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Functioning of the system development technology of the exoskeleton

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Abstract

Exoskeleton is a device designed to increase human strength due to the external frame. The exoskeleton follows the biomechanics of human rights to a proportional increase in effort during the movements. There should be sensors that monitor the state of the human body, the movement of his legs, arms, muscles (and in the future, perhaps his thoughts). That is, from the point of view of implementation, it is a mechanical skeleton with a system of limb drives and a computer program that works on the basis of a mathematical model of the movement of the human body, which on the basis of data from sensors controls all this exoskeleton. It should be recognized that the main customers of research and development work in this high-tech field are traditionally military agencies and companies operating in the military-industrial and space industries. Therefore, most of the development of exoskeletons takes place in the direction of military applications and only in the second place is their orientation (conversion revision) for civil and industrial needs. In this regard, in the disclosure of the topic, we are forced in any case to start from the concepts associated with the development of military ES.

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Keywords

Exoskeleton, calculation, analysis, structure, sensors.

Introduction

Exoskeleton, the external type of skeleton, is typical for most invertebrates, in which it is presented in the form of a shell (many protozoa, mollusks) or cuticles (chitinous shell of arthropods) in some invertebrates. Before arthropods include insects, crustaceans, arachnids and millipedes, and this group can be considered the most prosperous group of living organisms. The number of arthropod species exceeds the number of species of all other animals combined. Some typical representatives can be seen in Fig. 1.

Fig. 1 – Shells of crustaceans

Based on these data, we can conclude: the exoskeleton was invented by Nature. And man, at some point decided, based on his intelligence, to follow the path of nature, also creating an exoskeleton for himself. Such a device, in addition to increasing the possibilities of a healthy person, can help patients with disorders of the musculoskeletal system, on which even the leading companies of the world are working (Fig. 2).

Science and technology [Heo, 2015, 1600] is, without exaggeration, the most intense race of human and natural ingenuity. Throughout its history, people are trying to remake the world around them for their needs. Where she could, often not without harm to the environment. Somewhere you have to peek at her. And if most invertebrates in one form or another have an external skeleton, a person does not. But no wings?

The essence and types of exoskeletons

Nowadays, the term "exoskeleton" refers to a mechanical suit or part of it up to 2-2.5 meters high. Like so much else in our lives, exoskeletons are gradually crossing the line between bold dreams and everyday life. Being at first just ideas, concepts, myths and legends of science fiction, today almost every week there are new versions of this creation.

Fig. 2 – Exoskeleton from Honda

The first inventor of the exoskeleton is the Russian "mechanical engineer" Nikolai Ferdinandovich Yagn (Fig. 3), which in the 1890s registered a number of patents (Fig. 4) on the subject. He lived in America, where, in fact, he patented his miracles, showed them at exhibitions, and after returning to his native land again invented. His exoskeleton was supposed to facilitate walking, running and jumping in the first place, soldiers. Even then, the Russian genius foresaw the potential military power of such devices.

