Evaluation of a multi-joint soft exosuit for gait assistance

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1 Desired format of presentation

The preferred presentation format is a slide talk.

2 Motivation

Carrying heavy loads dramatically alters the biomechanics of walking [1] and adds significant burden to the musculoskeletal system. Previous studies [1] reported how these alterations cause a higher energy expenditure which in turns lead to an earlier onset of fatigue [1], possibly limiting the overall performance of load carriers. Based on this rationale, there is pressing need to develop assistive devices such as exoskeletons to augment human performance and to account for the metabolic burden experienced during load carriage.

3 State of the Art

Humans have long dreamed of and created ways to improve our strength, speed, and endurance through wearable assistive devices. Although research on exoskeletons started in the late 1960s, only recently two autonomous systems were able to successfully provide a net metabolic reduction in the cost of walking providing external power at the ankle joint [2 , 3]. Nevertheless, challenges associated with the design of rigid exoskeletons still stand and might currently limit further energy reductions during walking [4]. These shortcomings are mainly due to: 1) kinematic constraints due to misalignment between the robot and biological joints that will cause the wearer to deviate from their natural motion patterns and (2) large inertias or bulky self-aligning mechanisms which can in turn increase energy expenditure of the wearer.

4 Own approach to this question

To overcome the challenges associated with rigid exoskeletons and to effectively reduce the metabolic expenditure during loaded walking, we have been developing soft exosuits [5-12]. This class of 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, exosuits provide 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. Most recently we have developed a multi-joint soft exosuit that utilizes an innovative actuation concept to provide assistance to the ankle and the hip joint. This exosuit assists walking by creating ankle plantarflexion and hip flexion joint torques through a multi-articular load path, as well as hip extension torques as shown in Figure 1.

Figure 1: Load paths and components of the suit. An actuator is mounted on each side of the backpack and is connected to the suit with Bowden cables (the hip actuator is obscured). The suit includes load paths to actuate hip extension and the combination of ankle plantarflexion and hip flexion. Load cells are mounted where the Bowden cable sheaths connect to the suit, and a gyroscope is mounted on each heel.

The exosuit is an integration of the multiarticular ankle/hip suit and monoarticular hip suit described in [5-12], combined with improvements to each part. The exosuit assists walking by creating forces in two load paths, one that aids ankle plantarflexion and hip flexion (multiarticular load path), and one that aids hip extension (monoarticular load path). These load paths were chosen since the ankle and hip are the major power contributors to level-ground walking. By applying torques to both the ankle and hip, we expect that the biomechanics of walking will be better maintained as compared to applying torques to either joint in isolation. The suit's architecture and construction was designed so as to enable high forces to be applied to the multiarticular ankle/hip flexion load path (~300N) and the hip extension load path (~150N), which correspond to ~21% and ~19% of the nominal biological torques at the ankle and at the hip during level-ground walking, respectively. To reduce the carried mass, we developed a new actuation approach in which one motor actuates the multiarticular load path on both legs, and a second motor actuates the hip extension load path on both legs. Finally, we demonstrate a robust control strategy that utilizes minimal sensory information, yet actuates the suit consistently and in synchrony with the wearer during level-ground walking and makes the exosuit slack (non-restrictive) during other motions. In the following sections we describe the design of the multi-joint soft exosuit and present some experimental results with the system worn during outdoor walking.

5 Discussion

We will conclude the talk by presenting metrics for exosuit evaluation and some initial results from ongoing human subjects studies. Figure 2 illustrates our experimental setup and data collection methods.

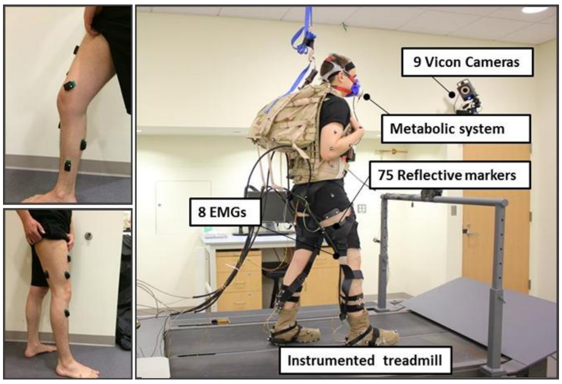

Figure 2: Lab facilities for human subject experimental protocol and EMG sensor placement.

During our experiments, kinematic data were collected through a 9-cameras Vicon optical motion analysis system (Oxford Metrics, Oxford, UK) using a 75-marker full-body protocol. Muscle activity for 8 muscle was recorded by means of a Delsys® Trigno® (Delsys, Natick, MA) wired surface EMG system. The activity of the following muscles was recorded: Soleus, Gastrocnemius Medialis, Tibialis Anterior Rectus Femoris, Vastus Lateralis, Vastus Medialis, Biceps Femoris, Gluteus Maximus. Electrodes are placed by trained physical therapists following SENIAM guidelines. The metabolic cost of walking was measured through a potable pulmonary gas exchange measurement device (K4b2, COSMED, Rome, Italy).

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