Recording and conditioning of surface EMG signal for decomposition

Antonín Pošusta, Jakub Otáhal

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***Abstract*— Electric activity of the muscles recorded on the body surface – an electromyographic signal - is composed of several individual signals originating from surrounding motor units. Conventional surface EMG setup does not allow analyzing single motor unit firing pattern particularly because of significant signal distortions due to passive electrical properties of skin and electrodes with large surface. In our work we have tested new design of surface electrodes and its arrangement to record EMG signal suitable for further mathematical decomposition. Furthermore, we have examined convenient detection sites on the human upper extremity and the head.**

***Index Terms*— surface electromyography, decomposition, EMGLab, prosthetics.**

I. Introduction

Surface electromyography (sEMG) is frequently used tool in biomechanics and kinesiology due to relatively easy to use setup, economical availability and because of potentially simple data analysis. sEMG can easily detect timing of muscle action and roughly estimate a level of muscle contraction during human movements although precise relation between sEMG and muscle force is not well understood. The electrical potential (sEMG) recorded on the body surface is summation of several signals of different sources which spread through a volume conductor. The sEMG thus contains signals from surrounding motor units (MU – muscle fibres inervated by single motoneuron), ECG, EEG etc. However, the signal decreases with third power of the distance from the source and thus proper positioning of the electrodes can improve signal quality. For common tasks in biomechanics and kinesiology sEMG is usually analyzed by rectification, smoothing and normalizes to maximal voluntary contraction (MVC). However, by this processing the use of sEMG is limited only to rough description of action of individual muscle or even muscle group in anatomically complex regions e.g. forearm [1].

For evaluation of firing properties of individual MUs an invasive needle or wire EMG is commonly performed despite the fact the sEMG contains most of the signal needed. Unfortunately, composition of skin defines its electrical properties as low pass filter which significantly affects signal. However, if the sEMG is detected by electrodes with very small contact area and if electrodes in differential lead are close enough (typically 2-10mm), sEMG contains mixture of motor unit action potentials (MUAPs). Decomposition algorithms can be then used to decompose sEMG signal to individual MUAPs. These algorithms are based on correlation, wavelet transformations or simple artificial intelligence. Quality of decomposition is highly dependent on the quality of input signal and thus on the recording setup. The firing properties of the individual MUs is of great interest because it can for example elucidate more precisely motor control strategy during voluntary movement (sports biomechanics) and can detect pathologies in their early stage [2].

Myoelectric prosthesis control usually uses sEMG amplitude as control variable. However, with fast development of prosthesis functions the rough sEMG becomes to the limit of the number of detection sites. Therefore, if the detection setup and decomposition algorithms will be able to increase number of control variables detected from same number of detection sites it can be considered to be used in myoelectric prosthesis control or in improved human – machine interfaces.

The present work was aimed to developed reliable recording procedure to record sEMG of high quality suitable for further mathematical analysis by means of signal decomposition algorithms. New five pin electrode and differential amplifier was developed. To verify quality of recordings from different muscles an EMGLab was used to decompose the sEMG signal.

II. Methods

To record high quality sEMG we have used selfmade small area electrodes with four signal and one reference channel (pentode). Each contact is made from silver pin with diameter of 0.5mm and rounded tip. Electrode pins are arranged into the square with edge 3.5mm. The reference electrode is placed in the center of the square of signal electrodes (see Figure 1).

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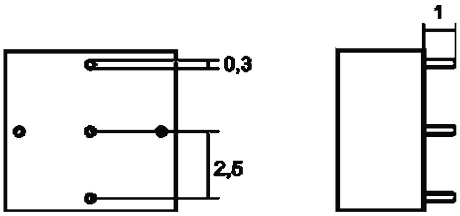

Fig. 1 Scheme of used electrode - pentode. Pins diameter is 0,5 mm distance between signal and reference electrode is 2,5mm.

To measure sEMG signal the pentode is gently placed above the selected muscle and fixed to the skin by means of adhesive plaster. The pentode is attached to the battery powered custom made four channels two level differential amplifier. Each channel is amplified against common reference 5000times and filtered by bandpass filter (250 - 2,5kHz). Amplified and conditioned analog signal (see Figure 3) is digitized at 22kHz using an USB 16bit data acquisition board USB-6221 (National Instruments, Czech Republic) and VisionBrain software [3, 4]. The whole setup is connected to the computer by USB cable (see Figure 2). To obtain suitable data for multielectrode decomposition signal channels were digitally substracted in following manner Ch2-Ch1, Ch3-Ch2, Ch4-Ch3, Ch1-Ch4. Before decomposition signals were filtered with simple FIR band pass.