Fig. 3 – Nikolai Alexandrovich Yagn (1849-1905) – a famous Russian inventor

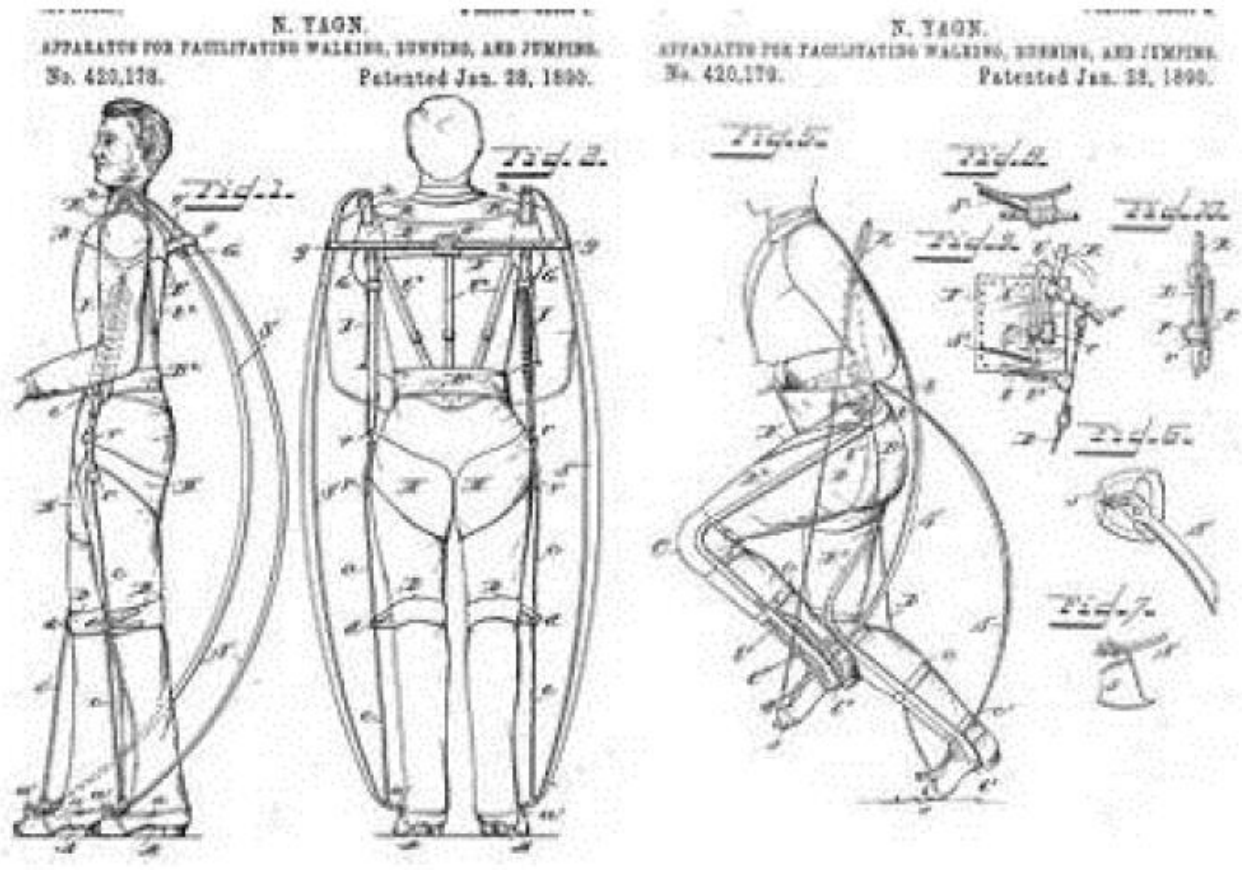
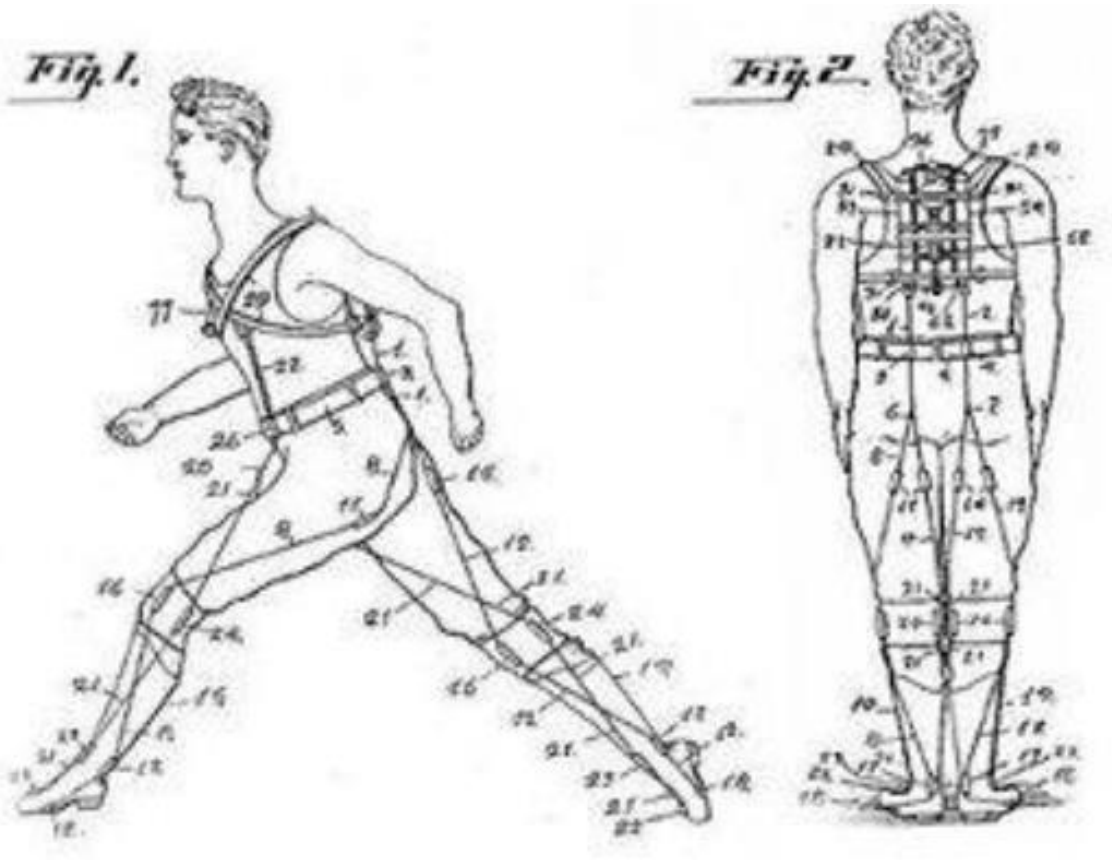


