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MULTIMODAL INPUT DEVICE WITH SEMG AND CONTACT FORCE SENSORS

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ABSTRACT

In myoelectric prostheses, movement artifacts are known to impair control performance. This study relates to a novel sensor which measures surface electromyograms (SEMG) as well as contact force at the electrode-skin interface. Its purpose is to explore the in-socket mechanical realities of movement artifacts in order to produce control algorithms that are more robust to said artifacts.

The new sensor includes a commercial SEMG electrode and four surface-mounted force sensors, stacked within a plastic housing. Preliminary experiments in an experienced transradial user showed that sudden lack of control was often caused by electrode lift-off or re-connection. Future work will include algorithms for alleviating these problems.

INTRODUCTION

In myoelectric prostheses, surface electromyogram (SEMG) sensors are located at the very same interface that transfers mechanical load between the prosthesis and the residual limb. Variations in this mechanical load are inevitable during normal use of the device. The accompanying variations in contact force and position between electrodes and residual cause disturbances (artifacts) in the SEMG signals that yield unpredictable electrode output, obscuring the user's motor intent and impairing prosthesis control performance. This is known to be a serious problem to some users of current myoelectric prostheses, to the extent that they choose to turn the prosthesis off in certain situations to avoid unsolicited movements that may cause harm to humans or objects.

The removal of artifacts from EMG signals has been researched extensively. When utilizing SEMG sites on or near the torso, electrocardiogram (ECG) artifacts are of particular interest; see i.e. [1] for a brief review.

When it comes to movement artifacts in prosthesis applications, the literature is considerably scarcer. Lovely et al. pointed out the problem, and suggested an implantable electrode as part of the solution [2]. In prosthesis control systems based on SEMG, movement artifacts are usually attenuated by high-pass filtering the raw SEMG signal with a cut-off frequency of approximately 20 Hz, as suggested in [3]. This filter removes the transient noise induced by most normal upper-limb movements. However, electrode displacement and contact force changes may also induce multiplicative disturbances of relatively low frequencies; this may happen e.g. when a heavy object is being lifted or in certain limb positions, causing the socket, and thus the electrodes, to be pressed harder against the residual, pulled away from it, or simply displaced sideways. Similar effects can be observed if the limb is moved to a new working position, a phenomenon known as the *limb position effect* [4]. This causes the amplitude of the SEMG signal to change, a form of motion artifact that cannot be removed through linear filtering. We propose to include explicit contact force measurements as a supplementary modality in order to identify and attenuate these unwanted phenomena. The resulting device is referred to as a multimodal myoelectric unit (MMU).

MATERIALS AND METHODS

The MMU

Each unit comprises a 13E200 electrode (Otto Bock), which has a built-in preamplifier and produces an output which is roughly proportional to the amplitude of the SEMG. Four FS1500 force sensors (Honeywell), each connected to one of four INA122UA instrumentation amplifiers (Burr Brown Corp.), are employed for contact force measurements. The electrode is coupled to the force sensors with a layer of elastic foam rubber, sandwiched between two semi-rigid plastic sheets, and all parts are eventually stacked within a plastic housing (Figures 1-3; the figures depict an older electrode than the one actually used). The foam rubber acts as a spring that allows the electrode an excursion of up to 3 mm when exposed to contact forces, similar to that of the electrode when mounted the traditional way. Table 1 summarizes the MMU's main characteristics.

The rationale for including four force sensors is as follows. Little is known about the in-socket mechanical realities of movement artifacts. While a single force sensor might enable detection of such states as global electrode lift-off or excessive contact force, with separate sensors in each corner of the device we achieve a joy stick-effect through which we can detect both magnitude and direction of the contact force, and thereby even sideways displacement. Furthermore, it facilitates the detection of partial lift-off, which may cause the electrode output to saturate and thus hinder all useful control of the prosthesis.

