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Performances evaluation of textile electrodes for EMG remote measurements*

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Abstract— **This work focus on the evaluation of textile electrodes for EMG signals acquisition. Signals have been acquired simultaneously from textile electrode and from gold standard electrodes, by using the same acquisition system; tests were done across subjects and with multiple trials to enable a more complete analysis. This research activity was done in the frame of the European Project Interaction, aiming at the development of a system for a continuous daily-life monitoring of the functional performance of stroke survivors in their physical interaction with the environment.**

I. INTRODUCTION

In the last decade significant advances have been made in building lighter and more versatile devices for rehabilitation in a remote environment [1, 2] Smart Fabric and Interactive Textile (SFIT) systems offer an alternative solution to the recording of EMG with respect to conventional electrode design. They enable design and production of wearable non-obtrusive well-fitting garments with a distributed number of electrodes. Electrodes can be located in the desired position, allowing the acquisition of signals from different muscles, moreover the possibility to use a redundant number of electrodes, can be convenient not only for the selection of the best configuration for the classic bipolar recording, but also for high-density surface EMG recordings [3]. Currently EMG systems cannot be used in a remote context since they require expert supervision for electrodes placement and very long preparation time. In this study we analyze the performance of textile electrodes for EMG measurements with respect a gold standard. The study proves that e-textiles can be used as recoding systems for highly accurate EMG control of muscles functionality and activity monitoring.

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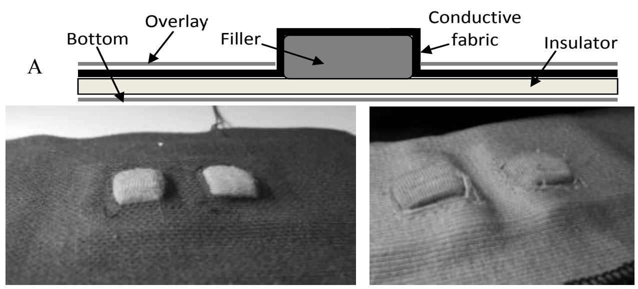
The use of textile materials for biopotential sensing allows performing EMG measurements outside of the typical clinical and laboratory setting for longer durations. The further technological advances with textile EMG electrodes and they integration into garments, will make it possible for daily life monitoring of outpatients, athletes, and use for prosthesis. However before textile electrodes can be used the overall signal quality and reliability must be established. Smartex company has been developing textile EMG electrodes for a multitude of applications. Preliminary work was done to evaluate the performance of the textile sensors in comparison with gold standard systems [4]. The study shown that EMG signals collected simultaneously from fabric and standard electrodes were very similar in terms of amplitude values and time intervals. Since this preliminary work, many technological improvements have been done; in term of conductive components, the previous electrodes were based on a continuous conductive monofilament, while the new one are based on conductive fibers; in term of textile structure, the new electrodes are realized with an higher elastic components resulting in a higher density and conductivity. Moreover a new design has been done for EMG measurements, as described in the following paragraph. Aim of this study was to compare EMG measurements across subjects and with multiple trials to enable a statistical analysis. To this purpose, a differential pre-amplifier has been integrated into the electrodes greatly reducing the overall noise and improving the signal quality. Now that the equipment set-up is similar to that of traditional EMG systems, a thorough comparison study of the fabric electrodes with standard commercial electrodes was achievable. In order to establish the signal quality and consistency of the measurement from the textile electrodes we compared the signal to noise ratio, variation in signal amplitude, median frequency, and signal quality of dynamic movement. We hypothesized that both the gold standard and Smartex electrodes will have a frequency spectrum within normal EMG range and there will be no significant difference between the median frequencies between the two systems. We further hypothesized that there will be no significant difference between the signal to noise ratio or the variation in signal amplitude between the two electrodes.

II. Materials and Methods

A. *Electrodes and acquisition system*

Smartex electrodes [5], shown in fig. 1A, are realized by combining conductive yarn (based on stainless steel fibers) and elastane. A multilayered structure is used to increase the quality of the skin contact, a filling pad was sandwiched between the textile electrode fabric and a more rigid back layer see fig. 1B.



B C

Figure 1: Smartex electrodes: A) Structure of electrodes B) patch with the sensors. C) particular of electrode padding to increase the skin contact, electrodes are integrated in a garment .

To customize shape (square), dimension (1cm x 1cm) and distance (2cm) of the electrodes, a mask of no conductive fabrics has been developed. The non-conductive fabric is composed of antibacterial polyamide and elastane. The connection is realized with yarns provided by Bekintex (100% of stainless steel fibers, with a PVC coating).

As gold standard, the Biometrics DLK 800 [6] system for the data acquisition was used. This apparel is a general-purpose data acquisition system allowing the collection of both analog and digital data from a wide range of sensors including Biometrics goniometers and proprietary pre-amplified active EMG sensors, see fig. 2.