Fig. 4 – Patents of Nikolay Yagn obtained in the USA: № 420178, 420179

He was not alone in his ideas and soon other people filed patent applications (Fig. 5).

We will not deny gigantic and immense contribution to the development of exoskeletons made fiction. In 1959, after a high-profile novel by Robert Heinlein's "Starship troopers" it became clear that the external frame suits – the future of military action and not only.



developed by inventor Leslie C. Kelley in 1917

Fig. 5 – It is vaguely reminiscent of the exoskeleton device "pedometer"

The first attempt to create an exoskeleton design was made in the 1960s. Developed by General electric in conjunction with the U.S. Department of defense the prototype of the "Hardiman" (Fig. 6) had a mass of 680 kg. Thanks to the exoskeleton, the operator can lift loads weighing up to 340 kg. It was planned to use the exoskeleton in the military arsenals, large-caliber aircraft ammunition, to carry out work under water and in space, as well as for use in nuclear power plants. Unfortunately, trials in 1965, the suit was not the best in the series did not go.

Power was supplied via an external cable. The system was equipped with computer control, which did not work very well both because of the imperfection of the computers themselves and because of the lack of, at that time, an adequate mathematical model. As a result, attempts to use a full set of exoskeletons led to uncontrolled movements of the latter (falling), although some of its elements (for example, the hand) worked successfully. Hardiman has never been tested with a man inside.

But the beginning was made. There was an experience that allowed the following developers to move on, not to start from scratch. The Hardiman project was closed in 1971 due to the lack of prospects for its development.