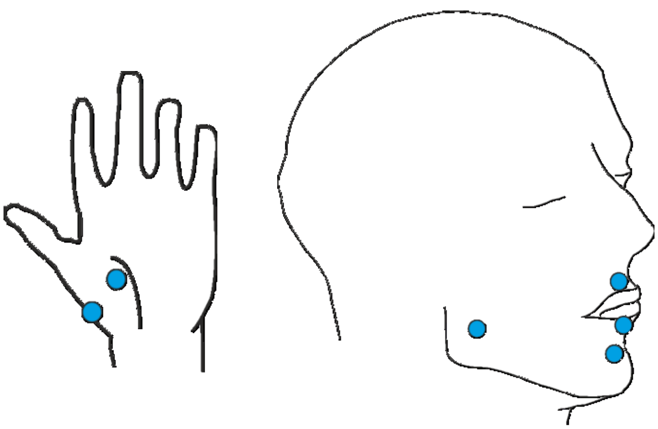

Fig. 2 Scheme of electrode placement

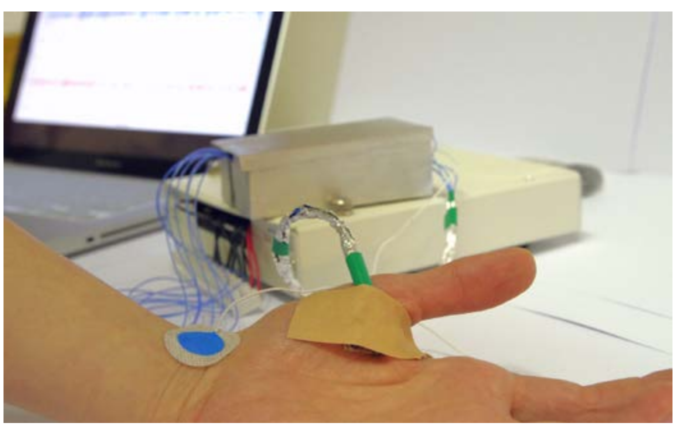

Fig. 3 System setup. Pentode is fixed to the skin with adhesive strip. Self-adhesive Ag/AgCl electrode ground electrode (blue) is attached to the skin on wrist.

To verify suitability of the signal for decomposition algorithms digital signals were then analyzed with EMGlab - an interactive EMG decomposition software package [5] for Matlab environment (Mathorks, USA). We have tried to find similarities in signals and to classify its properties – number of detectable unique action potentials, signal strength and also classify the strength dependence.

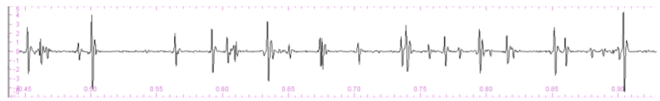

Fig. 4 A sample signal output from analog part

The measurement was done with 10 healthy persons, from which 3 were women and 7 men in age 21 to 52 years (31.4±3.6). The subjects were questioned for occurrence of any neurological and/or movement disorder. There were chosen 3 places on face, 2 places on palm, the pentode was tested above selected forearm and thight muscles. Each experimental session was started by evaluation of level of signal for maximal voluntary contraction (MVC) for each muscle tested. Subject was asked to perform maximal isometric voluntary contraction of the muscle. MVC value was calculated as RMS of signal in 10s window and was assumed to be 100% MVC. In next steps was subject asked to perform voluntary contraction with different effort to get recordings on different levels of MVC. Each measurement of contraction took 10 seconds and was 5 times repeated.

All data are expressed as mean±S.E.M.

III. Results

The signals obtained from surface pentode were in most places clear with low level noise and during contraction individual motor unit action potentials were observed. The best signal was obtained on the smaller muscles having delicate motor units. In these muscles during contraction the signal contains sharply separated individual MUAPs (Figures 3-5). However, the quality of the sEMG signal recorded with the pentode from large muscles (forearm and tight muscles) which consists of large motor units did not allowed further decomposition analysis. We have therefore tested pentode with longer edge and then the quality of the signal was improved.

