

## Methods of Acquisition and Signal Processing for Myoelectric Control of Artificial Arms

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**Abstract.** Myoelectric control of intelligent artificial arms, serving to replace amputated arms with prostheses, involves a lot of issues that have to be solved for achieving good results. It starts from the detection of electrical activity of muscles on the stump, which though does not develop a useful muscular exertion it can be used to control at will some predefined motions of artificial hand. An essential problem to be solved in this approach is the acquisition of the most useful controlling biosignals for the prosthesis, but the more important issue is to extract the control information from the raw myosignals. This approach is even more difficult as the amputation is older and those muscles are greatly atrophied, leading to weaker signals acquisition and more difficult signal processing. In this paper we present a simple method to separate the useful signal from noise and its processing in order to get clear myoelectrical signals. This

method is first presented using the software tools of the electromyograph used and then it is applied distinctly for separate processing of the signal generated by an amputated arm and extracting useful information.

**Keywords:** EMG, Myoelectric signals, Signal acquisition, Artificial arms control, Intelligent prostheses, Signal processing.

## 1. Introduction

Controlling intelligent arm prosthesis by the patient intention, to realize actions similar to those of the biological hand, is the main goal of the artificial arms and hands prosthetics. This goal involves a lot of issues that have to be solved in order to achieve the appropriate results [1].

In order to detect the patient's intention and use the information achieved for controlling different elements of the prosthesis there are several ways, among which the most important are direct acquisition of motor nerve signals and acquisition of electrical signals produced by muscles during their contraction (myoelectric signals). These options require the use of electrodes that can be implanted, in the case of nerve signals, and intramuscular or on surface, in case of myoelectric signals. One of the most used methods for intelligent prosthesis control is based on surface myoelectric signals picked up from the remaining muscles of the amputated arm. For this reason, the resulted prostheses can be named myoelectric prostheses.

## 2. Methods of measuring muscle activity on the stump of the amputated arm

Myoelectric prostheses are based on measuring the myoelectric activity of muscles that remained on the stump after amputation.

Muscle activity on the stump, which otherwise would not be useful, can be used to control at will some predefined motions of the artificial hand. To measure the activity of the stump muscles two categories of myoelectrodes are used: noninvasive (applied on the patient's skin) and invasive or intramuscularly. The second category involves some surgery in certain situations and, although more efficient, they are not agreed by most patients. For these reasons the measurement of muscle activity is done in most cases, using myoelectrodes that are applied on the skin. In order to control artificial arms there are used at least two myoelectrodes for extensor carpi radialis longus, flexor carpi radialis and flexor carpi ulnaris muscles. Methodology to capture myoelectric signals involves taking into account of anatomical and physiological particularities of each patient. The simplest method involves acquisition, processing and storing signals from these myoelectrodes for the nine situations in which the muscles of the stump would try to move the wrist of the amputated arm in the eight directions (up, down, left, right, and on the four diagonals). With the acquisition, processing and saving of myoelectrical signals during the execution of these movements by

the patient there are acquired eight commands that the patient who has an amputated arm can use in order to utilize and control the artificial arm and so the patient can grab certain objects (using fingers of the artificial arm) and to move the artificial arm's forearm.

### 3. Block diagram of myoelectric prostheses

Myoelectric devices are recommended for those patients who are unable to use devices operated by body strength, or who need improvement of the technique of grabbing /gripping. A myoelectric device enables the patient to control the grabbing force of the prosthesis arm.

Unlike devices operated by body strength, the myoelectric device operates the prosthetic member by electrical control that provides much more precise movements. Small electrodes are placed in the prosthesis' cavity, being in permanent contact with the stump. Electrodes perceive electrical activity of muscles, called electromyographic signal (EMG). Amplified EMG signal stimulates the device's motor to perform a function (movement). Myoelectric devices operate on rechargeable batteries and do not require cables or external equipment.

Myoelectric prosthesis does not require large, bulky body movements or additional space for effecting movement; it can operate in any position allowing muscle contraction and extension. The newest control systems incorporate programmable microprocessors that provide a wide range of adjustments, perform multiple functions and sequential operation of the movement of the elbow, wrist and hand.

