Experimental Study of EMG 8-electrode Active Circuit Placement on Forearm for Gesture Detection

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Abstract - This paper presents the results of experimental studies of developed active digital electrodes for surface electromyogram. Two layouts of 8 electrodes on the forearms of the test subjects have been investigated. Factors affecting the quality of the gesture recognition system by electromyogram have been considered. It has been demonstrated that the ring layout of electrodes around the forearm can be used in the manufacture of universal prosthetic sockets of upper-limb prostheses and makes it possible to achieve high accuracy of gesture detection. Recommendations on the use of specific motor gestures (up to 8 pcs.) to control different operation modes of the bionic prosthesis have been provided. The developed three-pin active electrodes operate according to the bipolar circuit and make it possible to use them without the necessity of the skin cover pre-treatment.

Keywords — *electromyogram (EMG), pattern recognition, bionic hand control, electromyography, biosignal amplifier.*

I. INTRODUCTION

A. Introduction to the problem

Millions of people in the world (~9.2 million people) suffer from loss of upper limbs, resulting in loss of labour capacity, job loss, and, as a consequence, a significant decline in quality of life.

Causes of the upper limbs loss are:

1) (~57%) Traumatic and non-traumatic amputations;

2) (~39%) Acquired diseases (myodystrophy, contractures, limb paralysis after stroke);

3) (~4%) Congenital diseases (Duchenne muscular dystrophy, various forms of Amelia).

Effective solutions for prosthetics of upper limbs are electromechanical robotic (bionic) prostheses, which copy the kinematics and motor skills of a healthy person hand when each finger can move separately, allowing the grasping of differently shaped objects.

The world practice uses the control of complex associated movements such as a pattern or gesture, with the help of a limited number of control channels.

For example, a bionic hand with 5 (five) fingers and independent electric actuators is put in motion by only one command (squeeze/unclench). In these conditions, the trajectories of the individual fingers are pre-determined through specific movement patterns. In this case, the subject to control is the behaviour of the fingers over time during the execution of the selected pattern.

The input signal for controlling the prosthesis through the electromyogram processing system can represent the following options:

1) A discrete command (1 or 0 – on/off) generated by the recognition system based on the simple comparison of the EMG amplitude value and a given threshold level;

2) A proportional command represents the result of complex electromyogram processing for detecting muscular compressive effort.

B. The problem significance study

Electromyogram (EMG) signal analysis studies [1-6] typically use (a couple per registration channel) either disposable contact electrodes or reusable electrodes with the application of conductive gels that provide low skin contact impedance. Some papers such as [7] for multi-channel electromyography use an approach of distributed single electrodes installed on the test subject's forearm, and the signal in each channel is measured relative to the common electrode. In this case, the distribution of electrodes on the forearm surface was selected by the authors based on the assumption that the installation of the electrode in front of large muscle groups should provide their significant contribution (weight) to the total level of the recorded signal. At the same time, the authors note that they did not have the purpose of selective signal recording from a particular muscle group.

The paper [8] presents an EMG signal gain circuit with 22 MOhm input impedance with three leads (two for differential signal measurement, and a common electrode). The electrode layout proposed by the authors is monopolar and differs from those traditionally used when the amplifier bonding pads are placed along one muscle under investigation (bipolar). The bonding pads of the two signal leads

were positioned on the central lines of the antagonistic muscles on the shoulder (one on the biceps, another on the triceps). Thus, the presented electrode layout makes it possible to implement power control of the executive element (for example, bionic prosthesis) through only one electrode, implementing two functions – closing and opening the palm.

The alternative option, according to paper [9] is to place the electrodes around the forearm in the form of ring bracelet, with the use of commercially available Otto Bock electrodes, which are widely used in prosthetics of the upper and lower limbs. It is noted that when applying EMG to the control of external devices in everyday life, the accuracy of gesture recognition depends on the mutual position of the electrodes, which requires a compulsory matching of the attaching points with those used during the training of the classifier.

As the result of the study of methods for the recognition of compressive forces based on the analysis of EMG signals from the forearm muscles published in paper [10], it was shown that the quality of the trained classifier is significantly affected by the displacement of the electrodes against the initial locations during reinvestigation, which, in particular, complicates the verification of the recognition algorithm by other research groups. The authors also note that in order to place the electrode on the muscle subjected to study, it is necessary to follow a simple rule: the electrode should be placed in the central area of the muscle fiber which is defined as the most protruding area of the muscle contraction. It can be easily checked by moving the electrode along the muscle during contraction (static muscular load) of the latter. However, it should be noted that when using EMG electrodes in prosthetics, their permanent position and orientation on the patient's residual limb is guaranteed by the stiffness of the prosthetic socket. Therefore, additional training of the classifier after the manufacture of the prosthetic socket, i.e., the manufacture of the personal prosthesis and its placement in the patient, is a standard procedure in the prosthetic treatment.

