Mobility Enhancing Soft Exosuits

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1 Introduction

In comparison to traditional exoskeletons, next generation wearable robots will use soft materials such as textiles to provide a more conformal, unobtrusive and compliant means to interface to the human body. These robots will augment the capabilities of healthy individuals (e.g. improved walking efficiency) in addition to assisting patients who suffer from physical or neurological disorders. In this paper, we describe the anatomy of a soft exosuit, showing examples of pneumatically- and electromechanically-powered exosuits our lab has built over the last couple of years. We describe advancements we have made in several areas in order to develop an exosuit to augment the normal muscle work of healthy individuals by applying assistive torques at the wearer's joints with the goal of reducing the metabolic cost of the wearer. This device utilizes flexible materials and actuators to specifically address human factors challenges and does not have a load bearing "skeleton" but rather relies on the biological skeleton to assist with the application of forces and transfer of load. Compared to traditional exoskeletons, the exosuit presented provides minimal additional mechanical impedance and kinematic restrictions. We use flexible actuation systems, detect the body's motion with movement sensors and suit tension measurements, and utilize control systems to work in synchrony with the body. We conclude by presenting metrics for exosuit evaluation and some initial results from the effect our exosuits have on the body.

Figure 1: Photos of different versions of soft exosuits developed by our lab. The left suit is pneumatically-powered and was a first proof of concept; the middle is an electro-mechanical version for actuating ankle plantarflexion and hip flexion through a multiarticular suit design and on the right is a more recent version that also actuates hip extenson.

2 Soft Exosuit Overview

An exosuit consists of an integrated garment that includes attachment points to the body, a structured textile that transmits loads across the body, and actuated segments that can reduce their relative length to provide controlled tensile forces in the suit. The suit creates moments around the joints as these forces are offset from the joint centers of rotation due to the tissue and bone structure surrounding the joints. A key feature of exosuits is that if the actuated segments are extended, the suit length can increase so that the entire suit is slack, at which point wearing an exosuit feels like wearing a pair of pants and does not restrict the wearer whatsoever.

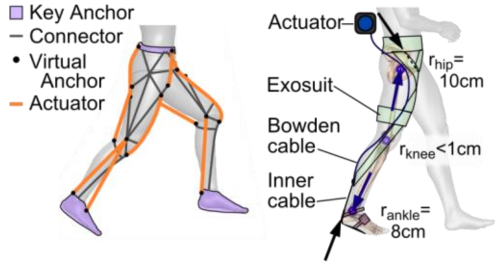

Figure 2: The top left diagram illustrates the concept of virtual anchors for connecting actuators to a mono-articular exosuit. The top right figures show the force distribution throughout a multi-articular suit and the moment arms at the ankle, knee and hip.

Exosuits show much promise as a method for augmenting the body with lightweight, portable and compliant wearable systems. We envision such systems can be further refined so that they can be sufficiently low-profile and fit under a wearer's existing clothing. In early work, we have shown that the system can substantially maintain normal biomechanics and positively affect a wearer's metabolic rate. Many basic fundamental research and development challenges remain in actuator development, textile innovation, soft sensor development, human-machine interface (control), biomechanics and physiology that provide fertile ground for academics in many disciplines. While we have focused on gait assistance thus far, numerous other applications are possible, including rehabilitation, upper-body support, and assistance for other motions.

4 Acknowledgement

This material is based on work partially supported by the Defense Advanced Research Projects Agency (DARPA), Warrior Web Program (Contract No. W911QX-12-C-0084 and W911NF-14-C-0051-P00003). This work is also partially funded by the Wyss Institute for Biologically Inspired Engineering and the Harvard School of Engineering and Applied Sciences.