Towards Neuromuscular Model-based Control for Robust Locomotion with Powered Transfemoral Prostheses

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1 Motivation

Currently, there are six hundred thousand transfemoral amputees living in the United States. Experts forsee further growth in this population over the coming decades due to a looming diabetes epidemic [1]. These amputees are often prescribed mechanically passive prostheses that cannot perform positive net work over a gait cycle. Consequently, amputees suffer from increased energy consumption, slow walking speeds, and limited ability to respond to unexpected disturbances such as terrain variations and trips [2]. To address these issues researchers have developed powered lowered-limb prostheses. The addition of active components in these prostheses necessitates development of high-level controls that specify joint behaviors in terms of desired torques. A promising approach to generate behavior-level controls for powered prostheses is to use neuromuscular models of human locomotion. Previous work has successfully employed these models to control powered transtibial prostheses [3] and has demonstrated that these models can produce natural and robust gaits for a simulated biped [4]. Motivated by these results, in this work we investigate the efficacy of neuromuscular models for behavior-level control of transfemoral prostheses.

2 Our Approach

To achieve this objective, we first design a transfemoral prosthesis capable of executing the behaviors commanded by the proposed control. The hardware, displayed in Figure 1A, features two series elastic actuators (SEAs) that drive the knee and ankle joints. During stance, the neuromuscular model generates torque references for the prosthesis' knee and ankle joints by simulating muscles and hypothesized neural feedback pathways. During the swing phase, the model commands torques according to a heuristic control that reproduces observed phases of human swing-leg control.

To design and validate neuromuscular control we have developed a simulation of an amputee wearing this prosthesis, which we use to rapidly evaluate changes to the proposed controller. We then test these controls through clinical trials with amputee subjects. We intend to evaluate our control based on its ability to reproduce unimpaired gait kinematics and kinetics and its ability to respond to unexpected disturbances such as trips.

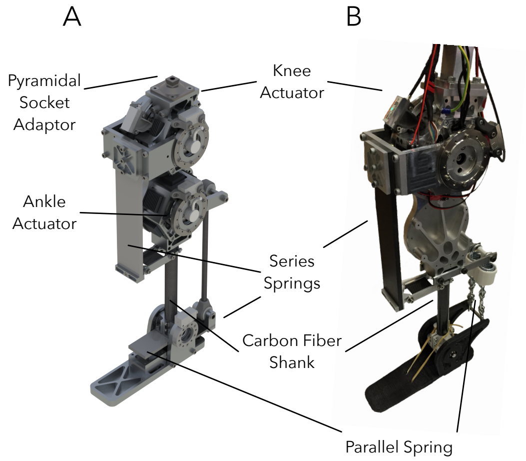

Figure 1: Prosthesis prototype. (A) CAD render of proposed design of powered knee and ankle prosthesis. (B) Current stage of prototype with active knee and passive ankle.

3 Current Results

At present, the transfemoral prosthesis prototype has a completed knee SEA unit and a passive ankle (Figure 1B). We have tested the knee portion of the control by connecting the prosthesis to a manually-actuated thigh link, which we mount to a stationary cage through a revolute joint that replaces the hip. We evaluate the stance and swing controls by simulating a virtual ground and adding the knee torque induced by the ground reaction force to the torque commanded by the neuromuscular model. Figure 2 shows the joint angles, torques, and muscle activations produced by the knee control and those of an unimpaired subject [5]. The stance control reproduces the extension and flexion seen at the onset of stance, albeit with a 10% of stride phase delay. Moreover, the stimulations of the model's hamstring and vastus muscles show that the control first flexes the knee to prevent knee extension at heel strike, and then extends the knee during stance to bear load and provide compliant leg behavior. During swing, we see a similar degree of knee flexion as seen in the unimpaired data.

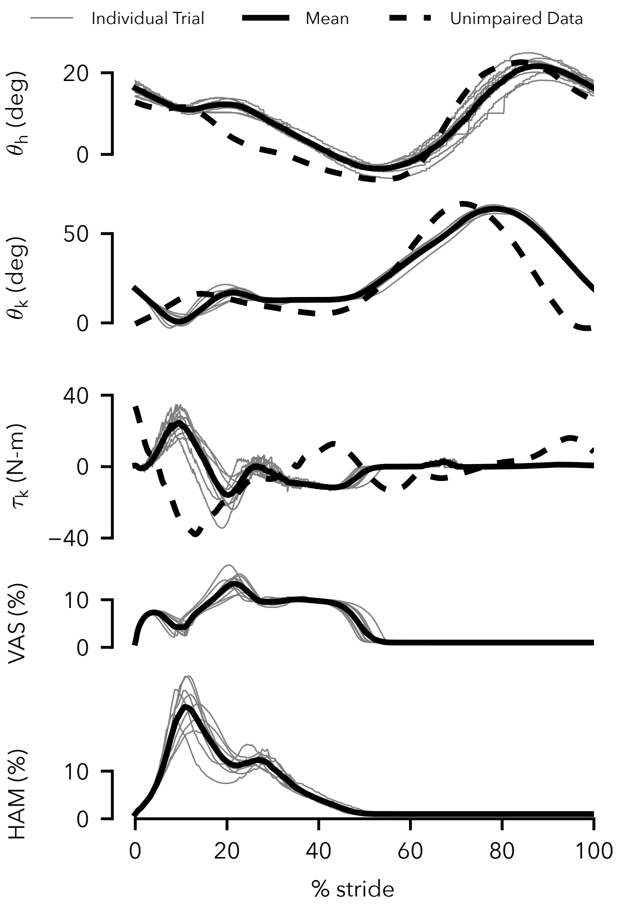

Figure 2: Generation of normal stance and swing leg behavior. Shown are the hip and knee trajectories, the knee controller torque, and the vastus and hamstring activations, generated by the prosthesis control in the testbed. Solid black lines show averaged data of 10 trials with the individual trials depicted in gray. Dashed lines show data of a 56.7kg subject based on [5].

4 Future Work

By the time of the conference, we intend to test the neuromuscular knee control on able-bodied subjects wearing the prosthesis through an adaptor. In proceeding work, we will add an active ankle to the prosthesis allowing for clinical trials of the full neuromuscular control on amputee subjects.

5 Acknowledgment

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