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Isometric Hand Grab Stand for Neuromuscular Activity Research Providing

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The paper presents the results of experiments of the relationship between the change in electrical impedance and the force of brush compression determination. Within the framework of the research, an isometric compression stand was developed, which allows recording the brush compression parameters. On the developed stand, experiments were carried out, during which the simultaneous registration of the impedance signal from the muscles of the forearm and the compression force of the stand was carried out. The relationship between the impedance change and the action force was determined. The use of this dependence in the development of bio-controlled devices will allow to control it more accurately.

Keywords: bioelectrical active devices, isometric hand grasping, neuromuscular activity, impedance, stand.

INTRODUCTION

Full or partial functional loss of upper limb due to amputation or some diseases has a great influence on human ability to do routine tasks. Active prosthesis and orthosis helps a disabled person to get back after losing the function of a limb. However, nowadays the usage of such devices is limited due to the complexity of its control.

The most modern active bioelectrical devices are controlled by signals of surface electromyogram. However, the disadvantage is the complexity of the interpretation, caused by the interference nature and the influence of signals from neighboring muscles. Therefore, it is impossible to determine the type of movement without increasing numbers of electrode systems [1].

For detection and quantifying muscle health a noninvasive electrical impedance myography (EIM) technique is generally used. It is based on sending high frequency current with low amplitude passing through the muscle area and measuring the consequent voltage [2]. Most previous EIM studies include the consideration of the stationary state of relaxed muscles without their contraction. Due to the study of the muscles anisotropy using the EIM method it is possible to determine muscle disuse or atrophy [3–6].

Some EIM studies have investigated that the muscle contraction leads to impedance signal changing [1, 7, 8]. It is well known that the architecture and fiber geometry of the muscle, the pennation angle and muscle thickness changes during contraction [9–12]. The change of such parameters as thickness of a skin-fat layer, cross section of muscles, conductivities and pressing force of the electrode system lead to an impedance value change during various actions performance. Moreover, it was shown that it is possible to determine the type of movement in case of the electrical impedance measurement from forearm antagonistic muscles [13]. Therefore, such signal can be used for management tasks as an alternative for electromyogram signal or these signals can be registered jointly [14].

Almost all EIM studies connected with the impedance change after muscle contraction were performed for the biceps muscle [8, 15, 16]. In a smaller number of studies, forearm muscles were explored during various actions performing [7, 17]. For the tasks of developing a control system for robotic devices, it is necessary to use reusable small electrode systems that are located on a specific area of the forearm, rather than along the entire length, as was done in the studies.

In addition, in the studies, the dependence of action strength on the impedance change was not found. To identify the dependence between change of the impedance signals and action parameters it is necessary to design the special stand for measuring the mechanical conditions of the movement and electrical impedance simultaneously [18]. Grasp is the most common type of the hand movement. Based on the data of Federal Scientific Center of Rehabilitation of the Disabled named after G.A. Albrecht it was found that the most demanded grasps described in literature are end grasp (in a pinch) and palm grasp (opened) (Fig. 1). Such grasps are used in the same movements to hold different objects (isometric type of movement). Therefore, it is necessary to design the special stand for such movements.

The aim of this study is to develop the isometric hand grasp force measuring stand and to conduct the investigation for searching the dependence between the electrical impedance signal and the hand grasp force. These results will be used in development of further bioelectric active electromyogram control systems analogues.

MATERIALS AND METHODS

Isometric hand grasping force measuring stand construction

The special stand was designed to register the force of isometric compression (Fig. 1), Mechanical scope of the stand consists of several units: handles, force sensors, pieces, guideways with linear friction bearings and guideway locks.

Force sensors located in handles register the isometric grasping force. Handle dimensions were chosen according to the average human's hand to place it in the hand conveniently. Force sensors and guideway locks are bolted immovably with the low handle. Linear friction bearings for guideways are bolted immovably with the upper handle. Such construction provides free movement of the upper handle along the guideway relative to the low handle. Therefore, it allows to regulate the stand width for different grasping degrees.

