

EVALUATING AN OPTIMIZATION METHOD TO MEASURE TREADMILL AND OVERGROUND WALKING MOTIONS USING IMUS

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INTRODUCTION

This study converted synthetic inertial measurement unit (IMU) data into corresponding joint angles using an optimization method applied to an 18-DOF lower body model. Tracking errors were compared for overground and treadmill walking data. The optimization method was accurate and robust, at the cost of a high computation time.

IMUs could provide an attractive alternative to video motion capture systems for measuring walking in a non-laboratory setting. An optimization method was used in this study to convert synthetic IMU data into corresponding joint angles.

METHODS

Experimental video motion capture and IMU data were collected from a single subject who performed overground and treadmill walking trials. The overground trial lasted approximately 3 seconds, while the treadmill trial lasted 30 seconds. 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). OpenSim inverse kinematics were then performed to calculate pelvis and lower body joint angles and 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 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. The actual values of the joint angles and its derivatives were used to set the initial states of the model.

RESULTS AND DISCUSSION

Overall, the optimization method was accurate and robust and tracked the correct joint positions well for the duration of both walking trials (average RMS errors of < 2 mm for translations and < 0.1 deg for rotations). Thus, the optimization method could entrain the kinematic model to the natural system dynamics. The main drawback of this method was increased computational cost, though no effort was made to improve it.

Parameter tuning was required to achieve the best tracking of the original joint angles. Different cost function weights for position, velocity, and acceleration errors needed to be identified. However, the method was relatively insensitive to these values. As seen in Table 1, the errors are fairly small compared to the scale of the motion, which proves that this nonlinear least-squares optimization is a robust way to recover joint kinematics from IMU data.

Table 1. RMS errors for the various joints for overground vs. treadmill walking data.

Coordinate	Overground error	Treadmill error
Hip Translations ($q_1 - q_3$)	0.463mm	1.21mm
Hip Angles ($q_4 - q_6$)	0.0474°	0.0447°
R Thigh Angles ($q_7 - q_9$)	0.0695°	0.0743°
R Knee Angle (q_{10})	0.0539°	0.0567°
R Ankle Angles ($q_{11} - q_{12}$)	0.0713°	0.0746°
L Thigh Angles ($q_{13} - q_{15}$)	0.0719°	0.0822°
L Knee Angle (q_{16})	0.0627°	0.0530°
L Ankle Angles ($q_{17} - q_{18}$)	0.0994°	0.0819°

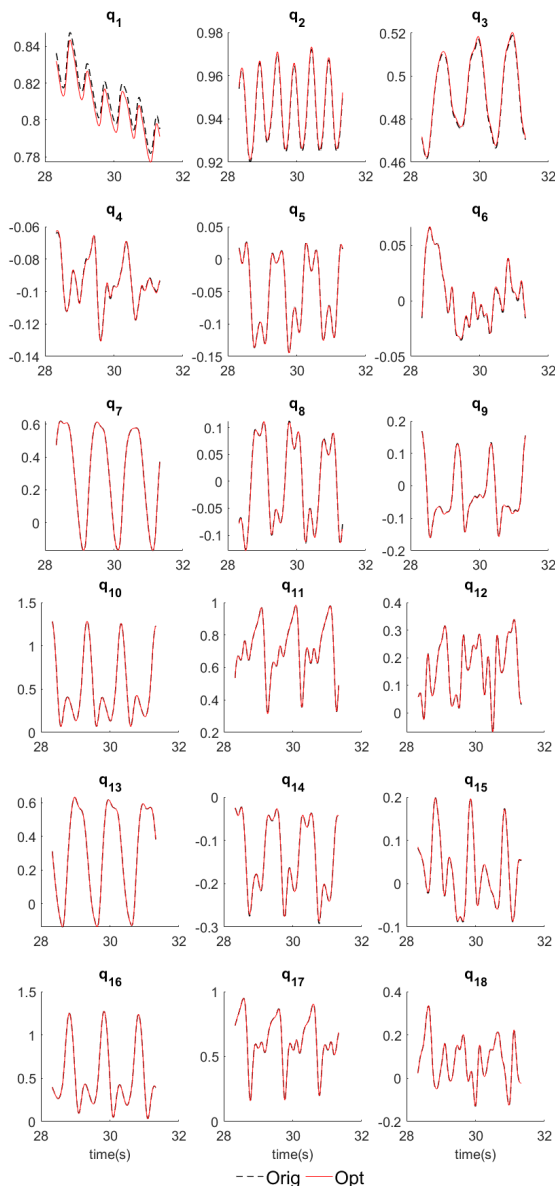


Fig 1: Optimization estimates for generalized coordinates during the last 3 seconds of treadmill walking.

CONCLUSIONS

The optimization method produced accurate and robust joint angle tracking at the cost of increased computation time. For this method to be useful in real-time applications in the future, computation time and efficiency will need to be improved. Work is also ongoing on a new dataset to recover joint coordinates from experimentally collected IMU data.

REFERENCES

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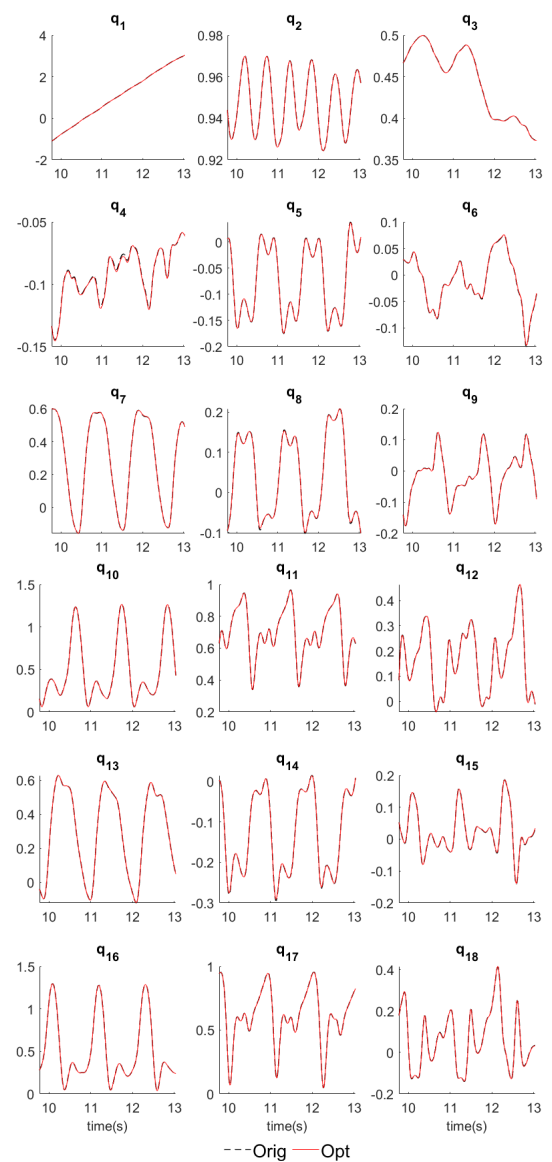


Fig 2: Optimization estimates for generalized coordinates during overground walking.

ACKNOWLEDGEMENTS

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