Simulating change of direction movements from inertial sensor data – Comparing optimal control problem setups

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Summary

We aim to develop an approach to measure kinetics and kinematics of change of direction (COD) movements on the sports field. We investigated three optimal control problem setups to estimate kinematics and kinetics from inertial sensor data and validated them using optical motion capture and force plate data. We found that an objective enforcing the COD angle on the pelvic rotation or on the velocity direction did not improve simulation accuracy, but the pelvic rotation objective allowed for a sharper change in direction.

Introduction

To better understand injury mechanisms, of e.g., anterior cruciate ligament injuries, it is necessary to measure injury-prone movements in real-life conditions. Inertial measurement units (IMUs) allow for measurements in the field, but estimation of biomechanical variables from these measurements is challenging. Previously, optimal control has been used to simulate walking and running movements [1], while a proof of concept of this approach has been shown for COD movements using virtual sensors [2]. Preliminary work found that this approach did not always lead to COD angles being estimated correctly with actual sensor data. Therefore, we compared optimal control setups to simulate COD movements effectively from measured IMU data.

Methods

We set up three different optimal control problems using a three-dimensional musculoskeletal model [3] in which a combination of effort and a tracking error between measured and simulated IMU data (linear acceleration and angular velocity) was minimized. Simulation A was created by solving the problem as already described, while simulations B and C included a pelvic rotation objective and a velocity direction objective, respectively. Each objective penalized the variable of interest when it was not between 125° and 145° at the time point of COD exit. We then generated simulations of a 135° COD movement of a single participant [4]. Eight IMUs were placed on the torso and legs, while optical motion capture and force plate data was recorded for validation. This validation data was processed in OpenSim [5] to estimate kinematics and kinetics.

Results and Discussion

We found similar root mean square errors (RMSEs) and correlations for the majority of kinematic and kinetic variables estimated by all three simulations, with respect to the measurements. However, simulations A and C resulted in improved hip adduction RMSEs (A: 24.4, C: 29.4 vs B: 36.0) and correlations (A: 0.8, C: 0.7 vs B: 0.02), for the cutting leg than simulation B. Simulation A improved the cutting leg's hip flexion and lateral pelvis translation, compared to the other simulations. Simulation B improved estimates for the contralateral leg's vertical ground reaction force (RMSEs for B: 0.3 vs A: 0.6, C: 0.6) and knee joint angle (RMSEs for B: 23.8 vs A: 30.4, C: 34.5). It also led to a more typical COD movement pattern, with a sharp and discrete change in direction, unlike the continuous, gradual turning trajectory of simulations A and C (Figure 1).

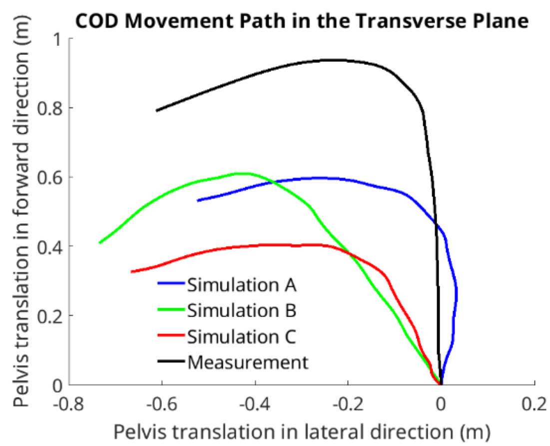

Figure 1: Top-down view of the movement path followed by the participant ('Measurement') and by each simulation.

None of these setups achieved good accuracy for the cutting leg's knee joint angle and GRFs, while also the body posture was more upright in the simulation than in the experiment.

Conclusions

We found that adding a pelvic rotation or a velocity direction objective did not improve the estimated kinematics and kinetics of a COD movement. We aim to further evaluate the optimal control problem setup and investigate approaches for improving ground contact, as well as objectives related to performance, like movement speed, which could improve the estimation of the cutting leg's joint angles and body posture.

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