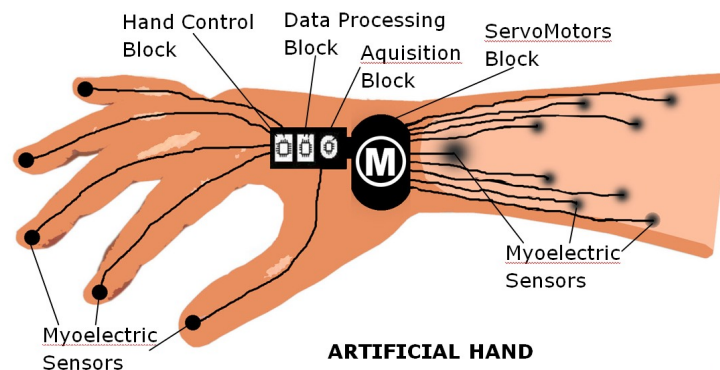


Fig. 1. Functional diagram of the artificial hand with myoelectric command.

### 4. The myoelectrods matrix

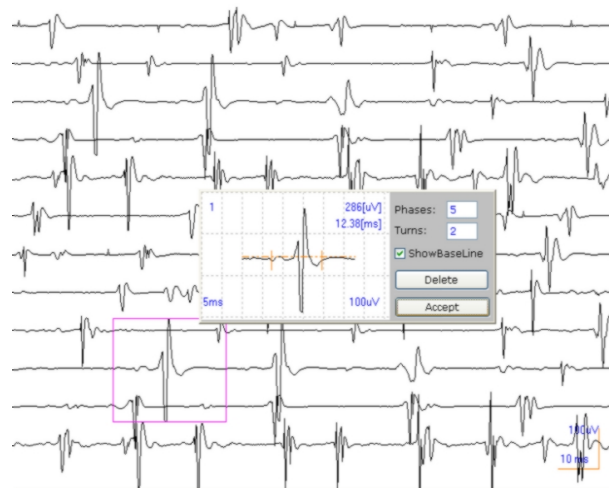
Myoelectrods are placed on the skin above the muscle to the proximal and distal end of the muscle, at 4–5 cm distance from each other to detect and capture bioelectrical signals arising in muscle when it contracts, bioelectrical signals that usually have the amplitude of  $10 \mu\text{V}$ .

The artificial hand control system take over the signals from electrodes connected in non-invasive manner in the patient's stump. To capture myoelectric signals from the stump it is used an array of electrodes placed directly on the skin surface of the stump of the amputated arm. This way of using an array of myoelectrods increases the degree of adaptation of the artificial hand to the patient specificities with relatively low costs. In the case of myoelectric prostheses, signals received by its controlling level from myoelectrods are processed and then used to drive the motor elements of the prosthesis for the patient to perform a limited and predefined number of movements. Maximum number of myoelectrods that can be placed is limited by the surface of the stump. The characteristics of signals taken by myoelectrods from the stump determine that the number of myoelectrods located on the stump to be essential.

The larger the number of sensors used, the higher the performance of the control system and prosthesis movements' resolution (dictated by the control system). The command and control unit takes, via transducers, signals from the myoelectrods and pressure sensors from the artificial hand phalanges:

- **myoelectrods** – located in the stump they detect electrical potential existing at its surface;
- **pressure sensors** – detect certain types of interactions that can occur while using the prosthesis between prosthesis and artificial objects manipulated by artificial hand.

Sensors located on the human body are placed on the contact area between the prosthesis and the human body. Myoelectrods detect the electrical potential in a large number of spots on the skin surface of the stump. Potentials values collected via myoelectrods reflect in some form the command intentions of the patient to the prosthesis. Changing of the potentials values is given by muscles acting. Each muscle acting cause a specific electrical potential that is taken by a certain area of myoelectrods matrix.



**Fig. 2.** Acquisition and evaluation of myoelectric signals.

After determining the optimal location of the myoelectrodes on the stump, the prosthesis adjustment will be done as follows:

- shall be set the extreme positions of the prosthesis according to its design. It will be selected a set of x positions for the prosthesis corresponding to the movement of a single actuator in maximum position;
- shall be determined the set of potentials values of myosensors on the patient's stump.

