Prospects for the development of functional expansion of individual low-cost prosthetic limbs for people with disabilities with intelligent sensors

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Abstract. Despite the development of medicine, as well as robotics aimed at helping people with disabilities, most disabled people with missing limbs cannot hope for a full life with the help of bionic prostheses, since these products are made strictly individually, and their control requires expensive surgeries to implant sensors. In addition, such prostheses themselves are very expensive. An alternative solution is to reduce the cost of such prostheses as much as possible and abandon the implantable sensors of signals of the human nervous system. The paper proposes a method for solving such a problem using a variety of sensors that remove signals from the skin surface without invasive surgery.

1. Introduction

Humanitarian goals sometimes force us to think not only about how to solve some difficult problems to restore the motor capabilities of disabled people, but also take into account the price ranges of such products. The incomes of the vast majority of disabled people from all sources are such that they cannot afford to purchase unique prostheses that almost completely replace the lost limbs. Despite the fact that there are many examples of such unique prostheses, the movement capabilities of which are completely identical to the movements of real human limbs, their cost makes them inaccessible to most disabled people. In addition, implantable sensors are needed to control such prostheses, which receive signals directly from human living nerves. Operations to implant such sensors also cannot be widely used, firstly, because of their high cost, secondly, such operations are contraindicated for some patients, and thirdly, not every patient is ready to agree to such additional surgical intervention. This paper offers an alternative method for solving this problem without the need for expensive technologies, without implanting sensors.

2. Statement of the problem

Biomechanical prostheses using invasive transducers are developing rather quickly, but at present these are piece goods of high cost [1–4]. But these items are very expensive. The development of robotics has led to the fact that individual MEMS nodes [5], which in very small dimensions implement complex...
electromechanical functions, have become widely available. Also, three-dimensional printing methods make it easy and relatively inexpensive to manufacture plastic parts of any arbitrarily complex shape [6], and computer-aided design methods greatly facilitate the design of such parts. Mathematical packages Solid Works and similar ones [7–9] allow not only to design such parts, but also to calculate their strength, and, if necessary, to correct the structure, for example, by strengthening it with stiffeners.

In order for a disabled person to benefit from the use of an artificial limb, in its simplest form, it is sufficient that he can carry out grasping movements with his hand, as well as turning the hand. In the simplest version, it is enough to bend separately on command the thumb prosthesis and jointly the prostheses of the other four fingers. A more advanced prosthesis may offer separate flexion and extension of the index finger. Finally, if each finger is equipped with a separate actuator at each joint and a separate command input that distinguishes the signal level, then each individual finger can bend and unbend on a separate command. In addition, clockwise and counterclockwise rotation of the wrist can be controlled by another signal, in which the level can indicate the angle of rotation or strength. Ideally, the steering force and steering angle are controlled separately. To improve the control technique, it is necessary to work in more detail with a specific disabled person, and this work can be performed by a computer simulator using neural computation methods.

At the same time, methods of reading neurosignals without implanting electrodes are actively developing [10]. The developers claim that the signals read are directly signals from the human brain. They are probably wrong, in fact, various rather sensitive sensors can read the external manifestations of changes on the skin, which include changes in temperature, humidity, and color changes in the skin that occur under the influence of changes in blood supply can also be read. Individual muscle movements can also be detected using optical sensors or touch sensors. Blood speed and pulse can also be read. Most of these sensors can be quite cheap, since they can be made using MEMS technologies or using hybrid optics and microelectronics (as well as nanoelectronics).

Thus, a lot of information about a person's feelings and intentions can be obtained using sensors that are simply placed on the human body without invasion. It remains only to discuss which sensors to choose, how exactly the sensors should be positioned, and how to establish a connection between the signals from these sensors and the necessary actions of the prostheses.

3. The proposed method for solving the problem

It is known that neural networks are able to reveal characteristic connections between various events by the training method. Mapping can be done by training such neural networks. For example, the patient cannot use those remaining limbs in order to operate the prosthesis, since this makes no sense. The purpose of using prostheses is to provide the patient with additional opportunities that he is deprived of due to the absence of a limb. Therefore, the sensors should pick up signals not from finger movements, but from those areas of the skin that are most convenient for the patient to control prostheses. Presumably, these are the areas of the stump that are closest to the place where a healthy limb should be. But it can also be the scalp, by analogy with how a device for detecting brain activity works [10].

The proposed procedure for establishing the relationship between control signals and control is as follows.

The patient is supplied with a large number of sensors for various skin conditions, including sensory sensors, for example, BPSDual v1.0 [11]. Optocouplers and sensors used to determine the pulse, temperature sensors can also be used. The patient is asked to mentally move an imaginary limb. For a more visual procedure, it is advisable to depict a mechanical limb on a computer screen, which is controlled by signals received from these sensors. The learning process will take place in the same way as the training of an infant to use its limbs. At first, random attempts to carry out the necessary movement lead to failures, but gradually an increasingly stable and successful unambiguous connection is established between the desired movement and the actual movement performed. If signals are not used, these sensors can be further excluded, if there are not enough available signals for control, you can try to find additional points for picking up commands.
4. Additional possibilities

Additional possibilities to this method are created by the use of sensors to control a virtual image formed on a computer. Even if the patient does not yet have a prosthesis, and also in the case when he does have one, but he needs to work with a computer, establishing unambiguous correspondences between the patient's desire and the direction of movement of at least the mouse cursor allows any patient to control actions on the computer without using fingers and without using voice commands.

For example, if with the help of any efforts formed mentally, the patient has learned to stably change some certain signals on the sensors placed on his body, then he can learn to move the cursor up and down, right and left, and also make a "click" ... This allows you to select the desired icon on the screen and click on it, that is, launch any program the user needs. If the keyboard is called up on the screen, the patient can type text in this way. If necessary, and after some training, the patient can also draw structures using such software tools as, for example, Word and Paint programs, can create and fill in spreadsheets, and carry out fairly complex calculations. This opportunity can be especially valuable for people who lack both arms or are paralyzed. A person in this state can write letters, memoirs, even scientific articles (for example, it is argued that Stephen Hawking participated in the writing of scientific articles even in the absence of the possibility of any movements and without the ability to speak) [12].

It may seem that the proposed technical solution requires placing too many sensors on the patient's body. This may require an unnecessarily large amount of wires that will wrap the patient like a spider web. Firstly, these wires can be placed in a small number of fabric belts with Velcro. In addition, individual sensors can be linked to the prosthesis using low-power Bluetooth channels. A large number of such channels can lead to an unnecessary increase in the cost of the device, therefore we do not insist on such a solution, however, in some cases, the connection between the place of pickup of signals and the place of their application may turn out to be inconvenient for using wires, in this case such a solution is also not excluded, the cost this decision is not prohibitively high. According to our estimates, a prosthetic hand with a sufficient number of sensors can be manufactured for 250-350 US dollars, and in case of mass production, this cost may be even lower. The training stand and software costs are negligible compared to these costs, so when these prostheses are mass-produced, they can be supplied for up to USD 100 or less. This can dramatically improve the lives of many patients who do not have enough funds to purchase expensive modern multifunctional limb prostheses.

5. Conclusion

This paper draws the readers' attention to the problem of providing disabled people who do not have sufficient material support with bionic prostheses that could be effectively controlled without the use of invasive sensors implanted into the patient's body. These studies are being developed in cooperation with the Technical University of Liberec and the Technical University of Sofia [13].

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