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Evaluation of a Nonlinear Optimization Method for Measuring Human Movement Using Inertial Measurement Units

***Anirudh S. Bhateja*[1], *Thor F. Besier*[2], *Benjamin J. Fregly*[1]**

[1]Department of Mechanical Engineering/Rice University/UNITED STATES, [2]Auckland Bioengineering Institute/University of Auckland/NEW ZEALAND

Introduction

Inertial measurement units (IMUs) are an alternative to traditional optical motion capture systems that allow for data collection outside the lab and continuous monitoring for daily activities. In this study, a non-linear least squares optimization was used to convert IMU measurements into joint kinematics. The optimization calculates joint angles simultaneously over all time frames by optimizing B-spline nodes, without integrating any IMU measurements. This approach enables an accurate solution that works well with noisy experimental IMU data since integration errors are eliminated.

Methods

Experimental motion capture and IMU data were collected from a single subject who performed treadmill walking at a self-selected speed. IMU data were low-pass filtered at 6 Hz using a fourth-order zero-phase-lag Butterworth filter and then downsampled to 100 Hz to match the motion capture sampling frequency. First, OpenSim model scaling [1,2] was performed to scale a generic OpenSim model [3] and attach dynamic markers and IMUs to the pelvis (6 DOFs) and lower body segments (6 DOFs per leg). Then, OpenSim inverse kinematics was performed to calculate model joint angles from the experimental motion capture data. Finally, a nonlinear least squares optimization method was implemented in MATLAB to calculate model joint kinematics over all time frames simultaneously from the noisy experimental IMU data. The cost function minimized errors between model-predicted and experimental IMU measurements by adjusting 30 B-spline nodes that defined the time history of each generalized coordinate and its first two time derivatives. Initial guesses for all nodes were set to zero.

Results

Compared to marker-based inverse kinematics results, the optimization predicted IMU-based joint positions with root-mean-square (RMS) errors of at most 2.8 deg for sagittal plane rotations and 5.7 deg for non-sagittal plane rotations.

Discussion

While RMS errors were large for all three pelvis translations, the estimated pelvis linear accelerations were quite reliable, suggesting that these errors could be significantly reduced if the correct pelvis initial position and velocity were known and the predicted pelvis linear accelerations were integrated. Errors could be further reduced by tuning the weights in the cost function using a two level optimization [4]. Future work will involve tuning these weights and working on ways to improve computation time.

Acknowledgments

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References

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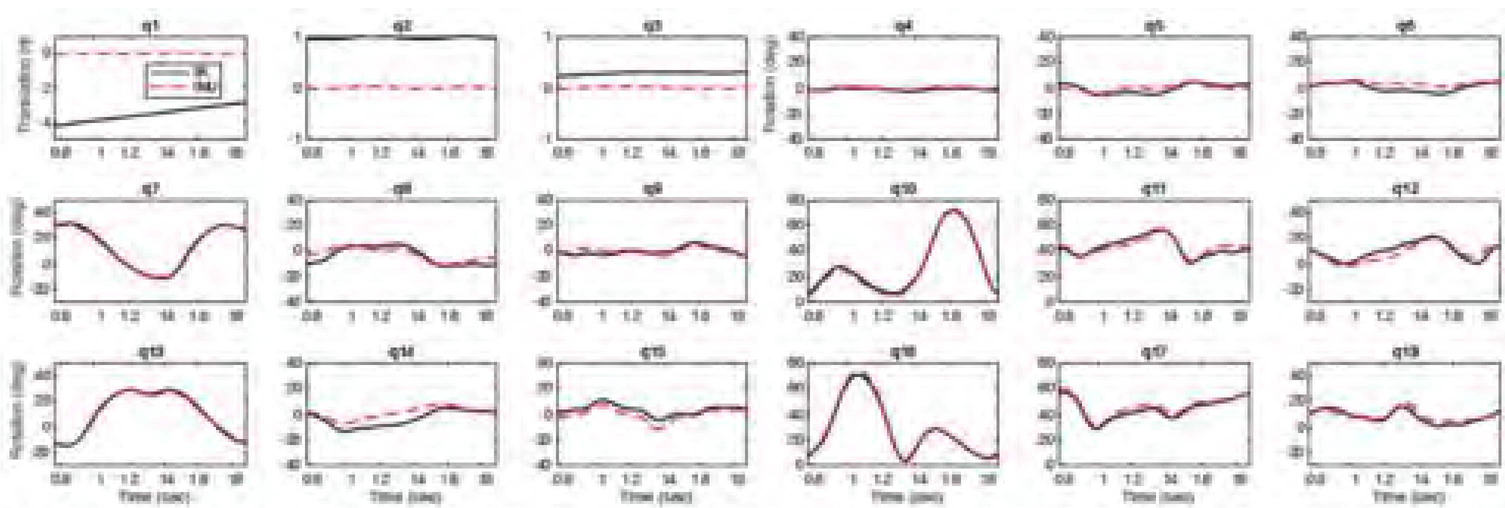

Figure 1. IMU inverse kinematics results obtained from the integrationless optimization (in red dashed line) compared with the inverse kinematics data from optical motion capture (in black solid line). q1-q3 are pelvis translations, q4-q6 are pelvis rotations, q7-q9 (R) and q13-q15 (L) are hip rotations, q10 (R) and q16 (L) are knee rotations, q11-12 (R) and q17-q18 (L) are ankle and subtalar rotations.

Keywords: inertial, wearables, simulation, optimization, gait