For each chosen position the patient is asked to “imagine” that movement as he wouldn't have an amputated member then the array values for adaptation is read. For each sensor in the array of sensors a specific index is determined which will be saved together with other data in the matrix.

## 5. Characteristics of myoelectrodes used in artificial hands command

The myoelectrodes used in artificial hands command can be:

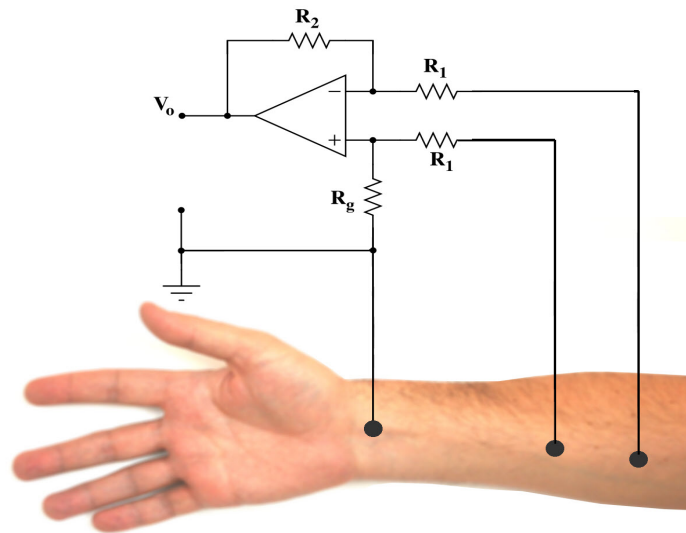
- of surface – has the advantage that they are noninvasive;
- passive or floating – the electrolyte gel is the only adjuvant used in signal acquisition, there is no amplification;
- active – are in direct contact with skin and incorporates pre-amplification of signal, the signal is raised at the skin surface by a factor of 10 or greater;
- intramuscular – which can measure potentials in depth and can be of two types:
  - Syringe needle type;
  - Wire type (bipolar) – two wires implanted in the muscle.

Myoelectrodes capture the electric potential in the muscles and convert it into electric signals. They are made of conductive materials, which can range from precious metals (gold, silver) to stainless steel. For the ones on the surface, the skin is wiped before applying and an electrolyte gel is applied. For intramuscular electrodes the electrolyte is the very fluid tissue. Myoelectrodes surface is frequently covered with Ag-AgCl and the electrolyte gel contains NaCl or KCl to form a very stable electrochemical combination. There are also exceptions when this combination may become unstable: sweating may change gel composition and excessive muscle heat could affect gel temperature and its electrochemical behavior may change. When the metal comes into contact with the electrolyte there are two phenomena that govern the signal recording by electrodes:

- metal attracts positive or negative ions (depending on the electrochemistry of the two) from the electrolyte, at the electrode surface. Complementary ions are grouped a little farther from the electrode towards the electrolyte so that between the two groups there is a small neutral space;

- metal tends to release metal ions into the electrolyte leaving an excess of free electrons, similar to the corrosion process.

The two electrochemical interactions give rise to a dipole charge layer that acts as a capacitor. Dipole layer is the source impedance of EMG input signal from the muscle to the electrode.



**Fig. 3.** Mode of measuring muscle activity using myoelectrodes.

Skin, electrolyte and electrode influence EMG signal in a deterministic way, the equivalent circuit being composed of a resistor given by the electrolyte resistance in series with a parallel combination of a capacitor and represented by dipole and a resistor representing the chemical reaction that distributes charges.

Potential of the stabilized reaction between the electrode and electrolyte is called half cell potential (half-cell). This potential produces a gap in biological signal which is canceled when using differential measurement (with two electrodes).

