Comparative Study of Hybrid Finite State and Variable Impedance Controllers Driven by Electromyography Neuromuscular Model for Active Ankle Prostheses

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Summary

This research investigates the performance of an EMG-driven variable impedance controller (VIC) against a hybrid controller (HC) combining a non-volitional finite-state machine (FSM) impedance controller with an EMG-driven neuromuscular model (NM). Both controllers were tested on a transtibial amputee during level-ground walking at self-selected and high speeds. The EMG from the antagonist muscle pair and ankle sensor input are used in both controllers to activate the muscle models. Experimental results show that both controllers adapt to varying walking speeds effectively, but the VIC offers better repeatability, while the HC produces more torque and power.

Introduction

Finding a balance between adaptability for unexpected or non-standard movements and repeatability for cyclic standard movements is a known control challenge for active lower-limb prostheses. This research compares the performance of two different EMG-driven controllers to achieve a balance between consistency and adaptability while emphasizing that understanding user-specific needs and environmental challenges is essential for advancing prosthetic technology.

Methods

The Gastrocnemius (GAS) and Tibialis Anterior (TA) muscles were modeled using a Hill-type muscle model to estimate joint torque and stiffness [1]. The HC combines this estimated torque with the FSM impedance torque to control the prosthetic during the stance phase [2], while the VIC dynamically adjusts stiffness based on the gait cycle subphases [3]. Surface EMG signals from the TA and GAS were recorded using Össur's prosthetic assembly in a transtibial amputee during level-ground walking at self-selected and high speeds. The Icelandic National Bioethics Committee approved the testing protocol (CII2019061252). Data collection utilized a 3D motion capture system (Vicon, Oxford, UK) with 10 cameras and six force plates (AMTI, MA, USA), sampling at 100 Hz and 1000 Hz, respectively. A customized lower-body marker set was employed to create a six-degree-of-freedom model. Data processing was performed using VICON Nexus and Cleanse (Moveck Inc.) software.

Results and Discussion

Both controllers showed adaptation, by effectively adjusting to the participant's self-selected and high-speed gait. However, the VIC Controller provided better repeatability compared to the HC (Figure 1), as demonstrated by the lower standard deviation of the torque. The VIC's repeatability is achieved by employing a single equation, whereas, inconsistencies of the HC are likely due to its many equations and complex relationships, especially when small changes or uncertainties in system parameters occur. Notably, during gait at self-selected speed, the VIC showed lower maximum torque (2.078 ± 0.082 Nm/kg) and peak power (4.87 ± 0.28 W/kg) than the HC (2.47 ± 0.18 Nm/kg and 4.91 ± 0.38 W/kg, respectively). At high speed, the VIC also had lower torque (2.38 ± 0.06 Nm/kg), and power (5.80 ± 0.05 W/kg) compared to the HC (2.68 ± 0.082 Nm/kg and 6.75 ± 0.20 W/kg), as shown in Figure 2.

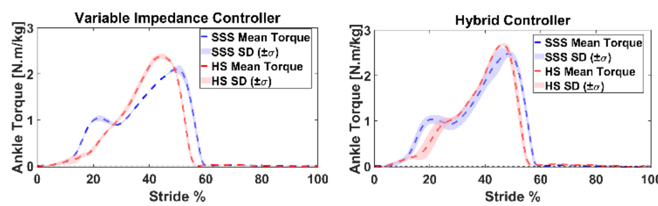

Figure 1: Ankle Torque throughout the gait cycle for both Hybrid and Variable Impedance Controllers during level-ground walking at self-selected speed (SSS) and high speed (HS).

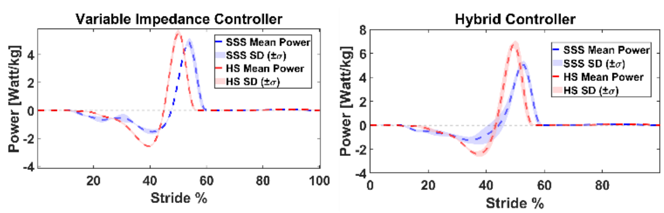

Figure 2: Power throughout the gait cycle for both Hybrid and Variable Impedance Controllers during level-ground walking at self-selected speed (SSS) and high speed (HS).

Conclusions

The VIC showed better repeatability and lower power, which makes it more likely to be suitable for level-ground walking. The HC generated higher torque and power, potentially better for activities requiring increased force, such as incline walking. More research will involve additional users and explore other functional tasks.

References

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