Optomyography (OMG): A Novel Technique for the Detection of Muscle Surface Displacement Using Photoelectric Sensors

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***Abstract*—Several techniques have been introduced for detecting, measuring, processing and analyzing the signals generated during muscular activities. With the development of more advanced technical solutions, the measurement and analysis of these signals help not only to understand the medical abnormalities and characterization of muscle activities but also to develop human machine interfaces of higher efficiency. In this work, a novel technique to detect and measure the displacement caused on the surface of the skin due to muscle activities was introduced and developed using near-infrared photoelectric sensors. The new technique was coined as OptoMyoGraphy (OMG). In order to evaluate the new technique, real-time pairs of signals were registered using two photoelectric sensors measuring near-infrared rays reflected on the forearm while moving the hand to make a number of different gestures. Different pairs of signals, changing over time and showing repeated patterns while repeating the same hand gesture, were measured for different hand gesture. The signal to noise ratio (SNR) of these signals was good enough to be able to differentiate among the pairs of signals which correspond to different hand gestures using visual inspection.**

Keywords—OptoMyoGraphy; OMG; moving-hand gesture; photoelectric sensor; near infrared; NIR; muscle surface displacement;

I. INTRODUCTION

Several non-invasive methods have been introduced, developed and are still being improved to study the muscular signals of the human body to diagnose various disorders and to also create better human-machine interfaces [1, 2, 3, 4, 5, 6, 7, 8, 9]. One of the most reliable and efficient methods is the surface-ElectroMyoGraphy (s-EMG) technique [10, 11], which is a non-invasive variant of EMG [7], and uses electrically-conductive surface-electrodes to measure the electric currents generated by the muscles. On the other hand, the mechanical tension generated at a tendon is accompanied by the surface displacement of the respective muscle. Several displacement sensors or accelerometers are used to record the surface MechanoMyoGram (MMG) signals generated due to these mechanical vibrations [8, 9, 12].

Although both s-EMG and MMG have been proven to be practical and efficient, they are still suffering from some limitations which are caused by certain factors which are not easy to control outside the laboratory, such as sweat, different skin conditions and types, interference with other signals, noise and low Signal-to-Noise-Ratio (SNR) [10, 13].

More specifically, regarding s-EMG, accurate measurements are contingent on factors, such as the wide range of the amplitudes of the detected bioelectrical signals which are between a few microvolts to a few millivolts, the intensity and timing of contractions, the properties of the used electrodes and amplifiers, motion artifacts, the chemical and physical properties of the overlying tissue, including the distance between each electrode and the active muscular region as well as the contact resistance or impedance between each electrode and the surface of the skin. In addition, excess noise generated from multiple sources is present in all s-EMG measurements. All these factors contribute to reducing the SNR in s-EMG measurements [10, 13].

On the other hand, one of the most efficient MMG approaches uses laser beams to detect the displacements on the surface of the skin caused by muscular actions [14]. However, this technique suffers from serious limitations, such as the complex installation of the system and that the laser exposure over the skin cannot be carried out for longer time durations. Thus, this makes the MMG technique not feasible to be used in daily life and during sport activities.

The aim of this paper is to develop a new instrument which can overcome most of the limitations of the existing techniques. Near-infrared (NIR) light-waves are successfully used in numerous applications to measure the distance between a target which reflects NIR-signals and an NIR-detector. In addition, NIR light-waves are efficiently used in many biomedical applications without complications [15]. Therefore, in this work, NIR photoelectric sensors are proposed for detecting and measuring (in real time) the displacements on the surface of the skin, caused by forearm muscular movements. The new technique is coined as OptoMyoGraphy (OMG).

II. MATERIALS AND METHODS

A. *Choosing the right sensor*

The goal of this work is to build a safe, non-invasive, non-contact and user-friendly instrument, which is robust to interference of bio- and other surrounding electromagnetic signals, mobile, reliable, cost effective, requires a simple installation and captures signals of high SNR, for the detection and measurement of any topographical changes of the landscape formed by the surface of the skin of any part of the body.