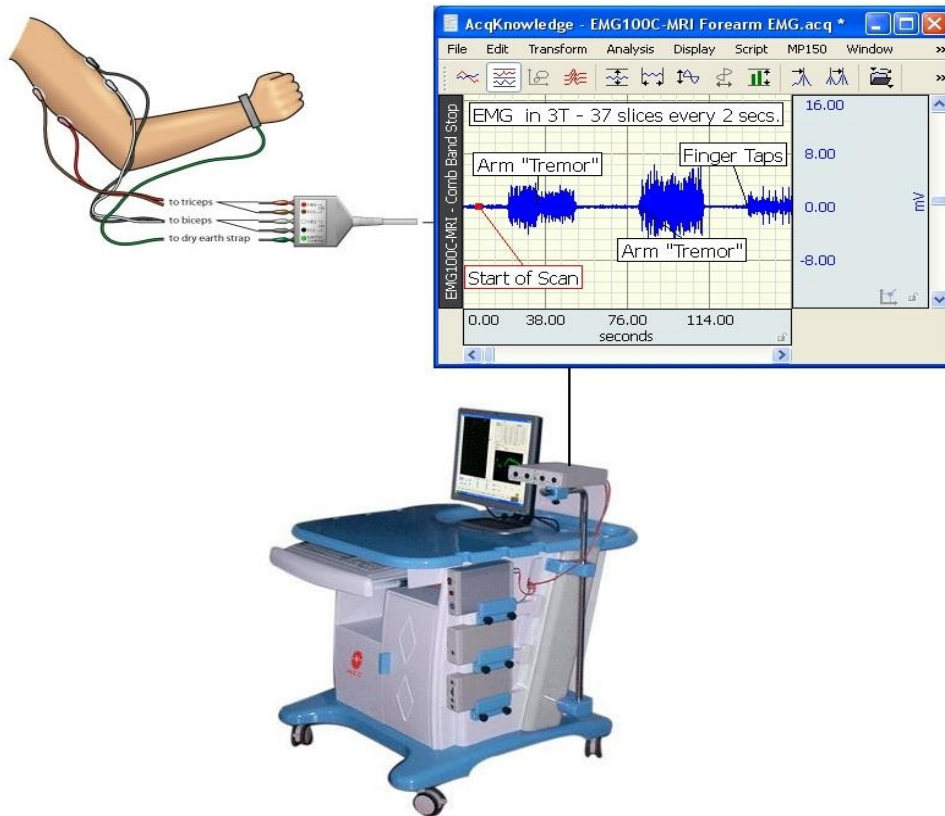
## 6. Myoelectric signals processing

EMG signal recorded values vary depending on the type of contraction, muscle size or other technical or methodological differences. Maximal isometric contractions can generate amplitude of 5 mV peak to peak for surface measurements. Intramuscular measurements are not attenuated by tissue and can reach a maximum of 10 mV. Maximum peak to peak amplitude (30mV) is usually associated with evoked potentials.

Propagation of currents through muscle tissue is dependent on frequency, as frequency increases there is a decrease in signal amplitude recorded by electrodes. Being

a progressive attenuation of high-frequency signal amplitude, the muscle acts as a low-pass filter.

This attenuation is also dependent on the electrodes distance from the muscle fibers and electrodes orientation towards the direction of muscle fibers.



**Fig. 4.** Function chart for capturing and processing myoelectric signals using electromyograph:

- Central unit: 16 Bit A/D conversion resolution, 200 kHz sampling ratio, 5–5000 ms analysis time, 0.1–50Hz stimulating frequency.
- Smart Amplifier with: four leads connectivity,  $0.05 \mu\text{V}$ –20 mV/Grid sensitivity, less than  $4 \mu\text{Vpp}$  earth noise EMG, over 100 dB CMR ratio, 50 Hz Ban wave setting, 0.01 Hz lower limit Filter-frequency, 20 kHz upper limit Filter-frequency, improved gain of  $25 \div 400\,000$  times, less sensitivity to electrode and transducer lead placement, continuous spectra in physiological signal frequency band, automatic acquisition oversampling, real-time analog output.
- Laptop: Core i7-740QM, 15.6", 8GB RAM, 500 GB @7200 rpm HDD, Graphic card ATI Mobility Radeon HD 540v@512MB, OS MS Windows 7 Professional.
- AcqKnowledge software with real-time EMG integration.
- A4 Colour Laser Printer.

## 7. Method for processing myoelectric signals

First we use the facilities of the AcqKnowledge software for the acquisition of the most appropriate EMG signals and then to made different signal processing of the raw EMG data. First we use envelope detection and low-pass filter, to obtain accurate EMG commands from the EMG signals, like in the following figure.