C. Related works

It was shown in papers [11], [12], [13], [14] that the force developed by the muscle fibers under the condition of the constancy of the displacement velocity is proportional to the integral of the recorded signal of electromyogram from the specified muscle group. Thus, when recording a bipolar EMG signal and estimating the value of the developed muscular effort, the following expression for the discrete signal can be used:

$$F_n = \sum_{i=1}^{n} |EMG_i| * dt \qquad \text{(1)}$$

$$dt = \frac{1}{F_{CLK}} \qquad \text{(2)}$$

where F_{CLK} is the sampling frequency of the analog-to-digital converter;

EMG_i is the signal value at the time $i * dt$.

Application of low-frequency filtration described in papers [15], [16], [17], [18] with a cut-off frequency in the range of 2-5 Hz, which can be implemented both under hardware control with the help of the active filter in the biopotential amplifier chain and software at the stage of digital post-processing, makes it possible to obtain a response proportional to the generated muscular effort.

The use of low-frequency filtration (as well as integration operations) of EMG signals inevitably leads to response delay. However, as noted in several studies [19], [20], muscle fiber is naturally characterized by delay (so-called electromechanical delay) between the passage of the signal through the nerve terminals and the actual beginning of muscle movement, in this regard, the value of the delay ranges from 30 ms to 150 ms. On the other hand, as is proven in paper [21], the electromechanical delay can be reduced by 4% when the muscle contractions are dynamically repeated. The electromechanical delay can be compensated by changing the VLF (low-frequency filter) order and frequency of the analog-to-digital signal conversion, thus providing real-time detection of muscular effort.

In papers [22], [23], the analysis of scientific and technical sources on the application of surface electromyography has been carried out, and two basic strategies of electrode placement were distinguished:

1) In the center (the most prominent part) of the muscle fiber;

2) Along the line between the signal innervation zone and the tendon.

In this case, pairs of bonding pads of electrodes should be oriented along the muscle fiber.

The effectiveness of the surface electromyography technology, as well as for use in the function of the system for generation of commands for controlling the bionic prosthesis, is dependent on several factors that affect the quality of the recorded signal:

1) Electrode orientation position relative to muscle fiber;

2) Monopolar or bipolar signal measurement;

3) Superposition of signals from several close muscle groups during registration with the help of the surface electromyography;

4) Effect of interference from 220V/50Hz public networks;

5) Electrode to skin contact resistance which has a significant impact on both the sensitivity of the amplifier circuit and the efficiency of common-mode interference suppression, which is significantly reduced under conditions of imbalance of input resistance of both contacts;

6) Signal waveform which can be initial bipolar (with the obvious zero level) or rectified unipolar

(zero level is difficult to determine because of its deviation).

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II. METHODS

A. Investigational plan

The following gestures were used when developing and debugging the recognition algorithm of muscle activity signals:

1) Wrist opening/closing;
2) Wrist left/right rotation (pronation/supination);
3) Wrist bend up/down;
4) Wrist left/right displacement.

Selection of gestures is determined by the fact that they involve the largest groups of forearm muscles, the signals from which can be effectively distinguished with the help of surface electromyography. In order to localize a separate group of muscles of the test subject participating in the gesture execution, the examination by touch was performed to find the most excited muscle fibers

simultaneously with visual control of the EMG signal presence.

For the research of the effectiveness of two electrode layouts, the following experiments were conducted:

1) A workstation (notebook) powered by the built-in battery was used to isolate the sensitive analog cascades of the biopotential registration modules from the electrical power network (50 Hz) interference;

2) The enhancement ratio of the biopotential registration modules was equal to 2220x.

3) To reduce the resistance of the electrode to skin contact, additional humidification of the skin cover of the subject's forearm was performed;

4) The magnitude of muscle contraction during the experiments varies from the minimum value, resulting in the movement of the respective joints without load, to the maximum tonus.