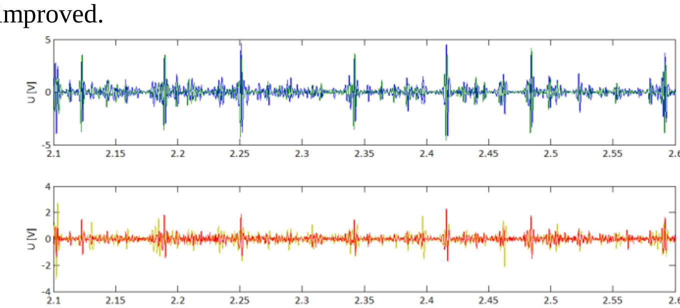

Fig. 5 Four channel signal measured on oponens policis

A. Signal characteristics

1) Signal to Noise Ratio (SNR)

Before each measurement baseline signal with 0% of MVC was recorded. Averaged power of experimental signals was then divided by power of baseline signal and logarithmized.

TABLE I
Basic characteristics of abductor policis signal

Characteristics		
MUAPs	**SNR**	**MVC**
4 to 7	Avg. 14db	10.00%
5 to 7	Avg. 15,5 db	30.00%
5 to 8	Avg. 18db	50.00%
14 to 22	Avg 21db	70.00%
Too complex	Avg. 26db	90.00%

Signal to noise ratio was dependent on body composition of measured subject. Persons with overweight (more fat in the skin) had noticeably weaker signals than persons with normal weight (calculated by body mass index). Our measurements have shown that persons with higher BMI (34 and 35) had weaker signals in comparison with subjects with normal BMI level (BMI 19 to 24). The two subjects having high BMI (one male and one female with BMI 34 and 35) was removed from averaged data presented in tables I and II.

TABLE II
Characteristics of sEMG signals (chosen examples)

Muscle	characteristics		
	MUAPs	**SNR**	**min MVC**
m.flexor pollicis brevis	5 to 8 (max 12)	Typical 28db best 35db	10%
m.abductor pollicis brevis		Typical 26db best 33db	10%
m.orbicularis oris	3 to 7 (max 8)	Avg. 20db	Approx. 30%
m.depresor labii inferioris	3 to 6	Avg. 20db	Approx. 30%
m.masseter	2 to 6	Avg. 12db	Approx. 50%
m.extensor digitorum	3-5 (6 max)	Avg 15db for high contraction levels	- (signal is weak)

2) Effect of different level of MVC

The occurrence of MUAPs in the sEMG signal is according to Heneman's principle dependent on magnitude of muscle contraction it means on percentage of MVC [6]. With more strength produced by muscle contraction we can obtain signal with more MUAPs and higher amplitudes. From view of signal decomposition the signal is also more superimposed which aggravates the decomposition of the signal.

The recordings from palm muscles obtained highest quality of the signal, these signals were clear and both selected muscles were tested during different levels of MVC (10%, 30%, 50%, 70% and 90%). Signals were simply decomposable up to 50 % MVC. 70% MVC took about 7 times longer to decompose. 90% MVC signals was not able to decompose with EMGLAB software.

3) Effect of different inter-electrode distance

In our recordings the small muscles (oponens policis, abductor policis, orbicularis oris, depresor labii inferioris and masseter) provided reasonable quality of signal. However, recordings of sEMG with pentode with 3.5mm edge on large muscles (leg muscles - gracilis or sartorius) we were not able to gather reasonable signal.

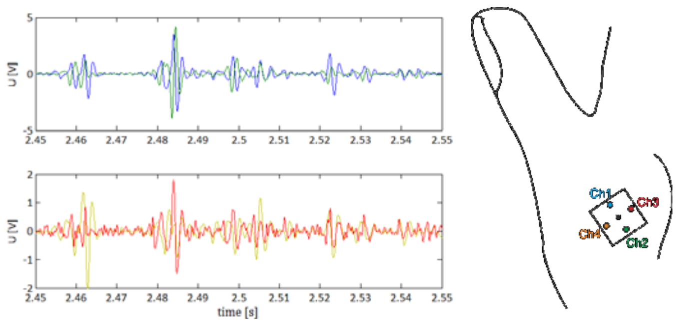

Fig. 6 Detail of signal from fig 4. As you can see on first graph (upper one), signal of channel 1 and 2 goes against each other, which can be easily explained with scheme on the right.

SNR was highly dependent on inter-electrode distance. Larger muscles had weaker signals than smaller face and palm muscles. However, with larger electrode (14mm, edge of pentode) we were able to measure signals from larger muscle groups (forearm muscles, biceps brachii). Signals had significantly better signal to noise ratio, comparable to SNR of 5mm electrode while gathering signal from abductor pollicis.

