The method of selection and pre-processing of electromyographic signals for bio-controlled prosthetic of hand

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***Abstract* — The method of electromyographic signals selection and pre-processing for the problem of construction of high-functional bio-controlled prostheses of hand is proposed. For this purpose, the design of dry active electrodes with a non-uniform shape of the sensitive surface and the type of their placement on the surface of the forearm are proposed. Electromyographic signals were selected and pre-processed using the method of spectral subtraction. The possibility of identifying the movements of individual fingers by such signals was estimated. For this purpose the Fisher criterion was used.**

***Keywords* — bio-controlled prosthesis, electrode, electromyographic signal, prosthetic of hand, data pre-processing**

I. Introduction

According to the Ministry of Social Policy of Ukraine, prosthetics and orthotics by the products with higher functionality on the latest technologies and manufacturing technologies that are absent in Ukraine, for the certain categories of citizens who participated in the anti-terrorist operation and / or ensured its carrying out and lost functionality of the limb or limbs is an important task in the field of rehabilitation biomedical engineering. According to statistics, more than 50% of the total number of prosthetics cases are prosthetics after upper limb amputation at the level of the forearm, with more than 12,000 people in Ukraine needing a prosthetic of hand. This rate is increasing annually, in particular among those affected by fighting in Eastern Ukraine. However, there are practically no high-effective bio-controlled hand prostheses on the prosthetic equipment market in Ukraine (only 58 companies make prostheses in Ukraine and only 6 of them make high-effective prostheses). This is due to the complexity of providing the required number of individual movements of prostheses, which is determined by the methods of selection and methods of processing the biosignals of the residual muscle activity of the amputated limb. Foreign analogues are high cost and require the installation, adjustment and further maintenance of prostheses exclusively abroad.

In organizing the principles of bio-controlled prostheses functioning, a number of approaches to generate signals for controlling the actuators of such prostheses are used today [1-9]. In the simplest case, the control signals are formed on the basis of the results of selection and processing of surface electromyographic (EMG) signals, which are registered in separate areas of the forearm part that remained after amputation [1-4]. In this case, the electrodes used for the selection may have different designs, in particular - contact passive disposable electrodes, organized matrixes of groups of contact active and passive electrodes, contactless electrodes. In all these cases, the electrodes are placed locally on the surface of the forearm, which limits the informativeness of recorded EMG signals , because their structure will contain information only about the residual muscle activity from the restricted area. The resolution of such EMG signal processing systems is low and the total number of movements that the prosthesis can perform does not exceed 14.

Another approach to generating the control signals is to use direct (invasive) methods to obtain information about residual muscle activity [1,5-8]. In this case, the selection and processing of signals recorded directly from the surface of the motor parts of the cerebral cortex [1,5,6] or from the nerve fibers of the truncated area of the hand, is carried out [1,7,8]. For this purpose microelectrodes are used, which are applied to the respective tissue structures. The signals obtained in this way contain the largest amount (compared to other methods) of information about residual muscle activity, but complex surgical interventions are required to obtain them. Implantation of microelectrodes into the surface structures of the cerebral cortex is dangerous and can lead to irreversible changes in the functioning of cerebral cortex motor parts. In all these cases, for the formation of control signals, an evaluation the morphological parameters of the enveloping component of the registered biosignals and their temporal structure is carried out, and the library of patterns - typical images of phantom movements of an amputated hand - are formed on their basis [1]. The use of intelligent algorithms [9] that are capable of learning and adapting to changing selection conditions and that operate on the basis of artificial neural networks is perspective, but it takes considerable time for their learning , and such algorithms are still in the development stage.

Summarizing all of the above, it is established that: the use of disposable electrodes present in the medical market is uncomfortable for the patient and complicates the need to ensure uniformity of EMG signals selection conditions; the use of multiple electrodes implies the need for regular application of additional materials to improve the contact of the electrode surface with the surface of the patient's skin (use of contact gels, additional wetting) and the removal (if any) of hair on the skin in the areas of EMG signals selection; the use of implanted electrodes requires surgery and regular monitoring of the contact state of the "electrode - nerve fibers".

Thats why it is important to develop a design of dry electrodes that would not contain these disadvantages, as well as methods of pre-processing of selected EMG signals.

II. The Construction of Electromyographic Electrodes

As non-invasive, it is perspective to use surface EMG methods using disposable passive electrodes. However, the disadvantage of such electrodes is the inability to reuse them, which is unacceptable for the problem of bioprosthetics. Therefore, the design of active dry electrodes with heterogeneous surface area was developed to better fit the latter to the skin surface. This significantly increases the input resistance of the contact of the electrode sensitive surface with the skin surface. Therefore, it is needed to be integrated into the structure of such electrodes the pre-amplifiers of biopotentials (voltage repeaters) in order to increase the input resistance of the electrodes. It will also reduce the level of sinphase noise and artifacts associated with spatial displacements of the electrodes due to forearm movements.