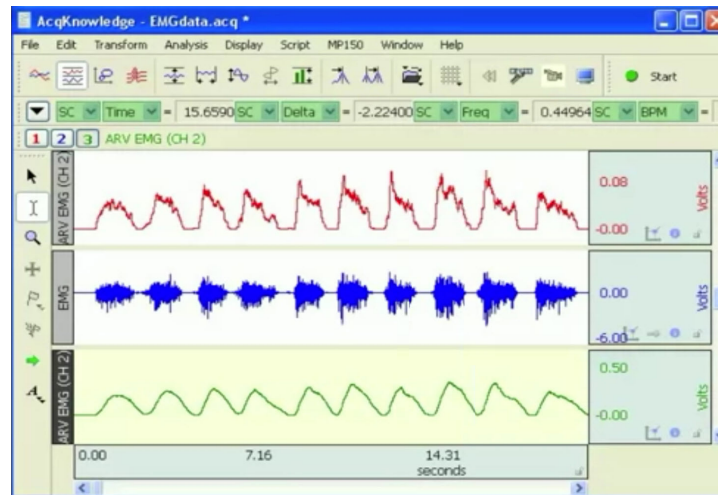


Fig. 5. EMG signal processing using envelope detection and low-pass filtering.

Then, the signals envelopes are compared with a threshold to obtain distinct square pulses corresponding to muscular activities and so to the intent of the patient.

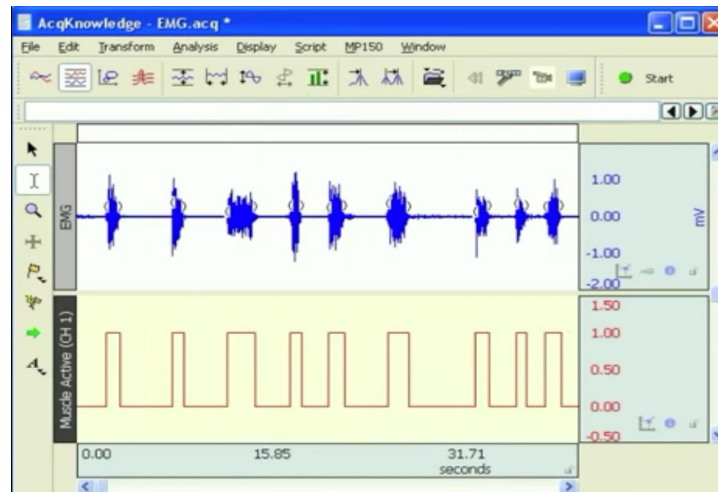
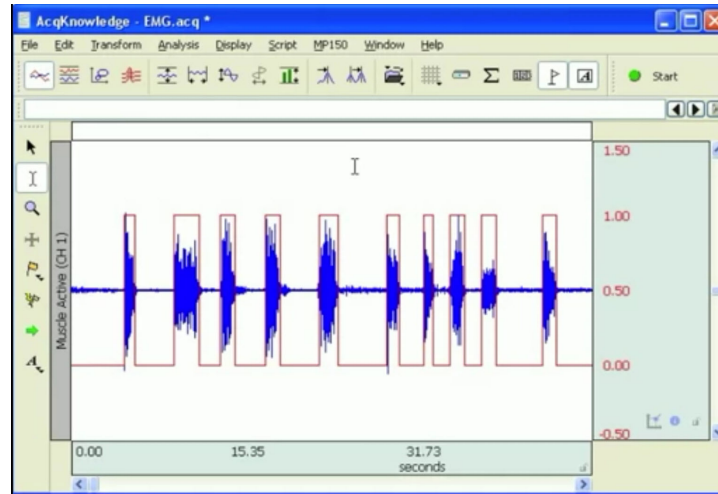


Fig. 6. Extraction of square pulses commands, corresponding to the patient intention.



Processing time can be reduced enough to achieve a real-time control of an artificial hand, as outlined in the following figure, where actually you cannot visually detect a delay of the control signal against the EMG signal of origin.