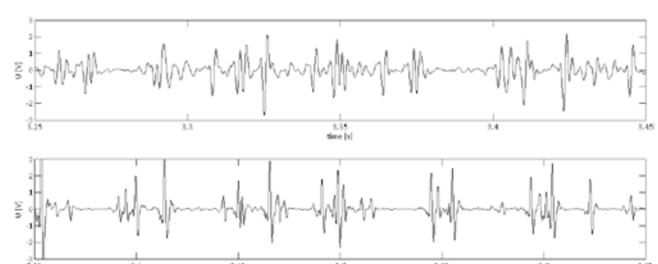

Fig. 7 Comparison between signal of abductor pollicis gathered with 14mm electrode (upper figure) and 5mm electrode (below) at approximately same MVC level

Signal gathered from abductor pollicis with 14mm pentode was also stronger, with better SNR characteristics; even MUAPs were noticeable at lower MVC. However, peaks of recorded MUAPs, which are highly important for decomposition, became more rounded which significantly worsened quality of decomposition. Therefore each type of muscle (motor unit) needs appropriate pentode dimensions to detect sharp signal from limited volume to provide an optimal quality of the signal for decomposition.

B. Signal decomposition

The signal obtained by our setup is clearly composed from low level background activity and noise and particularly from high amplitude individual MUAPs which makes signal suitable for mathematical decomposition (see Figure 3, 4 and 6). Results of decomposition, which can be seen in Table I and II and on figure 6 was done with multi channel decomposition – MTLEMG [7] based on genetic algorithm.

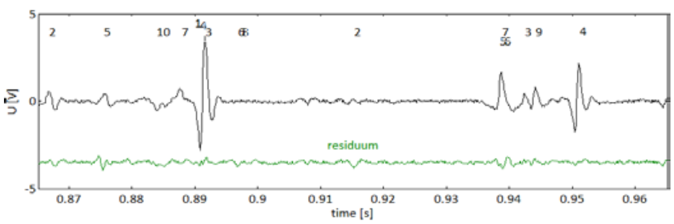

Fig. 8 Detail of marked and decomposed signal from oponens policis. (On figure channel 1. Decomposed 4 channel signal – ie MUAPs number 2,6,8 had their peaks on other channels.)

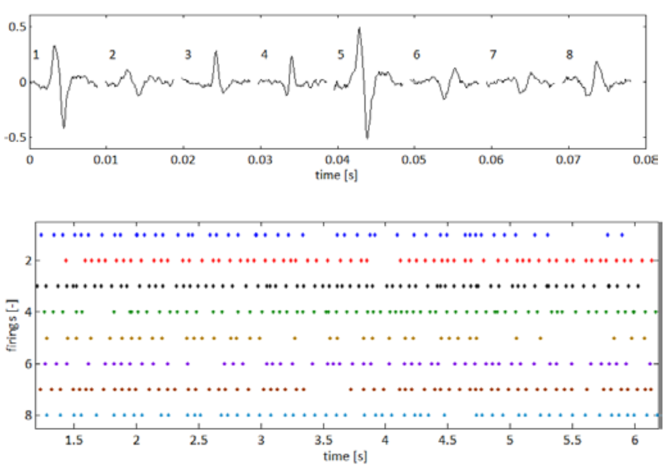

Fig. 9 MUAPs found on approximately 50 % MVC signal from depresor labii inferioris (upper figure) and time firings positions (bottom figure).

With more powered contraction, more motor units on higher frequencies are involved and more superimposed signal is then being obtained. This highly superimposed signal is then hard to decompose.

In our experiments we also tested decomposition with only 2 channel signal. These experiments were similarly accurate to 4 channel decomposition.

IV. Discussion

Our results show that pentode electrode layout is suitable for recording of high quality sEMG data which can be further used for mathematical signal decomposition. Important finding is that signal quality is dependent on inter-electrode distance and dimensions of motor units. The small pentode was suitable for fine finger and mimic muscles, however, for large muscles recordings is necessary to use pentode with longer edge.

Signal decomposition was highly effective in low or medium strength contraction, however, during high strength contraction (MVC > 50%) the motor units fire on higher frequencies and more superimposed signal is therefore being obtained. This highly superimposed signal is then hard to decompose because individual MUAPs coincide and thus algorithms seeking for spike patterns are ineffective. The main purpose for sEMG decomposition is to find firing properties during common voluntary movements which are usually under 50% of MVC.

V. Conclusion

Surface EMG signals measured with proposed pentode electrode is suitable for signal decomposition. Experiments showed that appropriate pentode dimensions have to be chosen according to muscle volume and motor unit composition.

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