DEVELOPMENT OF A COMBINED MYOELECTRIC AND NEAR-INFRARED SENSOR FOR PROSTHESES CONTROL

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ABSTRACT
The control of upper-limb prostheses is commonly realized via the detection, processing and classification of myoelectric signals. Pattern recognition techniques enable users to control prosthetic devices by contracting remaining muscles, so that up to nine hand positions can be distinguished with high accuracy. It is however difficult to identify single finger- or sophisticated finger-movements. This is due to the fact, that corresponding muscles produce crosstalk, entailing it impossible to distinguish delicate finger motion. For this reason, we propose sensor fusion incorporating a near-infrared spectroscopy sensor, to detect changes of oxygen concentration in the blood, and an electromyographic sensor. Experiments show, that the sensor combination allows to distinguish between contracted and non contracted muscles. In this contribution, we present a miniature combined myoelectric and near-infrared sensor that can be used for prostheses control. The sensor uses LEDs instead of Lasers, which ensures safe operation, cheap production and consumes little power. The near-infrared signal can be used as additional classifier input. We found, that the spatial resolution of the combined sensor is better than common electromyographic sensors.

KEY WORDS
Noninvasive measurement, prostheses, myoelectric signal, near-infrared spectroscopy, sensor development, finger movements, prostheses control, sensor fusion

1 Introduction
Control signals for prostheses are commonly acquired via non-invasive skin surface electrodes. These are able to detect electric signals, the so called myoelectric signals (MES), of the underlying muscles [1, 2, 3, 4]. When a muscle is contracted, single muscle fibers are activated with a certain activation frequency. The resulting signal, called action potential, travels through the fiber with about 2 to 6 m/s [5]. One nerve does not innervate only one, but several muscle fibers simultaneously. All of them together with the activating nerve are called a motor unit. The resulting Motor Unit Action Potential Train [6] is the summation of all muscle fiber potentials within this motor unit. The amount of activated motor units and the activation frequency define the level of muscle contraction and resulting force [1, 7]. Different MUAP trains travel through the fibers and affect the electrodes, located on the skin above the muscle. Electric potential differences between two electrodes are amplified and used as control input. Electrode distance, size and shape define the appearance of the acquired signal [5]. The distance of the electrodes is very important. In the literature electrode distances between 1cm and 2 cm are reported [8, 2, 5]. Effects of the electrode geometry are discussed in [9]. When the size, perpendicular to the muscle fiber is increased, more muscle fibers are in the proximity of the sensor and therefore the sensor has a ‘broader view’. If the size in the direction of the muscle fiber is increased, the action potentials are longer in the ‘observation area’ of the sensor. This has an integrative effect and can be described as low-pass filter, reducing high frequency components of the signal.

After the first amplification phase a bandpass-filter and a second amplification is inquired, to improve signal quality and avoid aliasing effects during the analog to digital conversion. Low frequency components as well as a DC offset are eliminated with a cut-off frequency of about 10 to 20 Hz [2, 10]. The upper frequency bound is chosen between 500 and 1000 Hz. After amplification and filtering the signal is digitized and specific signal features are calculated. This features can be originated either in time-, frequency- or time-frequency domain [6]. For classification purposes several features might be used, the so called original feature set [11]. Depending on the algorithm used, a dimensionality reduction is required to reduce the complexity and computation time.

There are several pattern classification techniques available. Algorithms based on statistical distribution [12], neuronal networks [13, 14] or fuzzy algorithms [15, 16] are published. Although an amputee can repeatably generate specific signal patterns, the resulting signal varies gradually. To distinguish between hand positions the underlying muscle signals have to be different. Common hand motions are wrist extension, wrist flexion, fist, radial deviation or ulnar deviation. Currently available algorithms tend to fail, when using single finger movements, instead of those hand motions, for classification. The corresponding muscles are
in close proximity to each other and sometimes one muscle participates in more than one finger motion. The poor spacial resolution of the electromyographic sensor is the reason for very similar acquired signals.

In the recent years, new five finger prostheses have been developed that offer a great flexibility, like the i-LIMB HAND from Touch Bionics™. Each finger can be controlled individually, but by using a pattern classification algorithm only a few predefined hand positions are actually used. It would be a great benefit for amputees if they could directly control individual fingers. In this contribution, we have enhanced a common electromyographic sensor with a near-infrared spectroscopy sensor.