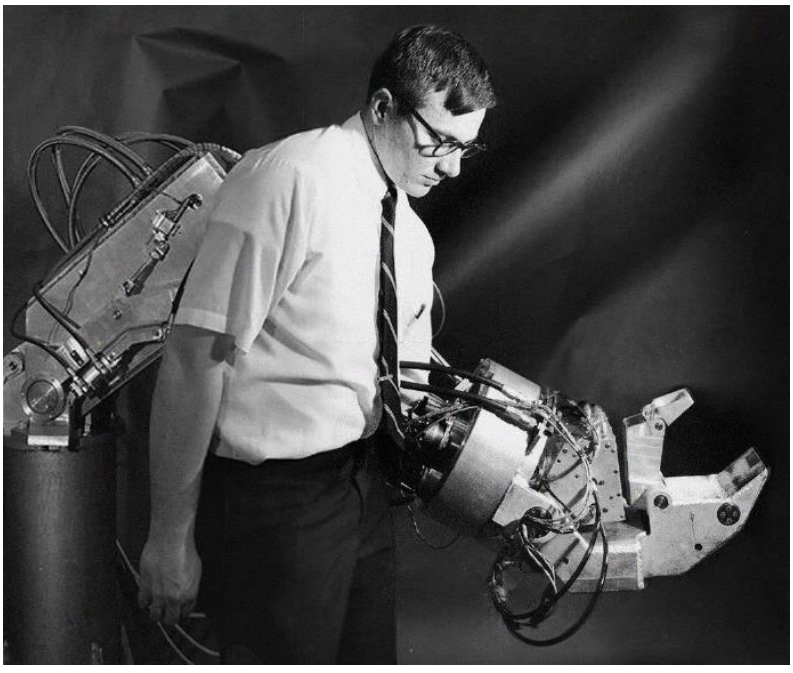


Fig. 6 – The prototype of the "Hardiman" in development

In 1968, Miomir Vukobratovich from Yugoslav Belgrade showed the first power walking exoskeleton, whose task was to enable people to walk with paralysis of the lower extremities. The device was based on a pneumatic actuator. Soviet scientists from the Central Institute of traumatology and orthopedics named after M. M. Priorov showed the first initiatives to develop exoskeletons together with Yugoslav colleagues on the basis of the work of Vukobratovich. But with the beginning of perestroika projects were closed, and we have no data about the secret underground development of exoskeletons. However, space exploration was good.

Then there were two decades not that stagnation, research and development, of course, were conducted, but there were no big breakthroughs, probably through small funding. But experience and knowledge, no matter what, accumulated. In parallel with this, there were changes in related areas: computer technology, batteries, materials, control systems, etc. All this came in handy when a breakthrough in this area began. And it happened when the exoskeleton was again remembered by the military.

Program "exoskeletons for people". In 2001, the Agency Defense Advanced Research Projects Agency (DARPA – Defense Advanced Research Projects Agency) of the Ministry of defense began the seven-year program, Exoskeletons, for Human Performance Augmentation Program, highlighting her $ 75 million. Projects from 14 companies and universities were considered. In the first phase of the project were selected: Sarcos Research Corporation, University of California at Berkeley and Oak Ridge National Laboratory. Sarcos and the University of Berkeley remained in the second phase of the

project. At the final stage of the program, which began in 2004, Sarcos Research Corporation was chosen as the main contractor for the development and development of fast, armored and powerful exoskeleton systems. Soon Sarcos was acquired by a larger company Raytheon, engaged in the implementation of various defense orders. However, work on the exoskeletons continued, and according to reports, very successfully [Jatsun, Savin, Yatsun, Gaponov, 2017, 22].

Fig. 7 – ReWalk Exoskeleton in use

Exoskeleton (Fig. 7) allows people suffering from paralysis of the lower limbs you to walk. Like an external skeleton or bioelectronic suit, the ReWalk device uses special sensors to detect deviations in a person's equilibrium, and then transforms them into pulses that normalize his movement, allowing a person to walk or stand. ReWalk is already available in Europe, and is currently approved by the FDA in the United States.

This exoskeleton was introduced in 2011 and was designed for people with disabilities. In January 2013, an updated version of ReWalk Rehabilitation was released, and in June 2014, the FDA approved the use of the exoskeleton in public and at home, thereby opening the way for it commercially. The system weighs around 23.3 kg, runs on Windows, and three modes: walking, sitting and standing. Cost: from 70 to 85 thousand dollars. Features and specifications:

1. The weight of the device is 25 kg.
2. The exoskeleton can withstand up to 80 kg.

3. The device can operate for up to 180 minutes without recharging.

4. Battery charging time 5-8 hours

5. Exoskeleton is actively used for the rehabilitation of patients with pathology of motor functions of the lower extremities through disorders of the central nervous system or as a result of neuromuscular diseases.

a) used; b) presented by its creators

Fig. 8 – Aksonova company REX Bionics

REX. Motorized exoskeleton suit (Fig. 8) (suit exoskeleton) providing upright people for people suffering from paralysis of the lower extremities. It is created by REX Bionics, its price is $175000-180000. Features and specifications:

1. Independent walking. Does not require crutches or other means to stabilize, while leaving your hands free.

4. Exoskeleton for legs allows you to: get up\sit down, turn, go back, stand on one leg, go up the stairs, walk on different, even inclined surfaces.

5. The device is very easy to operate − all functions are activated with a joystick.

6. The device can be used all day, thanks to a high-capacity removable battery.

7. With a small weight of REX, which is only 38 kilograms, it can withstand a user weighing up to 100 kilograms and growing from 1.42 to 1.93 meters.

