Proceedings of the 28th IEEE
EMBS Annual International Conference
New York City, USA, Aug 30-Sept 3, 2006

Contactless sensors for Surface Electromyography

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Abstract— **Muscle activity can be monitored by measuring the Surface Electromyography (SEMG) signal at the surface of the body. The SEMG signal is a combination of several activation signals sent through the muscle fibers triggering the contraction of the muscle. SEMG enables to access those signals non-invasively.**
Usually, metal plate electrodes in combination with electrolytic gel are placed in direct contact with the skin to measure SEMG. For prolonged monitoring of the muscle activity, this type of electrodes is not comfortable and can cause skin irritation.
In this paper, we demonstrate capacitive electrodes capable of sensing the SEMG signal. These contactless electrodes do not require direct contact with the skin and thus they can be suitable for prolonged monitoring of the muscle activity.

I. INTRODUCTION

Work related musculoskeletal disorders, mainly back pain and repetitive strain injury (RSI), are among the main international health and safety problems among workers nowadays. People suffering from this kind of injury would benefit from a continuous monitoring of their muscles activity. Another important aspect is to prevent musculoskeletal disorders for people at risk, which could also be done by a continuous monitoring of their muscles activity.
To enable continuous monitoring of Surface Electromyography (SEMG), a non-invasive type of electrodes should be used. Such a system should be wearable and comfortable to enable the user to use it while performing his/her regular activities.
Existing electrodes employed to record SEMG signals are usually metal plates electrodes combined with an electrolytic gel placed in direct contact with the skin. This type of electrode acts as an electric transducer converting the ionic current flowing in the body to an electronic current flowing in the electrode lead to the measurement device. By principle, these electrodes require direct electrical contact with the body. An alternative type of electrode has been proposed in literature. These electrodes [1][2][3][4], referred to as contactless electrodes, couple capacitively to the body detecting in this way a displacement current instead of a real charge current. Therefore no direct electrical contact between the body and the electrode is required. While the previous publications use contactless sensors for monitoring ECG, we are using such sensors for monitoring muscles by means of SEMG. Contactless electrodes are perfectly suitable for a continuous measurement of the SEMG signal.
Avoiding the contact with skin and the use of electrolytic gel prevent irritation of the skin. Moreover, the contactless electrodes can be integrated in a wearable system, which does not require a permanent good contact with the patient's body. The ConText project, funded by the European Commission, which started in 2006, is working on the integration of such electrodes into textile [6]. In this way, the user could wear a shirt or a vest with integrated sensors to measure continuously the SEMG signal from selected muscles.
In this paper, we present our results on the used contactless electrodes for SEMG. In particular, the noise measurements from the capacitive electrodes are shown. We present the first SEMG measurements obtained with the contactless sensors separated from the skin by a piece of cotton fabric.

II. INTRODUCTION TO SURFACE ELECTROMYOGRAPHY

Musculoskeletal disorders can be monitored by specialists analyzing electrical signals which cause muscle contraction. Muscles are constituted from muscle fibers. Motoneurons in the nervous system are connected to these muscle fibers, each combination of a Motoneuron with the connected muscle fibers constitutes a Motor Unit (MU) [5]. The activity of one muscle is controlled through several MUs. Different types of MUs exist, corresponding to different intensity and duration of the effort. MUs are recruited depending on the type of effort. When a MU is recruited, the Motoneuron sends a current through the connected fibers. The SEMG signal corresponds to the action potentials created by the current flowing through the muscle fibers. This signal varies in frequency during the effort. When measuring SEMG on top of the skin covering a muscle, the action potential recorded is an average of all the action potentials from the MUs under the electrode area. Assessing these signals enables specialists to understand and monitor musculoskeletal problems. The Surface EMG signal is normally measured by using two electrodes for a differential recording on top of a muscle. The electrodes should be placed at two different locations along the same muscle. The frequency of interest for the SEMG signals are in the range 10 - 500 Hz, and the maximum amplitude is about 1mV pp, depending on the size and depth of the muscle.

III. THE CONTACTLESS ELECTRODES

The contactless electrodes consist of a conducting plate covered by an insulating layer, in this way forming a parallel plate capacitor with the skin. Such a configuration can be used to couple the bio-potential signal capacitively to an amplifier. Figure 1 shows the principle of the contactless electrodes. In practice, two electrodes are used and connected to a differential amplifier. The differential signal is then sent

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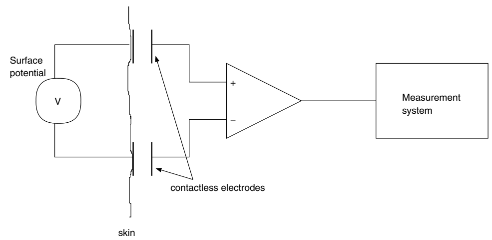

Fig. 1. Contactless electrodes principle

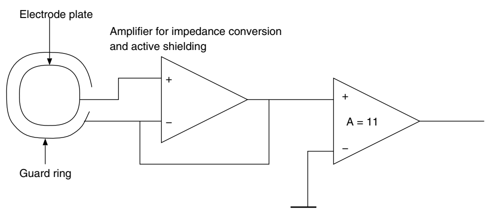

Fig. 2. Schematic of one contactless electrode with impedance conversion and active shielding

to the measurement system to be sampled, processed and analyzed.