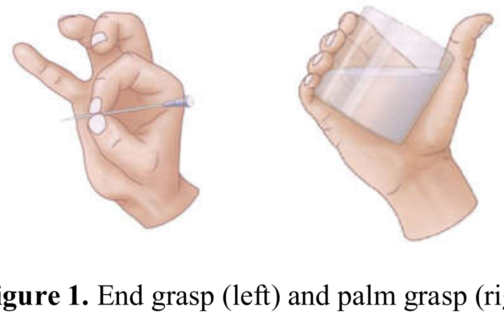

Figure 1. End grasp (left) and palm grasp (right)

Adjustment of the width of the stand is carried out by installing pieces of different thicknesses bolted immovably with upper handle, which press on the force sensors. The use of 4 guides allows to minimize the skewing of the stand due to the non-center effect across the stand. The use of 2 force sensors, which are arranged in parallel and opposite direction, allows to record the distribution of force along the stand.

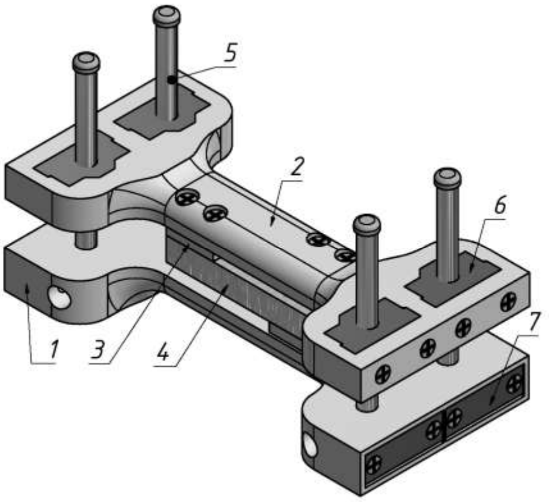

Figure 2. Isometric hand grasping force measuring stand: *1* – low handle, *2* – upper handle, *3* – piece, *4* – force sensor, *5* – guideway, *6* – linear friction bearing, *7* – guideway lock

Stand working principle is based on the transformation of the force created by hand isometric hand grasping into voltage by force sensors based on the tensoresistors arranged according to the Winston bridge scheme. Each sensor carries a load less than 20 kg. Therefore, it allows to register the grasping force up to 40 (daN) [19], which corresponds the maximal human's force (error up to 1 N).

Force sensors are connected with the stand registration unit, which is used for registration, processing and transmission signals from sensors to the Personal Computer (PC). Signal is registered by 24-bit sigma-delta Analog-to-digital converter (ADC) with differential analog inputs AD7799 from Analog Devices designed for force sensing applications. Such an integrated circuit is based on a high-precision instrumental amplifier with user-defined gain. Data are transmitted to the connected Microcontroller Unit (MCU) via Serial Peripheral Interface (SPI) interface. MCU processes registered data and transmits it to the PC via Universal Serial Bus (USB) interface.

It is necessary to perform calibration before using the stand. Force sensors were calibrated by installing laboratory weights of 100 g to 10 kg to the center of the stand handle. The common force was calculated as an average of signals from two force sensors.

Experiment

Figure 3. Location of the electrode system

Experiments with recording the electrical impedance for various isometric grasping forces were carried out on volunteers using a developed stand. Four volunteers participated in the experiments, with an average forearm arm circumference of 29 cm at the location of the electrode systems.

One electrode system was used, which was located in the area along the extensores carpi radialis muscles of the wrist, in place, which can be used to position the electrode systems in modern bioelectric forearms of the forearm (Fig. 3). Before the installation of the electrode system, the place was scrubbed and smeared with an electrode contact gel.

