Overview of Lower Extremity Exoskeleton Technology

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Abstract. The exoskeleton is wearable robot that can enhance the power of the wearer in various environments. The research goal of power-assist exoskeleton is to make it become more powerful, faster and more comfortable wearing experience. So far, some of the key technical problems are still not achieved practical breakthrough.

Keywords: Exoskeleton, Hydraulic driven, Exoskeleton Technology.

1. Introduction
In the rapid military revolution, the individual soldier system has become a weapon platform for various countries to develop. The individual soldier system can effectively improve the combat effectiveness of soldiers by using modern weapons and equipment to protect the lives of soldiers and enhance their mission execution capabilities. Strengthening protection, enhancing firepower, realizing rapid response, and improving task adaptability and combat capabilities are the common pursuit of all "soldier systems."

There is always a contradiction between the weight and speed of soldiers. According to the different environmental requirements of the battlefield and march, the load of soldiers can be divided into the load of weapons and equipment and the load of living materials. Our army stipulates that the combat load is 16kg, the general conditions of the army load is 25kg, and the army load of high temperature environment is 15kg [1-2]. In plateau areas, the load should be less than 20kg [3]. However, due to the requirement for soldiers to carry more ammunition and equipment, the individual load often exceeds the prescribed standards. Similarly, the U.S. Army stipulates an individual load of 25 kilograms, but in actual wars it even has to carry more than 60 kilograms.

Exoskeleton is an effective way to solve this contradiction. The exoskeleton has obvious characteristics such as wearability, ease of operation and intelligence. Fundamentally speaking, the exoskeleton is a human-machine integrated system [4], and humans play a decisive role in the system. The mechanical mechanism of the exoskeleton generally has good rigidity, which can play a role in supporting the load of the human bones. It is usually driven by a motor or hydraulic pressure to enhance the strength of the wearer. The purpose of designing the exoskeleton is to improve the wearer's strength and endurance, and significantly reduce the wearer's sense of weight [5]. The original intention of the exoskeleton design is that it can combine the high intelligence of humans with the powerful functions of machinery. By scientifically and systematically integrating the two, they can learn from each other to form a powerful war machine and production tool [6]. Exoskeleton revolutionizes the way equipment is carried and used. Infantry can easily climb over the mountains and quickly reach the combat area and start fighting. In the United States, the existing exoskeleton can
help soldiers carry a weight of 90 kg without affecting their marching speed, and can carry a large amount of war equipment. On the premise that soldiers have not reduced their operational capabilities, there are already worlds of difference in firepower and protection. The exoskeleton can also increase the effectiveness of the equipment. The weapon can be directly fixed to the exoskeleton to improve the way of use. In addition, the exoskeleton is also suitable for ensuring supply tasks and reducing the workload of logistics personnel.

In addition to the military field, exoskeleton can also be used in the following different fields.

In the medical field, in order to improve the self-care ability of many disabled people and enable more disabled people to recover their physical functions, it is necessary to design and manufacture rehabilitation medical exoskeletons for the disabled.

In the production and rescue and other fields, saving personnel in production and improving work efficiency; providing powerful assistance in rescue and accelerating the progress of rescue have urgent application prospects. If the exoskeleton technology is mature enough, the exoskeleton is used in earthquake relief and other occasions, and its benefits are self-evident.

As a complex electromechanical system, exoskeleton faces many problems, and its key technologies still have bottlenecks in many aspects. From the aspect of improving the mobility of the exoskeleton, every effort should be made to increase the driving force of the robot in order to improve the rapid response ability and following effect of the exoskeleton. However, due to the high energy density of the power source in the exoskeleton technology bottleneck, the driving force cannot be increased indefinitely, taking into account energy consumption, only the integration and lightweight design of the exoskeleton is a feasible way.

The development and accumulation of exoskeleton control technology, like the hardware design of the exoskeleton electromechanical system, is one of the two indispensable parts. The control of complex electromechanical systems needs to be designed from each basic module and coordinate the work of each part to complete the final control goal.

Currently, the United States, Japan and other countries are vigorously developing military exoskeletons with superior performance and strong practicability. In view of the urgent needs and broad prospects of exoskeletons in various fields, it is very necessary to accelerate the development of exoskeleton prototypes and breakthroughs in key technologies.

2. Introduction to the development of exoskeleton

In the 1960s, the United States took the lead in the study of exoskeleton technology. The ancestor of the exoskeleton, the Hardiman exoskeleton, was already able to lift heavy objects [7]. Although due to the limitations of various technologies at the time, the motor drive power density was limited, Hardiman failed to achieve success. But it played an important role in guiding the later exoskeleton. Afterwards, some universities and research institutes conducted exploratory research on exoskeleton technology. Typical examples include: Powered Exoskeleton of Vukobratovic in the early 1970s; Jogging Machine of Shulman in the late 1970s; and Monty Reed in 1987 Lifesuit Exoskeleton; SpringWalker by G. John Dick and Eric A. Edwards in 1990, Powered Arm in 1991.
Sensing, materials, and control technologies have made great progress after the 1990s, and the exoskeleton has been significantly improved over the previous decades. By the end of the 20th century, research on exoskeleton based on force feedback and touch technology had blossomed everywhere. The exoskeleton based on force feedback has good man-machine coupling performance, simple and stable control [8].

In the 21st century, benefiting from advances in energy, materials, and information, a large number of excellent exoskeletons have begun to move toward the stage of practical application. In the process of research in various countries, a number of exciting phased results have emerged. More successful examples include: HAL-5 exoskeleton from the University of Tsukuba, XOS exoskeleton from Raytheon, and Lockheed Martin's HULC exoskeleton.