Because of the small size of the electrode and the distance of the electrode plate to the conductive layer of the skin, the capacitance value of the electrode is very low and hence results in a very high input impedance of our sensor (estimated capacitance is in the order of 0.6 pF at 1 mm from the body surface). Due to this high impedance, the signal at the output of the sensor is very sensitive to all kind of interference signals. Two techniques are used in the design of the electrode to reduce interferences. First, an impedance converter circuit (a unity gain amplifier) is placed directly next to the electrode plate to convert the high impedance to a low impedance which is less sensitive to capacitive noise from the environment. Secondly, a guard ring is placed around the electrode to perform active shielding (bootstrapping). The unity gain amplifier used for the impedance conversion is also used to drive the guard at the same potential as the electrode plate. Figure 2 shows a schematic of the circuit constituting one contactless electrode with the amplifier used for both impedance conversion and active shielding. A second amplifier is used to amplify the electrode signal with a gain equal to 11. The electronic components on the electrode are placed in a shielded box.

Figure 3 shows the noise spectrum obtained from such a sensor. The sensor is connected to a metal box containing the batteries for powering the sensor, which is then connected to a PC containing a NI 4472 24 bits sampling card. The electrode was placed above a grounded metal plate to prevent the sensor from picking up any signal. The sampling frequency is equal to 1 kHz. The noise spectrum corresponds to the noise from the electronics. Notably, 1/f noise from the amplifiers can be observed in the spectrum. The slope which can be observed at the end of the spectrum is due to the anti-aliasing filter integrated in the sampling card. The cut-off frequency of this filter is equal to half of the sampling frequency. The noise level is in the order of 1 μV/$\sqrt{Hz}$ @10 Hz for a resolution bandwidth of 1 Hz. Since the SEMG signal of interest is normally in the order of 1 mV pp in the frequency band 10 - 500 Hz, the noise floor is quite acceptable.

To perform our measurements presented below in this section and in section IV, we used the following set-up. Two contactless sensors were placed along the biceps brachii of a test person, while a layer of cotton fabric with a thickness of 0.99 mm separated the sensors from the skin surface. We fixed the electrodes and the piece of cotton fabric to make sure that the distance between the electrodes with respect to the skin surface remained constant. The two electrodes have a round shape of 12 mm diameter. The distance between the two electrodes was equal to 37 mm from center to center. Both electrodes have an amplification gain equal to 11. The signals coming from both electrodes are sent to the PC containing the NI 4472 sampling card. The signals from the two electrodes were sampled simultaneously at a sampling frequency of 1 kHz, an anti-aliasing filter with a cut-off frequency equal to half of the sampling frequency was applied before sampling. After sampling, the signals from the two electrodes were digitally subtracted to obtain a differential signal, which is normalized by the electrode amplification gain to calculate the real surface potential. During the following presented measurements, we used the same above-described set-up.

Despite the design techniques applied to reduce the external disturbances on the signal, interferences due to the electric wiring in the building are still present in the signal because they are directly transmitted through the body. The body capacitively couples to the voltage sources in the room and there is always a potential difference between two positions on the body. The impact on the measurements, however, can be reduced by proper grounding as shown with the following experiment. The differential signal between the two sensors was recorded under two different conditions. In the first case, nothing was used to ground the test person. In the second case, the test person was grounded by touching the metallic box, which contains the batteries to power the sensors. The metallic box is connected to the ground of the computer, thus by touching the box, the test person was also connected to the

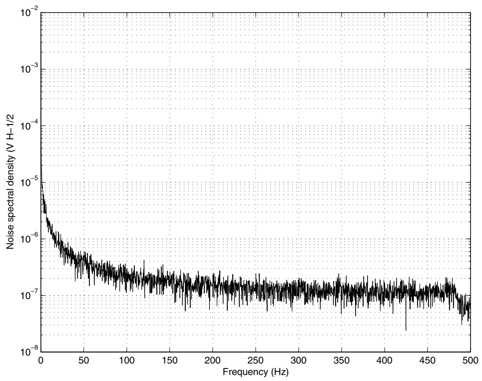

Fig. 3. Noise spectrum from the contactless sensors

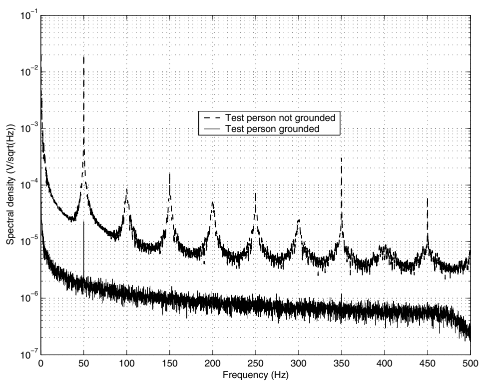

Fig. 4. Spectrum of the differential signal obtained with the electrodes along the biceps brachii of a test person with a layer of cotton between the electrodes and the skin surface.

