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Review on the development of occupation-related assistive exoskeletons

Yuxuan Lu

College of Mechatronic Engineering, Nanjing Forestry University, Nanjing, Jiangsu, 210042, China

L1738741328@163.com

Abstract. Many different types of beneficial exoskeletons have been developed in recent years. The majority of them are intended to lessen the likelihood of a variety of lumbar compression injuries and other types of ailments that workers may be subjected to when they are engaged in repetitive single-activity labour. Work-related muscular and skeletal disorders, often known as WMSDs, are the most prevalent type of muscular and skeletal disorder found in the working population. It is brought on by a single motion that is repeated over and over again. This condition of the muscular and skeletal system significantly lowers both the productivity and the happiness index of workers. In this study, recent research results from a variety of different research teams are presented, their research methods and research conclusions are analysed, and a discussion of the current and next research trends and directions pertaining to assistive exoskeletons is offered.

Keywords: assistive exoskeleton, robot, dynamic simulation.

1. Introduction

Exoskeleton-assisted rehabilitation training and the use of exoskeletons to lower WMSDs are the two most common applications of exoskeletons (Work-related muscular skeletal disorders, WMSDs). Several research organisations and corporations throughout the world have conducted pertinent study on preventing WMSD induced by employment over the years [1]. Work-related musculoskeletal disorders (WMSDs) are characterised by partial musculoskeletal tissue damage and persistent discomfort. Its predisposing variables are widely believed to include local muscular static strain, repeated actions, and musculoskeletal injury, with repetitive operations constituting a significant risk factor. Significant numbers of employees are motivated by repetitious tasks. Over the past few decades, chronic musculoskeletal problems associated to employment have become increasingly prevalent worldwide, impacting more than half of the working population. According to reports, this condition is second only to occupational skin disorders in prevalence among occupational diseases. WHO named 2000-2010 as "The Bone and Joint Decade" in an effort to increase government agencies' awareness and understanding of musculoskeletal illnesses, encourage international research [2], and eventually improve the quality of life for patients and workers. Hence, the research design and development of the exoskeleton helpful came to be. This paper presents the recent research results of several research teams, evaluates their research methods and research findings, and explores the future trends and directions of assistive exoskeleton research. The author hopes to provide inspiration and assistance for the future design and invention of assistive exoskeletons, and to produce helpful exoskeletons that are lighter, less hazardous to the human body, and capable of increasing manufacturing efficiency.

2. Introduction of exoskeleton

Exoskeleton was originally defined as an animal's external skeleton capable of supporting and protecting its body, as opposed to the human interior skeleton (endoskeleton). Certain big exoskeletons, such as those of shrimp and crabs, are referred to as "shells." This work describes a wearable mechanical structure with sensors, actuators, and controls as the exoskeleton [3-4]. It can help patients with hemiplegia caused by cerebrovascular disease or nervous system injury engage in rehabilitation training, meet the sports needs of the disabled in daily life, or reduce the labour intensity of workers, reduce the joint damage caused by repetitive labour, or provide workers with additional ability.

Several classification schemes exist for exoskeletons [5]. Depending to whether it has a power supply, exoskeletons can be categorised as either active or passive. The passive exoskeleton is driven by elastic parts that store and release energy. The power source is often equipment such as motors or cylinders. Depending to the material, the exoskeleton can be classified as either flexible or rigid. Exoskeletons can be split into rehabilitative exoskeletons, auxiliary exoskeletons for the crippled, military exoskeletons, and assistive exoskeletons based on their various applications and requirements. Among these, the assistive exoskeleton can minimise the workload of workers and unload all or a portion of the required weight [6]. These exoskeletons are also known as occupational or augmentation exoskeletons.

3. Development of assistive exoskeletons

3.1. Achievements from lumbar exoskeletons

In 2022, Mélissa Moulart et al. initiated an evaluation research on the effect of lumbar exoskeleton on workers' lower back discomfort in real-world work settings [7]. In this experiment, volunteers wear a dynamic boot orthosis during work to collect data on the stresses exerted on their waists by repetitive movements (carrying, lifting, etc.). And throughout the course of three weeks, there are three successive sets of tests. In the first week, workers are not required to wear exoskeletons for work and daily feedback is provided. The exoskeleton is worn by workers throughout the second week of working. In the third week, employees return to working without exoskeletons before providing feedback. The study data provides an approximation of whether the lumbar exoskeleton will create waist difficulties in humans based on workers' daily reports of waist pain. After the second week of wearing the exoskeleton, individuals reported reduced lower back pain at the end of the day, according to the results of an experiment. During the first week without the exoskeleton, 70% of the provided LBP individuals had greater pain on the weekend than they had at the beginning of the study, 10% had more pain during the second week while wearing the exoskeleton, and 10% had more pain during the third week. Pain without an exoskeleton was 30% worse in the first and final week. Utilizing week 1 data as a reference, 85% of specific LBP participants received alleviation between week 1 without exoskeleton and week 2 with exoskeleton, and week 1 without exoskeleton between week 1 and week 3, compared to 57% for bones. In conclusion, at the end of the second week of wearing the exoskeleton, the perception of lower back pain dropped dramatically, and the exoskeleton had a beneficial influence on the pain index perception of workers with mechanical lumbar disease.