**Fig. 7.** Almost perfect overlap of the control signals obtained over the initial EMG signal.

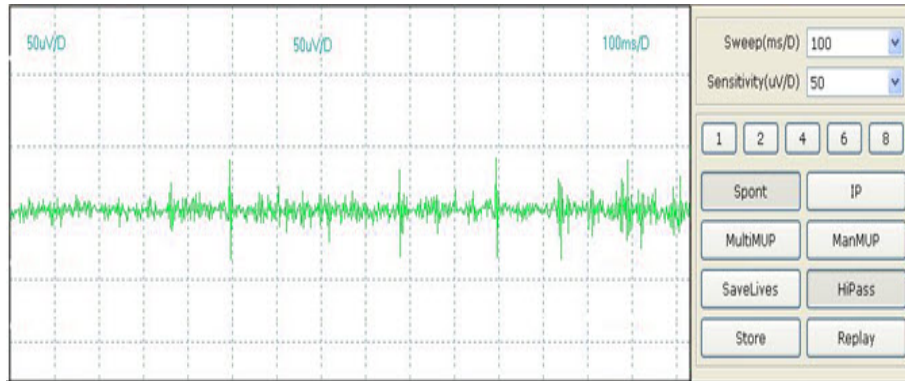
## 8. Results achieved in acquisition and processing of myoelectric signals

In our tests, we measured the EMG signals generated by different muscles of an one hand amputee. We obtain different results on different muscles but always the healthy hand give much strong myosignals on all muscles than the amputeed one.



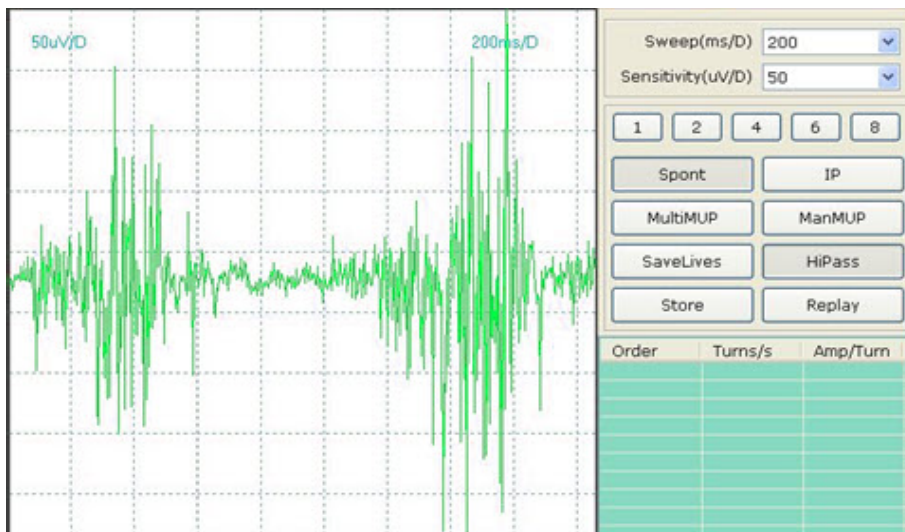
**Fig. 8.** Myosignals aquisition from the both flexor carpi radialis muscles of an one hand amputee patient.

As an example, in the following figures, some signals from the both arms' flexor carpi radialis muscles are presented.



**Fig. 9.** Electromyographic signals captured from the carpi radialis flexor muscle of a transmetacarpian amputated hand.