To adapt the textile electrodes to the DLK800 it was necessary to develop an electronics interface, according the scheme reported in fig. 3.

Figure 2: Biometrics system with electrodes and reference

The interface includes an instrumentation amplifier, an analog second order band pass filter between 10Hz till 500 Hz and an active body reference to cut as much as possible the power-line noise (50 Hz). This latter has been connected to the reference electrode of Biometrics system and placed on the wrist.

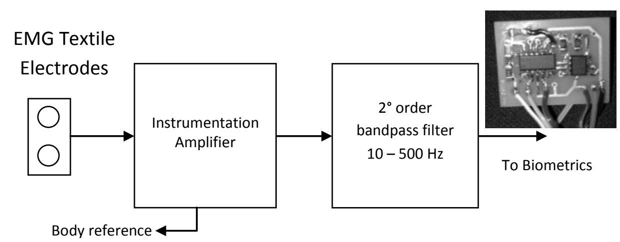


Figure 3: Electronic interface to adapt Smartex electrodes to Biometrics system

B *Subjects*

Six healthy, physically active individuals volunteered have been recruited for this study (3M/ 3F, age 35.5±6 years, height 1.63±0.87 m, mass 66±0.9 kg, mean±SD).

C. *Protocol*

Each subject first completed three maximum voluntary contractions prior to the trials. The subjects were instructed to hold their arm at a 180-degree angle with respect to the shoulder with their forearm bent at a 90-degree angle while contracting at their maximum force. The researcher provided added resistance by pushing down upon their arm to ensure their maximum voluntary force was achieved. Following the MVC trials the subjects completed isometric and dynamic contractions. At the beginning, middle, and end of the protocol a silent muscle activity trial was recorded while subjects relaxed their body, this was used to estimate noise. The subjects additionally completed five static trials with no weight, five static trials with 2 kilograms held at the wrist, and three dynamic movements. The static trials, or isometric contractions consisted of the subjects holding their arm in the same position as MVC. For the dynamic trials the subjects raised their arm from a parallel position with the torso to the position of MVC and lowered to the parallel position again; this was repeated four times for each trial. All the trials were 20 seconds in length and randomized with the exception of the MVC trials and silent trials.

D. EMG measurements

Prior to electrode placement, the skin at each placement site was cleaned with alcohol. The electrodes were placed on subject's right deltoideus medius, following recommendations of the SENIAM European project [7]. The textile electrodes were placed slightly rightward to the midline of the deltoideus medius and the Biometrics slightly leftward, see fig 4.

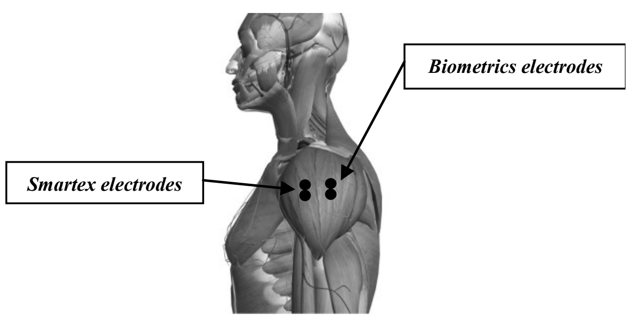


Figure 4: Placement of the Biometrics and Textile electrodes on deltoids muscle.

The confirmation of proper electrodes placement was done visually, by observing the EMG signals while subjects performed a series of standard muscular contractions as shown in fig 5.

Figure 5: Movements done during measurement.

The electrodes remained in place throughout the experiment. Both Biometrics and Textile data were collected with a sampling frequency of 1,5 KHz, but the first one with a gain of 1000 and second one with a gain of 600. The EMG data used for the amplitude variation comparisons were computed with a band pass filter in the range of 20 and 400 Hz, with a second order Butterworth filter and then rectified, and finally normalized to the first trial of the same condition for the same subject, i.e. the no weight static trials were all normalized to the first no weight trial of that subject and vice versa. The signal to noise ratio was calculated using the equation:

$$SNR = 20log_{10}(\frac{RMS(signal)}{RMS\ (noise)})$$

The signal RMS was calculated from the first, middle, and last two kilograms trial from each subject and the three silent muscle activity trials were used as the noise. We used the silent activity trials to represent the noise level since EMG activity covers a broad range of frequency (10-500 Hz)[8] so it is difficult to isolate the noise if it occurs anywhere within the 10-500 Hz range. Using the silent muscle activity trials ensures we are not encompassing any muscle activity while still encompassing all the noise. Comparing between the SNR and median frequency we used paired T-tests, $p \geq 0.05$. For the amplitude variation analysis we used an unpaired T-test, $p \geq 0.05$.

