Experimental Studies for Determining the Optimal Method of Measuring Biophysical Signals

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Abstract. The subject of the study is a system for collecting and processing biophysical signals for controlling anthropomorphic prostheses. As a result of the work, structural and electrical circuits for measuring biophysical signals, processing and filtering schemes were proposed, and the necessary filters were calculated. Designed filters allow you to get rid of noise caused by artifacts of movements and your own signal instability, and can be used to design a system for collecting and processing electromyography signals. In conjunction with a digital filtering system and further processing, it is possible to adequately determine the presence of muscle contractions. The resulting system is small-sized and in combination with the software part of signal processing will allow you to determine key signal patterns and control anthropomorphic prostheses.

1. Introduction
It is found that the upper limb has passed one of the most complex evolutionary paths. The anatomical structure of the human hand, the perfection of its functions is a direct result of a long specific evolutionary progress. The perfection of the human hand inevitably influenced the development and formation of both the spiritual culture of mankind and its material and technical capabilities. Nowadays, the implementation of any task, from daily household activities to industrial-scale operations, is impossible without the participation of fingers. The share of the upper limbs has to a huge part of how the simplest and most complex motor functions. The hand serves as the main assistant in everyday life, in self-service, in operations of interaction with modern digital gadgets, the control of which is designed for finger movements. And also in industries where machines and robots performing the most difficult physical, intense intellectual, especially accurate and other types of work are subject to the movements of the operator’s fingers [1].

At the same time in Russia each year, several thousand people are in need of prosthetics, as a result of post-traumatic loss of upper limb or for the development of pathologies. In addition, patients who have had amputation in previous years should be considered. As a result, the actual number of those in need in prosthetics with each annual increases. Every year, Russian prosthetic and orthopedic enterprises produce no more than five thousand units of traction and cosmetic prostheses of the upper limbs. Undoubtedly, providing the patient with the maximum set of functions of a lost arm is a very urgent task at the present time. At the same time scientific and technological progress of modern society creates electromechanical prosthesis similar to the natural limb not only performs the functionality, but also in appearance [2].

2. Theory
The functioning of modern anthropomorphic prostheses (bionic prostheses) is inextricably linked with the implementation of non-invasive methods for the perception of electrophysiological signals, based on the use of conducting myoelectric contacts that provide dynamic perception as a function of muscle activity. The number of places suitable for adequate placement of myoelectric contacts is limited by a
set of requirements for the information saturation of the information received and the general anatomical features of the structure of the human body. As a rule, in most typical cases, the number of functional zones for placing contacts does not exceed four. The latter aspect is one of the dominant factors limiting the functionality of the system. In this case, it is possible to implement a limited number of primitive monosyllabic actions associated with the capture, retention and movement of objects with simple geometry [3].

The implementation of more complex actions involves the involvement of two or more kinematic groups with several consecutive links, which necessitates a commensurate increase in the number of electrodes as sources of electrophysiological information [4]. It should be noted that it is necessary to correct the methods of perception of electrophysiological signals, which is explained by the presence of statistical heterogeneity of the electrophysiological signal, caused in most significant cases by additive noise and interference of industrial etiology [5].

3. Research

3.1. Signal acquisition block diagram

The acquisition of the electromyography signal occurs in conditions of a huge amount of interference and noise, which greatly affect the signal quality [6]. Also, the electromyography signal belongs to the class of very noisy and low-power signals, and, therefore, a preliminary amplification circuit is necessary for its processing [7]. To solve the problems associated with the acquisition and preprocessing, the following structural scheme is proposed. The block diagram is shown in figure 1.

![Block diagram of the biophysical signal acquisition system](image)

**Figure 1.** The block diagram of the biophysical signal acquisition system

In this scheme, 3 contacts are connected to the patient to receive an EMG signal. Contacts are stickable from Ag/AgCl material [8]. The electrodes are attached to the human body through an adhesive base with a high degree of adhesion to prevent their mobility. A conductive gel is applied to
the surface of the electrode itself to improve the quality of the received signal [9]. The signal from the patient enters the instrumental amplifier in differential switching. Instrumentation amplifier in differential mode is one of the most important components of EMG circuit, the subtracting signals and amplifies their difference [10]. This circuitry proposes the use of an INA333 instrument amplifier from Texas Instruments. The gain is set by two resistors between the terminals Rg [11]. The formula for calculating the gain is presented below:

\[
G = 1 + (100k\text{Ohm}/Rg)
\]  

(1)

To obtain the gain, it is proposed to use resistors with a nominal value of 50 Ohms, and, therefore:

\[
G = 1 + ((100k\text{Ohm}/50\text{Ohm}+50k\text{Ohm})) = 2V/V
\]  

(2)

This low ratio was chosen due to the fact that the higher G, the lower the CMRR (common-mode rejection ratio) of the circuit and, therefore, the signal quality leaves much to be desired.

Between the output of the INA333 amplifier and its reference output there is feedback – integrator. The integrator is necessary in order to remove the bias voltage of the DC component at the output of the amplifier, as well as to set the DC component equal to the reference (reference) voltage of 2.5 V. The integrator is the ISL28433 operational amplifier from Intersil Corporation / Renesas.

