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# Wearable Exoskeleton: A Review

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**Abstract:** With the development of technology, considerable steps have been taken in the last few years on wearable technology. As a result of these studies, wearable technology products have become accessible to meet the needs of people in their daily lives. Wearable outer skeleton used as wearable technology products are wearable electromechanical structures that interact with human structures. These structures are used for people with walking disabilities or in older people, assisted structure, rehabilitation in paralyzed people and power increase in healthy people. The fact that the design and control of the exoskeleton robots is very close to the human body's biomechanical functioning and nerve-muscle control will maximize the performance of these wearable exoskeleton robots. Studies on wearable exoskeleton The structure and control of exoskeleton robots are listed and explained in this review. Furthermore, the development of wearable exoskeleton structures is also provided.

*Keywords:* Wearable Technology, Control, Robot, Servo, Emg Sensor, Microcontroller.

# Wearable Exoskeleton: A Review

**Özet:** Teknolojinin gelişmesiyle beraber son birkaç yılda giyilebilir teknoloji konusunda oldukça büyük adımlar atılmıştır. Bu çalışmalar sonucunda giyilebilir teknoloji ürünleri insanların günlük hayatlarındaki ihtiyaçlarını karşılamada ulaşılabilir bir hal almıştır. Giyilebilir teknoloji ürünü olarak kullanılan giyilebilir dış iskelet insan yapıları ile birlikte etkileşim halinde çalışan, giyilebilir elektromekanik yapılardır. Bu yapılar, yürüme engeli bulunan ya da yaşlı insanlarda yardımcı yapı, felçli insanlarda iyileştirme ve sağlıklı insanlarda güç artırımı amacı ile kullanılmaktadır. Dış iskelet robotların tasarımının ve kontrolünün insan vücudunun biyomekanik işleyişi ve sinir-kas kontrolü ile çok yakın olması bu giyilebilir dış iskelet robotlarının performansını en üst seviyelere çıkaracaktır. Giyilebilir dış iskelet ile ilgili çalışmalar dış iskelet robotlarının yapısı ve kontrolü bu derlemede listelenmiştir ve açıklanmıştır. Ayrıca giyilebilir dış iskelet yapılarının geliştirilebilirliği de ek olarak sunulmuştur.

*Anahtar Kelimeler:* Giyilebilir Teknoloji, Kontrol, Robot, Servo, Emg Sensörü, Mikrodenetleyici.

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## 1. Introduction

Producers who want to create difference with increasing competition after industrial revolution give more importance to technology element. Wearable technologies are innovative products created with the help of technology and it can be considered as one of the most important technological elements of the 21st century. These technologies, which are integrated with the clothing used and the accessories used, information and communication technology and the products that transfer data to the smart devices with the help of sensors in their systems. Wearable technology products and markets are developing with many disciplines. In addition to important areas such as health, education, production, and security, it is now taking place in almost all elements, even in an ordinary field such as performing daily activities [1].

Over the past few years, many attempts have been made the wearable exoskeleton system. The wearable exoskeleton integrates the human body and a mechanical robot as a single system. The user wears on the body of this skeletal system and this system works with the body. Today, wearable exoskeleton robots have begun to develop and become widespread in areas that can

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serve people. In addition, the application areas of these robots are increasing day by day. User-oriented robots can be used in the field of transport to transport load in the military areas that require power. In addition, these robots are also used in the healthcare field to provide physical support to direct the orbit of their movement to assist patients with movement loss [2]. In this article, wearable exoskeleton systems which are wearable technology products and their controls and utilization areas are examined.