The challenge is to find an active technique which stimulates the human body by emitting then measuring signals of sufficient SNR. The signals of interest should be different from all other signals and noise-types which might be generated from the human body and/or the surrounding environment, such as electrical, magnetic and thermal signals. In addition, all or most of the other desired requirements mentioned previously should be fulfilled. Another important requirement is that blood flow and perfusion within the tissues, below the skin, mustn't affect the measured signals. For instant, the pulse signal shouldn't interfere with the skin-surface-displacement signal.

Therefore, NIR signals are chosen to be utilized as the information-bearing signals in this paper. More specifically, the used NIR signals have wavelengths around 800nm which can penetrate and dive approximately 2.4mm into the human skin tissues without reaching other tissues under the skin layer which is 2-3mm thick [16, 17].

The RPR-220 reflective photoelectric (photoreflector) is chosen for this work. This sensor is commonly used for industrial applications. It consists of two components as illustrated in Fig. (1). A Non-coherent NIR-emitting diode with a Peak wavelength of 940nm and a high-sensitivity photo-transistor which has a maximum sensitivity wavelength of 800nm (It has a built-in visible-light blocking filter) and detects the reflected NIR-light from any target, which is in this work, the human skin.

B. *Experimental setup and measurements*

Fingers of humans do not have muscles in them. Instead, they are moved by tendons which are pulled by muscles in the forearm [18]. Consequently, while performing actions using the fingers, one can feel the movements of the forearm muscles. Usually, the displacement of the surface of the muscle depends on the force exerted while performing an action or movement. Therefore, the experimental task is aiming at measuring the topographical changes of the landscape formed by the surface of the skin of the forearm, while moving the fingers and making a number of different gestures of the corresponding hand. The goal is to investigate whether different hand gestures change the topography of the skin-surface differently, making it possible to measure different and unique sets of signals (acquired at different small areas around the forearm) for each hand gesture, or not.

For this purpose, an arm-band was made (for the forearm) using a material made of a lower density rubber composite that is flexible. Two RPR-220 sensors were embedded on the inner side of the arm-band so that the sensing heads were focused over the skin-surface of the anterior and the posterior muscles of the forearm, as shown in the Fig. (2).

The two sequences of surface displacements (each sequence is measured by one of the two sensors), caused by the activity of the forearm's muscles for predefined movements, was displayed and visually inspected on the display of a two-channels oscilloscope. The arm-band was designed so that the distance between the skin-surface and each sensor head was approximately equal to the required focusing distance of the RPR-220 sensor (which is 6mm).

The signals measured when the hand was at rest were constant (+2V) and considered as reference signals. Measurements acquiring pairs of signals' sequences were performed for 14 different predefined movements of the fingers and the wrist of a hand (i.e. for 14 predefined hand gestures). Each hand gesture was repeated four or five times, consecutively, while measuring and displaying the pair of signals varying over time (the response time of the RPR-220 sensor is 10µs).

The experimental setup is illustrated in Fig. (3), showing an arm-band with two RPR-220 sensors placed around the forearm and connected to low-pass filters with cut-off frequencies of 20 Hz, then connected to a two-channels oscilloscope. This figure also shows the rest or reference position or gesture of the hand and five types of movements in different directions of the wrist and the fingers that can be combined to form the 14 different hand gestures mentioned previously.

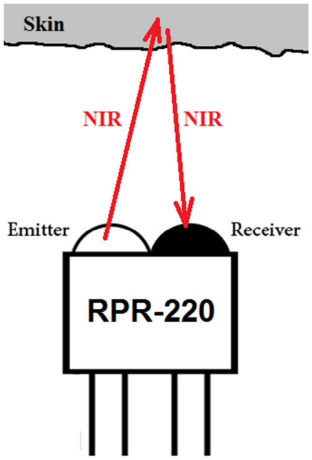

Fig. 1. The RPR-220 reflective NIR photoelectric sensor.

