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Review article

BIONIC PROSTHESES - FEATURES, KINDS AND POSSIBILITIES

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ABSTRACT

Purpose: The purpose of this article is to introduce bionic prostheses and the signal detection technologies used to drive them. At the outset, the term prosthesis is defined, and a classification of prosthesis types is made. Ways of detecting signals from neurons using properties of electromyography and electroencephalography are discussed. The sequence of steps in the operation of a system using bionic technology to control a prosthesis is described. Finally, a brief description of the Open bionics hero arm version 12.0 prosthesis is given.

Materials/Methods: The social aspect and need for the use of bionic prostheses is discussed. The types of prostheses are systematized according to their mode of operation, placement, purpose and functions. The most commonly used bionic signals are presented. An implementation model of a system using bionic technology is composed. The main factors causing inaccuracy and noise in recorded bionic signals are described.

Results: The main technologies used in managing bionic prostheses include electroencephalograph and electromyograph. Various external factors can indicate an influence over the received bionic signal. Bionic prostheses have been created to replace a patient's upper limb, but as of now, they are unable to fully recreate its functions.

Conclusion: The development and implementation of bionic technology in prosthetics would improve the social and domestic life of a patient with an amputated limb. Further research is needed on the use of bionic technology and refinement of techniques to remove external noises included in the received bionic signals.

Keywords: bionic prostheses, electroencephalography, bionic signals,

INTRODUCTION

The social aspects and challenges of people with disabilities, in particular limb amputation, represent a significant task for the health care system to overcome. The development of bionic technology and its incorporation into prosthetics would help address this significant problem. Combining medical examinations such as electroencephalography and electromyography with hardware devices using modern advances in computer technology would create new opportunities for patients to become actively involved in society. There is a need to increase research in this field and promote it among the population.

The social aspect of the problem

People with a certain degree of disability constantly face various difficulties and obstacles. They have limited access to services, including medical care and healthcare. Their health outcomes are lower compared to the rest of the population, they have lower educational and cultural achievements, their economic activity is lower at higher levels of poverty compared to people without disabilities.

Many of the obstacles existing in the environment (physical and social) can be avoided and overcome. Ensuring an improved and equal way of life for people with disabilities is mainly associated with improving access to services of all kinds. It is necessary to expand their participation in the various forms and spheres of education, appropriate employment, motor activity, including adapted sports activities, recreation and culture.

Many organizations, including the United Nations, WHO, etc., recognize motor disabilities as a global public health problem related to human rights as a priority for social progress. In other words, diseases of the musculoskeletal system are a public health problem, as people with these disabilities constantly face many obstacles - in the physical environment, in access to certain services, at work, in the pension system, in the field of rehabilitation and recreation, as well as in access to cultural and entertainment events. Some impairments are themselves risk factors for the occurrence of other adverse health events associated with further deterioration of health status and the occurrence of complications. In addition, movement disorders are a serious problem in ensuring people's rights because even in developed social systems, they continue to experience a certain degree of stigmatization, discrimination and violation of their rights.

All this imposes the requirements for a more extensive, non-intentional, objective and modern approach to diseases affecting motor activity, the basis of which is the person, regardless of gender, age, property and educational qualifications, religious or ethnic affiliation. Regardless of the absence or presence of certain physical and/or mental deficits, the social environment should ensure full access to all its components for citizens and their full and effective participation in the life of society [1]. The popularization of achievements in prosthetics and the use of bionic technology would contribute to the successful social inclusion in public life of people suffering from any disease of the musculoskeletal system.

Prostheses. Kinds

The term prosthesis is used in medicine to denote an artificially created and similar in function and appearance part of the human body, aimed at replacing a missing or removed one due to disease or accident. According to the method of operation, location, purpose and functions they perform, prostheses can be divided into several categories:

According to their way of working, they are defined as:

- passive - these prostheses are also known as cosmetics [2] because their main purpose is to replace a missing part of the human body without the need to perform any specific function;
- powered by the body - these are prostheses replacing a part of an upper or lower limb that, when attached to the patient, have a mechanical lever system that, when performing certain movements from the body of a person, can perform a corresponding action, for example, the contraction of an artificial finger;
- myoelectric - these prostheses provide the performance of certain mechanical movements resembling those of the real limb. They use the possibility of electromyography, which records the electrical signals leading to muscle contraction. After their detection, an electronic control board communicates with electric stepper motors located in the prosthesis, allowing a movement similar to that of the limb;
- bionic - the main purpose of these prostheses is to completely replace the missing limb, fully or partially performing its functions;
- mixed - these prostheses combine two or more of the listed types of prostheses.

