Teleoperation of an Ankle-Foot Prosthesis with a Wrist Exoskeleton

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Introduction

When people lose a limb due to amputation, they lose not only motor function, but also sensory information about the state of that limb. There have been a variety of approaches to reintegrate this sensory information, many of which are invasive [1]. We developed a system that substitutes this missing information from an ankle-foot prosthesis in a noninvasive manner. In our approach, a wrist exoskeleton allows users with amputation to both control and receive feedback from their prosthetic ankle in real time via teleoperation (Fig. 1A).

Methods

<u>*System Design*</u>: We built a wrist exoskeleton that senses wrist angle with an accuracy of 0.18° and provides up to 1 Nm of wrist flexion or extension torque using a capstan drive mechanism. This exoskeleton interfaces with an existing ankle-foot prosthesis emulator that previously operated only under torque control [2].

<u>*Control Schemes:*</u> We developed a position control scheme in which the prosthesis angle is commanded to a scaled position of the wrist angle. In addition, we tested position control with and without haptic feedback, where a user was able to feel torque at the wrist proportional to the ankle prosthesis torque. We also tested multiple low-level position control schemes for best control accuracy. For the purposes of this abstract, we only show the low-level controller with the best performance.

<u>*Pilot test:*</u> We verified the feasibility and performance of the system with one participant with a transtibial amputation. For each feedback and control condition, we analyzed position tracking of the prosthesis and how well the participant could track desired wrist trajectories. Although eventually we hope that participants can discover their own trajectories as they walk, in this study we dictated two seperate desired trajectories to the participant for each control condition, in order to evaluate user ability to control the wrist exoskeleton. We also provided real-time feedback showing desired position error to the partcipant.

The participant completed training trials that consisted of following two different desired sine wave trajectories while seated and standing, followed by walking with desired trajectories emulating passive walking or active push-off. Tests were completed over the span of two days, and each training and testing trial lasted five minutes. Data were analyzed for the last 60 seconds of each trial.

Results and Discussion

We achieved good control fidelity of the ankle prosthesis, with error lower than human proprioception (RMSE = 0.8°, ankle proprioceptive error = 2.3°) [3]. In addition, although the subject initially had high errors from the desired wrist trajectories (RMSE = 5.8°), by the end of the second day they were able to control the wrist exoskeleton with accuracy greater than human priopriocetion for both desired trajectories (RMSE = 1.57°, wrist proprioceptive error = 2.15°) [4]. Results from the second day are shown in Fig. 1B. Qualitatively, the participant preferred the haptic feedback conditions, which they said made the position control more intuitive. However, we noticed that providing haptic

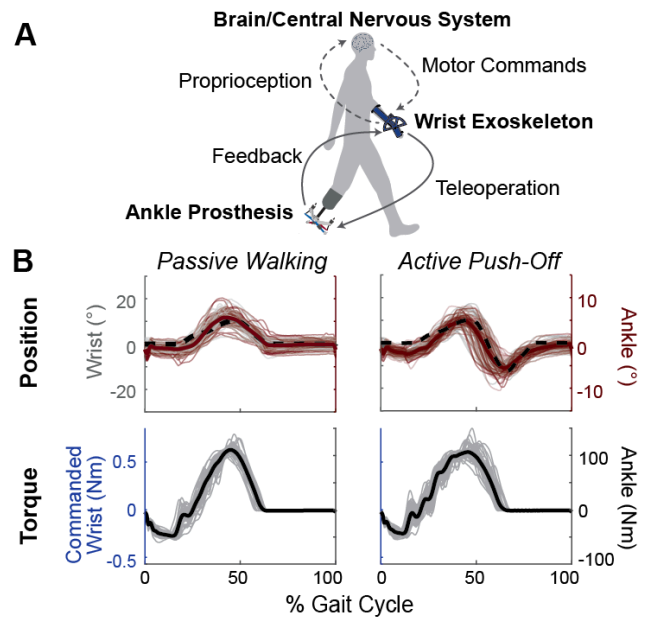

Figure 1: A. We use a wrist exoskeleton to both control and receive haptic feedback from an ankle-foot prosthesis to restore the motor control loop. **B.** The two desired trajectories with haptic feedback are shown, in addition to how well the wrist and ankle matched these trajectories and the resulting torque profiles. The dashed line indicates the desired trajectory, and bold lines indicate averages.

feedback caused small oscillations in the torque profiles. Future work will investigate the cause of and mitigate these oscillations.

Overall, we developed the hardware and control schemes necessary to provide a person with amputation both real-time feedback and control of their prosthesis. We demonstrated the feasibility of this system by validating both our system performance and the ability of a user to voluntarily modulate wrist position in real time with only limited training.

Significance

This teleoperation system will allow testing of novel prosthesis control and feedback strategies that could be used to provide more accurate sensory feedback and facilitate motor learning. Long-term, we aim to discover which parameters amputees intend to optimize during gait, and compare these strategies to those of automated prosthesis control systems.

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References

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