OPTICALLY-BASED CONTROL OF A PROSTHETIC DEVICE

David M. Schneider, Crystal M. Ripplinger, Kelly L. Gilbertson, Rajendra Katti, Mark J. Schroeder

Department of Electrical and Computer Engineering
North Dakota State University
Fargo, ND

INTRODUCTION

In this study, a novel technique for controlling a prosthetic device with the use of optical sensors was explored. Although several methods for controlling a prosthetic device, including the use of electromyography (EMG) and near-infrared spectroscopy (NIRS), currently exist, there are drawbacks associated with each of these methods. This project used readily available red (660 nm) light emitting diodes (LED's) and low-power phototransistors to characterize and detect non-fatigue skeletal muscle contractions.

BACKGROUND

Currently, the most common method of controlling a prosthetic device is with the use of EMG signals. This method, although commonly used, suffers from a variety of problems including electromagnetic noise and poor signal transmission due to perspiration between the prosthesis and residual limb. All of these factors can lead to improper functioning of the prosthetic device. Other methods of using optical sensing techniques to control a prosthetic device, such as NIRS, have been minimally explored [1,2]. In these studies, one or more near-infrared laser diodes and high-precision photodetectors were used to characterize skeletal muscle contractions. Although these experiments were able to consistently characterize muscle contractions, this technology has yet to be implemented into a device. An alternative to these methods would be the use of low-power LED's and phototransistors which may provide a low-cost option while obtaining similar results. Using optical signals would alleviate the drawbacks of these current technologies.

The use of optical signals to measure muscle contractions is based on several physiologic changes that take place in the muscle when a contraction occurs. When a muscle contracts it acts like a sponge, squeezing blood volume out of the muscle tissue. Therefore, changes in total blood volume in the region of the muscle being considered indicate a contraction or relaxation of the muscle [3]. Also, oxygen is required to fuel the contraction of a muscle, so changes in available oxygen content can also indicate a contraction has taken place. Hemoglobin carries 97% of the oxygen in the blood and absorbs light differently when the hemoglobin molecules are oxygenated or deoxygenated [4]. Therefore, changes in the amount of reflected light can indicate either a change in the amount of oxygenated blood present in the area or changes in the local blood perfusion.

MATERIALS AND METHODS

For this study, short-duration skeletal muscle contractions were measured simultaneously on both the extensor (carpi ulnaris) muscle and the flexor (carpi radialis) muscle of the forearm for a variety of experimental protocols. Two red LED's were coupled to two separate 1000 μm-core, plastic optical fibers which carried the transmitted light to the body. The reflected light was collected with a single optical fiber that was coupled to a phototransistor. The fibers were held perpendicular to the skin with a small rubber piece, which in turn was secured to the forearm with elastic straps. EMG recordings were also taken at these sites to verify the muscle contractions.

The EMG signals were pre-amplified with a CWE Iso-Z isolation head stage amplifier then filtered and amplified again with a CWE BMA 400 Amplifier. The passband of the filter was set to 100 – 1 kHz and the signal was then digitized at 2200 Hz with a National Instruments analog to digital converter. The optical signal was amplified with hardware and sent directly to the analog to digital converter. Both the EMG and optical signals were then acquired with LabVIEW software. Post-processing of the signals involved further filtering with the use of Matlab software. For each data set, both the optical and EMG signals were normalized to their respective maximum values.

Experimental Protocols

Two experimental protocols were performed in order to characterize skeletal muscle contractions by optical means. The first protocol was used to determine whether the optical signals qualitatively corresponded to simultaneous EMG recordings. Once this was verified, a second protocol was created to further characterize different types of contractions. A preliminary group of four subjects

(two male, two female) performed each protocol four or more times. The subjects were seated for the duration of the experiment with the right arm instrumented and resting on a table top. All subjects in the preliminary group were right-handed.

The objective of the first experimental protocol was to determine if the magnitude of the optical signals varied proportionally to the magnitude of a muscle contraction. For this experiment, optical and EMG measurements were taken only from the extensor muscle. The protocol consisted of five contractions, approximately eight seconds in duration with six seconds rest in between each contraction. The degree of each contraction was grouped into one of three categories: soft, medium, or hard. The magnitudes of the contractions were determined by the subject using visual biofeedback from the real-time EMG signal.

The second experiment was performed using optical instrumentation on both the extensor and flexor muscles, while still measuring the EMG signal from the extensor. The purpose was to determine if signals recorded from the two muscles could be used to characterize and differentiate between various types of contractions. The protocol consisted of three different movements; extending the hand so the palm faces outward (away from body), clenching the fist, and flexing the hand so the palm faces inward (toward the body).