5) Gestures used include wrist opening/closing, wrist left/right rotation (pronation/supination), wrist up/down bend, wrist left/right deflection;

6) The research is conducted on the right hand;

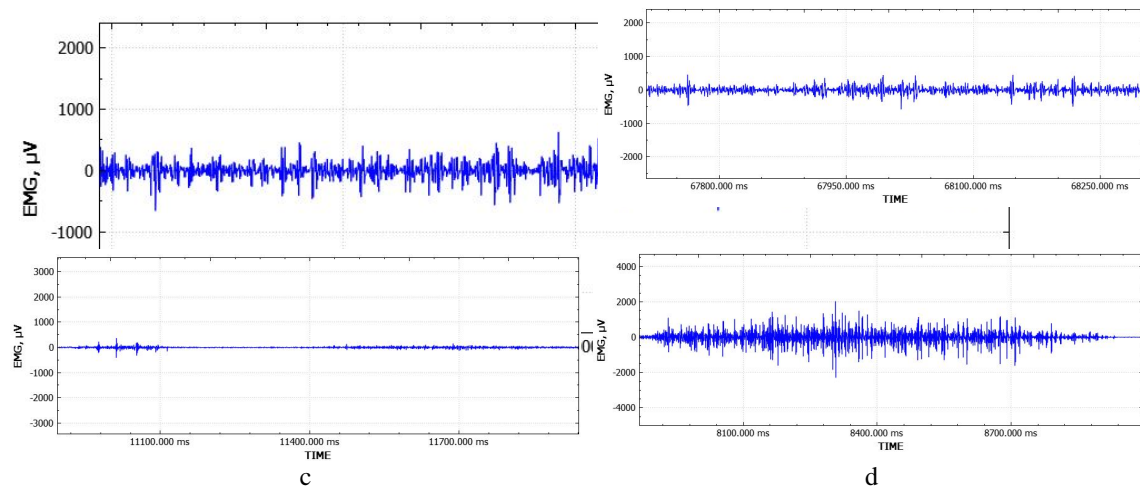7) Number of test subjects is 3 persons;

Fig. 1: (a) zone of signal innervation, (b) displacement of the electrode relative to the muscle midline, (c) tendon attachment site, (d) optimal position (muscle midline)
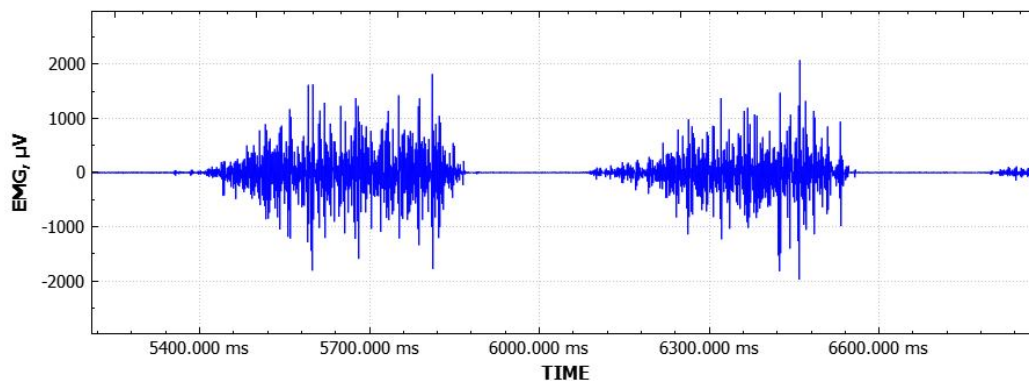

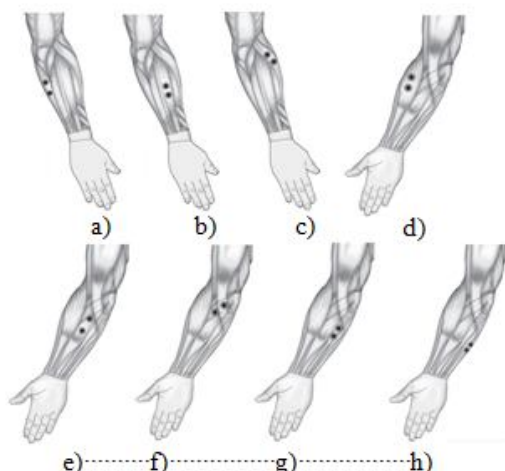Fig. 2: Example of the recorded EMG signal

Fig. 3: Potential layout of EMG electrodes on a healthy person's hand (Layout "A")

8) Number of repetitions of each gesture is 50 ones;
9) The duration of muscle excitation when performing a single gesture is at least 0.5 sec;
10) The duration of the cell dormancy between separate iterations of gesture execution is at least 2 sec.

In the course of preliminary examination of electrode locations, visual inspection of the EMG signal time schedule was carried out in order to reveal a pattern in the signal's waveform characteristic for different positions of bonding pads of the biopotential registration module relative to the muscle group under study. Four characteristic positions of the separate muscle have been confirmed:

a) The zone of signal innervation;
b) Displacement of the electrode relative to the muscle midline;
c) The tendon attachment site;
d) The optimal position (muscle midline).

