

HUMAN-EXOSUIT INTERFACES ABSORB AND RETURN ENERGY, RESHAPING EXOSUIT TO HUMAN POWER FLOW

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INTRODUCTION

Soft exosuits and rigid exoskeletons, two types of wearable assistive devices, have demonstrated the potential to improve mobility outcomes for individuals with disabilities, and to augment healthy human performance [1]. However, transmitting power from an assistive device to the human body is challenging because biological tissues and interface materials deform and displace when forces are applied, absorbing power. Inefficient device-to-human power transmission undermines the performance benefits of wearable assistive devices. Experiments on a recent running exoskeleton found that about 50% of the mechanical power provided by the device was lost in transmission to the body [2]. Although the practical difficulties of physically coupling wearable devices to the human body are well-known, only a few studies have published objective data characterizing interface dynamics [3], due partly to the lack of methods to quickly estimate these quantities. The objective of this work is two-fold: first to present a novel methodology for quickly estimating interface power during dynamic tasks using common motion capture and force measurements, and second to apply this method to quantify how a soft robotic exosuit interacts with and transfers power to the human body during locomotion.

METHODS

We performed a motion analysis study on one healthy male subject wearing a soft robotic ankle exosuit (Figure 1), similar to [4], while collecting synchronous motion capture, motor encoder, load cell, and ground reaction force data. The subject walked on an instrumented treadmill at 1.5 m/s for 5 minutes while the exosuit generated plantarflexion assistance about the ankle using a walking controller to apply peak cable force of up to 500 N. We then performed a new biomechanical analysis to quantify exosuit-to-human power transmission using force and motion data, which enabled us to parse augmentation power (powering ankle plantarflexion) vs. interface power (due to deformation and motion of interface materials and underlying soft tissues).

RESULTS AND DISCUSSION

We found that interface dynamics complicate the transmission of power from wearable assistive devices to the human body, resulting in three key consequences: (i) Augmentation power (and work) was reduced in magnitude during exosuit loading (as applied forces increased). During this phase, about 60% of exosuit end-effector power (i.e., power output from the device) was absorbed into the interfaces. (ii) However, during subsequent exosuit unloading (as applied forces decreased) most of the absorbed interface power was returned elastically. As a result, the majority (~80%) of exosuit end-effector work over each stride augmented ankle plantarflexion. (iii) Ankle augmentation power (and work) was delayed relative to exosuit power output, due to interface energy absorption and

return dynamics. Here, we found that peak augmentation power was delayed by ~25 ms (Figure 1).

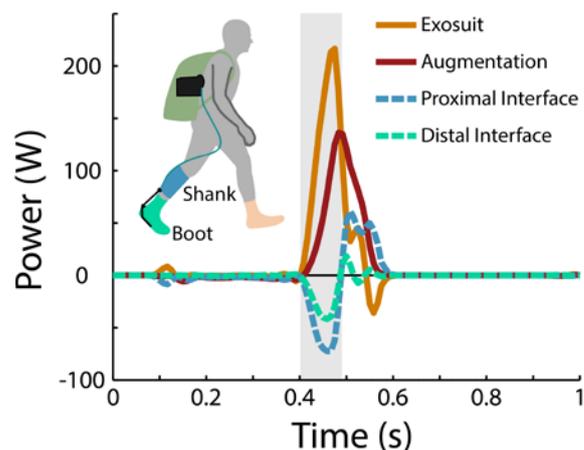


Figure 1: Human-exosuit interfaces absorb and return energy, reshaping exosuit to human power flow. Exosuit end-effector power (device output, orange) contributes to motion/deformation of the proximal (shank, dashed blue) and distal (boot, dashed green) interfaces, and augments ankle plantarflexion (red). Power is absorbed into interfaces during exosuit loading (increasing force application, gray box), then returned during unloading, contributing to ankle augmentation. Results are shown for a representative stride.

CONCLUSIONS

Physical human-device interfaces can absorb and return substantial energy, complicating power transmission. In order to optimize the performance of wearable assistive devices and fully realize their human augmentation benefits, it is important to account for these human-device interface dynamics. Here we present a new method to quantify power transmission and isolate power contributions from human-device interfaces using common force and motion measurements, which provides insight into how to improve the design and control of wearable assistive devices.

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REFERENCES

1. Dollar, et al., *IEEE Trans. Robot.* **24**:144–158, 2008.
2. Cherry, et al., *J. Appl. Biomech.*, 2015.
3. Asbeck, et al., *Int. J. Robot. Res.* **34**:744–762, 2015
4. Lee et al., ICRA, Stockholm, Sweden, 2016.