It is proposed to use as electrodes the electrodes with a needle surface with rounded vertices of needles, which are coated with chemically resistant (to the biological factors) conductive materials, in particular chlorine silver. Such form of the sensitive surface of the electrode will ensure the reliability of contact of the latter with the skin surface without removing the hair, because the needle elements of the contact surface of the electrode will freely penetrate between the individual hairs on the skin surface. Also, such design of the electrodes will be more resistant to the appearance of motion artifacts.

To make the electrodes it is planned to use 3-D printing technologies and antistatic bio-resistant materials, such as ABS Antistatic or nylon.

The configuration of the proposed electrode design is shown in Fig. 1.

Structurally, the two electrodes are made on the same basis (to ensure the same distance between the electrodes), with two groups of needles with rounded vertices. The distance between them is 15 mm. Both electrodes are coated with conductive material. Inside the electrode base are placed circuit boards with operational amplifiers. The base with the electrodes is placed inside the tissue cuff, which fixes the electrodes on the surface of the residual (after amputation) part of the arm.

To increase the informativeness of this selection method, it is also proposed to register EMG signals from a group of electrodes placed radially on the surface of the forearm. Taking into account the parallelization of the processes of nerve impulses in the structure of nerve fibers with phase shifts between separate sequences of nerve impulses, this approach will make it possible to improve the accuracy of differentiation of surface EMG signals into components responsible for providing phantom contractions of individual hand muscles, respectively signs of more movements by analyzing changes in the time-phase structure of the EMG signals group. Therefore, it is proposed to use at least four groups of electrodes, which will be placed evenly on the cuff.

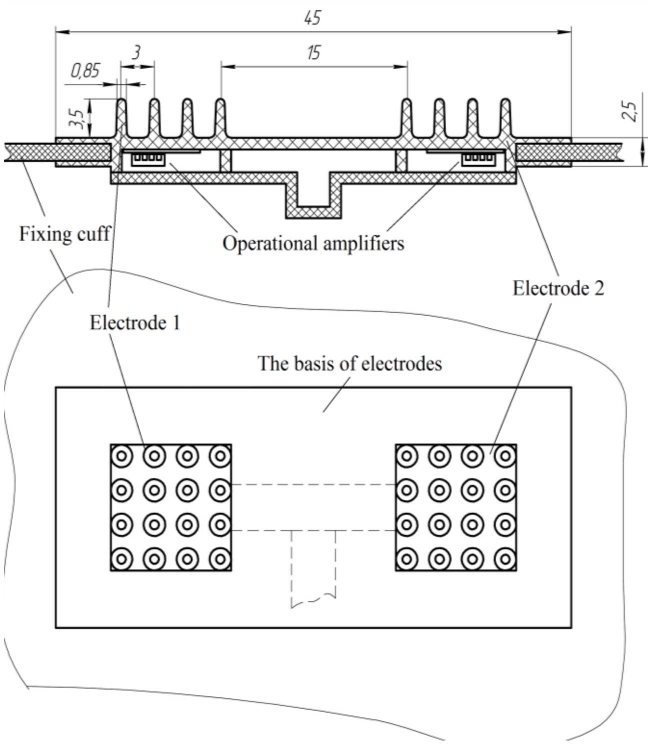

Fig. 1. The configuration of the proposed electrodes design, that are placed inside the fixing cuff

In order to increase the input resistance of the electrodes, it is proposed to integrate into each electrode the operational amplifiers included in the voltage repeater circuit. Besides, it is proposed to use low-power amplifiers with input channels on the unipolar and complementary structures, as an example, operational amplifiers TLC272.

III. Experimental Results

In research, the selection of EMG signals was carried out using a specially designed block of biopotentials amplification, which is made on two instrumental amplifiers AD620, which are connected in series [25]. There is included a high-pass filter between these amplifiers to suppress the constant component of the signal. The functional diagram of the proposed block of EMG signals selection is shown in Fig. 2.

Since the electrode design for the EMG signals selection is proposed but not implemented practically and because of the high cost of materials and the absence of 3-D printer, at this stage the disposable EMG electrodes and block of biopotentials amplification were used for the selection of EMG signals.