RESULTS

From the first protocol, it was determined that the magnitude of the fist clenches could indeed be characterized with the use of optical signals. When the magnitude of the contraction increased, as indicated by the EMG signal, so did the magnitude of the optical signal. Furthermore, the magnitudes of the two signals seemed to be proportional to one another during each contraction. It was noted, however, that the baseline of the optical signal shifted from its original value after each contraction. A plot of typical experimental results can be seen in Figure 1 with the absolute value of the optical signal plotted for ease of comparison to the EMG.

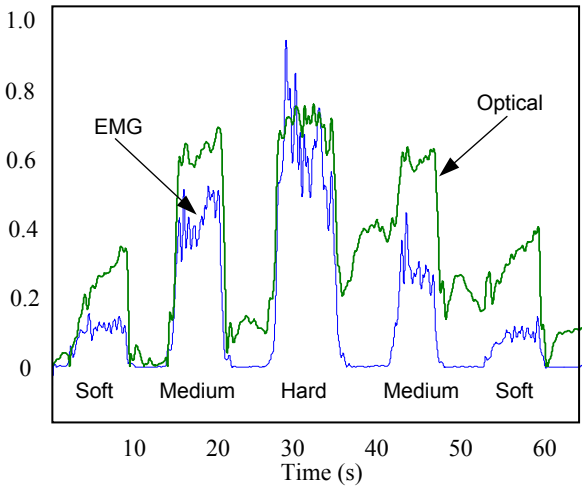

Figure 1. First Experimental Protocol

In the second experimental protocol, distinct characteristics for each type of contraction were established, although a shifting in the baseline of the optical signal occurred. As can be observed in Figure 2, when the extensions took place (first two contractions), the extensor output decreased for the duration of the contraction, while the flexor output remained relatively constant. When fist clenches were performed (second two contractions), both the extensor and flexor outputs decreased for the duration of the contraction. When the flexes were performed (last two contractions), the flexor output decreased for the duration of the contraction, while the extensor output remained constant relative to the shifted baseline.

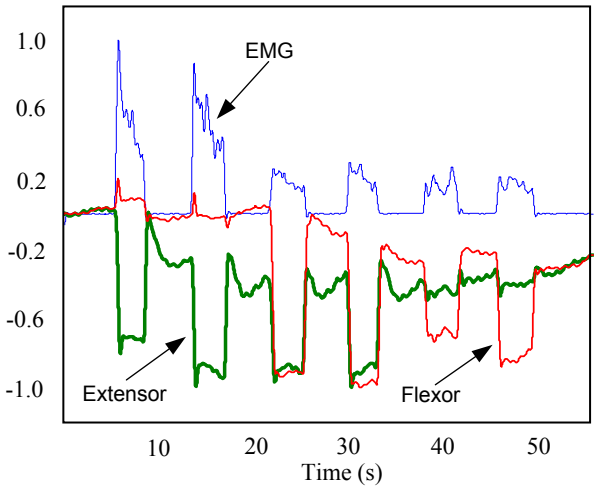

Figure 2. Second Experimental Protocol

DISCUSSION

These preliminary results indicate that the possibility exists for using LED's as a novel method of controlling a prosthetic device. The first experimental protocol demonstrated that the optical signal is qualitatively similar to the EMG in both magnitude and duration for the different degrees of contraction (soft, medium, and hard). The second experimental protocol indicated that with optical signals gathered from both the flexor and extensor muscles, different types of contractions could be differentiated from one another. With both of these experiments, however, a baseline shift in the optical signal occurred. This effect is most likely due to variations in the local blood perfusion or the metabolic consumption of oxygen over the course of the experiment. Both of these factors would have influenced the amount of light absorbed and reflected from the tissue. Additional studies should be performed in order to more accurately characterize this effect. It was concluded that the use of LED's and optical signals, which are free from electromagnetic noise, may be a low-cost, low-power, reliable alternative to current methods of controlling a prosthetic device.

REFERENCES

1. Bianchi, T., Zambarberie, D., Beltrami, G., and Verni, G., 1998, "NIRS monitoring of muscle contraction to control a prosthetic device," Proceedings of SPIE-The International Society for Optical Engineering, 3570, pp. 157-163.
2. Gelmetti, A., Giardini, M.E., Lago, P., Zambarbieri, D., Maestri, R., and Felicetti, G., 1998, "Preliminary study of muscle contraction assessment by NIR spectroscopy," Proceedings of SPIE-The International Society for Optical Engineering, 3199, pp. 61-67.
3. van Donkelaar, C. C., Huyghe, J. M., Vankan, W. J., and Drost, M. R., 2001, "Spatial interaction between tissue pressure and skeletal muscle perfusion during contraction," J Biomech, 34, pp. 631-637.
4. Schmidt, F.E.W., 1999, "Development of a Time-Resolved Optical Tomography System for Noenatal Brain Imaging," Ph.D. thesis, University of London, London, England, pp. 47-50.