Hybrid Volitional Control in Lower-Limb Prostheses

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I. Introduction

Many robotic lower-limb prostheses and their various control strategies allow users to achieve basic functionality - standing, walking, and stair ambulation. During weight-bearing activities, the user relies completely on the prosthesis, so control strategies must ensure robust and reliable motion. Due to the nature of the control, however, users are limited to basic movements, often rendering them unable to perform activities that deviate from standard gait dynamics, such as marching (as in a marching band), standing or walking on tip-toes, and reacting quickly to the environment.

To provide more freedom, strategies with full volitional control ensure that joint actuation depends directly on the user's intentions. These strategies, however, can misinterpret those intentions, and muscle fatigue or loss of concentration can lead to poor foot placement and eventually falls or injury. Therefore, full volitional control strategies are likely not reliable or robust enough to handle tasks associated with everyday living. These limitations motivate alternative approaches that are reliable enough for various walking gaits without the risk of falling, but also flexible enough to give the user more control over the limb to achieve a wider variety of tasks.

Prior work addressing this challenge, via what is referred to herein as Partial Volitional Control (PVC), has given users control over various gait parameters rather than joint positions or torques. Users can change, for example, ankle impedance [1], gait speeds and activity transitions [2], or lock and unlock signals for various joints [3]. While providing user control over dynamic properties, current PVC implementations have not allowed for participation in activities characterized by non-standard movements, like those identified above.

II. Hybrid Volitional Control

This research explores a new class of control strategies, termed Hybrid Volitional Control (HVC), that give the user freedom to override the system behavior. HVC consists of a baseline (non-volitional) control strategy enabling basic gait dynamics that can be volitionally altered to achieve voluntary movements. HVC-type approaches have been taken during terminal stance [4] and initial swing [5], but there has been no comprehensive HVC strategy that provides the user freedom throughout the gait cycle. Reaching the full potential of HVC could allow for a wide range of activities, including non-weight-bearing joint movement, standing, slow, normal, and fast walking, ramp and stair ascent/descent, uneven terrain navigation, sudden reactive movements, and other non-standard gait activities. Surface electromyography (EMG) sensors are one non-invasive approach to enable the volitional alteration that distinguishes HVC. By thresholding and calibrating the accepted levels of EMG activity for a given user, the basic gait dynamics can be altered only when desired, avoiding unnecessary physical and/or mental fatigue. HVC could allow individuals with lower-limb amputation to regain the freedom of moving the limb as desired, which would be a key step toward reducing the distinction between ability and disability from amputation.

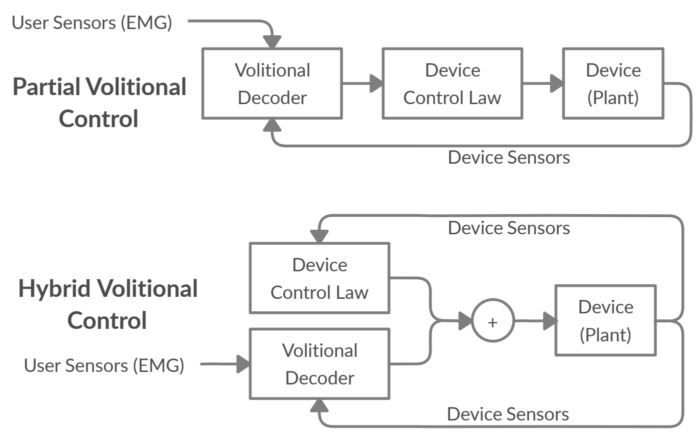

Fig. 1. Block diagrams of PVC (above) and HVC (below).

References

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