## 2. Wearable Technology

Technology is constantly developing as a decisive factor in the lives of individuals and becomes an integral part of the daily experience of consumers. In the most general sense, there is a fact about daily devices that can send and receive data over the Internet. Among these new technologies, the most prominent technology group is wearable technologies. Today, when the existence of internet technologies of objects is examined, it is seen that the most widely used devices are wearable technology products. [3]. With the development of technology and contraction of the electronic circuits, not only computers and smartphones, but also the clothes and accessories used in daily life, sensors and hardware can be converted into a smart device and can communicate among themselves. For this reason, the user can easily perform data exchange and calculation without the need for larger computers, because the electronic circuits installed on his body or the clothes he can wear can gain the ability of calculation and communication. Integrating information and communication technologies into a garment or fabric is the most important goal in the development of wearable systems [6]. Since the 2000s, it has gained a prominent place among the smart textile, textile and apparel sectors [7]. Wearable technology is becoming more evident in the market and wearable technology products are now becoming part of everyday life [8].Use of wearable technology; health, exercise, training, transportation, finance, play and music. The purpose of these devices is to incorporate functional, portable electronic devices and computers into their daily lives. Wearable devices are examined before entering the consumer market, have a major impact on military technology and health. These devices provide information such as the monitoring of physical functions and the acquisition of biological methods by technological methods [4]. In addition to developing sensor sizes (Micro Electro Mechanical Systems, MEMS), with the development of low-power connections and embedded operating systems, sensor technology has gained a new dimension and networks of sensors that collect information from different parts. [5]. While the process of creating wearable technology is a purely technical matter, it requires collaboration between end-users and professionals in many different fields, such as textile, electronics, fashion, design and manufacturing, and takes into account many aspects [15].

## 3. Wearable Exoskeleton

Determination of human walking movement has always been a difficult problem for medical professionals, engineers and mathematicians. Humanoid robots, which are wearable technology products in daily life, need to be kept close to human to help human activities. Due to its complexity, it is very difficult to develop a model of the lower extremity support system in which human walking patterns can be applied. To achieve this, it is necessary to simplify the high degree of freedom complex model of gait movement. To overcome these problems, many researchers have formed a biped robot model in their theoretical and experimental studies. In the design of the lower extremity support system, there are various constraints such as joint angle range limitation, limb kinematics, joint angle speed limitation, contact between the connections. The initial process of walking is examined by biomechanical analysis of mechanical recordings using pressure plates. Thus, the dynamics of human walking movement can be analyzed. Human walking movement is composed of dynamic movements in the side, front and upright planes. To obtain a complete walking motion of the bipedal gait, gait analysis should be performed in two or more planes. The walking motion is mainly located in the sagittal plane. The bipedal gait pattern in the sagittal plane is similar to human gait. All biped robots have the most splices in this plane. [9]. Exoskeleton robot should have the same structure with human body, and therefore study of the mechanism of human lower limb movement is essential [20]. Analysis of the most common daily living activities are used in the construction of exoskeleton robots. By means of this analysis, the amount of force and movement limits that the wearable exoskeleton robot can produce is determined. These robots can perform daily living activities with 10 to 15 N of power and free movement [18]. In addition, these robots change the hardness and damping in the joints they are connected to provide a flexible and stable movement with minimal energy consumption [19]. With the developing technology, the size of sensors, actuators and control units used in the exoskeleton systems diminish and their power increases. Despite the rapid progress in the design and technology of the exoskeleton system, there is limited data on the human physiological response to its use. However, it is possible to determine the torque and power requirements by determining the desired kinematics and range of motion of the joints [9].