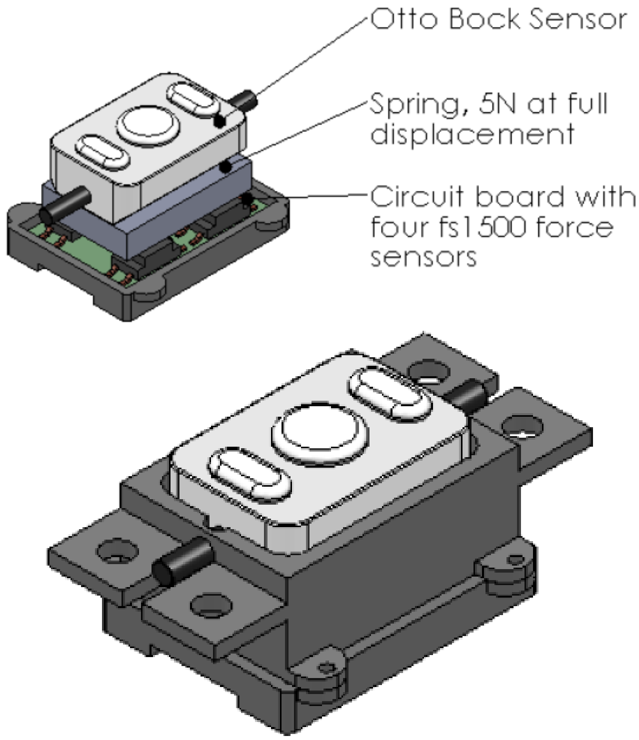

Figure 1: The inner structure of the multimodal device (top); fully assembled device (bottom).

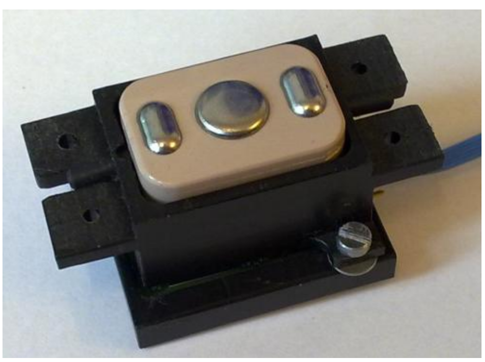

Figure 2: Fully assembled MMU (early version).

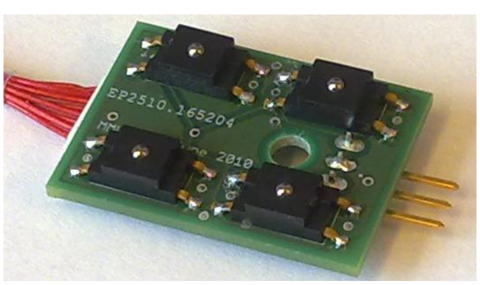

Figure 3: Circuit board with force sensors. The four instrumentation amplifiers are mounted on the opposite side of the board.

Table 1: MMU technical specifications

Parameter	Value
SEMG sensor	13E200 (Otto Bock)
Maximum excursion	3 mm
Contact force at maximum excursion	10 N (approx.)
Force sensors	FS1500 (Honeywell)
Number of force sensors	4
Output signal range (all outputs)	0-5 V
Approximate outer dimensions ex. flanges	W = 25 mm H = 30 mm L = 32 mm

<u>Experimental set-up</u>

Two MMUs were mounted in the socket of a transradial prosthesis with the attachment flanges on the outside of the inner socket. Care was taken to copy the conditions in the user's ordinary prosthesis as closely as possible. All input signals were fed to an analog input/output module, which was connected to a laptop computer via a 5 m USB cable extension. The computer software was configured to sample all MMU signals at 25 Hz and display them on the computer screen in real time. Also, the software is able to produce its own signals and write them back to the prosthesis through analog output channels, emulating electrode output signals. In this preliminary experiment, however, the electrode inputs were simply relayed back to the outputs without modification, in order to have the prosthesis behave in its normal manner.

The computer was set up to log all input and output signals to a storage device, along with video footage recorded during the signal acquisition. The video allowed us to thoroughly study significant events off-line, to establish exactly what happened and what caused it to happen.

The instrumented prosthesis was applied to an experienced transradial user, who was asked to carry out a number of tasks resembling activities of daily living (ADL). The tasks were selected among those reported by the user to frequently cause control problems, and the subject was asked to signal immediately whenever such problems were experienced. The time and type of event was recorded in a written log so that signals and video related to the event could be easily recalled from the database during subsequent investigation.

RESULTS

The user experienced a number of control problems during the experiment, including involuntary opening, failure to open and failure to close.

Figure 4 shows an example of the MMU readout, with the addition of explanatory annotations.

