Hybrid Volitional Control as a Framework for Lower-Limb Prosthetic Control

Ryan R. Posh
Aerospace and Mechanical Engineering
University of Notre Dame
Notre Dame, Indiana
rposh@nd.edu

James P. Schmiedeler
Aerospace and Mechanical Engineering
University of Notre Dame
Notre Dame, Indiana
James.P.Schmiedeler.4@nd.edu

Patrick M. Wensing
Aerospace and Mechanical Engineering
University of Notre Dame
Notre Dame, Indiana
pwensing@nd.edu

I. INTRODUCTION

Realizing the potential of active lower-limb prostheses to help users increase their mobility and efficiency requires safe, reliable, stable, and intuitive control strategies. The two prevailing classes of lower-limb prosthesis control can be categorized as volitional and non-volitional. Volitional control strategies (VCs) directly sense the user's intentions, but this generally intuitive approach can be quite demanding of users, leading to fatigue and misactivation of the device. Non-volitional control strategies (NVCs) sense the state of the system instead, often taking advantage of the cyclic nature of the gait cycle to produce robust and reliable outputs. NVCs, however, do not give the user freedom to realize non-standard movements. This work proposes and analyzes a Hybrid Volitional Control (HVC) approach that operates across the entire gait cycle and seeks to balance the reliability, safety, and low demand of NVCs with the freedom and intuitive control of VCs.

II. METHODS

In general, the output torque generated by an HVC is equal to the sum of the torque generated by a VC component and that generated by an NV base component [1]. The additive nature of this combination ensures that the HVC can operate even when the user provides no volitional input signals. In the HVC formulation herein, the volitional control input is thresholded in a way that freely allows volitional inputs during certain phases of the gait cycle and discourages them during others. The modular nature of HVC is explored in [1] by combining an idealized proportional VC with either a finite-state machine (FSM) impedance NVC from [2] or a continuous phase-based trajectory NVC from [3]. HVC was analyzed using an OpenSIM model of an individual with an active transtibial prosthesis, where the individual was assumed able to produce ideal volitional control inputs. Results are compared for the two configurations of HVC, the two NVCs, and the one VC, all aiming to match the able-bodied ankle torque profiles for level-ground walking from [4]. Activity modes of descending a 2.5-degree ramp, walking on level ground, and ascending a 5-degree ramp were assessed.

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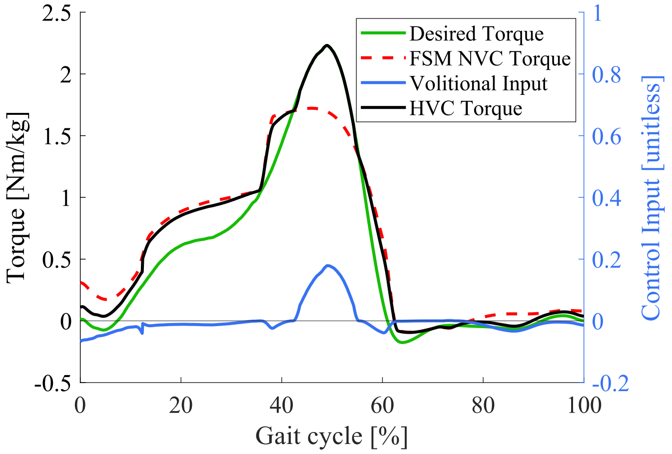

Fig. 1. Idealized HVC output ankle torque for 5-degree ramp ascent using finite-state impedance NV base controller. Volitional input is plotted on right-hand vertical axis, and desired able-bodied torque, FSM NVC torque (also representative of NV base controller), and resulting HVC torque are plotted on left-hand vertical axis. Positive torques and inputs represent plantarflexion.

III. RESULTS AND DISCUSSION

HVC shows an opportunity to reduce the torque error from an able-bodied reference compared to the two NVCs (by as much as 94%) and to reduce the volitional demand compared to a pure VC (by as much as 91%). As the NV base controller better approximates the desired torque profile, the volitional demands from the user are reduced, but the user retains the freedom at all times to alter or augment the motion. Conversely, if the NV base controller does not match the desired torque well, the user would be required to provide a larger volitional input to match the desired torque. HVC shows potential to supersede the limitations of both purely non-volitional and volitional control strategies. HVC could enable individuals with transtibial amputation to reliably participate in activities that deviate from basic gait dynamics.

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