Volume 8, Issue 5, 2018, 3514 - 3517 ISSN 2069-5837

Biointerface Research in Applied Chemistry

www.BiointerfaceResearch.com

Original Research Article Open Access Journal

Received: 09.06.2018 / Revised: 10.09.2018 / Accepted: 12.09.2018/ Published on-line: 15.10.2018

Bionic hand prosthesis with an improved muscle activity analyzer

Andrey N. Afonin [1,*], Andrey Yu. Aleynikov [1], Marina Yu. Nazarova [1], Andrey R. Gladishev [1], Anastasiya V. Gladisheva [1]

[1]Belgorod State University, 308015, Pobedy st., 85, Belgorod, Russia

*corresponding author e-mail address: ***afonin@bsu.edu.ru***

ABSTRACT

Based on the analysis of existing designs of bionic prostheses, the conclusion was made about the advisability of piezoelectric sensor use for record of muscle activity signals. The design of a muscular activity analyzer is developed and described, the sensors of which are represented by the matrix of the piezoelectric elements that registers the mechanical activity of the individual forearm muscles responsible for the manipulation of fingers. The registration research was performed by a developed analyzer of muscular activity of manipulations both for individual fingers of an arm hand and by a hand as a whole.

Keywords: *hand prosthesis; physiological signals; man-machine interface; matrix registration system; piezoelectric sensor.*

1. INTRODUCTION

Bionic prostheses equipped with mechanical drives are the most effective devices for the rehabilitation of people with amputated limbs. Scientists around the world are engaged in the development and the creation of bionic prostheses, in particular, the English company SLRStepper (Bebionic prosthesis), the German company OttoBock (Michelangelo prosthesis), the Scottish company TouchBionics (i-Limb prosthesis), etc. There are a number of Russian developments in bionic prostheses that are not yet been introduced into batch production. The need in bionic prostheses is very high among invalids, but such prostheses are not yet used widely. The most serious problem during the creation of bionic prostheses of the upper limbs is not the mechanics of their fingers or a hand, but the record of the laboratory conditions of indications about a user's intent to make a right gesture. The task of the signal record transmitted by a nervous system to the muscles is extremely difficult. The most effective from the point of view of informativeness is the use of invasive electrodes that take readings directly from nerve endings. However, the use of such sensors requires an extremely complicated surgical intervention. At the same time, the risk of rejection and other complications is very high.

The management by the majority of existing bionic prostheses is based on the use of electromyographic (EMG) sensors that record the changes in human skin electrical potential [1-7]. Its simplest implementation - the trigger one - is used in mechanical prostheses, controlling a hand squeezing or relaxation (if there is muscle activity then the movement is activated). The prosthesis control is reduced to the supply of two signals only, for example, in order to unclench a fist, you need to strain the outer side of a forearm, and in order to squeeze, on the contrary, to strain the inner side of a forearm. By combining these signals, various actions can be programmed. The surface electrodes in use measure the volumetric activity of large muscles, which makes it impossible to judge the activity of individual muscle fibers responsible, for example, for the movement of hand fingers. Also, trigger systems use smartphones or other devices that switch the grasp modes, like the existing prostheses. Therefore, it is problematic to carry out, for example, the manipulation of an artificial limb by individual fingers using these sensors. Also, such a control system can lead to false positives, so it is difficult and inconvenient to use such prostheses.

Basically, the developers of bionic prostheses use pre-made electromyographic amplifiers and, having received the signal, treat it primitively (one way or another, everything amounts to a "trigger" system). In some cases, cluster analysis is used, but this approach causes difficulties in practical application due to the variability of muscle activity over time.

There is another approach to solve the problem of management - a more detailed treatment of EMG signal from residual stump muscles and the allocation of specific motion patterns to reproduce them subsequently on a prosthesis using machine learning. For example, in [8,9], the design of a control system for a bionic prosthesis is considered, in particular, the task of individual movements of fingers recognition and identification by an electromyogram. In work [10] the issues of bioinformational system development are considered on the basis of electromyography data. A multi-level signal processing structure is proposed here that reflects the information on the movement of a wrist joint and provides the definition of motion type using a classifier based on fuzzy logic. In works [11-14] they performed the overview of modern approaches to the creation of bio-controlled prostheses, the classification of bio-controlled prostheses by the control system was presented, and also the mechanism of motion recognition based on the "man-prosthesis" interface was considered.