### 3.1. Purpose Of The Wearable Exoskeleton

Exoskeleton robots are wearable electromechanical structures that work in interaction with human limbs. These robots are now available in many areas. Military, health It is widely used in education and transportation areas. The sensors that are on the soldier and can be defined as wearable sensors are the group which includes personal health status, operational environment, combat field identification, sensors. Passive acoustic firing sensors, health monitoring sensors, directed energy threat sensors, positioning sensors, active camouflage sensors and shielded exoskeleton structure are the main examples of this group [12]. Wearable exoskeleton robots are also widely used in healthcare. Technologies in health care provide two ways to achieve better health outcomes. First of all, by improving the quality of life and prolonging the life span, it provides a direct improvement of health outcomes. Secondly, it plays an auxiliary and curative role in the movement of patients with mobility disabilities [14]. The exoskeleton robot is expressed as a structure that supports the user and protects it from the outside environment. Exoskeleton robots that can be worn by the user help increase the ability to provide support and load bearing to the user. Over the past few years, upper arm training devices have been developed to help patients rehabilitate and treat patients suffering from loss of arm movement or descending stroke [34]. In addition, these robots are used in walking disability or elderly persons for assistive limb, rehabilitation in paralyzed people and for increasing power in healthy individuals. The interaction forces between the human-exoskeleton robot must be minimized. For this purpose, the dynamic analysis and kinetics of the human lower limb joints with an exoskeleton robot should be performed appropriately [21]. The design and control of exoskeleton robots will be similar to the human body's biomechanical functioning and nerve-muscle control, which will maximize the performance of these robots. The nerve-muscle system of the human body provides a flexible and safe mobility with minimal energy consumption by continuously changing the stiffness of the joints. Nowadays, studies on hardness changeable actuator designs are continuing rapidly. The major ones of these designs are antagonistic and prestressed actuator designs. Exoskeleton robots are mobile systems that work with equipment such as batteries and should be energy efficient and the power requirements of the engines to be used in design should be kept to a minimum. [13]. Thus, an easier movement situation is provided [40].

The use of wearable exoskeleton robots in different sectors around the world is becoming widespread. In many countries, especially Japan, these robots are used in the construction sector. It is widely used in the transport of heavy loads and construction materials [24].
In biomechanical applications, human movements must be measured very precisely. Biomechanical disease is used to monitor physiological functions and to collect data related to them, in order to identify malfunctions resulting from aging, accidents, and stresses. On the other hand, it can be used in the treatment and rehabilitation of living systems, design of prosthesis and artificial organs, examination of anatomical structures and identification of functions [17].

### 3.2. Structure of Wearable Exoskeleton Robots

The human body's nerve-muscle system, stiffness-modifying actuators (soft actuators) have significant advantages in minimizing the impact of sudden high forces on energy storage / release, safe interaction with elements in their design. Nowadays, studies on the designs of smaller sizes are continuing. These actuators can be grouped when viewed. These are regulated actuators, controlled actuators, and mechanical actuators, which are regulated by antagonistic controlled actuators, equilibrium controlled actuators. It can be changed by changing the hardness of the actuators can be set [20]. In order to provide movement and power support, the skeleton body attached to the user from certain points must be compatible with human anatomy as well as adequate degree of freedom and range of motion in order not to cause any discomfort to the user. However, the skeleton body must be durable enough to carry the loads. The actuators providing the forces and moments required to achieve the desired movements at the desired speed should be as small and light as possible due to the design requirements.In some exoskeleton applications; electric motors, hydraulic cylinders, pneumatic cylinders etc. Many active actuators can be used such as spring; damper etc. passive actuators are also used [10]. In some of the studies, it was evaluated by walking analysis (CGA) which includes angles, torque and power graphs generated by measurements taken on human to obtain information about human joint movements, limb lengths and movement characteristics. The motion range and power requirements of each hinge were examined and preliminary preparation was made for the design phase. Large-capacity actuators are required for the foot joint due to the large torque requirement in the foot joint during the walk [22]. In the actuator design arranged by the transmission ratio, the stiffness of the actuator can be adjusted by changing the transmission ratio between the spring and the outlet and the balance position of the system can be controlled by a second motor. In this embodiment, no energy is required to change the hardness as no force is applied to the pedestrian at the equilibrium point. In this design, the position of the pivot and spring points on the movement arm mechanism is constant, and the position of the force application point can be controlled by adjusting the hardness. It is understood that it is more appropriate to use actuators regulated by the transmission rate in terms of minimum energy consumption and minimum power requirement in the exoskeleton robots supplied with energy needs [23]. In the different exoskeleton studies, "polycaprolactone" polymer material which does not contain any toxic substances, which is recyclable in nature (which is soluble in soil) and which can be resilient with heat is used. Dc servo motor (mini servo) as the actuator and the "Arduino Uno" card as the control card [16]. Many wearable exoskeleton robots were examined in the scanned literature. Another exoskeleton robot made in the structure of the user's back part of the user by powerful dc motor movements were performed. In this structure, the tendons of the robot transmit the torque generated by the motor. When the motor starts to rotate, it gives a torque to the connection points on the shoulders and the knees, and a single dc motor is located on the back and moves on the joints of the person [25].

