Prospects for the use of wireless reading of prosthetic control signals and methods for generating commands

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Abstract. The paper provides a rationale for the use of low-power wireless communication to create non-invasive bionic limb prostheses. The need for such a connection is dictated, on the one hand, by the expediency of using sensors located in various parts of the body, often very remote from each other, on the other hand, by the desire to free the disabled person's body from the wires that would envelop it like a spider web. For each of these positions, arguments are given.

1. Introduction
The Internet of Things implies a big leap forward in the development of Internet technologies, with quite a lot of emphasis being placed on wireless communication systems. Already, wireless systems play a large role in social contacts and information requests of the average user. Wireless communication has organically entered everyday life on the example of Wi-Fi for connecting computers and gadgets with the Internet in homes and public places, wireless manipulators such as "mouse", keyboards, and so on. There are tendencies in the use of sufficiently developed software tools for household appliances (refrigerator, dishwasher, washing machine, coffee maker, and so on) that can be programmed for certain actions remotely. Also, the idea of a smart home is actively developing in the concept of a large number of video cameras and devices to ensure the comfort of the residents of this house. Along with communication by means of radio frequency communication means, optical communication is widely used, in particular, to control a TV set, air conditioner, and some types of other household equipment. The advantage of the optical method is high noise immunity, the advantage of the radio frequency method is that there is no need for optical visibility, since, for example, to successfully control a TV from an optical remote control, if not direct optical visibility, then at least the possibility of light entering due to its scattering from the walls is required or ceiling.

Our concept, which is to use signals that can be read from the human body by non-invasive methods as efficiently as possible to control prostheses, leads to a proposal that, at first glance, seems unexpected and strange, but if it is detailed investigate and test it, it may be quite workable. In this case, we are talking about the use of very unexpected ways of controlling the prostheses, for example, using the toes to control the prosthetic hand.
2. Statement of the problem
In research carried out in collaboration with the Technical University of Liberec (Czech Republic) [1, 2], one of the directions was to create the cheapest hand prostheses and manage them as easily as possible, without implanting electrodes into the human body [3–6]. This study was completed quite successfully, but the obtained control methods turned out to be insufficiently useful, since, for example, control of the left-hand prosthesis with the right hand, on the one hand, gives the disabled person extra opportunities, but on the other hand, it takes away the already existing possibilities of action with the hand that is ... Only a very few actions that require synchronous and completely identical work of two hands can be done in such a case more successfully than without such a prosthesis. In most manual operations, the hands act separately and autonomously, copying the movements of one hand in the movements of the prosthesis of the other hand is in most cases useless.

In addition, the most acute problem of providing hand prostheses is to help such a group of disabled people who do not have both hands. For them, the ability to control the prosthesis must be reliably provided without using the other hand.

The functions of the human legs are significantly less than that of other primates; finger movements are almost unnecessary. At the same time, a person, like any primate, has the ability to move all toes separately. On this basis, we consider it quite expedient to investigate the possibility of controlling prosthetic hands using the simplest commands sent by leg boys. This, in our opinion, will not interfere with movement when walking, since the corresponding buttons can be programatically blocked when performing certain actions or, for example, by pressing the corresponding key combination. At least most people can use their toes to press three different groups of buttons, which gives six buttons when using two feet. With the appropriate training, apparently ten buttons can be used, moreover, the toes (except for large ones) can also perform a movement similar to scrolling the mouse roller up and down in addition to a simple press, and if the buttons are located not only at the bottom, but at the top, they can be pressed as well. That is, the set of commands that can be sent from the legs is quite large. You can also consider at least such an option when the patient uses this method of controlling the prostheses while at rest, sitting in a comfortable chair. In this case, he can devote all his muscular efforts to precisely controlling these prostheses with the greatest concentration.

3. Implementation of the data transmission system
Of course, wires that would go from shoes to hand prostheses are an unacceptable option, it creates too much inconvenience for the patient. The ideal option is to create special inserts in the socks of the shoes. In this case, it is not necessary to use slightly larger shoes, since these devices can be made quite thin. These tabs can contain individual wireless communications. In this case, contact with the prosthesis is carried out only by wireless methods.

In this case, it is necessary to assess the speed of such a connection, safety for the patient, and sufficiency of power. Through our preliminary research, we have determined that a low-power Bluetooth system is best suited for these tasks. Bluetooth Low Energy – BLE – provides a solution to this problem completely [7].

To test the idea, a program for simulating the work of a hand was developed in the form of displaying a graphic image of a hand on a monitor screen.

This application is developed in the C# language in the Unity3D development environment. A 3D model of the hand has been created and animated using four basic gestures.

