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Design Challenges and Principles of Hustar Footwear Exoskeleton

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ABSTRACT

The aim of the study was to suggest an approach for designing footwear exoskeleton and to present an affordable footwear exoskeleton by Kuntai Robotics. The objective was to explore the markets and discuss the needs for exoskeletons in rehabilitation sector. We found that there is a need for affordable exoskeletons that can be used also outside of clinics. We suggest testing the Hustar lower limb exoskeleton in supporting rehabilitation of lower limbs.

Keywords: Exoskeleton, Lower limb, Robotics, Rehabilitation

INTRODUCTION

There are number of taxonomies and classifications of robots being based on their functions, outlook, features, and materials (e.g., Onnasch and Roesler, 2021). The three main classes are mentioned as industrial robots, service robots and medical robots. The wearable robots are also the sub-class of wearable technology, which consists of all the devices that people can wear. The wearable robots are the sub-class of service robots and further belongs to assistive robots. The wearable robots can be classified into rigid or soft structure, and further passive or active mode (Xiloyannis et al. 2021). We classify wearable robots (exoskeletons) as upper or lower limb devices and active or passive devices. The aim of the study is to discuss and present the design challenges of an active lower limb exoskeleton robot Hustar by Kuntai Robotics.

Over the past 15 years, smart textiles and soft exoskeletons have been studied in a variety of fields, such as medicine, sports, and manufacturing (e.g., Schwarz et al. 2010; Berglin, 2013), but data on soft exoskeletons and smart clothes in rehabilitation purposes are still limited (McLaren et al. 2016; Wang et al. 2017). The development of smart textiles has been technology-driven, and important aspects, such as users' needs and usability, have received little attention (Lobo et al. 2019). In general, the combination of textiles and electronics, a lack of standards, and a lack of expertise and training have been identified as barriers to wearable intelligence (Schwarz et al. 2010). Only a few studies have taken into account the adoption of smart textile and clothing innovations, understanding users' needs and contexts, or have taken into account "soft" approaches (Schwarz et al. 2010).

Technology assisted work and rehabilitation are actual issues just now. Robot assisted work and human-robot interaction have recently been the interest of many manufacturing companies. Exoskeleton robots are widely used among construction industry (Kim et al. 2019) and in automotive industry (Spada et al. 2017; Sield and Mara, 2021). Also, rehabilitation centers and hospitals have shown interest towards the use of exoskeletons in two ways; for assisting employees and patients. Even if the exoskeletons have been found to be useful for supporting employees, some unintended negative consequences have been reported (Fox et al. 2020). Although the importance of robotics has been addressed and argued to be functional and cost-effective (Lo et al. 2019), there are no universal cost benefit analyses of the use of exoskeleton robots in workplaces. However, there are some estimates concerning the clinical use of exoskeletons (Lin et al. 2020). From the economic point of view, the exoskeleton design should take into account the possibility to modify an exoskeleton for different work tasks and employees for making possible to use exoskeletons in multiple ways.

The rehabilitation business is currently under a transformation, where need for rehabilitation is going to increase whereas a number of therapists may decrease (Soltani-Zarrin et al. 2017). The need for rehabilitation is increasing globally, due to e.g., longer living people, and the likelihood of increased diseases with age (WHO, 2020). The demand and market for service robotics is high, and it is estimated to be about EUR 35 billion by 2022 (Malani and Lanjudkar, 2016). The global market for rehabilitation robotics is estimated to be about USD 2.6 billion by 2026 (Fortune Business Insights, 2019) and another report estimate is to be USD 6.4 billion (Research and Markets, 2020). The total value of the rehabilitation equipment market is estimated to be about USD 17.5 billion by 2025 (Grand View Research, 2020). There will be high demand especially in devices that can be used in home environments (Globe Newswire, 2021).

There is a need for wearable lightweight solutions (Szmyt, 2018) that can support a rehabilitee in recovering from ailments. The solutions must be affordable, functional, durable and follow the user -centered design. Existing affordable solutions are based on 'passive' technology that measures the user (Lorussi et al. 2016), whereas 'active' physical assistance with help of textiles is still in novice stage (Persson et al. 2018; Jager et al. 2020). Exoskeletons offer a new perspective on robot rehabilitation. Light-weight passive and active exoskeletons have been launched to the market recently for supporting people with reduced mobility, and for assisting workers in construction and factory work. The great number of passive exoskeletons such as SuitX, Mate XT, EksoEvo and Laevo are developed for supporting upper body. The number of active exoskeletons for supporting lower body and walking is well studied concerning clinical rehabilitation, but studies regarding passive devices is limited (Zhou et al. 2020).