Near-infrared spectroscopy is a relatively new measurement technique, that offers a very good spatial resolution [17]. A sensor can be build at low-cost, battery operated and is safe for application [18]. Common applications of this technique, are monitoring changes of blood oxygen concentration or detection of neural activity [19]. It could also be shown that it is possible to monitor muscle activity [20, 21]. While biological tissue is almost opaque to light in the visible spectrum, it is relatively transparent to light in the range between 700 and 900 nm [19]. The range between 700 and 1300 nm is called the near-infrared spectrum. Near-infrared light is mostly absorbed by blood chromophores, namely oxygenated- and deoxygenated-hemoglobin [18]. Changes in the intensity of backscattered light represent a change in blood chromophore concentration [22]. By using different wavelengths, concentration changes in blood chromophores can be predicted by application of the Modified Beer Lambert Law [18, 23]. This is an empirical description of optical attenuation in a highly scattering medium [22]. In this contribution, we are not interested in changes of chromophore concentration, but in changes of total amount of backscattered light. Muscle contraction leads to changes in chromophore concentration and a shift in the amount of detected light. The light intensity shall be used as additional control input for the prostheses.

A light source injects photons into the tissue, where these interact in several ways: reflection, absorption and scattering [24, 25]. The photons scattered, follow a so called 'Banana Shape' and exit the tissue some distance away from the light emitter [18, 24]. The penetration depth of these photons is roughly half the emitter detector distance. By adjusting this distance, the depth of the measurement can be tuned.

Since energy is transmitted to biological tissue, safety precautions must be followed. We are using LEDs instead of Lasers, therefore electromagnetic waves are not focused on a small spot and the sensor is harmless for the eye. There are two potential hazardous effects by applying energy to biological tissue that are described in [26] and [18]. On the one hand there is tissue ionization. On the other side thermal injury can occur. Fortunately near-infrared light is non-ionizing, meaning that there is no altering of genetic information. But thermal injury still is a problem. We have to differentiate between radiated heat and conducted heat, caused by a temperature increase in the semiconductor junction [26]. The effect of radiated heat is minimal, the increase of tissue temperature is up to 0.5 degrees and not dangerous. The temperature increase through semiconductor junction heating can be up to 10 degrees [26]. To prevent skin burns, it is necessary to reduce tissue heating, for example by applying a thermal insulator top to the LED, using a heat sink or by applying a pulsating waveform to ensure cooling between on-cycles.

2 Method

The fusion of a myoelectric- and a near-infrared sensor enables us to better discriminate between hand motions. The myoelectric measurement is done by a single differential pickup with 1 cm spacing. The bar shaped electrodes are 1 cm wide and 3 mm thick. Signal amplification is provided by a BurrBrown INA 121 instrumentation amplifier with a gain of 2000. The input signals are high-pass filtered at 15 Hz to remove unwanted DC-offset. The near infrared sensor consists of 12 individual LEDs with three different wavelengths at 730nm, 805nm and 850nm. The LEDs are combined in a metal housing, which serves as heat sink, and has a glass top for thermal insulation. The monolithic photo-amplifier, an OPT101 used as detector, is located 4 cm away from the light-source. The signal is low-pass filtered at 1.5 kHz before analog-to-digital conversion. The schematic for the sensor is given in Figure 1, and the prototype is depicted in Illustration 2. In order to achieve a small footprint the sensor is realized with two layers. The electronics is enclosed in a permanently soft, taste- and odorless bio-compatible cushion material to ensure a constant distance between the components and the skin and to reduce ambient light from reaching the detector.

To prevent heating, the LED is pulsed at a frequency of 20 Hz with a 10% duty cycle. This is achieved with Mathworks Matlab™ (Version V.7.8) and the Data Acqui-
Figure 2. Combined EMG and NIR sensor with cushion material (above) and without (below).

After filtering and amplifying, the EMG, NIR and LED-enable signal are digitized with a sampling frequency of 4096 Hz. The raw near-infrared signal possesses an offset induced by ambient light that reaches the sensor. During the off-phase of the LED, this offset is estimated and used to correct the signal. Afterwards the signal is filtered, using a FIR filter, and level-adjusted. The processing steps are visualized in Figure 3.

Digital post processing is also applied to the EMG signal. First a bandpass filter is used to remove remaining DC offset as well as high frequency components. Then a 50 Hz notch filter is employed to remove power line noise.

Our goal was to verify that the acquired near infrared signal resembles the muscle activity. Therefore it was compared to the electromyographic signal. The sensor was placed over the musculus biceps brachii on the right arm of a proband. To prevent as much ambient light as possible to reach the photo detector, the sensor was covered with thick garment which also was used as cuff. During 10 second intervals the muscle was flexed and released.