III. RESULTS

In order to determine the possibility of detecting electrical activity signals typical for different motor activity patterns, examinations of the subjects' forearms have been carried out using the method of examination by touch for precise localization of separate muscle groups according to the diagram in Figure 3.

Then experiments have been performed with the purpose of determining the presence of EMG signals in each of the electrodes ("a"-"h") when implementing different patterns of motor activity. In this case, an extended set of gestures, including independent movements of the separate fingers, has been used (Table 1).

TABLE I.
SUMMARY TABLE OF ELECTRODE POSITIONS AND DETECTABLE GESTURES

No.	Electrode layout / Gesture	"a"	"b"	"c"	"d"	"e"	"f"	"g"	"h"
1	Wrist opening	+	-	-	-	-	-	-	-
2	Wrist closing	-	-	-	-	-	-	+	-
3	Wrist left rotation (pronation)	-	-	-	-	-	+	-	-
4	Wrist right rotation (supination)	-	-	-	-	+	-	-	-
5	Wrist bend up	+	+	+	+	-	+	-	-
6	Wrist bend down	-	-	-	-	+	-	+	-
7	Wrist left displacement	+	-	-	-	-	-	-	+
8	Wrist right displacement	-	-	-	+	-	-	-	-
9	Separating fingers	+	-	+	-	-	-	-	-
10	Pinch close	-	-	-	-	-	-	-	-
11	Index finger bend	-	-	-	-	-	-	-	-
12	Index finger extension	+	-	-	-	-	-	-	-
13	Long finger bend	-	-	-	-	-	-	-	-
14	Long finger extension	+	+	+	-	-	-	-	-
15	Ring finger bend	-	-	-	-	-	-	+	+
16	Ring finger extension	+	+	-	-	-	-	-	-
17	Little finger bend	-	-	-	-	-	-	+	-
18	Little finger extension	+	-	-	-	-	-	-	-

As can be seen from Table 1, at certain positions of the electrodes there is a superposition of signals (presence of response during movement) from different muscle groups due to their close location. In the course of the experiment, it was found out that in order to provide signal recording for recognition of 4 gestures at least 4 electrodes located according to the layouts "a", "b", "e" and "g" are needed.

It was followed by research into the accuracy of gesture recognition for two electrode layouts. During the research, the layout pointed out in Figure 3 (Layout "A", electrode positions "a"-"h") was accepted in the function of the reference electrode distribution as optimal, according to paper [24] in line with the anatomical organization of the human body.

However, during the manufacturing of prosthetic sockets in the process of prosthetic positioning in the patient's residual limb, the relevant objective is to reduce the labor required for the examination of the residual limb and the search for electrode placement. One of the options for the solution is the distribution of a set of electrodes (up to eight pieces) in the form

of the ring around the forearm (Layout "B"). It is obvious that in case of uniform distribution around the forearm, some electrodes may be at some offset from the optimal position (the midline of the muscle) which, according to the conducted studies, affects (reduces) the amplitude of the recorded signal.

Let us present the research results in the form of radar charts (see Figure 4 and Figure 5).

The experiments also revealed a simplified algorithm (Table 2) sufficient to identify a limited number of gestures. In this case, the value of logical "1" is taken according to the individual threshold for each of the electrode sets ("a"-"h").
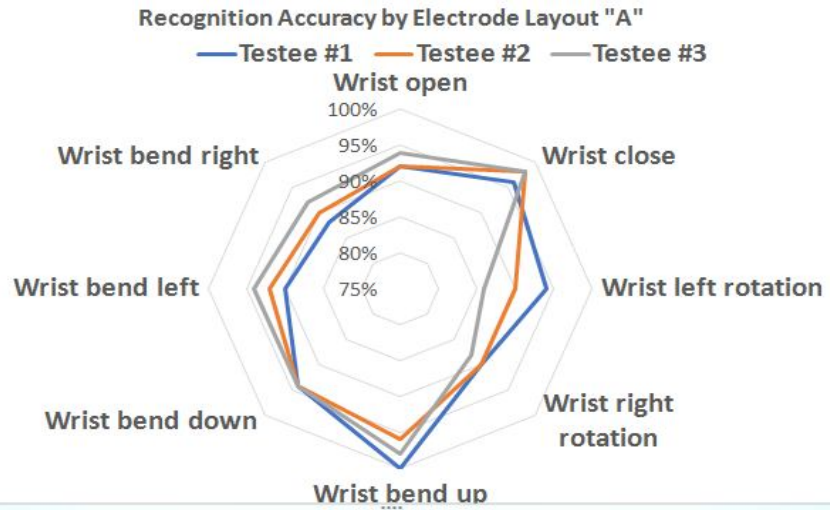

