Development of a device for registration and processing of EMG signals for a prototype of a bionic prosthetic hand

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Abstract. This paper presents the stages of development of the device registration and processing of the EMG signal, the structural and schematic diagram of the device and the PCB of the device. The experimental results of testing the device in the form of oscillograms of EMG signals and control pulse signals that control the operation of the prototype bionic prosthetic hand are also presented.

1. Introduction

Loss of limbs for any person is a very serious injury not only physically but also psychologically. According to statistics, occupational injuries of the hands are characteristic of 60% of the working population under the age of 39 years [1], and 61.8% of all injuries [1–2] are among injuries of the upper limb, from 2.6% to 5.4% of which are the detachment of fingers and parts of the hand, which in 52.8% of cases leads to disability [1]. This is undoubtedly a serious problem that undermines both the psychophysiological and economic condition of a person. In some cases, it is necessary to put up with it, but modern means of prosthetics are able to make a person "with disabilities" a person with "augmented capabilities". In this regard, the task of creating prostheses, at least partially returning a person to the lost function, is a promising area of modern medicine [3].

Many manufacturers from different countries, including Russia, produce functional bionic prostheses of the upper and lower limbs, allowing people to return to the usual way of life. As examples of prostheses that have proven themselves in the market, we can cite such models as "Hero Arm", "bebionic", prostheses "i-limb", "Michelangelo" and "Stradivarius". These models allow for a large number of different tongs and gestures, have decent performance and load capacity. However, despite all these advantages of these and similar prostheses, their cost is often very high.

2. EMG signal recording and processing device

2.1. The choice of method of recording the EMG signal

Each of the methods of recording muscle biopotentials has its advantages and disadvantages. Needle EMG allows you to register very weak EMG signals in small areas of the muscles, but not as convenient as the surface EMG [4]. Since convenience, in this case, is very significant and surface EMG will achieve the desired result, it was decided to choose the use of surface EMG and abandon the idea of using needle electrodes.

Of course, the direct connection of the electrodes to the ADC will not give the desired result, since the EMG signal is unstable and its amplitude is hundreds of microvolts [5]. In this regard, it is necessary to pre-process the EMG signal using analog amplification and filtration circuits, in particular with the use of so-called instrumental amplifiers. This will highlight the useful component of the signal, to save it from extraneous noise and interference, as well as to strengthen to an acceptable amplitude, suitable for processing in the ADC.

For the transmission of electrical impulses from the muscles to the EMG signal processing device, it is necessary to use electrodes that are able to provide high-quality contact between the electrode pad and the skin surface in the study area. It is recommended to use specialized EMG electrodes with silver chloride sputtering (AgCl) and an isotonic 0.9% aqueous solution of sodium chloride (NaCl) [5]. It should be noted that in this development, it is advisable to use disposable ECG electrodes, because they contain a sufficient amount of contact gel, have a suitable means for securing the electrode on the hand and are widely available.

2.2. Description of structural and schematic diagrams of the device

As already mentioned above, the scheme provides for the use of an instrument amplifier as a preamplifier. This choice is due to the fact that the characteristics of the instrument amplifiers are much better than the characteristics of general-purpose operational amplifiers. Their use increases the chances of correct registration and pre-amplification of weak EMG signals in conditions of strong interference [6]. These amplifiers provide both the ability to easily adjust the gain, and the possibility of implementing a common-mode signal suppression circuit.

The use of an instrument amplifier will not only simplify the process of development, production and testing of the prototype, but also reduce the weight and overall performance of the finished device. The block diagram of the device is shown in Figure 1.

Common-mode signal suppression circuit is necessary to eliminate strong interference of the supply network and other interference that can interfere with the correct operation of the device. The principle of operation of the scheme is to invert the common-mode signal, its amplification and supply to the test area of the skin, resulting in the differential inputs of the instrument amplifier is only a useful signal, and the common-mode noise develops with itself in the antiphase in the region of the electrodes [7].