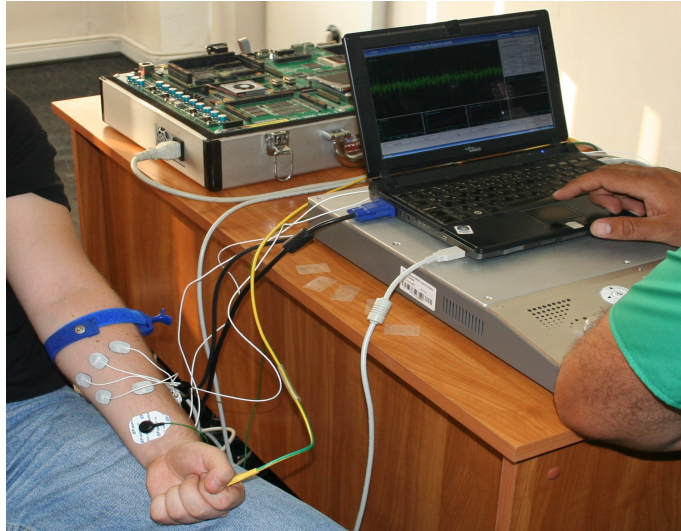
As can be seen easily, EMG signal is much weaker for the muscle of the amputated hand, being almost covered by noise. The signal amplitude varies from  $50 \mu V_{pp}$  to  $80 \mu V_{pp}$ . The noise maximum level is about  $30 \mu V_{pp}$  and, for this reason, it is difficult to extract the control signal from the noisy one.



**Fig. 10.** Electromyographic signals captured from the carpi radialis flexor muscle of a healthy hand.

In the case of the healthy hand's signal, the amplitude varies from  $150 \mu V_{pp}$  to  $450 \mu V_{pp}$ , while the noise maximum level remains the same (about  $30 \mu V_{pp}$ ), making this primary signal easy to process, in order to obtain the control signal.

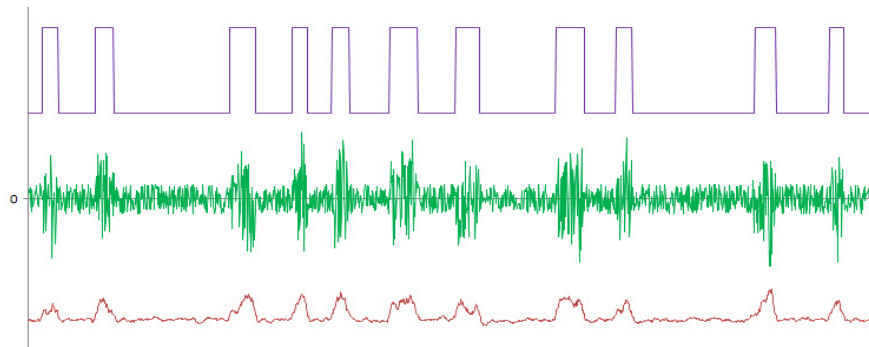
In both case, the signals are collected with a set of disposable electrodes applied in pairs alongside of every target muscle and, additionally, one single reference electrode. An example of electrode application is shown in the following figure.



**Fig. 11.** Acquiring 2 pairs of myoelectric signals from left forehead's muscles.

Our solution for extracting control signals from the primary data was tested and adjusted to work even with a low level of signal, as the one obtained from the stump's muscles. The extraction method is working by applying an appropriate mediation (or low-pass filtering) and then a comparison with an individualized threshold. In this way, useful commands to control an artificial hand can be obtained for a patient.

The result of such a procedure is presented below. This was achieved with proper experimental software, based on data previously acquired by EMG equipment.



**Fig. 12.** The method of extracting control information from a myoelectric signal acquired from a muscle on the stump.

Although there are some gaps up to 1–2 ms on rising or falling of some impulses, to the EMG signal of origin, the control signal resulted shows delays well below noticeable limit of a command that can be considered effective (300 ms) [34].

## 9. Conclusions

There were presented the basic principles involved in real-time operation and control of artificial hands.

There were identified and presented several ways to select and acquire myoelectric signals necessary for real-time controlling of artificial hands.

There were presented amplitude and frequency characteristics of surface myoelectric signals and their correlation with the types of muscle activity.

There was elected a hardware-software package suitable for EMG signal acquisition and processing in real time in order to extract useful information for the motor control of the artificial hand from myoelectric signal.

A method for raw myoelectric signal processing and relevant information extraction was presented. The envelope detection and low-pass filtering was used in order to obtain accurate EMG commands from the EMG signals.

The presented method was applied both for surface EMG signals picked up from the flexor carpi radialis muscles of the both forearms of an one hand transmetacarpian amputee subject.

The method was able to extract a reliable command signal even from the weak and noisy signal picked up from the atrophied muscle of the amputated hand.

**Acknowledgements.** This work is supported by POSDRU/89/1.5/S/63700 project.

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