### 3.3. Yield on Wearable Exoskeleton Robots

Performance in exoskeleton robots is an important concept. The availability and efficiency of these robots should be high. To achieve optimal performance in exoskeleton robots;

- Exoskeleton robots should be anthropomorphic and ergonomic not only in shape but also in function. The human lower limb should have a similar structure. Thus, the user should provide comfortable walking.
- The status of the common positions of human movements and the distribution of degrees of freedom should be examined and formed according to the data obtained.
- The number of actuators and sensors must be high enough. Thus, the movement will be more active.
- The cost of the exoskeleton robots should be low.
- The length of the limbs in the exoskeleton structure should be adjustable. Both the lower and upper parts of the robot should be set in a wide range, so users with different physical properties can use it.
- The exoskeleton should be firm and light. The structure of the metal exoskeleton must support heavy loads.
- The exoskeleton robot must have a stable control mechanism.
- The energy of the robot should be long-lasting and self-rechargeable [26].
- Perform the soft and continuous walking movement which is compatible with clinical gait analysis data and be able to meet the required speed and torque requirements
- It should be in a structure that will not harm the user in terms of the risks related to mechanical and electrical hazards and provide the necessary safety conditions. [11].

### 3.4. Wearable Exoskeleton Control

The control methods used in the exoskeleton applications vary according to the externals and the input signals available from the user. Input signals required for the controller; encoders, force sensors, pressure sensors, EMG sensors, accelerometers etc. many standard measuring elements. In some applications where standard measuring elements are not sufficient, specially designed sensors are used to measure the required input signals.

The use of a portable power unit is required to ensure that the power needs of the external frameworks, actuators and other electronic equipment, which are intended to be used in external environments, are sufficient for a sufficient period of time [10]. In the design of the exoskeleton systems, two control methods have been tried. The first one is the control method by ground response force (PTC) using PID controler. Another is the network-based fuzzy logic control method. It is calculated by the controller that the force should be applied to the cylinders according to the measured ground reaction force by means of force sensors placed in the shoe in the intended ETC control architecture. The force applied by the load cell connected to the hydraulic cylinder shaft is measured by the controller and made error correction [22]. In an exoskeleton development, an effective control strategy and activation scheme is very important. A successful overall approach at the level of decision-making and execution should be applied to optimization of control efficiency. The hierarchical control scheme for the control of autonomous beeping has three stages. These stages are hiking planning, walking choice and walking synthesis [26]. The design of the exoskeleton should be appropriate to combine the skills of the human and the exoskeleton and to increase the exoskeleton activity, allowing each to perform tasks in a simplified manner. There are some basic requirements for control strategy. These;

- Optimized actuator, number of sensors and control scheme should be as simple as possible.

- Machine learning is necessary for adaptation to terrain and external conditions [27].

The movement of the muscle in the human body consists of three modes. These are active mode, passive mode and free mode. Active mode also produces muscle contraction. In passive mode, muscle relaxation occurs. In free mode, the muscular release oscillates. With the pressure sensors to be added to the user, the pressure signal cannot be measured in free mode and the exoskeleton can disturb the movement of the user. The joint angular velocity method is used to solve this problem in free mode. When the pressure sensor detects the contraction of the muscle, it transmits it to the motor via the control mechanism and starts operating from the motor joints [28]. The torque generated by the engine is transmitted through the joints [29]. Another important aspect of these robots is wearability and kinematic compatibility, testing. [35]. The exoskeleton was constructed using an exoskeleton made of aluminum sheets in a different exoskeleton study due to the fact that plastic and iron are not extremely heavy. Sensors (EMG) are located where muscle movements are evident [37]. A human body is divided into two main parts: the upper extremities and the lower extremities. In these regions, the upper extremities DOF (Degrees of Freedom); 1. DOF wrists, 2.DOF elbows, 3.DOF shoulder. Thus, the upper extremities have a total of 6-DOF The pluggable robot is connected to the human body through the exoskeleton, and the rotation centers of the wearable robot must be adapted to the human center rotation centers. In particular, it is difficult to adapt the shoulder joints of the exoskeleton to the rotational centers of the human body, because a human shoulder joint is spherical. And, it is difficult to generate the command signal in the robot, because the collective movement of the human arm has many DOFs. For the correct placement of the motor placement on the shoulders. it is necessary to select a specific motor placement parameter. [30]. If the force of the motors in the joints is not sufficient, additional torque control is required for stronger movement to these zones. [31, 32].