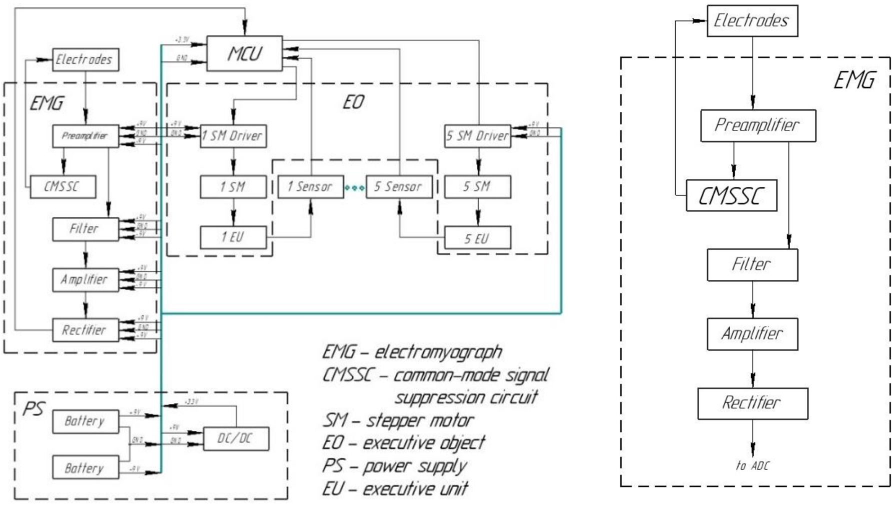

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Figure 1. Structural scheme of the prototype of the prosthesis (a) and the device registration and processing of the EMG signal (b).

The frequency range of the measured EMG signals will be approximately 10 – 1000 Hz [8]. In this case, both low-pass and high-pass filters of the 2nd order and a band-pass filter can be used as filters. The frequency characteristics of the filters of the 2nd order are undoubtedly higher [6], but this reduces the compactness of the device, in contrast to the use of a bandpass filter. The notch filter at 50 Hz, theoretically, can not be used, since at this frequency can be a useful signal, and the guidance of the supply network is previously eliminated described above common-mode signal suppression circuit.

The amplification scheme will amplify the signal to a value corresponding to the voltage limit in the ADC of the microcontroller and for further correct conversion into digital code and software processing. The rectifier circuit is necessary for converting a bipolar signal into a monopolar one, since the ADC of the microcontroller is able to digitize only a positive monopolar signal. It is also possible to use the rectifier circuit as an amplifier, using a circuit of a two-half-wave rectifier with summation of currents. Schematic diagram of the device registration and signal processing is shown in Figure 2. Figure 3 shows the PCB of the EMG signal registration and processing device.