According to its position relative to the human body:

- prostheses located in the human body - a characteristic feature is their inconspicuousness. In most cases, they are passive. Examples of such prostheses are artificial joints, dental prostheses, cosmetic implants. Some prostheses can perform certain actions (for example, the heart valve interacts and works as part of the heart pump);
- prostheses located on the human body - their purpose is to replace or support a missing or damaged part of a person's body. An example of such prostheses is an artificial leg, arm or exoskeleton.

According to the function performed:

- prostheses performing a life-sustaining function - they work continuously or are activated automatically in a certain condition. An example of such prostheses are heart valves;
- prostheses that do not perform mechanical movements - perform a cosmetic or supporting function. This group includes cosmetic and passive prostheses;
- prostheses replicating the characteristics and functions of a part of the human body – their purpose is to reproduce to a large extent the functions of the missing/damaged limb or organ. An example of this is an exoskeleton or a robotic arm.

Bionic prostheses

The World Health Organization defines primary health care as care for all people of all ages [3]. Musculoskeletal problems affect a large part of the population, and bionic technology can be successfully used to overcome these problems. It can be defined as part of the intelligent human-computer interaction, which studies the way the human body works and, using electromechanical methods, recreates it in robotics or prosthetics [4]. The implementation and use of this technology require a good knowledge and understanding of various techniques and properties from medicine, informatics, physics and other sciences. An important condition for obtaining a functional bionic prosthesis is the correct and precise registration of the control signals. It must have the ability to accurately and in a short time report the desired action that the patient wants to perform, for example, curling a leg. In modern bionic prostheses, the principles of electromyography and electroencephalography are most often used.

Electromyography

Electromyography measures the electrical signals used to control muscles. Nerve cells create electrical impulses that make the muscle contract or relax. These values, using an electromyograph, are recorded in the form of values and graphs and are used to control the bionic prosthesis. There are two approaches by which this reading can be done: invasive and non-invasive. In the first, microelectrodes are embedded in tiny needles that are injected into the muscle. In this way, even extremely weak electrical impulses can be detected. In the second method, electrodes are placed on the patient's skin above the muscle, which reads the pulses. This is the gentler option of the two, but it is prone to gaps and inaccurate reporting.

Electroencephalography

Electroencephalography studies the electrical impulses through which brain cells interact with each other and control other parts of the human body. Such impulses are also observed during sleep. Those of interest in robotics and bionics are presented in Table 1.

Table 1. EEG frequency band

Band-width	Frequency, Hz	Signal Occurrence
α	8-15	Peace, eyes closed
β	16-31	Strong thought, attention, keen attention, concern
γ	> 32	Combining two different actions, for example, reading and writing
δ	<4	Waves in newborns
θ	4-7	Higher in young children, disappear in adults
μ	8-13	Motor imagery at rest

For the management of bionic prostheses, it is important to consider the "μ" rhythms, which have a frequency of 8 to 13 Hz. These are the so-called motor images that are built when a person decides to perform a certain movement/action. Such images are created even when a person wants to raise his hand but is physically unable to do so due to some disease or amputation. The measurement of pulses is carried out using electrodes that are placed on the head or implanted in it. When using the first method, it is necessary to measure certain parameters of the cranial box and determine the points on which the electrodes are placed. There are several types of electrodes:

- dry - they are applied directly, without the need for a lubricant or a special solution;
- semi-dry - it is desirable to treat the electrodes with a physiological solution before use or during a certain time interval;
- wet - to work, it is necessary to use a conductive gel.

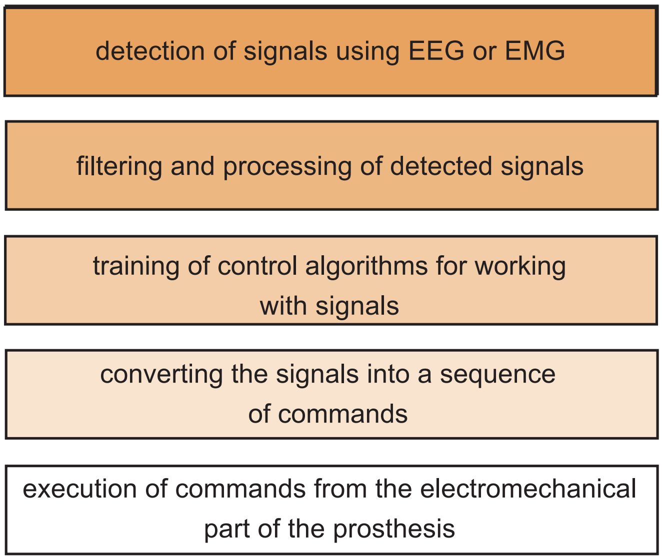
When the electrodes are implanted, a better reading of the impulses is achieved, and it is possible to detect those from inside the brain. Regardless of the chosen method of placing electrodes, the control system must be trained to work with the reported signals. For example, after placing or implanting the electrodes, the patient begins to read a certain text, after which he is stimulated to perform certain actions - lifting a limb. In case of impossibility of performing this action, he must mentally attempt to perform it. Training the system can take from an hour to several days, even months. If the patient can perform partial movements, the recording of the signals using electroencephalography can be combined with video recording, which facilitates the correct recognition of the motor images created by the neurons, which optimizes the training of the system.