8. Convenient fixation system does not cause any discomfort even if you wear it all day.

9. Also when the user is not moving, and just standing REX does not spend battery power.

10. Access to buildings without ramps, thanks to the ability to walk up the stairs without assistance.

XOS. A series of military XOS exoskeleton (Fig. 9) is in active development (in turn XOS 3). Weighs about 80 pounds and allows the wearer to easily lift 90 pounds. The latest models of the costume are so mobile that they allow you to play with the ball.

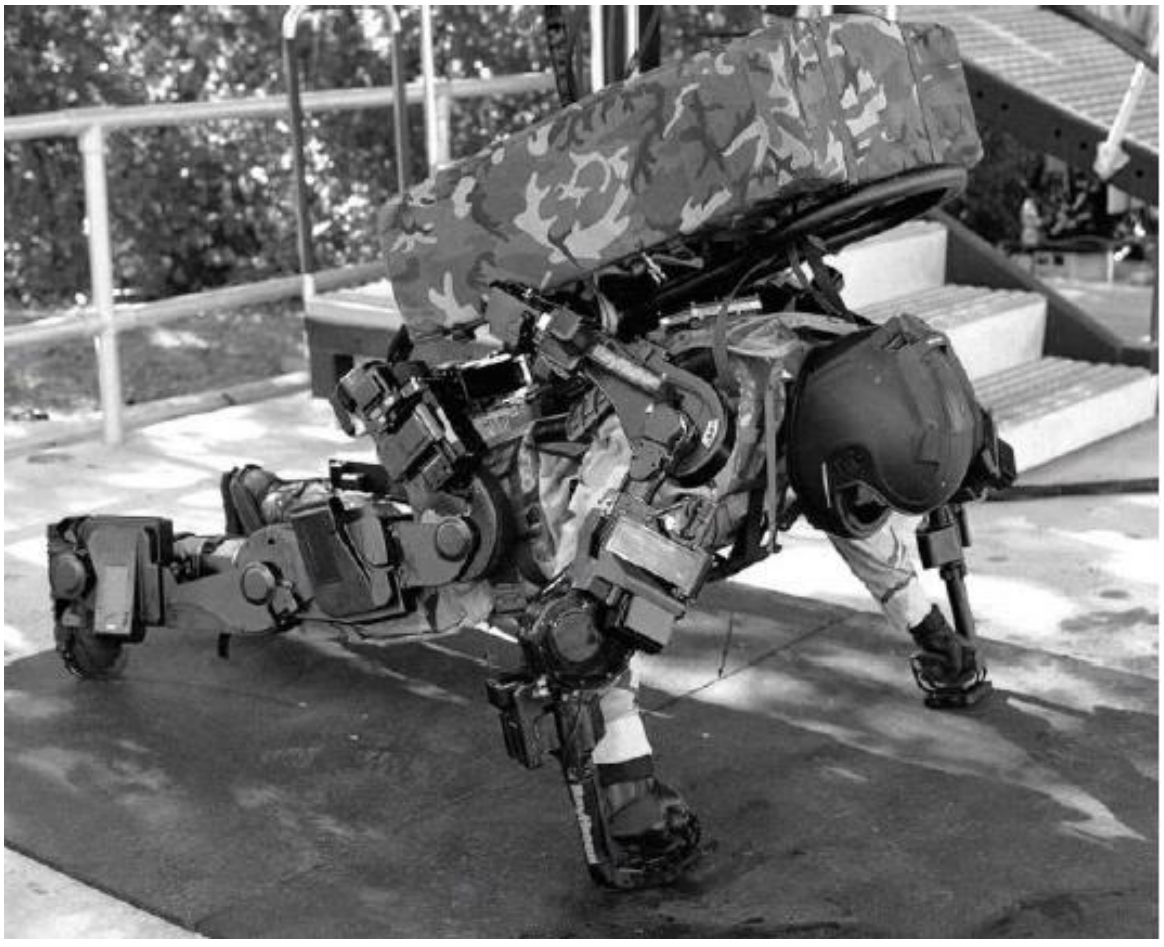


Fig. 9 – XOS Exoskeleton in testing

As noted by manufacturers, one XOS can replace three soldiers. Perhaps the third generation of the exoskeleton will be closer to what we see on the screens of science fiction films in recent years. Unfortunately, so far it is tied to an external power supply.