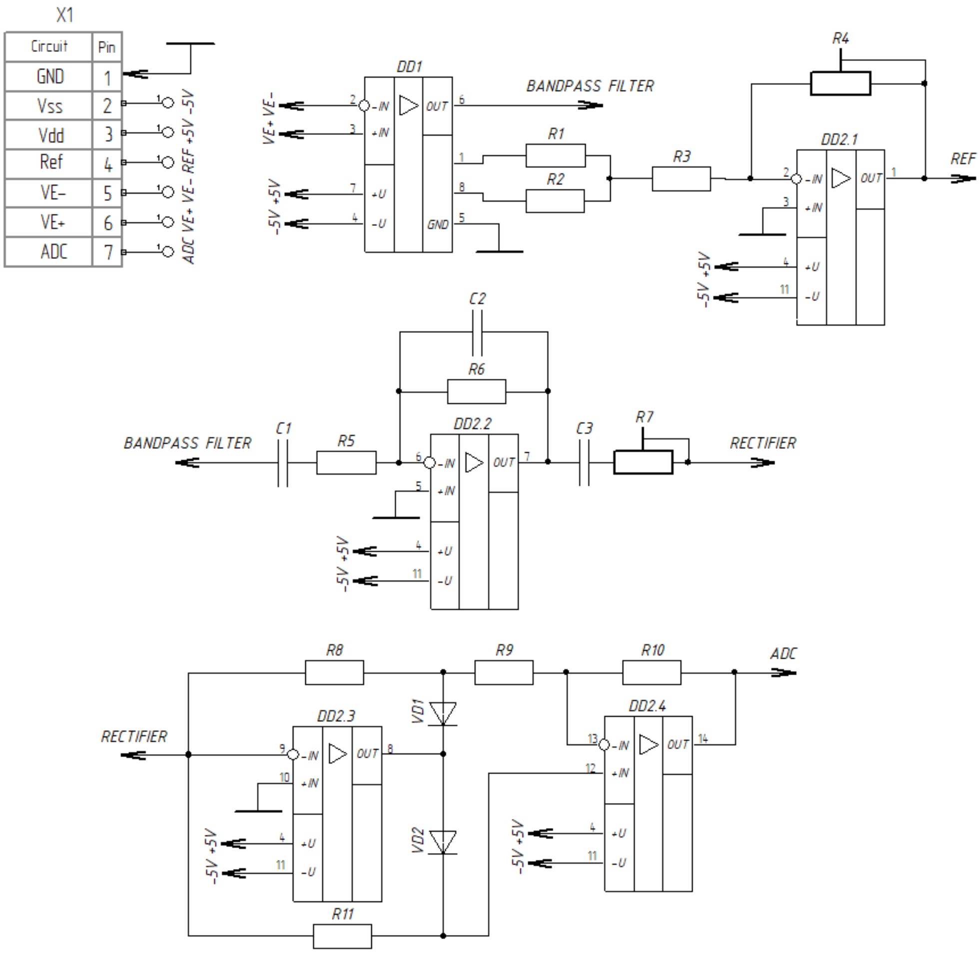

Figure 2. Schematic diagram of EMG signal recording and processing device.

After carrying out all the necessary calculations and tracing of the PCB, a model of the EMG signal registration and processing device presented in Figure 4 was made. To conduct experiments on the study of the activity of the flexor muscles of the fingers and extensor muscles of the fingers, 2 copies of the devices were made. This is necessary for simultaneous observation and recording of flexor and extensor muscle activity.

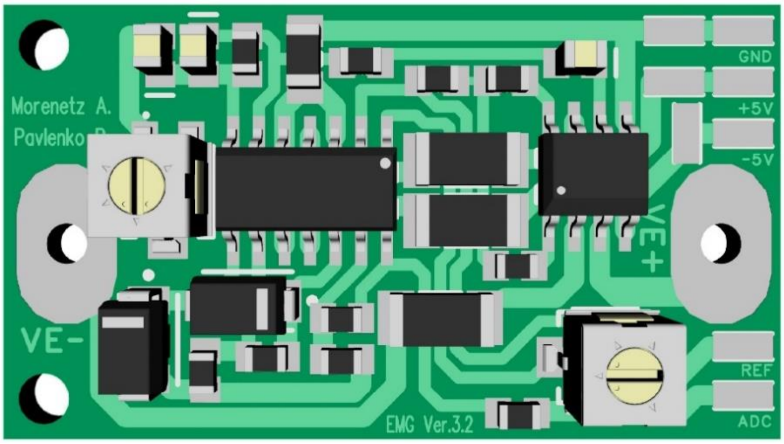

Figure 3. PCB of EMG signal registration and processing device.

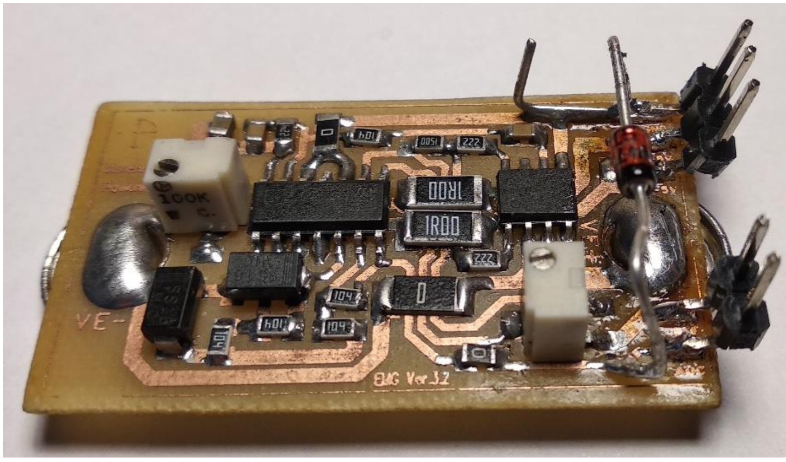

Figure 4. Produced PCB of EMG signal registration and processing device.

3. Experimental result

As a result of tests of devices of registration and processing of an EMG signal the following oscillograms testifying to their suitability for further use in a bionic prosthesis of a hand (Figures 5-6) were received. Upper ($U_1(t)$) waveform – EMG signal from the forearm extensor muscles, lower ($U_2(t)$) – from the flexor muscles.