3.2. Advancement via a singular actuation mechanism

Gao Honggen et al. from the Convergence Technology Development Team of the Strategy & Technological Institute of Hyundai Motor Company, Republic of Korea, developed in 2018 a design and control approach for an electric waist-assistive exoskeleton line operated by a single actuation mechanism [8]. The proposed mechanism intends to transfer a substantial waist-assistive torque for the wearer's industrial operations with a single actuator; this modality enables the construction of inexpensive, lightweight waist-assistive exoskeletons. Even without the operation of the actuators, this mechanism enables walking with minimal mechanical resistance on both hips. As walking motion only accounts for a portion of the total power consumption, the working time for back muscle support can be expanded substantially to reduce muscle fatigue and further protect employees from back injuries caused by repeated and intense waist repetitive motions. Gao Honggen et al. constructed a Hyundai Waist Exoskeleton (H-WEX) to test its performance based on this mechanism. H-WEX is a lightweight (about 4.5 kg when batteries are included), electrically powered, mobile waist exoskeleton with an inbuilt controller that determines the necessary torque to transmit based on a developed control algorithm. The experimental results of H-WEX indicate that the electromyography test of nine individuals wearing H-WEX revealed that throughout the experimental process of lifting weight, the activity of the primary muscles involved in waist movement decreased by 10 to 30 percent. This mechanism successfully provides waist support for a variety of wearers, suggesting that a single actuation mechanism can provide a low-cost, lightweight, energy-efficient, and dependable lumbar support system. The team suggests, among other things, that a single actuator positioned on the robot's rear operate both legs simultaneously through wire and a differential gear system. The applied differential mechanism allows the natural movement observed in human walking with almost no mechanical resistance, but the lumbar movement for lifting heavy objects can be assisted by the dynamic extension of the legs, then It is designed to achieve the robot's objectives via a current control algorithm embedded in a microcontroller. Electromyography (EMG) activation signals on the primary muscles of the working user related with waist motions were monitored in order to evaluate the lumbar help offered by the designed robot. In addition, usability was evaluated based on questionnaire replies. Consequently, the final effectiveness of the suggested method for helping the waist via a single actuation mechanism is confirmed.

3.3. Emergence of model of a power-assisted exoskeleton robot

In 2020, the team led by Zhang Jingshuai modelled a power-assisted exoskeleton robot and performed a comprehensive simulation investigation [9]. A power-assisted exoskeleton robot with a reasonable construction and flexible movement is meant to aid personnel in completing handling tasks efficiently and without difficulty. The team employs a homogeneous transformation matrix to represent the position of the connecting rods in the base coordinate system. Using the D-H parameter method, models of the exoskeleton robot's lower and upper limb kinematics were developed, and forward and inverse kinematics were solved. Utilizing Pro/E to develop a three-dimensional solid assembly model of the power-assisted exoskeleton, and then importing it into ADAMS to create a virtual prototype model for kinematics simulation. To lessen the difficulty of simulation analysis and prevent jamming during the analysis process, the lower and upper limbs of the exoskeleton robot were analysed using kinematics simulation. The results of the simulation are essentially compatible with the theoretical outcomes. The exoskeleton for the lower extremities can accommodate human movement. The exoskeleton thigh mass centre front and rear position, upper and lower position, speed change, and other curves have almost the same changes, which is consistent with the human body's walking characteristics. Moreover, the upper limb exoskeleton adjusts to the human body's handling support. The speed change curves of the upper arm and forearm centre of mass are comparable with respect to the features of lifting things. During the process of exoskeleton lifting items, the front and rear positions of the upper arm and forearm centre of mass of the exoskeleton rise, and the change trend of the upper arm mass centre and forearm centre of mass are opposed, but they coincide at the end of the movement [9].

4. Conclusion

With the ongoing reduction of manufacturing costs, the introduction of novel materials, and the miniaturisation of actuators and sensors, there are increasingly more approaches to prevent WMSDs. The design of professional exoskeletons has shifted from the initial bulky and stiff metal exoskeletons to one in which the load of exoskeletons on the human body is given greater consideration. Utilizing low-density, high-strength materials and hollowing out the design eliminates the majority of unneeded weight. Presently, research teams from numerous nations have produced significant discoveries and advancements in the field of professional exoskeletons, and the market for professional exoskeletons is constantly expanding. Future development may be able to add motors to the passive exoskeleton to make it an active exoskeleton, so enabling it to assist employees in avoiding various hazards of waist compression and injury. Thus, such workers who require exoskeletons typically perform a single repetitious task. In order to reduce the worker's stress, physical activity, and injury risk, a collection of programmes can be designed to adapt the movement or force required by the worker to the worker's repetitive motions. With the assistance of active exoskeletons, workers may work more comfortably and effectively. Currently, we face a number of obstacles, including high costs and energy concerns, such as how to make outdoor use durable. The high cost of exoskeletons precludes their broad use, and several manufacturers cannot afford the high price and hence do not contemplate popularising their use in factories. In addition, power-assisted exoskeletons are typically utilised in repetitive job situations. Normal job conditions necessitate that employees work for extended periods, therefore the active exoskeleton's energy storage problem and how to prolong the battery's life are worthy of in-depth examination. In conclusion, occupational exoskeleton research and application are still in their infancy, and their future is full of problems and opportunities.

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