III. RESULTS

The textile electrodes and the biometrics electrodes had a power spectrum within the standard range for EMG: 10-500 Hz. The dynamic trails were comparable between the two electrodes. You could clearly identify the periods of activation and level of force from both the raw data and linear envelopes (fig 6).

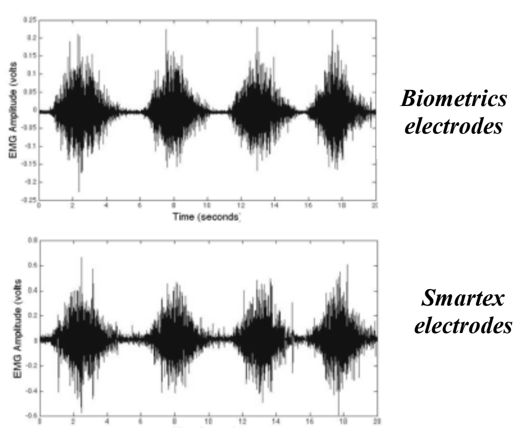


Figure 6: Example of signals acquired.

In some subjects there were motion artifacts present in the dynamic trail signals, although filtering was able to remove most. No significant difference was observed in the median frequency between the two electrodes, for either the no weight or the 2 kilograms trials ($p=0.09$ and $p=0.23$). The average median frequency for the biometrics was 96.2 ±11.1 Hz and 94.6±9.6 Hz for the two kilograms trials (mean ± std). The average median frequency for the Smartex textile electrodes was 102.5±19.8 Hz and 98.6±13.9 Hz. There was no significant difference in the amplitude variability for the no weight or two kilogram trials ($p=0.56$ and $p=0.23$). The Biometrics electrodes had a standard deviation of 13% and the textile electrodes 11% as reported in Table 1.

Electrode	*Test done with 0 Kg*		*Test done with 2 Kg*	
	Amplitude SD	*Median Frequency*	*Amplitude SD*	*Median Frequency*
Biometrics	12.60%	96.2 Hz	13.00%	94.6 Hz
Smartex	10.70%	102.5 Hz	21%	98.6 Hz

Table 1: The standard deviation of the amplitude and the average median frequency for the zero and two Kg trials.

No significant difference between the signal to noise ratio (SNR) between the Biometrics and textile electrodes ($p=0.27$) has been observed. The mean SNR for the Biometrics electrodes was 12.81±1.68 dB and for the Smartex electrodes 11.89±2.33 db. There was no correlation with time observed for the variation in SNR, as reported in Table 2. The variability of SNR values, in terms of subject and system, is due to the physiological diversity of muscle subjects and relative positioning of the electrodes.

SNR [dB]	*Number of Subject*					
	1	*2*	*3*	*4*	*5*	*6*
Biometrics	9.931	16.129	6.571	13.100	15.883	15.256
Smartex	13.285	11.600	9.580	9.480	11.828	15.590

Table 2: Signal to noise ratio for each subject and electrode. The SNR was calculated from the three silent muscle activity trials.

Frequency analyses were performed in Matlab using the Welch method with 1-second time window. The unrectified signal was used so that there was no skewing in the frequency spectrum. The magnitude of the frequency spectrum was normalized to the maximum for each respected electrode, for the frequency spectrum graphs so that the gain differences did not interfere with the interpretation of the graphs (fig 7).

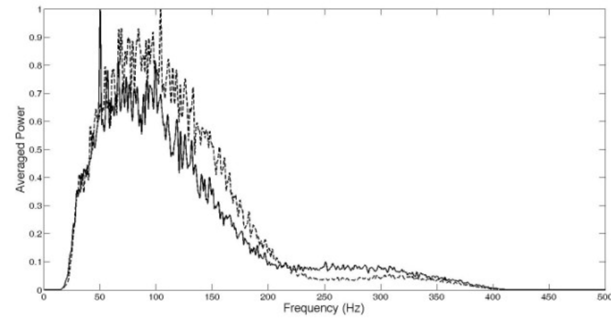


Figure 7: Averaged power spectrum of 0 kg. trials from subject 5. The dotted line is the Biometrics electrodes, the continuous line the Smartex electrodes. The power is normalized to the maximum power for each respective electrodes to make them easy to compare.

IV. Conclusions

In this study we compared textile electrodes for EMG signal acquisition with a gold standard, with the aim to assess the feasibility of the use of textile material for a remote acquisition of reliable signals. We have shown that the performance of textile electrodes are comparable with standard electrodes, moreover due to the conformability of the textile electrodes to the body shape, the improvement of comfort in comparison with standard electrodes; systems based on fabric sensors are suitable for remote monitoring, tele-rehabilitation and innovative care.

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