method required identifying different cost function weights for position, velocity, and acceleration errors and was relatively insensitive to the selected values. In contrast, the unscented filter method required state and measurement covariance along with α , β , and κ algorithm parameter values and was more sensitive to the selected values.

Conclusions

The optimization method produced more accurate and robust joint angle tracking than did the unscented filter method but at the cost of increased computation time. The next step will be to repeat the evaluation using actual IMU data that can be properly synchronized with the motion capture data.

Acknowledgments

This work was by the National Science Foundation under award number 1805896.

References

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