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Current Work in the Human-Machine Interface for Ergonomic Intervention with Exoskeletons

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ABSTRACT

This literature review of exoskeleton design provides a brief history of exoskeleton development, discusses current research of exoskeletons with respect to the innate human-machine interface, and the incorporation of exoskeletons for ergonomic intervention, and offers a review of needed future work. Development of assistive exoskeletons began in the 1960's but older designs lacked design for human factors and ergonomics and had low power energy density and power to weight ratios. Advancements in technology have spurred a broad spectrum of research aimed at enhancing human performance and assisting in rehabilitation. The review underwent a holistic and extensive search and provides a reflective snapshot of the state of the art in exoskeleton design as it pertains to the incorporation of exoskeletons for ergonomic intervention. Some of the remaining challenges include improving the energy density of exoskeleton power supplies, improving the power to weight ratio of actuation devices, improving the mechanical human-machine interface, and dealing with variability between users.

KEYWORDS

Assistive Technologies, Biomechanics, Exoskeletons, Human-Machine Interface, Human-Robot Interaction, Physical Ergonomics

1. INTRODUCTION

The field of exoskeleton design is broad and expansive. This paper serves as a cogent literature review of exoskeleton design with respect to the human-machine interface. It provides an outline of a brief history, current research, the potential benefits of exoskeleton use, and finishes with a discussion of the possible future of exoskeletons.

It is imperative to begin this paper by clearly defining the difference between exoskeletons and orthotics. It is also important to note that these two terms often overlap in the media as well as in the scientific literature.

An exoskeleton can be identified as an external mechanical structure whose joints matches those of the human body. This mechanical structure shares physical contact with the operator and enables a direct transfer of mechanical power and information signals through either passive or active actuation (Pons, Rocon, & Morenso, 2007).

An orthotic, or orthosis (plural: orthoses) refers to a device that is externally applied to the body. It is different from a prosthetic where a device substitutes a missing body part. External devices, such as dental braces, insoles, or a pair of glasses are examples of orthotic devices (Sarakoglou, Tsagarakis, & Caldwell, 2004). Active orthoses are limited by the daunting issue that the specific

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nature of disability varies from one person to another. This makes it difficult to create one generally applicable device. Ideally, a compact, energetically autonomous orthosis can provide the wearer assistance and therapy in everyday life. The issue of portability is one of the major factors that limits the application of active orthoses outside of clinical therapy (Dollar & Herr, 2008).

Hugh Herr defines exoskeletons and orthoses as follows: "The term 'exoskeleton' is used to describe a device that augments the performance of an able-bodied wearer, whereas the term 'orthosis' is typically used to describe a device that is used to assist a person with a limb pathology (Herr, 2009)."

Initial development of exoskeletons can be traced back to the early 1960's with the US Defense Department's interest in the development of a man-amplifier. A man-amplifier was a "powered suit of armor" which could augment a soldier's lifting and carrying capabilities (Kazerooni, Steger, & Huang, 2006).

General Electric (GE) developed the first exoskeleton device, beginning in the 1960's and continuing until 1971, called the Hardiman. It was developed by Ralph Mosher, an engineer for GE. The suit made carrying 250 pounds seem like 10 pounds. It was a hydraulic and electrical body suit. The outer body suit followed the motions of the inner body suit in a master-slave system. It was determined to be too heavy and bulky for military use. The general idea was well received, but the Hardiman had practical difficulties due to its own weight of 1500 pounds. The walking speed of 2.5ft/sec limited its uses. Any attempted practical testing with the exoskeleton was impossible with a human inside due to the uncontrolled violent movements (Ali, 2014).

In 1962, the US Air Force commissioned the study of a master-slave robotic system for use as a man-amplifier from the Cornell Aeronautical Laboratory. Through their study, the Cornell Aeronautical laboratory found that an exoskeleton, even one with fewer degrees of freedom (DoF) than the human body, could accomplish most desired tasks (Mizen, 1965). However, the master-slave system that the man-amplifiers used were deemed impractical, had difficulty in human sensing, and were overly complex, making walking and other tasks difficult to complete (Kazerooni, Steger, Huang, 2006).

Exoskeleton research and design continued. The University of Belgrade, located in Serbia, developed several designs throughout the 1960's and 1970's to aid paraplegics. These exoskeletons were limited to predefined motion with limited success. The balancing algorithms developed for these exoskeletons are still used in many bipedal robots (Vukobratovic, Ciric, & Hristic, 1972).

2. OVERVIEW OF EXOSKELETONS

2.1. Uses and Market

Exoskeletons are used in two primary roles: rehabilitation and human performance augmentation. However, their use is quickly expanding into other fields such as sports, firefighting, and law enforcement. According to Rocon (Rocon et. al., 2007) and Harwin (Harwin et.al., 1998), rehabilitation robotics, and by extension rehabilitation exoskeletons, can be classified into three categories:

1. Posture support mechanisms
2. Rehabilitation mechanisms
3. Robots [and exoskeletons] to assist or replace body functions

The goal of human performance augmentation (HPA) is to enhance the capabilities of otherwise healthy people. Applications include fatigue reduction and heavy lifting, with much research focused on military uses, such as enhancing the ability to carry large loads onto the battlefield and increasing the endurance of the soldier. Other possible markets for HPA include emergency services such as fire and disaster response, and construction and material handling (Brown, Tsagarakis, & Caldwell, 2003), or any application that requires heavy gear and heavy lifting in rough terrain impassable by vehicle.

This paper divides exoskeletons into four broad categories of lower body, upper body, hands/feet, and full body exoskeletons.