It has been estimated that the market for wearable robots will grow. The Covid-19 pandemic will have its own impact on increasing rehabilitation needs in home and work environments (Azhari and Parsa, 2020). The users of exoskeleton robotics are expected to consist of the elderly as well as people with a neurocognitive disorder such as a stroke, a MS, a spinal cord injury, or some other similar disease (Duret et al. 2019). One potential exoskeleton user group is senior workers whose work is physically strenuous, and they need physical support to perform at work. Although the market reports indicate the increased demand for human-centered robotics in rehabilitation such as exoskeletons, the following challenges have been identified. There are only limited number of exoskeletons that can be used outside of clinics, the technology of active exoskeletons is complex and the price of exoskeletons for private use is too high. For example, rehabilitation robots for professional use, such as Lokomat (Nam et al. 2017; Lin et al. 2020) or L-EXOS (Frisoli et al. 2012), cannot be used independently in home or in work environments.

Number of exoskeletons for private use is scarce, and there are no experience or comprehensive reports available on private exoskeleton usage, excluding some experiments (Hyakutake et al. 2019). However, the development of exoskeletons and textile technology (Nguyen and Zhang, 2020) and new material innovations in wearable intelligence (Maziz et al. 2017) make it possible that exoskeleton assisted self-rehabilitation could be used at home and in work environment.

IDENTIFIED CHALLENGES OF WEARABLE INTELLIGENCE FROM A REHABILITATION PERSPECTIVE

Based on the literature and on-going research work, we have identified three challenges for wearable intelligence and exoskeleton robots. The first challenge is that the integration of sensors, and actuators into soft structures is still under development. Various sensors have been integrated with clothes in the past, but only some attempts have been done for combining actuators with soft materials. The design challenge is that actuators may need a supportive structure that is able to offer steady base for transferring power. Materials, such as composites, can be used for designing a lightweight and rigid structure that makes possible to attach actuators to a garment.

Second challenge is that the materials used in wearable robots are passive. Materials used in functional clothing are e.g., elastic materials which are able to store energy. Phase change materials, which are based on physicochemical properties of the material, have also been used to some extent in smart clothing and light-weight exoskeletons. However, motion or power provided by phase change materials have been uncontrollable. We state that the displacement and power of phase change materials could be controlled, allowing the materials to be used in rehabilitative smart exoskeletons.

Third challenge is that exoskeletons require more human-oriented design. The user experience is a key factor in acceptability of exoskeletons. The design of exoskeletons for rehabilitation tasks should be user-centered, taking into account and understanding the user needs, use cases, and the operating environment. There are only few experiences and reports on the use of exoskeletons in self-rehabilitation in the home and in work environment (Mohamaddan et al. 2015; Soltani-Zarrin et al. 2017). The current exoskeletons designed for home use are comparable with clinical devices

Figure 1: Hustar exoskeleton footwear modeling figure.

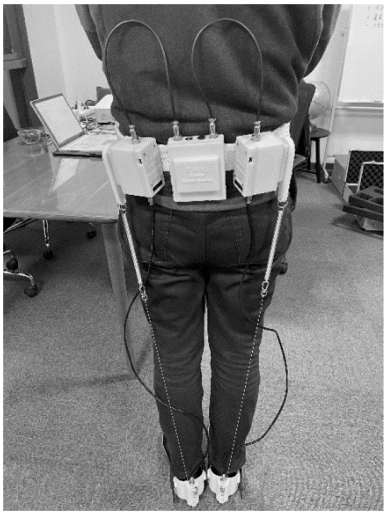

Figure 2: Photo of wearing a Hustar.

(Díaz et al. 2018) and thus cannot be used for supporting daily activities. Also van Dijsseldonk et al. (2020) have reported that an exoskeleton may be applicable for rehabilitation and socialization at home and in the community, although it did not function as a supportive device in everyday tasks.

Hustar Footwear Exoskeleton

Hustar exoskeleton footwear is presented in Figures 1 and 2. Hustar is designed as a light-weight and active exoskeleton robot, integrated with battery, sensors, controller and tendon drivers. This system realizes the synchronous motion of the exoskeleton robot and the human lower extremity and a real-time active control to help wearers to walk easily. The design principle of Hustar has been that it can be used by many users and technology is easy to maintain. In addition, Hustar is meant to daily use anywhere, such as at home, leisure and work. Hustar can also be used in self-rehabilitation. Therefore, Hustar is affordable, easy to use and easy to maintain.

CONCLUSION

There is a need for the affordable exoskeleton footwear that can be used outside of clinics. The rehabilitation markets are growing, and new exoskeleton design approaches and products are needed, especially for private use at home and in work places.

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