A sequence of steps in the operation of a system using bionic technology in the control of a prosthesis

Figure 1 presents the workflow for controlling a prosthesis using bionic technology.

The first step is to successfully and accurately record the bionic signals (electrical impulses) created by the neurons. The technique that is used must realize the recording in a very short time because otherwise, there is a large time gap between the patient's desire to perform a certain action and the realization of this by the prosthesis. Another important requirement is that the equipment used should be compact in size, weight and shape, without causing discomfort and tension to the user.

Fig. 1. Workflow for controlling a prosthesis using bionic technology



Once the system has recorded signals, those that are not of interest to the process should be removed to reduce computational time for processing and analysis. When only those that are important and necessary remain, they should be analyzed to see if they match already recognizable signals from the recorded database or if they need to be further investigated and processed.

If new and unknown signals are detected in the system, they are fed to special self-learning algorithms. This training should not be lengthy, but if it is, the system should move on to processing the next ones, leaving those for post-processing and adding them to the existing database of recorded data after they are completed.

When the signals are recognized, it is necessary to convert them into commands (controlling electrical signals) recognizable by the electromechanical part of the prosthesis. In most cases, it is a combination of a lever system driven by stepper electric motors.

The last phase is the execution of commands from the electromechanical part of the prosthesis.

Problems in the detection of bionic signals

When detecting bionic signals by means of an electroencephalograph, electromyograph or other equipment, it is possible to obtain erroneous readings. This is due to various external factors that need to be considered and analyzed further. Depending on the functional capabilities of the bionic prosthesis, it is necessary to take measures to limit the consequences of working with inaccurate data and create a mechanism to overcome their impact.

Using the non-invasive approach to capture EEG signals, brain activity is recorded in an indirect manner. Various noises of a physiological or other nature are added to the recorded signal. This can be caused by voltage fluctuations in the skin, muscle movement, cardiac activity, external electromagnetic field, etc [5].

Changing the oxygen concentration for more than twenty minutes leads to a change in cortical signals. This is reflected by an increase in the amplitude of the á and â1 range signals recorded in the parietal and occipital regions. In contrast to the observed rule, for ä and è signals, the amplitude decreases in the occipital area, which may generate the following phenomenon: at high oxygen concentration for more than twenty minutes, there is a decrease in the relative strength of slow rhythms and an increase in that of fast rhythms [6]. This leads to a change in the strength of the signals detected by the cortex when a patient is exposed for a prolonged period of time in an oxygen-rich environment, which in turn may result in erroneous execution of commands when controlling the bionic prosthesis.

The frequency range of heart activity ranges from 0.3 to 6 Hz, which overlaps with that of brain activity. In neonates, this problem is even greater because the frequency of brain activity is usually below 5 Hz, and the amplitude of EEG signals is even smaller. An additional problem is created by the small thickness of the skull and the different structural composition of the scalp. The newborn skull has four open sutures in the temporoparietal regions and two fontanelles along the midline of the skull. This causes strong inhomogeneity of the EEG signals obtained. The pulsations of the arterial vessels located next to the anterior fontanelle can be identified as a major source of cardiac-related disturbances [7].

The singular gyrus, located inside the brain, is responsible for emotions, basic impulses (hunger, thirst, etc.), and memory formation. It is divided into two parts - anterior and posterior. When EEG signals are detected, the anterior is of greater interest, as it is responsible for regulating behavior, assessing fairness, analyzing conflicting or ambiguous situations, evaluating possible consequences, controlling attention and concentration, and creating short- and long-term memories. To detect its signals, electrodes are placed frontal-central along the midline on the scalp. When the singular gyrus is damaged, the absence of basic impulses and emotions is observed [8]. In bionic prosthesis management, mild forms of its damage do not affect it.

Vertical eye movement during blinking creates a positive and symmetrical potential on the electroencephalogram signal with the strongest influence on the anterior scalp [9]. If a patient performs it unconsciously and erratically, it may deteriorate the quality of EEG signals and lead to their misreading.

For optimal cognitive performance, the patient must be in good mental condition. With mental fatigue, there is a progressive decrease in attention, leading to a decrease in self-regulation. In this condition, the management of bionic prostheses is particularly difficult [10].

When using self-learning neural networks, a serious challenge is determining the size of the buffer containing data used for training. For command recognition from received and processed EEG signals, this size is of utmost importance [11].

