Footstep-Based Detection of Intended Gait Speed for Exoskeleton Users

Roopak M. Karulkar[1], Patrick M. Wensing[1]

I. Introduction

The safe and effective use of lower-extremity exoskeletons requires high fluency in the Human Robot Interaction (HRI) for the user to accurately convey their desired movements to the robot. High fluency is characterized by the robot's ability to anticipate the user's actions [1] which is possible only through accurate intent detection. This work aims to create a framework that intuitively detects intent changes without additional interfaces. Interacting Multi-Model Estimation [2] was previously used to estimate the user's gait phase and velocity by comparing exoskeleton measurements to gaits of the Bipedal Spring-Loaded Pendulum (B-SLIP) model. Since gait stability is highly influenced by choices of ground contacts, the work herein hypothesizes that user intent changes may be inferred from changes in footstep placement alone. The work presents a Bayesian estimation framework that relies on measured changes in footsteps to estimate the user's intent to change gait speed before it is realized physically. The framework was evaluated on experimental data from walking trials of an able-bodied (AB) and a non-able-bodied (NAB) subject in an Ekso GT exoskeleton.

II. Methods

Intent detection was posed as a state estimation problem in this work. The estimation was considered over an extended state vector $\mathbf{z} = [\mathbf{x}^\top, v_x^d]^\top$ where $\mathbf{x}$ contains the position and velocity of the center of mass (CoM) and v_x^d is the desired velocity of the exoskeleton user. The presented framework used a two-stage estimation approach to reinforce estimates by incorporating measurements at phase transitions.

Since foot placement at touchdown (TD) is influenced by velocity perturbations at midstance (MS) [3], it was hypothesized that changes in intended gait speed could be inferred through changes in step length. The first stage of the estimator used a simple data-driven model of step length as a function of the velocity at MS v_x, desired velocity v_x^d and leg length l_{leg}:

$$l_{step} = [v_x \;\; (v_x^d - v_x) \;\; l_{leg}]\boldsymbol{\kappa} \tag{1}$$

where $\boldsymbol{\kappa}$ is a vector of regression coefficients. In the estimator, the CoM state at MS was corrected with a Bayesian update driven by the difference between the measured and predicted values of step length. The updated state was then passed to a Kalman filter that performed a second update at the subsequent MS.

Using step length measurements alone was not sufficient for estimation during NAB trials due to the effects of exoskeleton assistance. Therefore, the measurements used in the Bayesian update were supplemented with the root mean squared current of the hip motor I_{RMS}, during the swing phase, modeled by:

$$I_{RMS} = [v_x \;\; (v_x^d - v_x)]\boldsymbol{\alpha} \tag{2}$$

where $\boldsymbol{\alpha}$ is a vector of regression coefficients. Experimental data was used for regression on $\boldsymbol{\kappa}$ and $\boldsymbol{\alpha}$, with the velocity at the subsequent MS used as a proxy for the desired velocity.

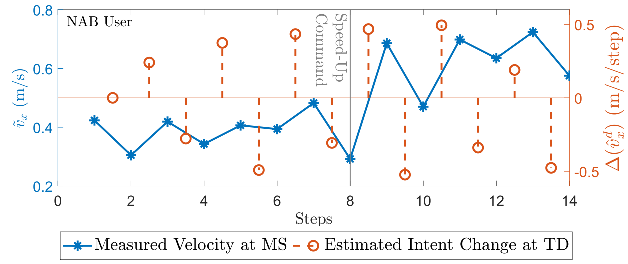

Fig. 1. Estimator performance for a Speed-Up trial for a NAB user.

III. Results

The estimator was tested on experimental data from two experienced exoskeleton users, one AB individual and one with a chronic incomplete spinal cord injury. Both used the exoskeleton with a walker at a self-selected speed. Subjects were issued a verbal speed-change command while walking at steady-state, and underwent three speed-up (SU) and slow-down (SD) trials. Fig. 1 shows the result from one of the SU trials with the NAB user. The stem plot represents the user's estimated intent at TD; positive/negative values indicate anticipated SU/SD relative to the previous MS. The oscillations in the measured velocity after the SU command are reflected in the intent signal as the estimator anticipates step-to-step speed change. However, the magnitude of the intent signal does not correspond to the magnitude of the velocity change due to the simple measurement model used. An intent change detection delay of one step was permitted after the command was issued to allow for the user's processing delay. Similar performance was observed across all trials with the AB subject and across all but one SU trial with this subject. Speed-up changes for the NAB user were the most difficult to estimate, as these users may be at their physical limit [4]. Using a more comprehensive measurement model may improve the precision of the estimates for v_x^d.

References

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[1] Authors are with the Department of Aerospace and Mechanical Engineering, University of Notre Dame, Notre Dame, IN, USA. This work was supported by the National Science Foundation under Grant IIS-1734532.