However, the authors of these papers emphasize the complexity of EMG signal use, which is associated with the following circumstances: a small amplitude of signals, the presence of interference with a significant amplitude in the "informative range" of frequencies; a complex spectral composition of a signal that varies in time. EMG signals also depend on the internal structure of the subjects, including individual skin characteristics, blood flow velocity, skin temperature changes, skin tissue structure and other factors. Therefore, it becomes necessary to use the signals of a different nature or a combination thereof to increase the informativeness of hand bionic prosthesis problem control.

2. EXPERIMENTAL SECTION

During the model of a bionic prosthesis design, its digital 3D model was developed. The main elements of the layout were made using 3D printing method on the Picaso Designer PRO 250 printer from environmentally friendly PLA plastic. In order to process muscular activity signals, Arduino Nano hardware platform and the software for the Arduino IDE computer were used [15,16], and a manufactured bracelet with a set of piezoelectric sensors was used as a muscle activity analyzer. The design of the muscle activity analyzer was developed on the basis of the well-known basic principles of human anatomy and biomechanics. During the research, digital signal processing methods were also used, in particular, the method of averaging using a cyclic buffer and a moving average.

3. RESULTS SECTION

The authors of the article offered to use the information about the residual stump muscle mechanical contractions to control the bionic prosthesis of a hand. In order to determine the mechanical deformations of muscles arising as the result of their contraction, it is proposed to use piezoelectric sensors, which are the registers of very weak mechanical deformations. Using them, it is possible to single out the movements of individual muscles responsible for the movement of hand fingers, thereby ensuring the control of each finger of an artificial limb separately. Piezoelectric sensors have a unique ability to perceive the minimum mechanical strain (up to several nanometers), transforming them into the currents of considerable magnitude [17, 18].

The proposed analyzer of muscular activity is based on the use as the sensors of data registration on the activity of matrix muscles, consisting of many piezoceramic elements [19].

Structurally, the device consists of two separate modules: the module 1 to record and process a signal (muscle activity analyzer) and the actuator control module 2 (the main controller) (Figure 1).

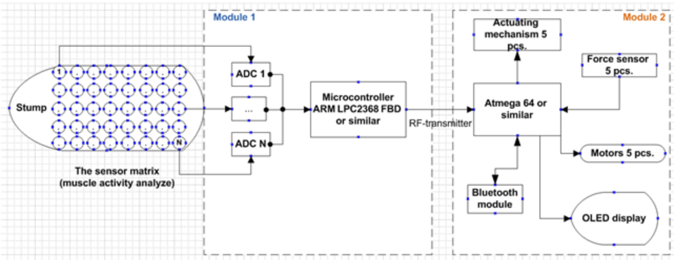

Fig. 1. Structural diagram of the analyzer of muscle activity.

The basis of the control system by muscle activity analyzer module (module 1) is a LPC2368FBD microcontroller with the advanced architecture of ARM version S or the equivalent. Its task is to register and to process the information from sensors, to exchange data with the main controller module via a wireless receiver and a transmitter.

The basis of the main controller module control system (module 2) is the Atmega 32 microcontroller or a similar one. Its task includes a set of basic and auxiliary functions: the implementation of control of operating modes of servo drives, the exchange of data with a personal computer via a Bluetooth module, the exchange of information with the module of muscular activity analyzer through a wireless receiver and a transmitter, and the display of information on OLED display about the main parameters of the system.

The sensor array is mounted on a stump in the receiving sleeve of a prosthesis. After the sleeve fixing to a patient's stump, the recorded signal (the strain that occurs after mechanical deformation of the piezoceramic plate) with the contraction of the corresponding muscles goes to the ADC of the microcontroller LPC2368FBD, processed and transmitted to the second Atmega 32 microcontroller by the means of RF transmitter that drives the corresponding (for each individual finger) servo drives.