A serious problem when detecting EEG signals is the level of contact between the electrode and the skin. The type of skin, hair, and the state of the person's endocrine system have a strong influence, and studies have shown that the signal received from the electrodes improves as the duration of the measurement increases due to sweating and creating better contact with the skin [12].

The main goal of the EEG device is to be able to remove all the noise contained in the original raw signal and, as a result to obtain a new digitized signal composed of the principal component related to brain activity [5]. The algorithms used to remove the noises depend on the age of the patient.

In modern EEG measurements, a wireless connection is increasingly used to transmit the signals. In addition to convenience, this is also done to prevent the introduction of noise into the amplified EEG signals caused by the generation of eddy currents in the conductors [6]. As a future development, refinement of the design and device of the electrodes used and the possible integration of the amplifier circuit board into the electrode itself is necessary [13].

In recent years, hardware devices for the detection of EEG signals have undergone significant development. In contrast, a major problem is the lack of a standardized procedure for the analysis and interpretation of EEG data, leading to the inability to compare and use data from different studies. Significantly less progress has been made in studies concerning the removal of noise introduced into the signal. Policies to ensure more people have access to biomedical technologies developing bionic prosthetics should be pursued [14].

Bionic prosthesis Open bionics hero arm version 12.0

Hero arm bionic prostheses are made to order for each specific case. Hand control uses the properties of electromyography. The prosthesis has a Bluetooth connection, through which it can communicate with a smartphone on which the " Sidekick " application is installed, which serves for additional settings and achieving correct and fast training for working with it.

Fig. 2. Bionic prosthesis Open bionics hero arm version 12.0. [15]

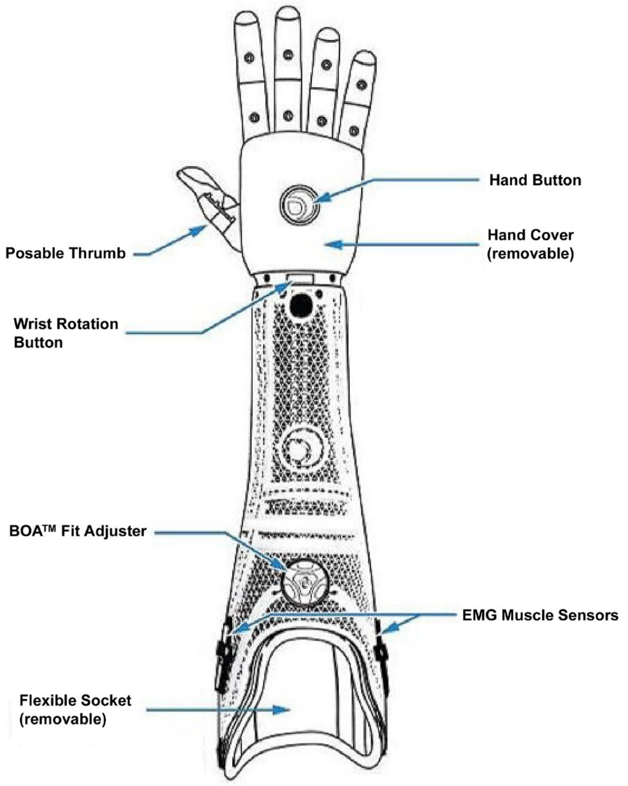


Figure 2 presents the bionic prosthesis of Open bionics hero arm version 12.0 [15]. There are two versions of this prosthesis, and three or four motors can be built into the wrist. With three built-in motors, the index and middle fingers move simultaneously, while if four are installed, they can perform independent movements. The prosthesis has a built-in or surface-mounted battery. The operating temperature range is from -5ºC to +50ºC, and the relative air humidity is from 15% to 90%. The prosthesis has two EMG sensors. Depending on the patient's disability, it can use both or only one, and its management in this case differs. For the fingers to be extended, the patient must imagine extending the wrist with the palm outstretched, whereupon the finger opening sensors read and generate an electromyographic recording controlling the electromechanical system of the prosthesis. The user can rotate the wrist 180Ú by pressing the button located at its base, conveniently located on the back of the hand. When released, the wrist locks into the desired position. After placing and switching on the prosthesis, a calibration is performed in which all fingers are contracted. They must be free of load. During calibration, the diode located on the prosthesis emits a pulsating violet light, and after successful calibration, it lights up white. The prosthesis is not able to replace the missing limb, but it offers the performance of its main functions.

CONCLUSION

Bionic technology gives people with musculoskeletal problems hope to restore their usual way of life. The main methods of detecting signals use the properties of electromyography and electroencephalography. There are prostheses on the market that have EMG sensors that can perform basic movements. The multidisciplinary approach, related to combining different technologies, can be defined as an optimal and acceptable solution for patients with different motor deficits.

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