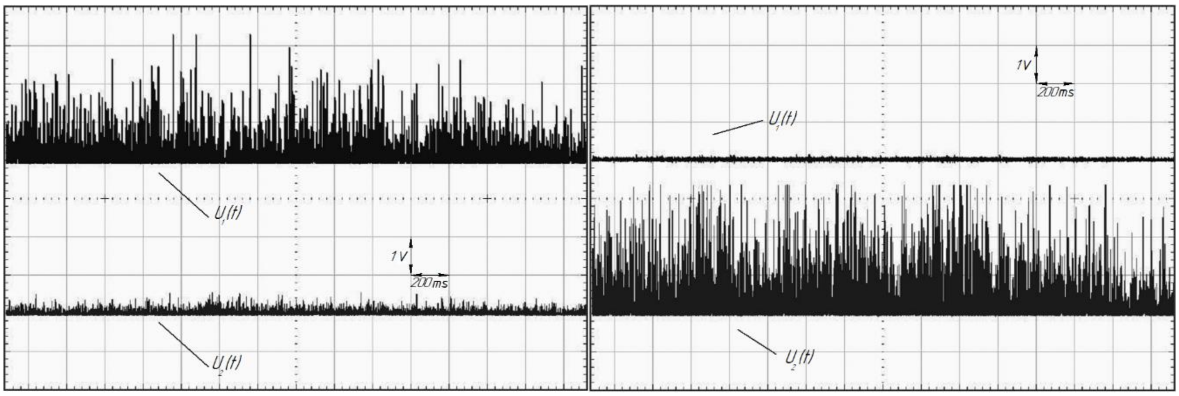

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Figure 5. Oscillograms of activity of extensor muscles (a) and flexor muscles (b) of fingers.

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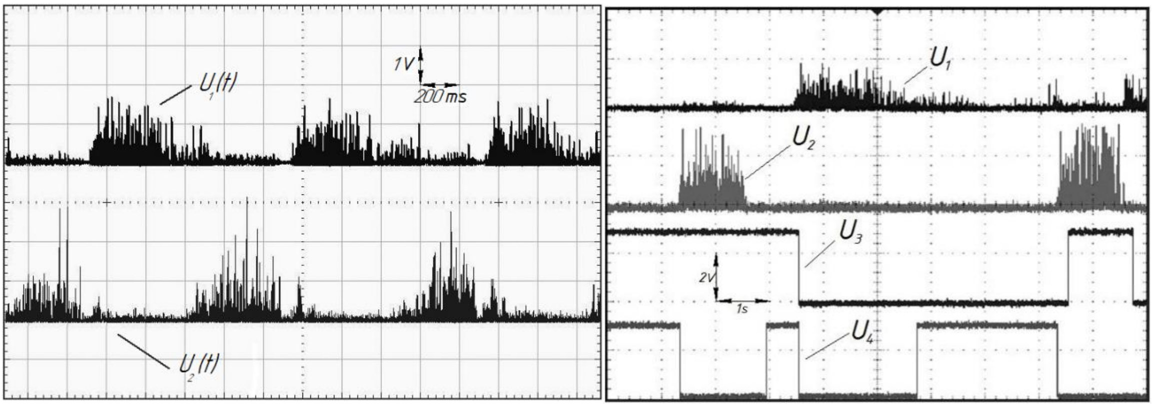

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Figure 6. Oscillograms of activity of flexor and extensor muscles of the hand (a) and control pulses of the microcontroller (b).

From the oscillograms in Figure 6a it can be seen that there is practically no influence of some muscles on others, which will differentiate the types of movements of the prosthesis, such as compression and unclenching of fingers, the choice of gestures. This gives almost complete control over the prosthesis for its most comfortable use. It is important to note that a great influence on the quality of the signals have factors such as: the presence of hair on the study area of the skin; the presence of fat layer on the study area of the skin; the right choice of the study area of muscle. Depending on these nuances, the signal may be completely unusable, which obliges to comply with all the necessary stages of preparation for the registration of EMG signals.

Figure 6b shows the oscillograms of the control pulses. Diagram U_3 defines the direction of movement of the finger (compression or unclenching), U_4 – allows the engine to operate in the presence of EMG signal and prohibits in the absence of EMG signal (0 – allows, 1 – prohibits).

Figures 7-8 show the work of the prosthesis in the compression of the brush. At this stage of development, one gesture is presented – compression and unclenching.