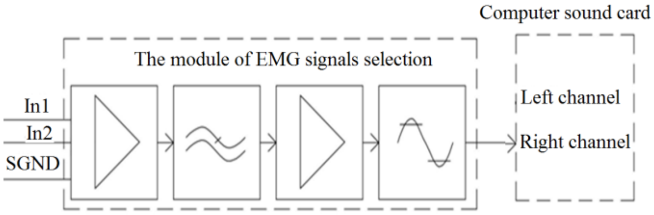

Fig. 2. The functional diagram of the proposed block of EMG signals selection

From the output of the selection block, a useful EMG signal is applied to one of the inputs of the PC sound card. Recording was performed using disposable ECG electrodes that are suitable for the selection of EMG signals. The electrodes were placed at the level of the forearm, in particular the reference - at the level of the tendon, and the active electrode 15 mm below, the grounding electrode was placed on the other side of the hand. The recording was made with the flexion of the index and big fingers. For recording EMG signals Adobe Audition 3.0 environment was used. For further processing, the signals were loaded into the Matlab environment. An example of such EMG signal is shown in Fig. 3.

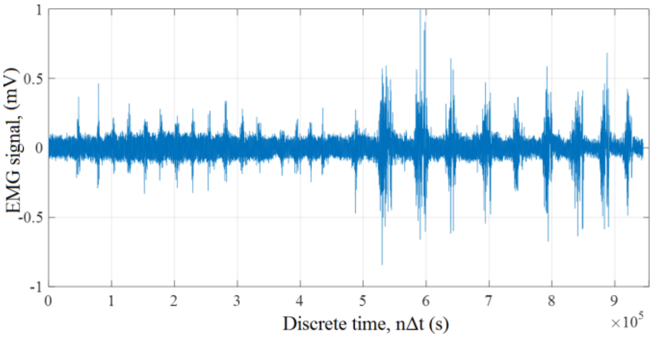

Fig. 3. Loaded into the Matlab environment EMG signals characterizing the movements of individual fingers.

From Fig. 3 it can be seen that the EMG signal contains considerable noise. Thus it has been filtered in order to increase the signal/noise ratio. For this purpose the method of spectral subtraction [10] was used, which is implemented as a separate function in the Adobe Audition environment.

Spectral subtraction is the method of restoring the power spectrum or the amplitude spectrum of a signal with additive noise by subtracting the estimate of the average noise spectrum from the noise signal spectrum [10]. To estimate the noise spectrum, those areas of signal and noise mixture are analyzed, in which there is practically no useful signal and only noise is present. The assumption is that noise is a stationary or slowly changing process.

Analytically, the noisy EMG signal in the time domain can be specified as $p(m)= q(m) +r(m)$, where $q(m)$ is useful EMG signal, $r(m)$ is additive noise and $p(m)$ is a noisy signal [10].

According to the spectral subtraction method, the input signal $q(m)$ is recorded and divided into segments of length n samples. Each signal segment is divided into windows (usually Hanning or Hamming) and then converted to n spectral samples [10]. Further, the noise spectrum is subtracted from the spectrum of each part of the mixture and the inverse Fourier transform is used.

To use such a method it is necessary to specify the signal area, which is noise and does not contain a useful signal. In our case, it can be the first two seconds of the EMG signal (Fig. 3). According to the spectral subtraction method, the amplitude spectrum estimates that are broken down into narrow frequency bands are calculated for this area. Within each band, the parameters of the noise spectral components are calculated and subtracted from the spectrum of the entire signal and the transition from the spectral to the time domain one takes place. The shape of EMG signal after applying the spectral subtraction and normalization methods is shown in Fig. 4.

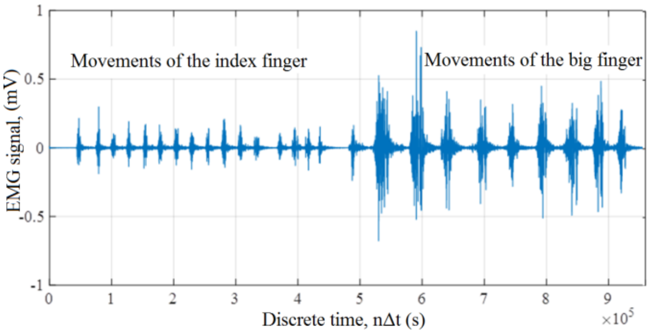

Fig. 4. The form of EMG signal after applying the spectral subtraction and normalization methods with the signs of movements of individual fingers

It is proposed to use the variation of power spectral density distribution as a criterion for identifying individual motions. In this case, the null hypothesis H0 is put forward that the values of variation of power spectral density distribution will have the value dξ1 for the same motion. For the alternative hypothesis H1 we assume that the motions of another type will have values of variance dξ2, but dξ1 ≠ dξ2. To evaluate the statistical significance of the results of research, we use the Fisher criterion, which allows us to compare the dispersions magnitudes of two observations series. Denote by d1 and d2 the estimates of the dispersions dξ1 and dξ2. Then, statistics of Fisher's criterion will be:

$$F = \frac{d_1}{d_2}$$

By this value, using tabular data, we can estimate the level of the results significance of the EMG signals samples processing, to construct the axis of significance, to form a conclusion about the hypothesis H0 or reject it in favor of hypothesis H1.