3 Results

The combination of a myoelectric sensor with a near-infrared sensor is advantageous. Both sensors individually resemble the muscle activity. Figure 4 shows the RMS, WFL and near infrared values of a muscle contraction. The NIR signal is ‘wider’ compared to the EMG features. It starts slightly earlier and the decay is slower. While the muscle is relaxed the NIR signal inherits an offset. This is the normal amount of light that is backscattered to the sensor by the non-contracted muscle.

The combination of a near-infrared sensor with a myoelectric sensor yields a new type of EMG-signal artifact, due to spikes superimposing the EMG signal while switching the LED. Figure 5 depicts that type of artifacts. Current changes during the switching process lead to a ground voltage drift. The artifacts occur regular with the frequency of the LED switching and its amplitude is far greater than the EMG signal. Removing this effect is important to achieve meaningful sensor values. This might be done in hardware or through software. By separating the power supply of the two sensors the artifacts are reduced. Because the time of the artifacts are known, via the enable signal of the light source, the spikes can be removed by digital post processing, for example by interpolating the EMG value.

Like the electromyographic signal, the near-infrared signal also exhibits artifacts. Two of the most common artifacts are the electrode lift- and motion-artifacts. Figure
Figure 4. Comparison of EMG signal and near-infrared signal. The upper plot shows the Root Mean Square and the Waveform Length of a muscle contraction. The lower plot shows the corresponding NIR signal.

Figure 6. Electrode lift artifacts in the EMG and NIR signal. Figure 7. Motion artifacts in the EMG and near-infrared signal.

6 shows the signals during an electrode-lift artifact. When the sensor looses contact to the body, light is being reflected on the skin and does not penetrate the tissue, causing the signal to increase.

A similar behavior is observed, when the sensor is moved on the skin. Analog to the EMG motion artifact the near infrared signal shows noise, Figure 7. By moving the sensor, the observation area of the sensor changes, therefore leading to different signal values.

Besides the artifacts, already known in EMG measurement, a new type of signal noise might also occur. If the cuff material shifts or is lifted from the skin, the amount of measured light intensity may change. The EMG signal is unaffected by that kind of noise. This is depicted in Figure 8. The upper plot shows the EMG signal. A single motion
Figure 8. Lifting or shifting of the cuff material leads to signal changes of the near-infrared signal and does not affect the EMS.

artifact is shown in the center of the recorded graph. During the rest of the time the EMG signal is nearly constant whereas the near-infrared signal changes rapidly.

4 Conclusion

The combination of EMG and NIR sensor works very well. The prototypic sensor that was build is slightly larger than our traditional EMG-only sensors, but it is still small enough to be integrated in an arm prosthesis. The measurements show, that the near-infrared signal is similar to the results obtained with the standard EMG method. There are still some problems with the prototype which must be solved, like the artifacts induced by LED switching. Until now, some of the artifacts were removed with digital signal processing techniques. A hardware solution, employing a specialized DSP or circuit design, is preferable and currently under development.

Another problem is the ambient light which affects the measurement. The sensor has to be held in place cutaneously and a cuff is required to block out as much ambient light as possible. In addition both, the LED and the photo detector, must contact the skin surface to prevent light being reflected by the skin and signal alteration.

A sensor that only relies on the near-infrared signal has certain drawbacks. The drift of the signal-offset makes it difficult to use for prostheses control. On the contrary a combination of both measurement methods seems promising. For the ambient offset within the near infrared signal can be extracted from an EMG signal. When there is no muscle activity detected via EMG, the current light amount is considered as offset.

We are planing to use a combined EMG / NIR sensor to differentiate and classify finger movements. Figure 9 depicts a first test. The sensor was placed on the right forearm of a male volunteer, above the flexor digitorum muscle. The volunteer was 28 years old with no known muscular disorders. He was asked to perform different individual finger flexions as well as flexions of the whole hand. We can not differentiate between ring- and middle-finger movements only using the EMG signal. The NIR signal, however, enables us to distinguish both movements. Because of the better spatial resolution of the NIR system, the middle finger movement is hardly noticeable. We have used a threshold of the RMS of the EMG signal to remove offset within the NIR signal. As a result, ring and middle finger movements are well distinguishable by amplitude. Furthermore, the finger movements are clearly different from the signal representing a wrist flexion.

In the future this new combined sensor hopefully will enable us to directly control individual fingers. This would be a great benefit for patients in comparison to common used pattern recognition techniques.

References


Figure 9. Differentiation of finger movements by combining EMG and NIR signals.