Table 1 compares the characteristics of BLE and Bluetooth technologies. In terms of basic parameters, BLE technology is not inferior to Bluetooth, the data transfer rate remains sufficient, the range is not critical. In this case, the low level of radiation is an advantage.

The problem of interpreting signals sent by the patient is the problem of converting the original set of signals into the required set of output signals \( \{ I_n \} \rightarrow \{ O_m \} \).

In the general case, the task is to convert signals from the original set of sensors into signals for controlling the existing set of motion organs (fingers, hand, possibly the elbow joint, and so on).
Table 1. Comparison of BLE and Bluetooth technologies [7].

|                          | Classical Bluetooth | Energy efficient Bluetooth |
|--------------------------|---------------------|---------------------------|
| **Radio frequency**      | 2.4 GHz             | 2.4 GHz                   |
| **Distance**             | 100 m               | >100 m                    |
| **Airspeed**             | 1–3 Mb / s          | 1 Mb / s                  |
| **Bandwidth**            | 0.7–2.1 Mb/s        | 0.27 Mb/s                 |
| Minimum total data transfer time (depends on battery status) | 100 ms | 3 ms |
| **Power consumption**    | 1 W as initial      | From 0.01 W to 0.5 W (depending on use cases) |
| **Maximum current consumption** | < 30 mA | < 15 mA |

For example, when controlling the hand of one hand, in the simplest case, we have three flexor muscles (thumb, forefinger, and a group of middle, ring fingers and little fingers), as well as five extensors. In a more complex version, we have five flexor muscles for each of the fingers separately and five extensor muscles. You can also complement the commands to rotate the brush up and down, right and left, and rotate clockwise and counterclockwise. Thus, in a complex hand, a lot of commands are typed, and this is just a very primitive model of the hand. Indeed, a real hand also allows you to fan out your fingers or squeeze them into a tight palm. There are also other figures that a hand can fold (a boat, a handful, and so on). On this basis, we can say that, in fact, a lot of commands may be required to control the hand, that is, even twenty commands (ten toes with pressing up or down) may not be enough, and besides, such dexterity of the toes is perhaps not really achievable. We do not consider this example with twenty commands as real, realizing that it is unnecessarily difficult for most practical cases. However, it is known that a person who has lost one of the senses becomes more receptive to other senses, a blind person perceives auditory signals better, and so on. Therefore, if a person has set himself the task of achieving the most virtuoso mastery of an artificial hand, then it would be very desirable to provide him with such an opportunity, especially since there are no technical limitations in this case. In general, the equation for transforming body movements (inputs) into commands for a prosthesis (outputs) is as follows:

\[
\left[\begin{array}{cccc}
I_{11} & \cdots & I_{1n} \\
\vdots & \ddots & \vdots \\
I_{m1} & \cdots & I_{mn}
\end{array}\right] \rightarrow \left[\begin{array}{cccc}
O_{11} & \cdots & O_{p1} \\
\vdots & \ddots & \vdots \\
O_{1q} & \cdots & O_{pq}
\end{array}\right].
\]

In the simplest version, for complete controllability, it is necessary that the number of inputs is not less than the number of outputs

\[
m \times m \geq p \times q.
\]

Ideally, it is still desirable that the number of possible ways of sending commands be much greater than the required number of elementary movements, since this makes it possible to make redundancy and increase reliability.

For example, it is impossible to exclude the accidental sending of “false” commands, as well as the possibility of not sending a command when it is needed. To protect against false commands, you can use the "AND" logic, that is, only if all variants of this command are generated, it is perceived as actually sent:

\[
O_{ij} = I_{ij} \cup I_{2j} \cup \ldots \cup I_{kj}.
\]
To ensure the execution of the command in any case, if at least one of the commands is sent, you can use the "OR" logic:

\[ O_{ij} = I_{ij} \cap I_{2j} \cap ... \cap I_{kj}. \]

Greater redundancy of control commands would be very desirable, since it would allow both methods to be applied simultaneously, that is, the use of duplicate commands, combined through the logic "OR", and the application of the need for confirmation, combined through the logic "AND".

\[ O_{ij} = (I_{ij} \cup I_{2j} \cup ... \cup I_{kj}) \cap (I_{is} \cup I_{2s} \cup ... \cup I_{ks}). \]

The software modules are implemented in Python using the Keras machine learning library.

4. Conclusion
This paper proposes a method for controlling hand prostheses using signals received from the patient's body without implanting invasive sensors. It is proposed to connect sensors with prostheses using a low-power BLE network [7]. Preliminary experiments have been carried out showing the effectiveness of the proposed method. In this case, a virtual image of a hand prosthesis was used.

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