![HAL-5, XOS, HULC](image)

**Figure 2.** Some typical exoskeletons in the 21st century

3. Current research status of exoskeleton technology at home and abroad

Thanks to years of accumulation in the field of exoskeleton, the exoskeleton technology in the United States and Japan is more advanced than other countries. Japan has a lot of research on exoskeletons for the civilian market. The most famous exoskeleton is the HAL-5 system of the University of Tsukuba in Japan. HAL-5 is controlled by a computer on the back; through the active control system of HAL-5, the robot legs are completely controlled by the wearer during movement without any console or external control signals. Its biggest feature is that it uses EMG sensors to detect weak EMG signals to monitor the wearer's action intentions. Then, according to the electromyographic signal as the control input, the driving component is controlled to realize the auxiliary function for the wearer's daily activities.

As one of the earliest countries to develop exoskeleton prototypes, the US exoskeleton technology has always been at the world's leading level. The exoskeletons studied in the United States are mostly power-assisted exoskeletons, and their military and industrial production implications are more obvious. In 2000, The Pentagon National Defense Advanced Research Projects Agency began a seven-year, tens of millions of dollars in mechanical exoskeleton research project. The main funding targets are: "Millennium Jet" company, University of California, Salt Lake Institute of Human Function Research, Raytheon Company, etc.

XOS exoskeleton is a mechanical exoskeleton launched by the American Sachs Company to enhance soldiers' combat and support capabilities [9]. So far, the XOS series has been developed for two generations, and the third generation is under development. In 2010, the second generation XOS exoskeleton performed an excellent demonstration and is the top work in this field today. The whole body of XOS is hydraulically driven and integrates a large number of sensor equipment to monitor the state of the exoskeleton. The sensor detects the force condition hundreds to thousands of times per
second, and transmits it to the computer control center for calculation and analysis, and then the computer quickly completes it. Control of hydraulic actuators. XOS adopts hydraulic drive. The weight of the entire system is 90kg, which is smaller than the first generation. The driving force is greatly improved compared with the first generation. It can lift a load of about 100kg and can also break 3-inch-thick ordinary boards. The main disadvantage of XOS is that it requires an external hydraulic power source. The reason is that XOS has a large energy demand and cannot carry a limited energy module for a long time. Even though the power system of the second-generation XOS has changed, XOS still needs to drag the tubing to work. If a high-energy-density hydraulic source can be designed and the lightweight design of XOS exoskeleton can be achieved, it can greatly promote the practical process of XOS.

On February 26, 2009, the HULC system was launched by the US defense giant Lockheed Martin, and is currently equipped with a small amount of the US military. The HULC exoskeleton only includes the lower limbs and is dedicated to improving the soldier’s endurance and reducing the pressure caused by the load on the soldier. The HULC exoskeleton structure is simplified and the basic functions are relatively complete. With lithium battery as the power source, it can work for 1 hour under normal conditions and the speed can reach 16km per hour. HULC is currently the only exoskeleton that has been partially practical.

In addition to the United States and Japan, South Korea has also conducted a series of research on exoskeletons. Among them, Hanyang University and Sogang University are more prominent. They have published a series of research articles and developed their own exoskeleton prototypes, such as EXPOS, SUBAR, etc. [10-14]. But they did not build a complete set of exoskeletons, most of the articles are for upper limb exoskeletons or lower limb exoskeletons, focusing on the principle of human-machine coupling and exoskeleton control methods [15-16].

Exoskeleton technology started late in China, but the research enthusiasm is high. Tsinghua University, Zhejiang University, Shanghai Jiaotong University, Harbin Institute of Technology, Xi’an Jiaotong University, Tianjin University, Naval University of Engineering, Hebei University of Technology, Hefei Institute of Intelligent Machinery, Chinese Academy of Sciences, etc. are involved in related fields, especially medical rehabilitation exoskeleton. One direction. Zhejiang University has carried out research on flexible exoskeleton technology, and has developed a pneumatically assisted exoskeleton for upper and lower limb exercise rehabilitation training of hemiplegic patients. The Institute of Intelligence of the Chinese Academy of Sciences has also produced a power-assisted lower limb exoskeleton, as shown in Figure 3.

![Figure 3](image_url)

**Figure 3.** The wearable booster robot developed by the Institute of Intelligence of the Chinese Academy of Sciences in the early days
4. Conclusions

In addition to the whole-body exoskeleton, the human-computer interaction technology of the upper and lower extremity exoskeletons has achieved a series of development results [17-21]. The upper extremity exoskeleton is generally defined as the exoskeleton facing the upper extremity of the human body. The structure mainly includes the shoulder joint, the upper arm, the elbow joint and the forearm. At present, the structural design of upper extremity exoskeleton is contended, each with its own characteristics, and the sensing and control technology has also made great progress. Kazerooni has developed a six-degree-of-freedom upper limb strength enhancement system that uses hydraulic pressure as a power source. It measures the interaction force between the human and the exoskeleton through a six-component force sensor and uses it as a control input [22]. Immediately afterwards, Caldwell developed a set of seven-degree-of-freedom upper limb exoskeleton, which was also controlled by force sensors to measure the human-machine interaction force [23]. Cavallaro estimated the torque required by the upper limb joints through the EMG signal, and used it to control a seven-degree-of-freedom upper limb exoskeleton [24].

In China, exoskeletons are mostly driven by motors, which are usually lacking in power. They are only suitable for rehabilitation training. The research and development of exoskeletons for military and industrial production is relatively blank. With the emergence of a series of hydraulic robots with excellent performance in the United States, research on hydraulic robot technology has emerged worldwide. The success of XOS exoskeleton has allowed people to see the advantages of hydraulic robots in terms of strength, which has greatly stimulated people's enthusiasm for research on hydraulic exoskeletons. It can be seen that hydraulic exoskeleton is also full of opportunities and hopes in China.

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