Development of a portable ankle-foot orthosis actuator system

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***Abstract*— As the growth of clinical ankle-foot orthosis (AFO) rehabilitation, it has shown that the improvement has a positive relationship with a number of trials of rehabilitation. Previous emulator systems have been proven beneficial for rehabilitation; excluding the restriction of the clinical site may increase the frequency of rehabilitation for a patient. Thus, a portable device is developed, which is capable of delivering 30Nm to assist plantarflexion. EtherCAT communication protocol is implemented, and in turn allows the researcher to deploy control algorithms for examination with real-time performance. Bayes-Optimization is used to tune the parameter of a walking assistance controller. Preliminary testing shows tracking error under 15%, this suggestes the system can be used for future development and test control algorithms.**

Keywords— Exoskeleton, Portable actuation, Emulator, Testbed, Human-in-the-loop optimization

I. Introduction

Robotic ankle-foot orthoses have shown the positive results of gait improvement [1]. A portable system, without the restriction of rehabilitation site, allows the higher frequency of rehabilitation [2, 3], thus allowing a user to explore the household environment and increase motivation for rehabilitation. In this study, a cost-efficient and versatile portable actuator with an algorithm development platform is presented. This device also allows sophisticated control action included human-in-the-loop parameter optimization for an individual user [4].

II. Methods

Hardware - The AFO system consist a MAXON EC-90 motor (Maxon motor ag [Sachseln, Switzerland]) and a EtherCAT capable EPOS4 controller (EPOS4 Compact 50/15 EtherCAT; Maxon motor ag [Sachseln, Switzerland]) to drive the cable then deliver power to the commercially available AFO device (EXO-001 Ankle Exoskeleton; Humotech, Inc [Pittsburgh, PA, USA]). The EPOS4 controller contains a series of digital and analog I/O that retrieve sensor signals for gait detection by using a pressure sensor for gait event (e.g., heel-off, heel-strike, flat-foot). A desktop computer with i7 – 7800X 3.50GHz processor is used for gait assistance algorithm; a Simulink model is deployed into Visual Studio and generates a torque command based on gait event, although the controller can be executed on a laptop, in this study, a desktop PC is used for equipment convince.

Computation and Communication - EtherCAT protocol is implemented in the system, which is capable of real-time communication and computation. The gait assistance algorithm is built with Simulink and deployed into Visual Studio with TwinCAT 3 for EtherCAT communication. The MATLAB/Simulink contains a code generator that generates a corresponding C/C++ code from the Simulink model. Once the TwinCAT 3 runtime started, the model is executed in real-time. Now a computer or laptop can be used as a target machine for a portable system.

Controller: Human-in-the-loop Optimization - The AFO system assists plantarflexion during specific gait events, starting from Heel-off and end at Toe-off. The rise time parameter of the assistance torque is optimized by Bayesian Optimization, a sequential design strategy for global optimization of black-box function [5].

III. Result and Discussion

The overall structure of the system is shown in (Fig 1(a)). The EPOS4 controller resolves the EtherCAT communication signal, while the computer sends the signal with a step-solver executed every 2ms. The overall delay from command to actuation is under 6ms. Instead of having a force sensor for the torque control, the controller estimates the torque by motor rpm and motor current. This approach shows reliable results, as Fig 1(b) depicts without a force sensor. The tracking error was 15%, normalized by max torque.

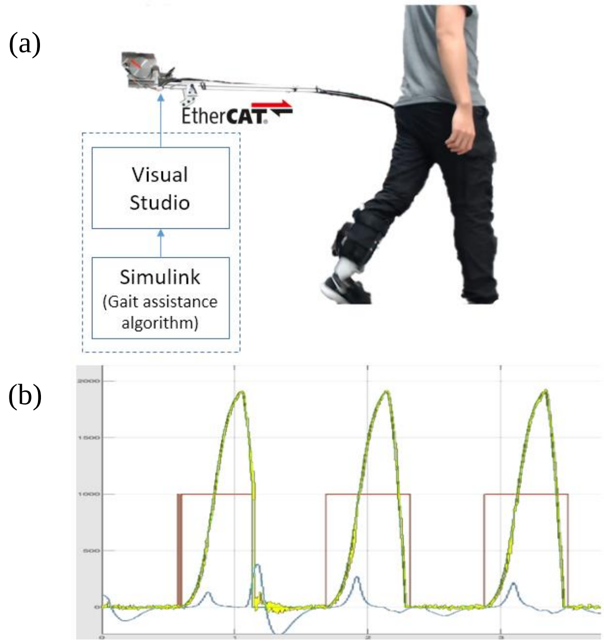

Figure 1 (a). Portable actuator structure: The control algorithm communicates with the EPOS4 controller through EtherCAT. (b). Assistance profile tracking performance: Yellow: estimated torque, Orange: foot sensor state, Blue: motor speed, Green: torque command (under yellow line))

IV. Future Work

The aim of future work includes the optimization of assistance profile for a time-based gait assistance controller, a portable power source and enhance the tracking performance between command and measured torque by applying pre-tension torque.

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