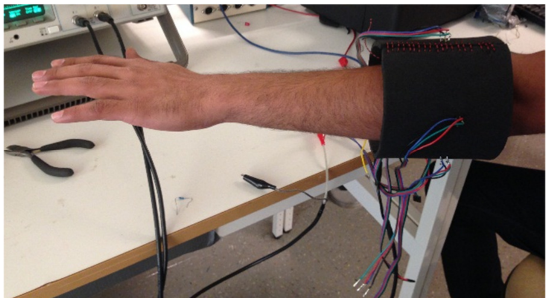

Fig. 2. The arm-band prototype used in the experiments.

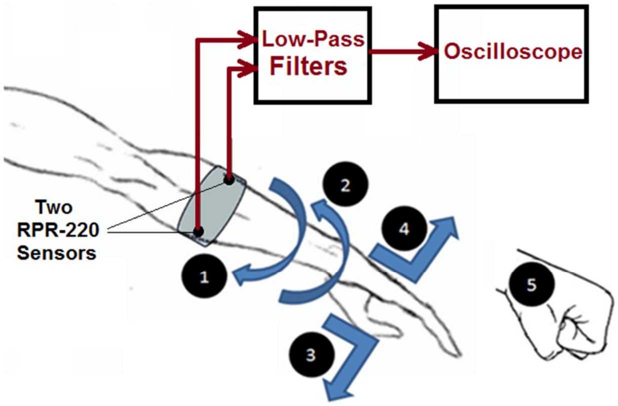

Fig. 3. The experimental setup (the arm-band, the low-pass filters and the oscilloscope) and the five types of movements of the wrist and the fingers that can be combined to form the 14 different hand gestures considered in the experiments.

III. DISCUSSION

The results of the experiments are shown in Fig. (4). Visual inspection of these results shows that the captured pairs of signals (time series) have patterns which are different and unique for different hand gestures. The signals were varying differently with a peak-to-peak variation of about 150 mV for signal (1) when closing and opening the hand (as shown in Fig. 4e) and about 5 mV for signal (1) when moving one finger downwards in Fig. (4c). Note that the wrist and/or the fingers are moving during the acquisition of these pairs of signals. In these experiments, the mobility of the used prototype as well as the user is limited to a particular region near the oscilloscope due to the fixed lengths of the used cables.

Otherwise, the experimental setup is safe, simple, cost effective, robust against noise, and well protected against stray-light interference by two means: measuring the smallest possible spot by keeping the right focusing distance between the active sensing side of RPR-220 sensor and the skin-surface, in addition to using a built-in visible-light blocking filter to cover the sensing area of the phototransistor.

IV. CONCLUSIONS AND FUTURE WORK

The work performed and presented in this paper concludes that reflective photoelectric NIR sensors, such as RPR-220, can be successfully implemented for the detection of skin-surface displacements which are associated to muscular activity. Furthermore, the new technique can be used to recognize and differentiate among different moving-hand gestures. Preliminary, visual inspection was used to assess the resulting pairs of signals which correspond to different moving-hand gestures. however, it is possible to use automated signal processing and analysis methods instead of visual inspection.

The experimental setup can be improved by increasing the number of sensors, increasing the mobility by using a battery for power supply and using Bluetooth or Wi-Fi instead of the cables. The prototype can be developed further into a user-friendly human-machine interface that can be used for a wide range of applications, such as controlling prosthesis, robots and video-games. Another possible application is using such a device in combination with an interactive video-game for therapeutic and rehabilitation purposes. The goal here is to keep training the muscles and the nerves that are responsible of controlling, for example, the fingers (in case of suffering from disorder, disability or amputated fingers) by taking OMG measurements around the forearm and showing on the screen the corresponding moving-hand gestures in 3D.

ACKNOWLEDGMENT

The authors would like to thank Gunnar Nihlen (at KTH-STH in Stockholm) and Khurram Yousaf (at Karolinska Institute in Stockholm) for fruitful discussions, tips and help in constructing of the prototype.