In statistical data processing, some level of significance α is usually given, which characterizes the probability of a first-order error for the research. Using the Fisher criterion, we can evaluate the level of significance of the processing results. In this case, the value 1-α is called the reliability of the correct decision. If we denote the probability of a second kind of error through β, then the value of 1-β is called the power of the criterion, and in this respect, when comparing the dispersions of two numerical series that can be represented by two samples of EMG signal, the Fisher criterion is a powerful criterion.

To use the Fisher criterion, the estimation of the dispersions of obtained power spectral density distribution estimatios was performed (Fig. 4.10, Fig.4.12). Herewith: d1 = 2.4237 mkW2, d2 = 2.3358 mkW2 - dispersion estimations for the EMG signal samples corresponding to the movements of the index finger; d3 = 578.8250 µW2, d4 = 948,13 µW2 - dispersion estimations for the EMG signal samples corresponding to the big finger movements.

The three values of the Fisher criterion were calculated:

$$F_1 = \frac{d_1}{d_2} = 1{,}0376; \quad F_2 = \frac{d_3}{d_2} = 247{,}805; \quad F_3 = \frac{d_4}{d_3} = 1{,}7$$

The criterion value F_1 was calculated for two dispersions corresponding to the EMG signal area when moving the index finger. The null hypothesis of an insignificant difference between the two dispersions must be confirmed.

The criterion value F_2 was calculated for two dispersions, the first of which corresponds to the area of the EMG signal when moving the index finger and the second - when moving the big finger. In this case, the null hypothesis should be rejected in favor of the alternative - the difference between the values of the dispersions is significant.

The criterion value F_3 was calculated for the dispersions corresponding to the EMG signal region when moving the big finger. The null hypothesis that the difference between these dispersions is an insignificant should also be confirmed.

In order to confirm the assumptions made, it is necessary that the values F_1 and F_3 falls into the criterion insignificance zone and the value F_2 falls into the significance zone. For this purpose, the significance axis was constructed (Fig. 5).

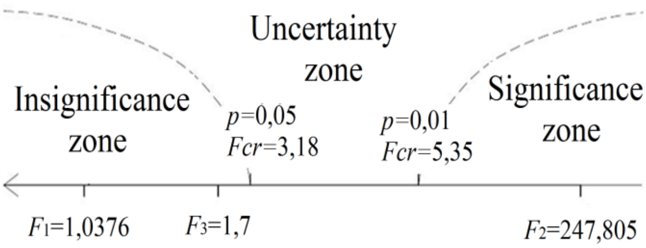

Fig. 5 The Fisher criterion significance axis

For degrees of freedom n-1>200 and m-1>200 for the samples according to the tabulated data, the critical values of the Fisher criterion Fcr were found for probabilities p = 0.05 and p = 0.01. These values are placed on one axis and the significance, insignificance zones and the zone of uncertainty are denoted. If the calculated value of the Fisher criterion falls within the insignificance zone, then the null hypothesis with a probability greater than 0.05 is accepted; if the criterion value falls within the significance zone, then the null hypothesis is rejected in favor of the alternative with a probability of 0.01; if the criterion falls within the uncertainty zone, then the null hypothesis cannot be unambiguously accepted or rejected.

In Fig. 4.12 the calculated values of the criterion F_1 - F_3 are placed on the significance axis and it is found that the values of F_1 and F_3 falls into the insignificance zone and the values of F_2 falls into the significance zone.

Accordingly, the use of the proposed criterion for estimating the dispersions of the power spectral density of the EMG signal samples makes it possible with the probability of 1-α=1-0,01=0,99 to distinguish the signs of movements of index and big finger.

IV. Conclusion

The design of dry active electrodes for the EMG signals selection and the application of spectral subtraction method for filtering the useful signal is proposed. It is established that after the application of such a method, it becomes possible to identify the signs of individual fingers movements. For this purpose it is proposed to use the estimates of variation of power spectral density distribution calculated within the sliding window. The validity of the obtained results was further confirmed by using the Fisher criterion.

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