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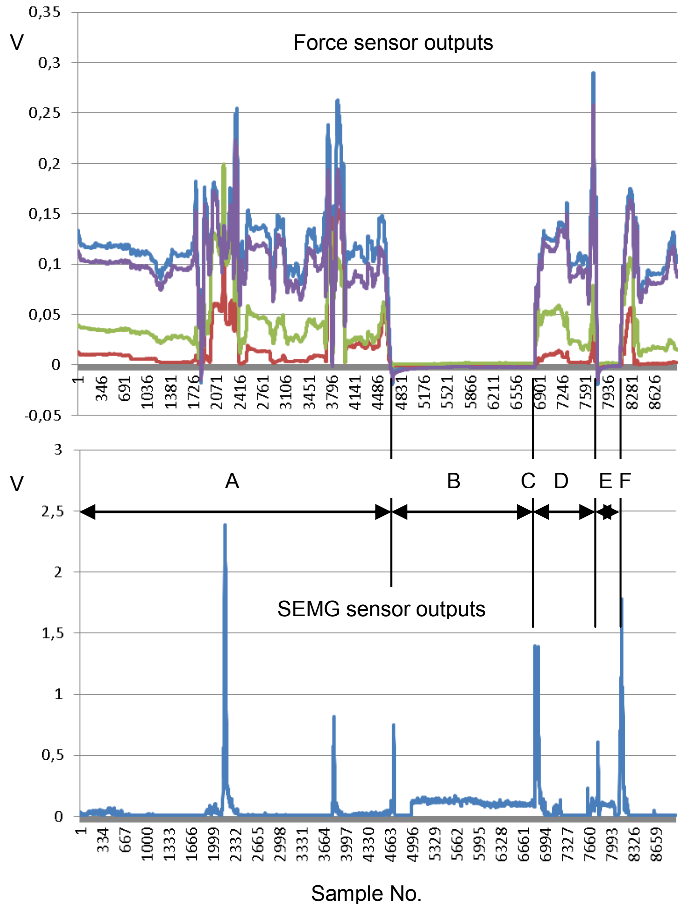

Figure 4: Example of MMU read-out. The graphs show the outputs captured from the extensor MMU, i.e. the one used for opening the terminal device, as the subject was instructed to hold an object with his prosthesis alternately behind his back and in front of him. Significant events have been marked manually off-line.

The events corresponding to the annotations are as follows:

A: Normal operation
B: Arm behind back; failure to open
C: Involuntary opening
D: Normal operation
E: Arm behind back; failure to open
F: Involuntary opening

The following interesting inferences can be made on the basis of these results:

1. The lack of ability to open the terminal device during intervals B and E is caused by total electrode lift-off, as apparent from the corresponding zero valued force signals.

2. The spontaneous opening of the terminal device at C and F are caused by spikes in the electrode output signals. In the force graphs one can see that these spikes occur exactly when the SEMG electrodes re-connect with the residual limb after a period of lift-off.

DISCUSSION

The preliminary results presented in this paper, illustrates that the MMU facilitates detailed studies of various modes of control failure in transradial myoelectric prostheses. This information may be used to optimize socket geometry or mechanical properties of the electrodes, in order to avoid electrode lift-off and similar phenomena that cannot effectively be compensated for through signal processing. Other phenomena, such as changes in signal amplitude due to changed contact force, may in principle be compensated for or reduced through proper processing. The practical applicability of such techniques cannot be established without an extensive amount of data, and ultimately through field testing in the participation domain. This will also require a redesign of the MMU to a smaller form factor and a completely self-contained device.

Although SEMG has been the predominant input signal source for externally powered transradial prostheses, several investigators have demonstrated that even other quantities, used alone or in combination, carry robust information relevant to the user's motor intent. Some relatively recent examples include; myo-pneumatic (pressure) sensors for measuring muscle bulge [5], coupled microphones and accelerometers for acoustic myography and dynamic artifact reduction [6], SEMG combined with near-infrared sensors to quantify local muscle activity through tissue oxygenation [7], and SEMG combined with accelerometers to reduce the position effect [8]. The multimodal device presented here thus fits into a larger family of devices that try to exploit new or supplementary information through *sensor fusion* in order to improve prosthesis control. We note that force (or pressure) sensors have been used by others, but to our best knowledge this is the first attempt at combining high-quality contact force measurements with SEMG.

In compliance with this perspective, the force signals (and any other relevant input information) can be used as full-fledged input signals, not merely for explicit artifact identification and reduction. Such "unified" approaches have been showed to outperform more *ad hoc* methods in certain cases [8]. Whether this approach will yield significant improvement in control performance remains an interesting subject for future research. Obstacles to approaching this goal include the identification of sufficiently general yet realistic methods for adapting the control parameters to each user, as well as relevant and realistic outcome measures.

ACKNOWLEDGEMENTS

K. Tomm Kristensen of Norsk Teknisk Ortopedi AS, Ottestad, Norway, and Hans Petter Aursand of the Orthopaedic-technical Department, St. Olav's Hospital, University Hospital of Trondheim, Norway, and their respective technical staff, are acknowledged for their invaluable contributions to the identification of relevant subjects, production and adaptation of prosthesis sockets, and for innumerable helpful hints during the course of the work.

This work was funded by the Research Council of Norway under grant 199924/O30.

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