A Neuromuscular Controller for Predictive Simulations of Pathological Gait

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1 Introduction

We are developing a neuromuscular controller for synthesizing gait, based on high-level optimization criteria such as gait speed, gait stability and energy efficiency. Our controller allows integration of neurological constraints such as motor noise and neural delays, as well as models of spasticity and obligatory synergies. Our goal is to use subject-specific neuromusculoskeletal models and optimized controllers to perform predictive simulations of pathological gait patterns found in children with cerebral palsy (CP). Eventually, this will develop into a tool that can help clinicians predict the outcome of surgical intervention and increase the effectiveness of orthoses.

2 Related Work

Existing work on predictive neuromuscular simulation can be categorized into *a*) methods that optimize feedforward muscle excitation patterns (e.g. [1] and [2]), and *b*) methods that optimize the control parameters of a feedback controller (e.g. [3] and [4]). Our approach is a continuation of the latter strategy, which has the advantage of treating model simulation as a black box, allowing easy integration into existing research pipelines.

3 Methods

Our controller consists of the following components:

- A feedforward controller that provides goal-driven excitation patterns without stability demands, analogous to central pattern generators (CPGs) in humans.
- A "low-level" feedback controller based on proprioceptive feedback (position, velocity and force feedback, delays of 25-40ms), which helps stabilize gait and simplifies control by adjusting the mechanics of the musculoskeletal system to accommodate bipedal gait.
- A "high-level" feedback controller based on vestibular and visual feedback (delays of 150-200ms), allowing recovery from large disturbances and stabilizing gait over multiple cycles.

All control parameters are optimized using Covariance Matrix Adaptation (CMA) [5], based on high-level objectives. We use OpenSim [6] for simulation, but the modular setup of our framework allows easy integration of alternative simulation engines. Even though previous studies that use a similar approach have demonstrated promising results on simplified models with a limited number of musculotendon actuators, attempts to scale to more comprehensive "clinical-grade" models have so far been unsuccessful. We have identified a number of challenges related to musculoskeletal modeling and parameter dimensionality, and are investigating the following methods to overcome these challenges:

- *Modal feed-forward control*. Instead of optimizing individual trajectories for each muscle, we take advantage of the correlation between signals by optimizing a number of "modes".
- *Reduced model*. To reduce the number of parameters in proprioceptive feedback control, we optimize in a lower-dimensional representation.
- *Adaptive dimensionality increase*. To avoid local minima, we gradually increase control resolution based on the current optimization rate.

Our subject-specific neuromusculoskeletal models will be derived from MRI and data from a physical exam, using measurements from 30 CP children.

4 Current State and Validation

Our system is in an advanced stage of development, and while our initial results look promising, we have yet to acquire data for validation. This data – from both healthy subjects and CP children – will include motion capture, force plate and EMG data, and will be compared to our simulated kinematics, dynamics and neural commands.

References

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