In order to debug the work of muscular activity analyzers, a debug dummy model of the hand prosthesis was designed [20], presented in Figure 2. The anatomical features and limb dimensions were taken into account during a dummy model debugging. Each finger of the prosthesis 1 consists of three separate segments. MG90S 2 servo drives (one for each finger) and a nylon string that serves as a link for the servo drive pulley 3 - finger (cable system) are used to move fingers. The drives are controlled by a PWM signal. The turning of the servo pulley by 180 degrees winds the string, which leads to a full bending of the prosthesis finger. The prosthetic control system has a feedback. The load on each finger is determined by the current consumption of its servo drive. The finger 4 has the ability to move in two planes, imitating a correct anatomical structure of a hand and ensuring the capture of objects of various shapes.

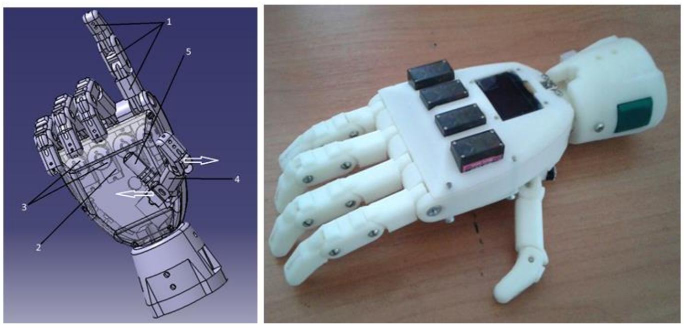

Fig. 2. The layout of the bionic prosthesis of a hand.

This movement is carried out using a miniature electric motor 12GADC 5, by its brief switching on placing a thumb in a set (lateral) or reduced (opposite to the index and middle finger) position. The hardware is implemented in the form of two interconnected modules: a prosthetic module and a feedback module with a control function. The power is provided by Li-on battery, the charge level of which is reflected on the OLED display 6. The operating mode of the servo drives depends on the operation of the muscular activity analyzer. A feedback, which allows a patient to feel the gripping of objects with a prosthesis, is accomplished by the current measurement on the servo drives with the transmission of a vibration signal to a stump, the power of which is proportional to the motor current.

The developed and the manufactured analyzer of muscular activity in the form of a bracelet with a set of piezo elements is shown in Figure 3. To control the movement of prosthesis fingers, the bracelet is equipped with 4 sensors: 1 - index finger, 2 - middle, 3 - ring finger and little finger, 4 - thumb. Each piezoelectric element is located in the zones of characteristic mechanical activity that results from the flexion-extension of the corresponding hand fingers. The bracelet is mounted on a hand surface; the sensors are in a tight contact with skin. The signal is registered in real time and displayed as a graph on a computer by the serial connection of the Arduino IDE software.

For low-pass filtering, during signal processing, they used the averaging method with a circular buffer when each new metering with the current index is stored in the data array. When the last cell is filled, the index value is reset and new measurements will be recorded instead of the old ones. For high-frequency filtering, they used the saving of a moving average for several measurements. Figure 4 shows the graphs of the signals from four piezoceramic elements processed by the above-mentioned methods during the performance of the motor actions: flexion 1, holding of the position 2 and hand extension 3 (index finger - red, medium - orange, thumb - green).

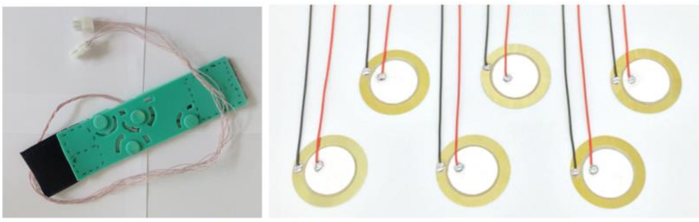

Fig. 3. Bracelet analyzer muscle activity with a set of piezoelectric elements.