Fig. 4: Radar chart of the research results according to electrode Layout "A"
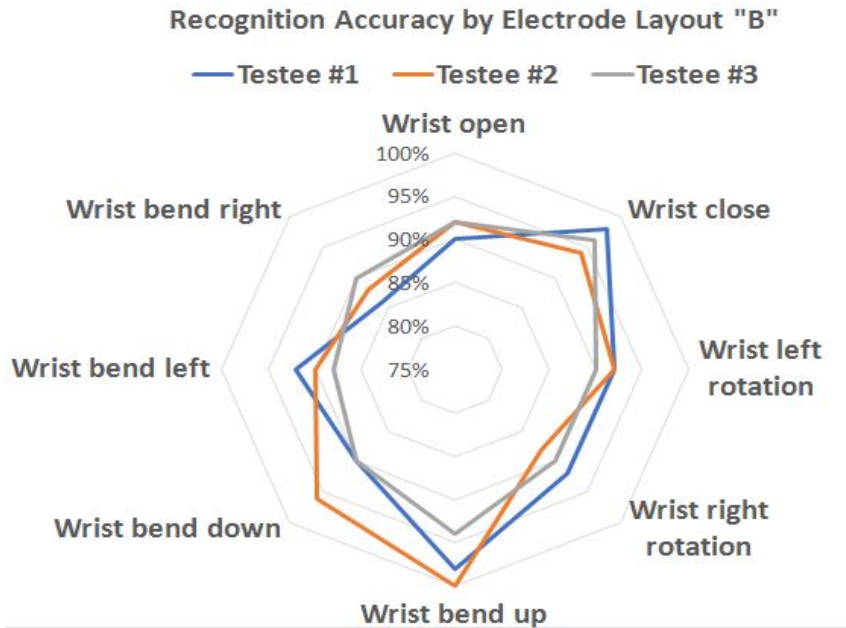

Fig. 5: Radar chart of the research results according to electrode Layout "B"

TABLE II.
SIMPLIFIED ALGORITHM FOR DETECTING GESTURES

Logical operation	Gesture
A & (!B) & (!C) & (!D) & (!T) & (!F) & (!G) & (!H)	Wrist opening
G & (!A) & (!B) & (!C) & (!D) & (!E) & (!F) & (!H)	Wrist closing
F & (!A) & (!B) & (!C) & (!D) & (!E) & (!G) & (!H)	Wrist left rotation (pronation)
E & (!A) & (!B) & (!C) & (!D) & (!F) & (!G) & (!H)	Wrist right rotation (supination)
A & B & C & D & F & (!E) & (!G) & (!H)	Wrist bend up
E & G & (!A) & (!B) & (!C) & (!D) & (!F) & (!H)	Wrist bend down
A & H & (!B) & (!C) & (!D) & (!T) & (!F) & (!G)	Wrist left displacement

IV. DISCUSSION

Experimental studies with the participation of 3 testees have demonstrated identical (with a decrease in accuracy of less than 5%) detection accuracy of 8 gestures.

As can be seen from the results obtained with the use of the ring layout (Layout B), the confirmation has been obtained that gesture recognition accuracy has decreased by 3% on average. Consequently, Layout B can be effectively used when manufacturing the prosthetic socket of the prosthesis. As a result of the experiments, mnemonic aids have been revealed, which make it possible to implement a simple algorithm of gesture detection through the simultaneous analysis of the amplitudes of friendly signals in 8 channels.

V. CONCLUSIONS

As the result of the experiment, it has been found that the highest probability of detecting a gesture (more than 95%) corresponds to three gestures – "Wrist closing", "Wrist bend down" and "Wrist bend up" resulting from the volume of muscle fibers that lead to these movements.

It is reasonable to use these gestures during the prosthetics of the patient to generate commands for controlling the bionic prosthesis, which requires precise and fast response. These gestures are:

1) Closing the fingers of the bionic prosthesis;
2) Opening the fingers of the bionic prosthesis;
3) Wrist rotation module control.

Gestures with lower detection accuracy such as "Wrist left displacement", "Wrist right displacement" and "Wrist opening" are reasonable to use when generating control commands for operating modes of bionic forearm prosthesis:

1) Switching the active grasping (compression) pattern of the prosthesis;
2) Switching between the modes of motion control – proportional control of the grasp force and proportional control of the grasp speed.

As the result of the conducted experiments, it has been demonstrated that the ring layout of electrodes around the forearm can be used in the manufacture of universal prosthetic sockets of upper-limb prostheses and makes it possible to achieve high accuracy of gesture detection.

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