The emergency button is included in the wearable exoskeleton robots in case of emergencies or when out of control [33]. Another important aspect of these robots is wearability and kinematic compatibility testing. [35]. Modes are selected to enable the operator to control a robot. Thanks to these modes, torque is produced according to the required forces and energy efficiency is ensured. [36] The exoskeleton is constructed using aluminum sheets due to the fact that plastic and iron are not extremely heavy. Sensors (EMG) are located where muscle movements are evident [37]. In developed exoskeleton systems, free movement is allowed in cases where robot does not require active effort. [38] In these robots, muscle activity is derived from the bioelectric signals detected on the surface of the muscles, and the torque produced by the actuators is calculated from the estimated joint torque [39]. The local ELM algorithm can be applied to the outer frame to determine the desired movements for the elbow joint [41]. The device needs to be compact and easy to wear. External Motors are small and fixed, the weight of the exoskeleton is reduced by structural optimization [42]. The robot should not give the user unbearable weight. The exoskeleton robot must produce natural movements. With the user does not feel any vibration in the upper limb, jerk or sudden movement change. Small-size high-torque actuators are required to develop such a high-power-to-weight ratio of exoskeleton systems [46]. The weight of the exoskeleton systems should be low. To ensure this, units such as sensors, actuators and power supplies used in exoskeleton systems must be light. It is possible to say that these units can be used more efficiently by reducing their size. Technological advances that will arise in the measurement sensitivity for sensors, the increase of the force / mass ratio for the actuators and the increase in the feed time / mass ratio for the power supplies will enable the development and expansion of the exoskeleton robots [44]. The traditional neuro-fuzzy control method was used to control the exoskeleton in different studies [43]. The design of the exoskeleton system is based on the suitability of the human to the anatomical structure in accordance with the biomechanical rules. Another important criterion is that the system can stand and the motors and electrical elements that will be used on the system during the movement do not affect [45].

## 4. Discussion and Conclusion

In the scanned literature, it was observed that many researchers from different countries were working on wearable exoskeleton system. These studies were carried out in different areas. Designed to be used in areas such as military, health construction, exoskeleton robots. In addition, only the arms, legs and whole body studies were determined in these studies. In the scanned literature, it was seen that wearable exoskeleton robot, which is a wearable technology product, performed in different control mechanisms. Structures such as PID control, Fuzzy logic, Neuro-fuzzy control method are used. It has been determined that different types of engines are used for different purposes in wearable exoskeleton structures. It is observed that servo motors are preferred in high power structures and dc motors are preferred in the exoskeleton robots that need to provide motion only. Microcontrollers such as arduino and pic have also been used to provide control. When the scanned literature is taken into consideration, the wearable exoskeleton robot can be worn for easy operation, lengthening of the length of the user according to the user, making it a light and durable material, having a long-lasting energy requirement and having a self-charging structure and using light and powerful motors the rate of movement should be high. In addition, wearable exterior framed robots can be designed to provide full body control in subsequent studies. A long-lasting structure can occur. Energy can be created with a structure that can renew itself. It can also be controlled by microcontrollers that can respond more quickly. In addition, these robots can be made of a lighter and more durable material, considering the application areas.

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