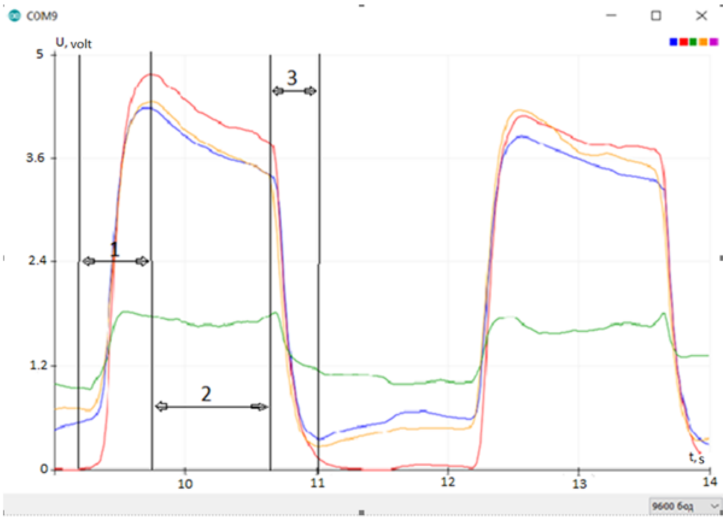

Fig. 4. Graphics of processed signals with 4 x sensors when bending and unbending the hand.

The graphs of signals from four piezo elements processed and obtained by the manipulation with individual fingers are shown in Figure 5. (index - green, medium - blue, ring and pinky - orange, thumb - red).

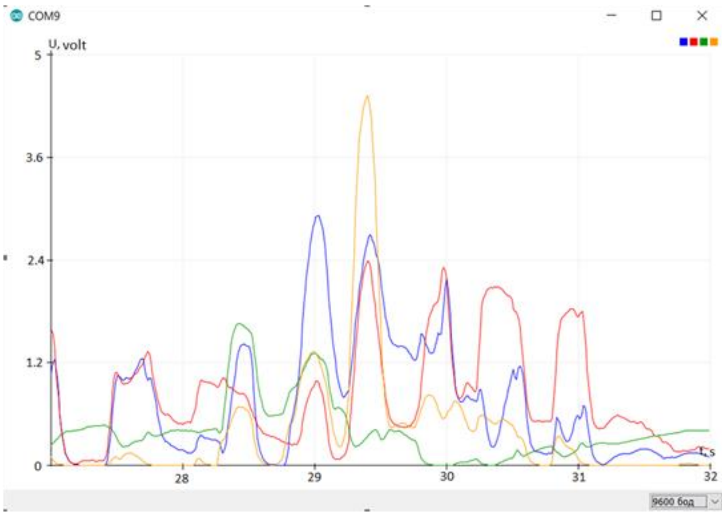

Fig 5 - Graphs of processed signals from 4 sensors when manipulating individual fingers.

In order to increase the efficiency of muscular activity signal processing from an analyzer, artificial neural networks can be used in the future [8, 21, 22, 23, 24].

4. CONCLUSIONS

The experimental study signals from the piezoelectric elements of the proposed muscle activity analyzer confirmed the possibility of these sensors use to control the manipulation of individual fingers of a bionic prosthetic hand. They can be used in the cases when the use of EMG sensors does not provide positive results due to a weak signal or significant interferences. The proposed analyzer of muscle activity will allow a patient to implement control of each finger of an artificial limb individually (depending on the degree of amputation and physiological characteristics of a patient) without resorting to surgery. The combination of control signals from EMG sensors and piezoelectric sensors seems to be very promising.

The obtained result will be used to create a prototype of a bionic hand prosthesis.

5. REFERENCES

[1] Slavutsky Ya. L., Physiological aspects of prosthesis bioelectric control, *M.: Medicine*, 289 (in Russian), **1982**.

[2] Geethanjali P., Myoelectric control of prosthetic hands: state-of-the-art review, *Medical Devices (Auckland, NZ)*, 9, 247, **2016**.

[3] Muzumdar A., Powered Upper Limb Prostheses: Control, Implementation and Clinical Application, *Springer-Verlag Berlin Heidelberg*, 220, **2004**.

[4] Tomashevich D., Yulia B., Prosthesis control system of the upper limb, *Open Innovations Association (FRUCT)*, 2017 20th Conference of. IEEE, **2017**.

[5] Ciancio A.L., et al., Control of Prosthetic Hands via the Peripheral Nervous System, *Frontiers in Neuroscience*, 10, 116-133, **2016**.