ground of the computer. Figure 4 shows the two spectrums obtained from the differential signals when the patient is not grounded and when the patient is grounded. When the patient is not grounded, the harmonics of the 50 Hz interference signal can be clearly observed in the spectrum, and the interferences are highly attenuated when the test person is grounded

The 50 Hz interferences are dominating in the signal if the test person is not connected to ground. Therefore, during the following presented measurements, the test person was connected to the ground. Even after grounding, some interferences remain at 50 Hz. However, those can be canceled by a 50 Hz (digital) notch filter if needed.

IV. First SEMG measurements with the contactless electrodes

The SEMG measurements were performed in the same conditions as described in section III. This time, the biceps brachii was contracted by lifting a weight of 2.5 kg. The differential signal coming from the electrodes was filtered. The filtering part consisted of a single notch filter to remove the 50 Hz interference and a high-pass filter with a cut-off frequency f_c=10 Hz. Since the test person was connected to ground, most of the interferences from 50 Hz to 450 Hz were canceled as was explained, but an additional interference at 50 Hz remains with a non-negligible amplitude, a notch filter at 50 Hz was used to remove it. Low frequency disturbances due to small movements and breathing of the test person are removed by a 10 Hz high-pass filter. Figure 5 shows the differential recorded signals during respectively, 1 second of contraction and 1 second of rest. We can notice a clear amplitude difference between the contraction signal and the resting signal, SEMG is therefore correctly detected by the contactless electrodes. From the previous measurement, two parts of the signal were selected, one corresponding to 30 seconds of resting period and one corresponding to 30 second of contraction period, to compare their spectral content. Figure 6 shows the spectrums of respectively, the resting part and the contraction part of the previous signal. The contraction signal recorded with the contactless electrodes can be clearly distinguished from the resting signal recorded with the same electrodes. The spectrums show a difference of about 16 dB between the two signals, which is enough to distinguish the contraction from the resting period. These measurements show that it is possible to use the contactless electrodes to detect the SEMG signal from a contracted muscle.

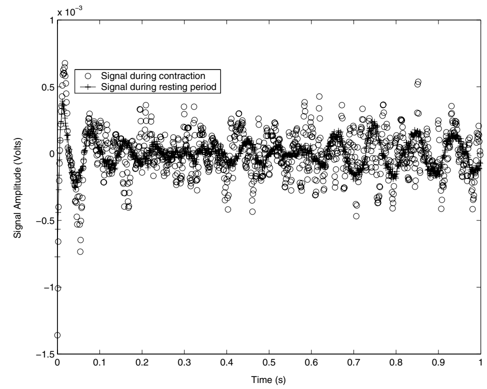

Fig. 5. Continuous contraction of the biceps brachii measured with contactless electrodes.

V. Conclusions and future work

We propose to use the technology of contactless electrodes to sense the Surface Electromyography signal in order to have a continuous monitoring of the muscle activity. The first SEMG measurements with the contactless electrodes

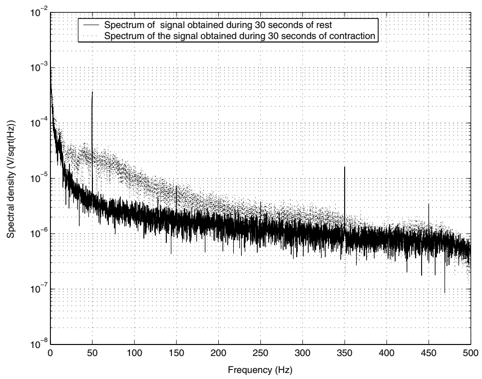

Fig. 6. Spectrums of the measured signals during respectively 30 seconds of contraction and 30 seconds of rest

show that it is possible to detect the SEMG signal on a the biceps of a test person, with a layer of cotton fabric separating the electrodes from the skin. Our future work will be concentrated on improving the measurement set-up and the sensor design in terms of robustness against interferences. We would also like to prevent the need in grounding the body and find another solution to reduce interferences. A possible solution of using a capacitive feed-back circuit has already been introduced in literature [7].

VI. Acknowledgments

We thank the European Commission for funding part of this work under contract IST-027291 (ConText). We thank the ConText project partners: Clothing+ (Finland), Katholieke Universiteit Leuven (Belgium), TITV (Germany), TNO (the Netherlands)and Technische Universität Berlin (Germany).

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