The electrical impedance was registered by the rheographic system "ReoKardioMonitor". To measure the electrical impedance directly from the forearm

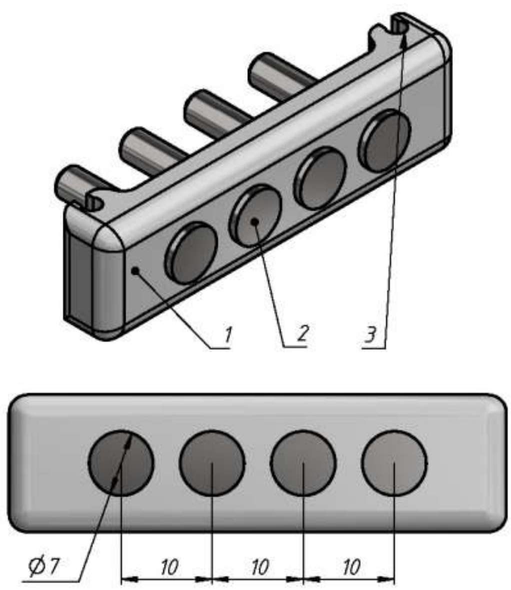

Figure 4. Electrode system: *1* – electrodes platform, *2* – electrode, *3* – the place of the rubber band attachment for fixation. Pairs of electrodes located closer to the periphery - current, closer to the center - measuring. Dimensions in millimeters

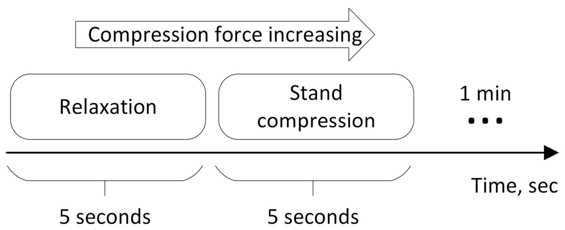

Figure 5. Scheme of experiments

region, special electrode systems have been developed (Fig. 4), including a platform and reusable electrodes in the form of rivets with a countersunk head made of stainless steel, 7 mm in diameter, arranged according to the tetrapolar lead system (two current electrodes along the edges and two measuring electrodes in the middle).

Electrode systems had the same distance between the electrodes, equal to 10 mm, and were fixed to the forearm by means of rubber bands. The registration of the isometric compression force was performed with the help of the developed stand simultaneously with the measurement of the electric impedance signal.

During the experiment, the brush was located in a neutral position (between pronation and supination). The time of each study from the series was 1 minute, during which the following actions were performed: 0–5 seconds – the volunteer does not compress the stand (state without load), 5–10 seconds - the volunteer isometrically compresses the stand (load condition) (Fig. 5). The compression force increased iteratively in the framework of one study.

An example of registered signals within the framework of one study depending on the different degrees of compression of the stand is shown in Fig. 6. On the graphs, midpoints of activity are marked in red, midpoints of the periods of the relaxed state – in yellow.

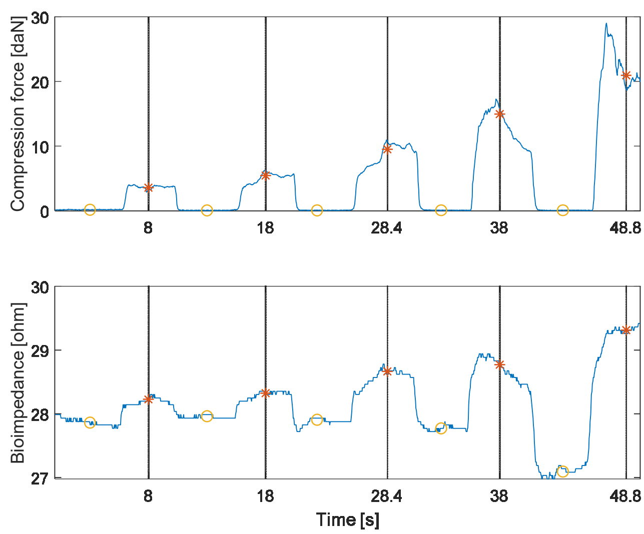

Figure 6. Example of registered signals within the framework of one study depending on different degrees of the stand compression

Results

With an iterative increase in the compression force of the stand during the experiment, an increase in the bioimpedance value was observed. For electric impedance signals, the drift of the isoline is specific, which is included in the shift of the base value of the signal over time and in the action performance, as shown in the graph (Fig. 6). Thus, for the subsequent analysis, the difference between the signal at the time of compression and the signal at the moment of relaxation was taken.