[6] Peerdeman B., et al., Myoelectric forearm prostheses: State of the art from a user-centered perspective, *Journal of Rehabilitation Research & Development*, 48, 6, 719–738, **2011.**

[7] Taşar B., Gülten A., EMG-Controlled Prosthetic Hand with Fuzzy Logic Classification Algorithm, *In Modern Fuzzy Control Systems and Its Applications.* InTech, **2017.**

[8] Vorotnikov S.A., Strunin V.S., Vybornov N.A., Biometric control system for a prosthetic arm, *Caspian Journal: Management and High Technologies*, 3, 147-162, **2013**.

[9] Fan X., Dai L., Chang W., Ren X., Sheng S., Duan F., Verifying the gesture identification effect of WNN and DWT for an interference driven prosthetic hand, *In Control And Decision Conference (CCDC)*, 2017 29th Chinese (pp. 5862-5867). IEEE, **2017.**

[10] Gavrilov A.I., So So Tav U., Bioinformational system of classifiers of wrist joint movements on the basis of fuzzy logic, *Bulletin of MSTU named after Bauman. Ser. Instrument making*, 6, 71-82 (in Russian), **2016**.

[11] Zavyalov S.A., Meigal Yu A., The technologies of biocontrolled prostheses today and tomorrow, *Journal of Biomedical Technologies*, 2, 36–42 (in Russian), **2015**.

[12] Vujaklija, I., Farina, D., 3D printed upper limb prosthetics, Expert review of medical devices, 15(7), 505-512, **2017.**

[13] Safin D.R., Pilshchikov I.S., Urakseev M.A., Migranova R.M., The issues of neuro-controlled prosthesis development, *Medical technology*, 4, 16–21, (in Russian), **2009**.

[14] Micera S., Raspopovic S., Petrini F., Carpaneto J., Oddo C., Badia J., Stieglitz T., Navarro X., Rossini PM, Granata G., On the Use of Intraneural Transversal Electrodes to Develop Bidirectional Bionic Limbs. In Converging Clinical and Engineering Research on Neurorehabilitation II 2017 (pp. 737-741). Springer, Cham, **2017.**

[15] Monk S., Programming Arduino Next Steps: Going Further with Sketches, McGraw-Hill Professional, 288, **2014**.

[16] Davitadze, Z., Partenadze, G., Djincharadze, E., Graphical visualization of data measurement of programmable microcontroller according to ARDUINO-project example, In East-West Design & Test Symposium (EWDTS), 2016 Oct 14 (pp. 1-5). IEEE, **2016.**

[17] Steinem C., Janshoff A., Piezoelectric Sensors, *Springer-Verlag Berlin Heidelberg*, 210, **2007**.

[18] Karaseva, N., Ermolaeva, T., & Mizaikoff, B., Piezoelectric sensors using molecularly imprinted nanospheres for the detection of antibiotics, Sensors and Actuators B: Chemical, 225, 199-208, **2016.**

[19] Gladyshev A.R., Gladysheva A.V., Development, implementation and research of a muscular activity analyzer for a bionic hand prosthesis control, *Fundamental and Applied Problems of Engineering and Technology*, 5, 325, 116 – 123, (in Russian), **2017**.

[20] Afonin A.N., Aleinikov Yu A., Gladyshev A.R., Popova A.V., The development and the implementation of hand bionic prosthesis model, *Robotics and technical cybernetics*, 3, 68-71, (in Russian), **2016**.

[21] Morita S., Shibata K., Zheng X.Z., Ito K., Human-EMG Prosthetic Hand Interface using Neural Network, *Technical Report of IEICE*, 118-123, **2000**.

[22] Antuvan, C.W., Bisio, F., Marini, F., Yen, S.C., Cambria, E., Masia, L. Role of muscle synergies in real-time classification of upper limb motions using extreme learning machines. Journal of neuroengineering and rehabilitation, 13(1), 76, **2016.**

[23] Balbinot A., Schuck Júnior A., Winkler Favieiro G., Decoding Arm Movements by Myoelectric Signal and Artificial Neural Networks, *Intelligent Control and Automation*, 4, 87-93, **2013**.

[24] Samuel, O.W., Zhou, H., Li, X., Wang, H., Zhang, H., Sangaiah, A.K., Li, G., Pattern recognition of electromyography signals based on novel time domain features for amputees' limb motion classification. *Computers & Electrical Engineering*, 67, 646-655, **2018.**