HULC. Human Universal Load Carrier (Fig. 10) is the creation of the famous company Lockheed Martin together with Berkeley Bionics. This exoskeleton is for the military. The basis-hydraulics and lithium-polymer batteries. Correctly loading the outer frame, with its help, the user can carry up to 140 kilograms of excess cargo. It is assumed that the soldiers will be able to use the HULC for 72 hours.

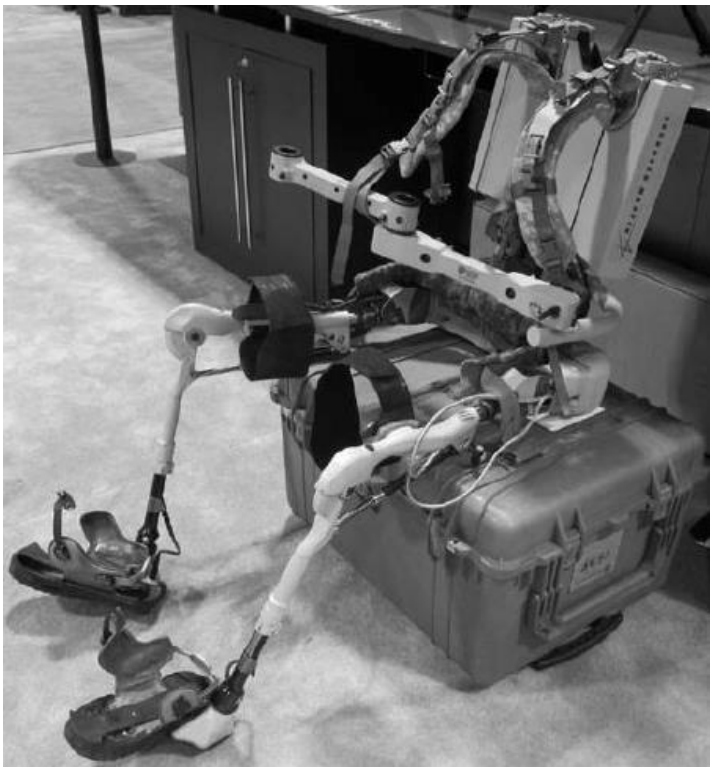


Fig. 10 – Hulk Exoskeleton

Fig. 11 – Prototype from the company Berkeley Vops for general use

Prototypes again Berkeley Vops (Fig. 11) designed to perform various tasks. The first is to help travelers carry cargo up to 50 kilograms, was introduced in February 2005 and weighs about 10 kilograms. Given the small solar panel, can work very, very long. ExoClimber is desyatitsentovoy addition to EchoCG that allows the media to jump and climb stairs. In 2010, developments Berkeley Vops resulted in Elegs. This system is a complete hydraulic exoskeleton that allows paralyzed people to walk and stand. In 2011, Elegs was renamed to Ekso. It weighs 20 kilograms, travels at a maximum speed of 3.2 km / h and works for 6 hours.

HAL. HAL (Hybrid Assistive Limb) (Fig. 12) is a robotic exoskeleton with upper limbs. At the moment, two prototypes have been developed − HAL 3 (restoration of motor function of the legs) and HAL 5 (restoration of the work of the hands, legs and torso). With the HAL 5, the operator is able to lift and carry objects five times the maximum load under normal conditions.