Based on the obtained data, a regression analysis was performed. For each volunteer regression curves with a confidence interval of 95 % were constructed. These curves for each volunteer is different and displaying them on one chart is not presentable. Therefore, the graph (Fig. 7) shows the regression curves for the considered case (Fig. 6).

As a result of the regression analysis and the least-interval method, it was found that the curve in the form of a second-order polynomial is more accurate for interpreting the experimental data.

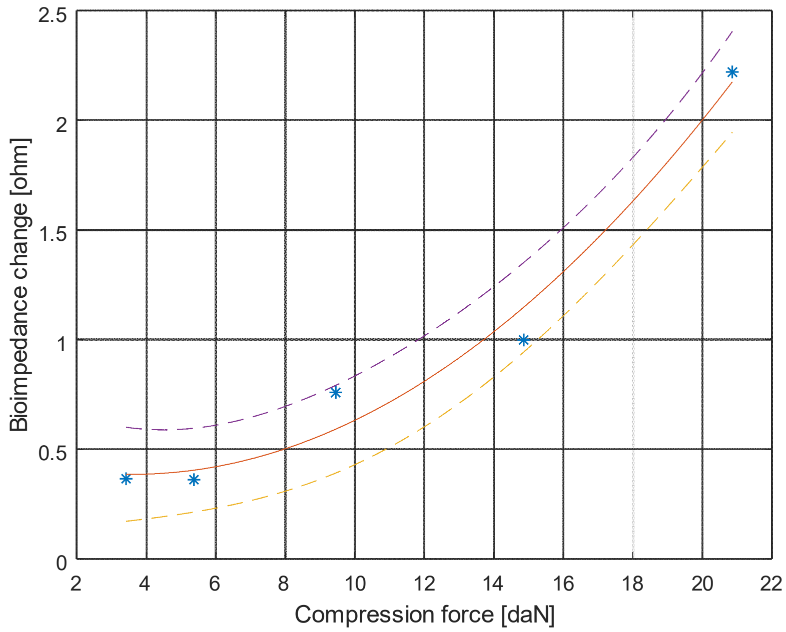

Figure 7. Regression curve with confidence intervals for the change in the electrical impedance dependence on isometric compression force

CONCLUSIONS

The need for bioelectric prosthesis according to the federal service of state statistics is increasing every year, and the development of control systems for robotic devices is becoming more urgent. One of the main tasks in this direction is to improve the quality of control, for which it is necessary not only to register a qualitative and stable signal, but also to know the optimal arrangement of the electrodes, their physical parameters, the contribution from the integration of the sensors when they are added, etc. To justify the requirements for the parameters of the above features, it is necessary to organize research, for which it may be necessary to develop special stands that allow establishing the relationship between the parameters of the recorded signal and the parameters of the performed actions.

To enable the realization of studies aimed at determining the relationship between the change in the electrical impedance and the force of the grasp action, an isometric contraction stand was developed. In the course of the research, it was possible to identify the relationship between the compression stand force by brush and the change in the electrical impedance, as a result of which it can be used to generate control signals for controlling robotic devices.

For each volunteer regression curves were different, but similar in form. It means, that in case of bioimpedance signal using as control signal it is necessary to provide a calibration of control system for the use by different operators in various physical conditions. To solve the problems of isoline drift the difference in signal during action with filtering slow signals changes could be used.

Thus, taking into account the change in the electric impedance signal during the performance of the action will allow not only to determine the type, when using several electrode systems, but also to supplement the electromyogram signal to determine the force with which it is performed.

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