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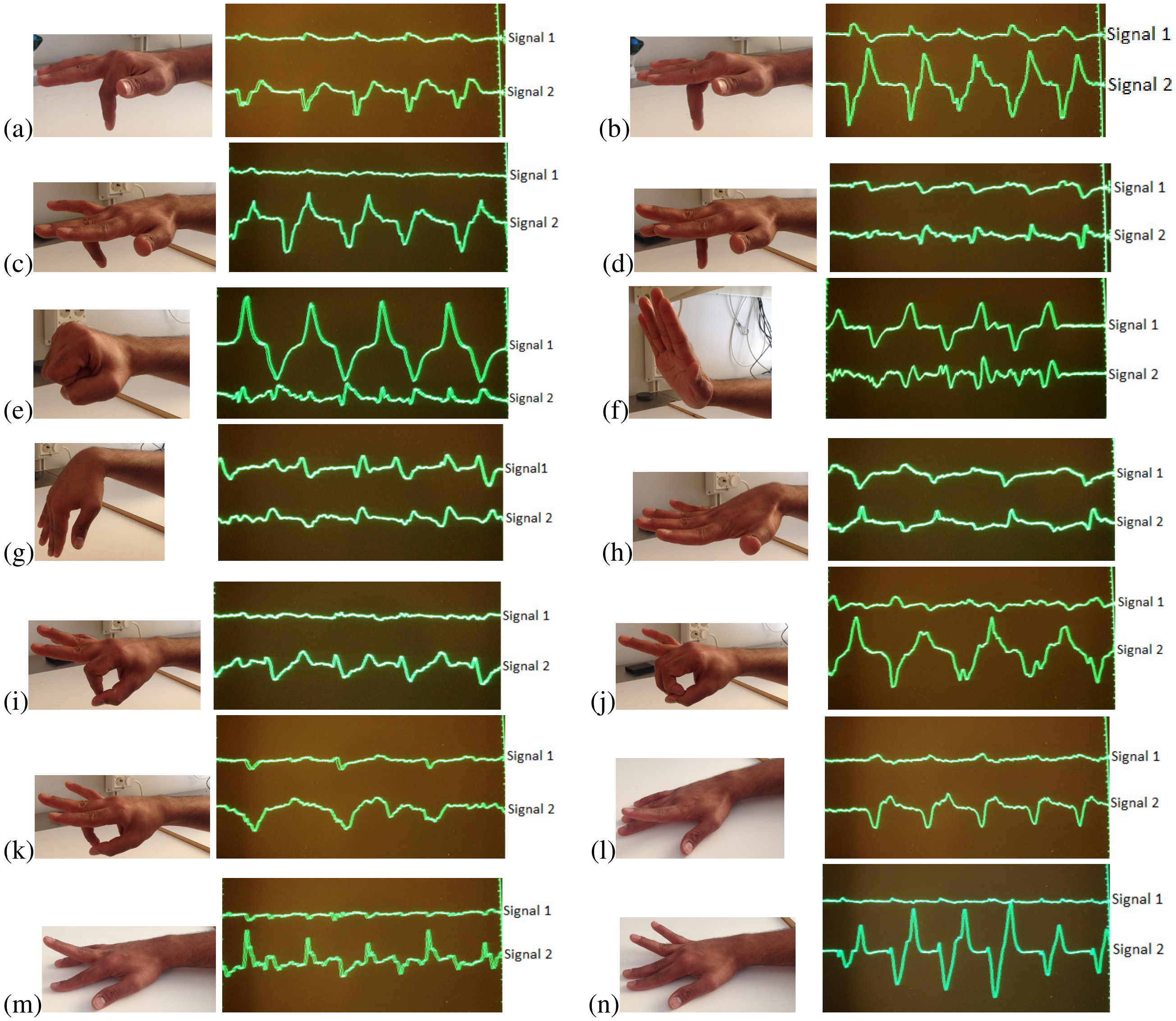

Fig. 4. The experimental results: 14 moving hand gusters and the corresponding pairs of signals as dislayed on the oscilloscope.