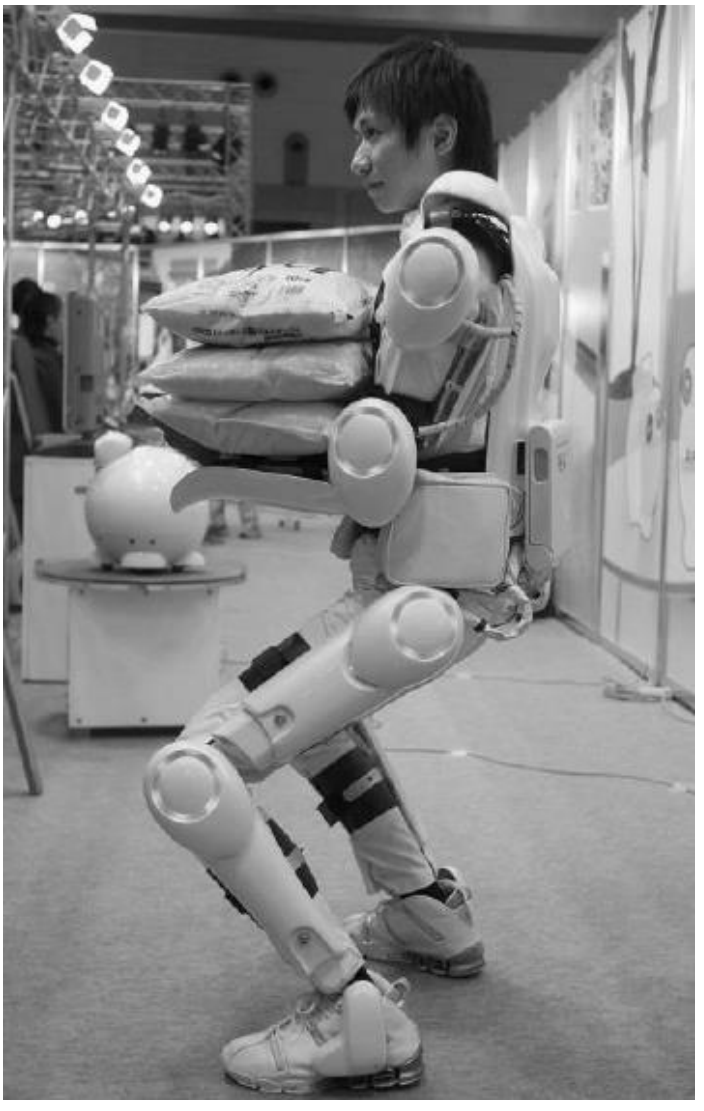


Fig. 12 – HAL in operation

Another well-known Japanese exoskeleton manufacturer is Cyberdyne robots. Its purpose is to provide an opportunity for people with disabilities to walk. There are two main options: HAL-3 and HAL-5. Since its launch in 2011, more than 130 medical institutions across the country have adopted HAL in less than a year. In August 2013, HAL received a carte Blanche for use as a medical job in Europe. The newest model of the suit weighs about 10 kilograms. Price: $5,000. The information could not be confirmed in open sources. Features and specifications:

1. The weight of the device is 10 kg.
2. The exoskeleton can withstand up to 80 kg.
3. The device can operate from 60 to 90 minutes without recharging.
4. Exoskeleton is actively used for the rehabilitation of patients with pathology of motor functions of the lower extremities through disorders of the Central nervous system or, as a consequence, neuromuscular diseases.

Fig. 13 – Ekso GT is put to the user

EKSO BIONIC. Ekso GT (Fig. 13) is another exoskeleton project that helps people with severe diseases of the motor apparatus to regain the ability to move. Price: from $ 150,000 (under the order). Features and specifications:

1. The weight of the device is 21.4 kg.

2. The exoskeleton can withstand up to 100 kg.

3. Maximum hip width: 42 cm;

4. Battery weight: 1.4 kg;

5. Dimensions (HxWxD): 0.5 x 1.6 x 0.4 m.

6. Exoskeleton is actively used for rehabilitation of patients with pathology of motor functions of the lower extremities through disorders of the Central nervous system or as a result of neuromuscular diseases.

In addition to serious full-body exoskeletons, limited exoskeletons designed to perform specific tasks are increasingly popular. For example, the Chairless Chair exoskeleton was shown, allowing you to sit standing. Daewoo and Lockheed Martin independently from each other showed exoskeletons for workers in the shipyards. These devices allow workers to hold a load or a tool weighing up to 30 kilograms without straining.

In Russia, the development of an exoskeleton called "Exoatlet" is engaged in a team of scientists assembled on the basis of the Research Institute of Mechanics of Moscow State University. They continue the development of Vukobratovich started in the USSR, which was mentioned earlier. The first working passive exoskeleton of this team was developed for emergency workers, firefighters and rescuers. With a weight of 12 kilograms, the design allows you to effortlessly carry up to 100 kilograms of cargo. The company plans to develop a power model ExoAtler-a, which will carry up to 200 kilograms, as well as a medical exoskeleton for the rehabilitation of people with disabilities.

The main direction of development is the military use of exoskeletons. The goal is to create armor that combines the firepower and armor of the tank, the mobility and speed of a person, and at times increasing the strength of the one who uses the exoskeleton.