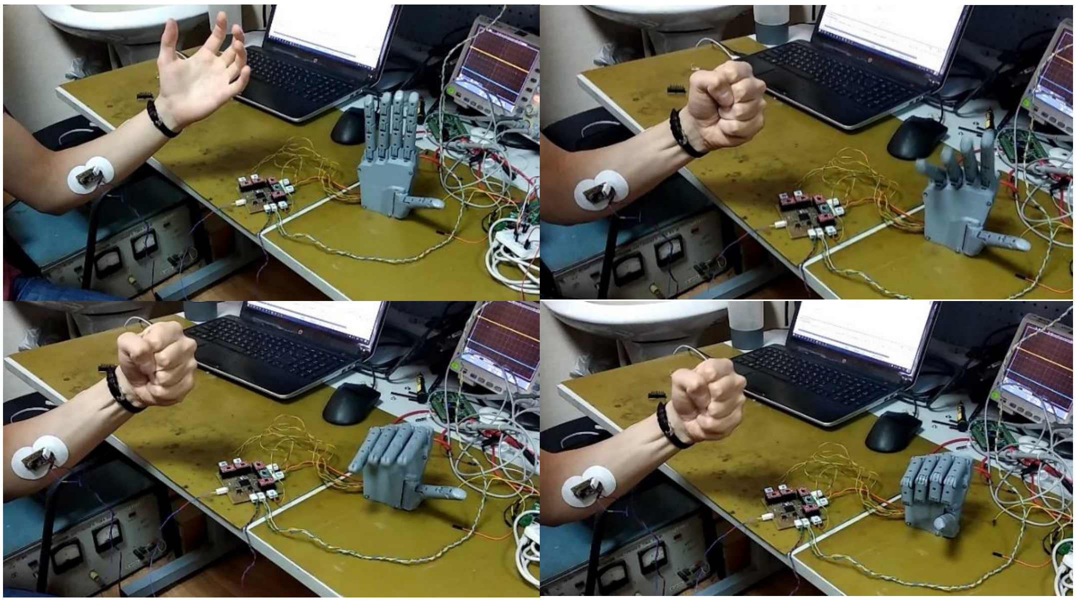

Figure 7. Storyboard of the process of compression of the prosthesis.

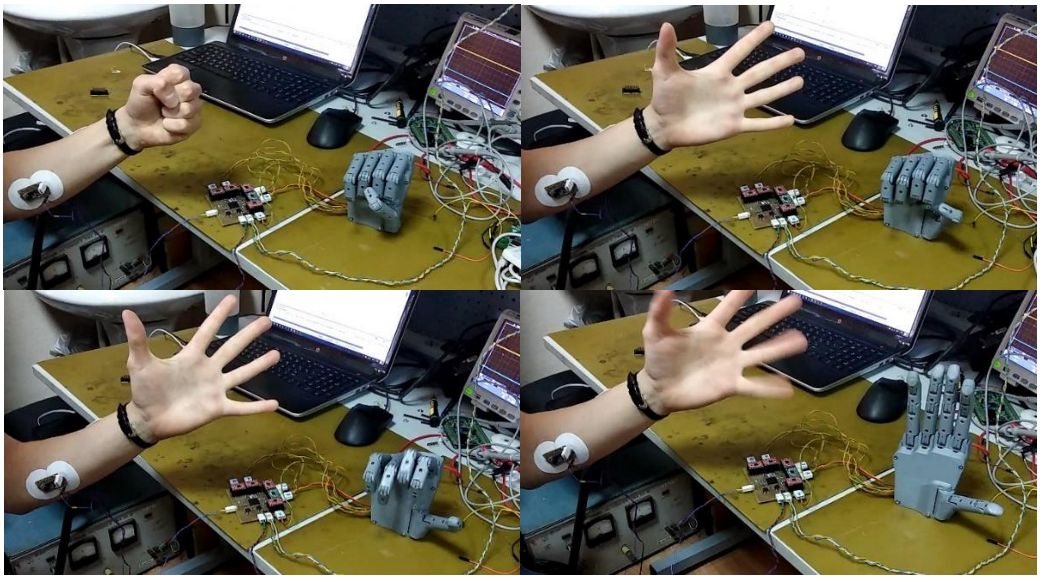

Figure 8. Storyboard of the process of unclenching of the prosthesis.

It can be seen that when registering the activity of flexor muscles, the prosthesis performs compression, and when registering the activity of extensor muscles – unclenching. In the absence of muscle activity, stepper motors do not move, which can be observed on the U_3 waveform shown in Figure 6b. Step motors are triggered when a certain level of EMG signal is reached on the ADC. The value of this level is set programmatically.

4. Conclusion

As a result of the work done, an EMG signal recording and processing device was developed, produced and tested. The obtained EMG signals are used in the control system of the model of bionic prosthetic hand. Further digital processing of the received EMG signals will allow to adjust the speed of stepper motors depending on the signal level.

Next, it is planned to increase the number of sensitive electrodes for a more detailed study of muscle activity. This will make it possible to develop a better control system for the bionic prosthesis of the hand.

Also in the future it is advisable to abandon the use of AgCl electrodes in favor of capacitive [9]. This is due to a number of advantages of capacitive electrodes over AgCl electrodes, in particular, the absence of the need to use NaCl and prepare the skin surface for the registration of myographic biopotential [10].

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