3.2. Selection of control signals (patterns)

One of the significant issues associated with receiving an EMG signal is the noise signal of a power line. The human body works like an antenna, taking various types of radiation from different sources, the amplitude of the noise of the power line can be three orders of magnitude higher than the amplitude of the EMG signal, and this noise completely covers the information contained in the signal. A method based on RLD (Right Leg Drive), a circuit used in ECG analysis, is proposed. The RLD – circuit minimizes voltage in the general mode and voltage from the patient with respect to the differential amplifier, and thus increases CMRR [12]. The circuit is shown in figure 2.

![Figure 2. Right Leg Drive circuit](image_url)

The midpoint connector between the resistors Rg and the patient's body is an operational amplifier. Providing a return signal in general mode eliminates the noise signals of the power line. The non-inverting input of the op-amp must be connected to the midpoint. The RLD electrode is the virtual ground for the entire system and should be located on the electrically neutral tissue of the human body. The RLD diagram is shown in the figure 3, the place of attachment of this electrode (point 1) is the elbow of the hand, on which two other (signal) electrodes (points 2, 3) are fixed. The elbow is selected
because it lacks muscle tissue, and therefore it is electrically neutral (or more neutral than the muscles of the person).

Figure 3. Electrodes fixing

The first part of the circuit is a high impedance buffer amplifier, because instrumentation amplifiers are sensitive to stray capacitances at the resistor contacts, and is an ISL28433 operational amplifier from Intersil Corporation / Renesas.

The second part of the circuit is designed to improve CMRR, the general mode voltage is amplified to feed back into the human body, the operational amplifier used in this part is ISL28433, the op-amp output is connected to the third electrode located on the patient's elbow [13].

During the acquisition and registration of biophysical signals that carry information useful for this type of measurement, in combination with the main signal, various noises and noise are also recorded. Interferences include some distortions of useful signals, depending on the influence of various destabilizing factors on the measurement processes, such as interference from working industrial equipment, the influence of lightning discharges, and others.

In order to get rid of motion artifacts and fix the instability of the EMG signal, it is necessary to use a high-pass filter at a cutoff frequency of 20 Hz (since the most unstable band is in the range from 0 Hz to 20 Hz). The most common high frequency is 500 Hz. The development of filters has been reviewed previously [14].

Figure 4. Block diagram of signal filtering and amplification [14]
The amplitude of the EMG signal is in the range from 0 to 10 mV (at peak values) or from 0 to 1.5 mV (RMS value). In order for the signal to be received by the data acquisition board and to be informative, it must be amplified. Figure 5 shows the circuit subsequent signal amplification.

![Subsequent signal amplification circuit](image)

**Figure 5.** Subsequent signal amplification circuit.

The proposed amplification scheme consists of two stages on inverting operational amplifiers. The first inverting amplifier has a gain of -5V/V, and the second has a variable gain with a range of -1V/V to -50V/V, which gives a full variable gain equal to 5V/V to 250V/V. Considering the gain adjustment of the INA333 instrumentation amplifier, the overall gain is in the range of 10 V/V to 500 V/V.

4. Results of Experiment

An experimental verification of the prototype was carried out. EMG signal processing is carried out using National Instruments (NI) equipment in the LabView software environment [15]. The signal from the output of the amplification circuit goes to the NI USB 6009 data acquisition board, the device has a built-in ADC, does not require additional power and connects to the computer via USB. Next, the signal is collected, digitally signal processing, and then filtered based on the wavelet transform [16]. This work is described here (Fig. 6).

![The front panel in the LabView program. EMG signal without noise](image)

**Figure 6.** The front panel in the LabView program. EMG signal without noise.
EMG control signals go to the prototype of the anthropomorphic prosthesis, connected to the Mitsubishi RV-2AJ industrial robot arm based on the FESTO Robotic Station training stand. Measurements are taken on the muscle tissue of the subject. The compensation electrode is located on the elbow joint. RH electrodes are attached at the beginning of the muscle. At the first stage of the experiment, the operability of the device with a muscle signal is checked. If necessary, the gain of the amplifier board is adjusted. The next step is to study the signal propagation along the muscle and the search for the most optimal electrode attachment along the muscle.

This working model of the hand, receiving a signal from the muscles, reproduces most of the movements of the human hand.

The motion phases of a bionic manipulator repeating the actions of a human hand are shown in figure 7.

![Figure 7](image)

**Figure 7.** The operation of the control system of the model of the anthropomorphic prosthesis of the hand.

During the experiment on signal acquisition from one muscle (Fig. 7), it was found that the most stable signal from the muscle can be obtained in some positions of the hand: for a relaxed hand, the signal is practically not recorded; when compressed into a fist, a signal appears with a variable frequency from 100 to 500 Hz and an amplitude of 1-2 mV (with simple compression) and with an increased amplitude when trying to unclench a fist.

5. **Conclusion**

As a result of work has developed a system for acquisition and processing biophysical signals. Structural and electrical circuits for measuring biophysical signals were developed. Also developed were schemes for analog filtering of electromyography signals. The developed filters allow you to get rid of interference caused by motion artifacts and your own signal instability. In combination with a digital filtering system based on a discrete wavelet transform and further processing, the presence of muscle contractions can be adequately determined. The resulting system is small-sized and in combination with the software part of signal processing will allow you to determine key signal patterns and control anthropomorphic prostheses.

Obtaining biophysical signals using surface electromyography in combination with the software part of signal processing will allow you to identify key signal circuits and control anthropomorphic prostheses.

Digital processing of EMG signals is performed in the LabView software environment using National Instruments equipment. A prototype of the signal acquisition and processing system was developed.
with the ability to transmit data to the prototype of the bioprosthesis. An experimental test of the layout was carried out.

6. References

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