Another possible area of application of exoskeletons is to help injured people and people with disabilities, the elderly, who due to their age have problems with the musculoskeletal system. Modifications of the exoskeleton, as well as some of their models can be of great help to the rescuers when parsing the rubble of collapsed buildings. This exoskeleton can protect the rescuer from falling debris.

Any of the compact power sources today can provide the exoskeleton only a few hours of battery life. Next – the dependence on the wire. Non-rechargeable batteries have their limitations, such as the need for replacement or slow charging, respectively.

Internal combustion engines should be very reliable, but not particularly compact. In addition, in the latter case, you will need an additional cooling system, and the internal combustion engine itself is

difficult to set up for an instant release of a large amount of energy. Electrochemical fuel cells can be quickly refueled with liquid fuel (for example, methanol) and give the necessary and instantaneous emission of energy, but operate at extremely high temperatures. 600 degrees Celsius is a relatively low temperature for such a power source.

The first exoskeletons were made of aluminum and steel, inexpensive and easy to use. But the steel is too heavy, and the exoskeleton must work to lift its own weight. Accordingly, when a large weight of the suit and its efficiency will fall. Aluminum alloys are light enough, but accumulate fatigue, and therefore not particularly suitable for high loads. Engineers are looking for lightweight and durable materials like titanium or carbon fiber. They will inevitably be expensive, but will ensure the effectiveness of the exoskeleton.

Reasons are a particular problem. Standard hydraulic cylinders are quite powerful and can operate with high accuracy, but heavy and require a pile of hoses and tubes. Pneumatics, on the contrary, is too unpredictable in terms of processing movements, because the compressed gas springs, and the reactive forces will push the reasons.

However, new electronic servos are being developed, which will use magnets and provide precise movements, consuming a minimum of energy and being small. You can compare this with the transition from locomotives to trains. Note also the flexibility that should be in the joints, but here the problems of exoskeletons can be solved by the developers of spacesuits. They will also help to deal with the adaptation of the suit to the size of the carrier [Onishi, Arai, Inoue, Mae, 2003, 95].

A special problem in the creation of an exoskeleton is the control and regulation of excessive and unwanted movements. You cannot just go and make an exoskeleton with the same reaction rate of each member. Such a mechanism may be too fast for the user, but it is not efficient to make it too slow. On the other hand, you cannot rely on the user and trust the sensors to read intentions by body movements: unsynchronization of movements of the user and the suit will lead to injuries. Both sides need to be limited. In addition, it is necessary to detect in advance an accidental or undesirable movement, so that an accidental "sneeze" or cough does not lead to an ambulance call.

Conclusion

Taking into account the urgency of the development of rehabilitation exoskeleton technology and relying on the obvious problems in this direction, we form the following task:

1. To ensure an increase in the time of autonomy of the system.

2. To increase the speed and accuracy of human movements, which provides a rehabilitation device such as "exoskeleton".

3. To provide power parameters as close as possible to the necessary for the implementation of normal human movements (according to the anatomist norms).

4. To reduce the cost of the final product of the rehabilitation apparatus of the "exoskeleton" type in comparison with analogues, to specify the scope of this work.

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Принцип работы экзоскелетонного комплекса

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Аннотация

Экзоскелет – устройство, разработанное для увеличения силы человека за счет внешнего каркаса. Данное устройство повторяет биомеханику человека для пропорционального

увеличения усилий при движениях. Экзоскелет оснащен датчиками, которые следят за состоянием тела человека, движением его ног, рук, мышц (а в будущем, возможно, и за его мыслями). Иными словами, механическим скелетом с системой приводов конечностей и компьютерной программой, работающей на основе математической модели движения человеческого тела, которая на основе данных с датчиков управляет всем этим экзоскелетом. Следует признать, что основными заказчиками научно-исследовательских и конструкторских работ в этой высокотехнологичной сфере традиционно являются военные ведомства и компании, ведущие свою деятельность в оборонно-промышленной и космических отраслях. Поэтому большая часть разработок экзоскелетов происходит в направлении военного применения и только во вторую очередь происходит их ориентация (конверсионная доработка) для гражданских и промышленных нужд. В связи с этим при раскрытии темы мы вынуждены в любом случае отталкиваться от концепций, связанных с разработками военных экзоскелетов.

Для цитирования в научных исследованиях

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Ключевые слова

Экзоскелет, расчет, анализ, структура, датчики.

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