Evaluation of Optimal Control Formulations for Obtaining Dynamically Consistent Walking Motions

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Abstract

Introduction

In recent years, interest has grown in predicting human motion, for example, to study cause-effect relations for a specific task [1]. To predict human motion, researchers typically use optimization-based methods that minimize a certain cost function. The objective of this study is to analyze two different optimal control formulations that track experimental data from a healthy gait cycle to obtain a dynamically consistent walking motion, i.e., with minimal residual wrench applied to the pelvis.

Methods

Experimental walking data were collected from a healthy male subject using optical infrared cameras and two force plates. The skeletal model was based on a 3D model with lower limbs and HAT (head, arms and trunk segment), developed in OpenSim [2] and scaled to specific dimensions. The optimal control problem for both formulations was to find joint positions, velocities, accelerations, jerks (only in the second formulation), and torques that minimized differences between experimental and predicted motions while reducing the pelvis residual wrench. The equations of motion for the multibody system, obtained from OpenSim, were introduced as algebraic path constraints. The problem was solved using GPOPS-II [3]. Four different cases were studied for each formulation by modifying the weights of each term in the cost function. Computational time, number of iterations, reduction of residual wrench (with respect to that of inverse dynamics) and differences between predicted and experimental motion were calculated to assess results.

Results

Joint positions and computational time for the four cases without jerk (second formulation) are shown in Figure 1. The joint positions that differed the most from the experimental motion were hip flexion and lumbar extension coordinates. Both formulations produced the highest computation times and iterations when the torque tracking weights were low. In contrast, the lowest computation times and iterations were achieved using equally weighted terms and, in particular, with low weights on tracking joint positions and velocities but not jerks (Figure 1). All solutions showed high reduction of residual wrench components, especially those without jerk minimization.

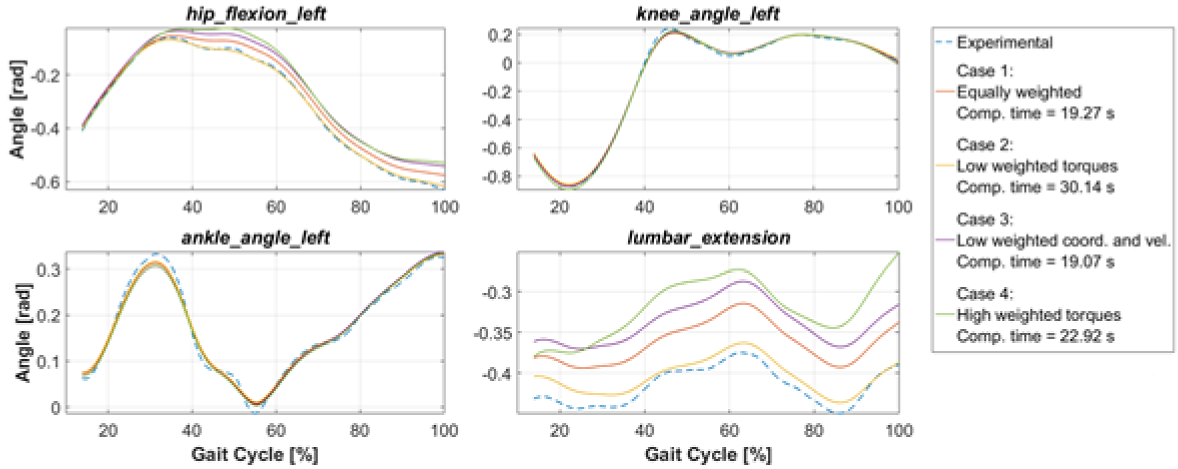

Fig. 1: Evolution of left leg and lumbar coordinates in the sagittal plane for different study cases. Computation time and description of each case are shown in the legend

Discussion

Results showed that better convergence was achieved when giving more weight to torque and acceleration variables, and better tracking of experimental values when giving more weight to kinematic variables. Adding jerk minimization to the cost function improved convergence and smoothened evolution of joint positions, but increased computation time per iteration. We conclude that the formulation without jerk minimization and with all terms equally weighted presents a good tradeoff between convergence and tracking, together with low computational time.

Acknowledgments

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References

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