Human-in-the-loop optimization of a hip-knee-ankle exoskeleton emulator

Patrick W. Franks[1], Gwendolyn M. Bryan[1], Steven H. Collins[1]
[1]Department of Mechanical Engineering, Stanford University, Stanford, CA, USA
Email: pfranks@stanford.edu

Summary

Lower-limb exoskeletons have demonstrated the ability to improve walking performance, typically measured as reductions in metabolic energy expenditure. Effective assistance strategies have been found when these devices are paired with human-in-the-loop optimization, a process in which device parameters are optimized based on measurements of the user. So far, this approach has been limited to devices that assist one or two joints. We have built a hip-knee-ankle exoskeleton emulator that can apply high torques and powers at each joint. We will pair this hip-knee-ankle exoskeleton with human-in-the-loop optimization to find assistance strategies during level-ground walking. We will optimize assistance at all joints simultaneously to account for interactions between joints. Optimization for each participant will be conducted over multiple days to allow adaptation to the device and ensure convergence for the large control parameter space. We anticipate that the assistance strategies found will inform the design of future multi-joint lower limb exoskeletons.

Introduction

Some exoskeletons have demonstrated improvements to energy economy during walking, typically measured as reductions in metabolic energy expenditure. So far, these exoskeletons have been limited to assisting only one or two joints [1-3]. Both experiments and simulation have indicated that multi-joint exoskeletons could produce greater metabolic reductions than single joint exoskeletons [3, 4]. For many devices, their most effective assistance strategies have been found using human-in-the-loop optimization [1, 2]. This approach has not yet been tested for a multi-joint lower limb exoskeleton. Recently we have built a hip-knee-ankle exoskeleton emulator that can apply high torques and powers at each joint. Our aim is to pair this hip-knee-ankle exoskeleton with human-in-the-loop optimization to find effective assistance strategies during walking.

Methods

We have begun pilot experiments for this study. We will be using Covariance Matrix Adaptation – Evolutionary Strategy as our optimization algorithm, as it has been successfully paired with similar devices [1] and is theorized to scale well to higher parameter spaces [5]. Based on ongoing studies, we anticipate multiple days of optimization to ensure the user adapts to the device, as well as to ensure convergence of the optimization. We will optimize assistance at all joints simultaneously to account for interactions between joints. Currently we are exploring parameterizations of the torque profiles for each joint (Fig. 1). We are hoping to find a trade-off of enough parameters for successful customization to the user, as well as few parameters so that the optimization can converge in a reasonable timeframe. Currently our plan is to use time-based features for the hips and ankles, similar to previous work [1,2]. For the knees we are exploring state-based controllers, including damping during swing and a simulated spring during stance based off approximations of the biological quasi-stiffness of the knee during walking. Once we find a reasonable parameterization, we will begin optimization experiments.

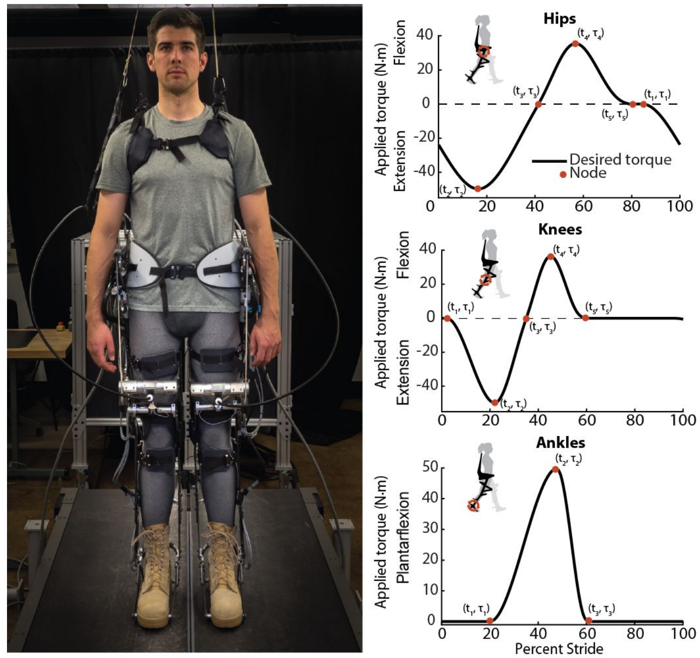

Figure 1: (Left) User wearing hip-knee-ankle exoskeleton emulator. (Right) Example parameterizations of each joint torque profile as a function of percent stride during walking.

Anticipated results and discussion

We expect to have preliminary results by the time of presentation. For evaluation of the optimized assistance, we will measure the metabolic cost of walking in the device with the optimal assistance profile, as well as walking in the device with no assistance and walking without the device. Will also record kinematics using motion capture and muscle activity from EMG to be used for analysis of assistance. We anticipate that the assistance strategies found will inform the design of future multi-joint lower limb exoskeletons.

References

[1] Zhang et al. (2017). *Science*, **356**: 1280-1284.
[2] Ding et al. (2018). *Sci. Robot.,* **3**: eear5438.
[3] Malcolm et al. (2018). *Front. Neurosci.,* **12**: 69.
[4] Dembia et al. (2017). *PLoS ONE,* **12**: e0180320.
[5] Hansen et al. (2006). *Towards a New Evolutionary Computation;* Springer.