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Implantable Myoelectric Sensors (IMES) for Upper-Extremity Prosthesis Control – Preliminary Work

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Abstract— **We are developing a multi-channel/ multifunction prosthetic hand/arm controller system capable of receiving and processing signals from up to sixteen Implanted MyoElectric Sensors (IMES). A BION® II package will house the implantable electrode electronics and associated circuitry. An external prosthesis controller will decipher user intent from telemetry sent over a transcutaneous magnetic link by the implanted electrodes. The same link will provide power for the implanted electrodes. Development of such a system will greatly increase the number of control sources available to amputees for control of their prostheses. This will encourage the design and fitting of more functional prostheses than are currently available.**

Keywords—**Neuroprosthesis, Myoelectric, Prosthesis, implant, Sensor**

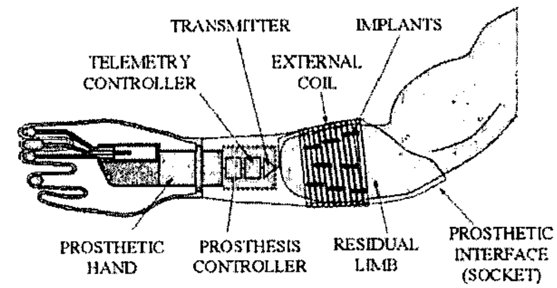

Fig. 1: Schematic of the proposed implantable myoelectric sensor (IMES) concept. The external coil is laminated directly into the prosthetic interface during socket fabrication and the telemetry controller is incorporated along with the prosthesis controller in the body of the prosthesis.

I. INTRODUCTION

Current state-of-the-art electric prosthetic hands are generally single degree-of-freedom (opening and closing) devices usually implemented with myoelectric control. Current prosthetic arms requiring multi-degree-of-freedom control most often use sequential control. Locking mechanisms and/or special switch signals are used to change control from one degree-of-freedom to another. As currently implemented, sequential control of multiple motions is slow, consequently trans-radial prostheses are generally limited to simple opening and closing of the hand, greatly limiting the function of these devices. Persons with recent hand amputations expect modern hand prostheses to be like their natural hands. Because these devices fail to meet user's expectations they tend to be under utilized or rejected. The major factor limiting the development of more sophisticated hand/arm prostheses is the difficulty in finding sufficient control sources to control the many degrees-of-freedom required to replace a physiological hand and/or arm.

While it is possible to locate three, possibly four, independent surface EMG sites on the residual limb, our preliminary work suggests it is both physiologically and technically feasible to create many more independent EMG sites in the same residual limb using implanted electrodes. We believe intra-muscular EMG signals from multiple residual muscles can be used to provide simultaneous control of multiple degrees-of-freedom in a multifunction prosthesis. More importantly, we believe that a user will be able to use this information in a meaningful and coordinated fashion. At the very least, we believe this controller would allow for seamless sequential control, i.e. sequential control without intermediate steps such as muscle co-contraction or actuation of locking mechanisms. This in and of itself would be a big improvement over the current state-of-the-art.

II. METHODOLOGY

Implementation of this system will involve development of a multifunctional prosthesis controller capable of taking the output of a transcutaneous telemetry link and using this output to decipher user intent. Fuzzy logic techniques [1] will be used to detect EMG onset and classify user intent from multiple EMG signals. Once intent has been deciphered the prosthesis controller will execute the desired prosthesis function. This controller will be able to drive and control up to eight degrees-of-freedom (DOF).

The implantable myoelectric sensors (IMES) will be transcutaneously-coupled through a magnetic link to an external exciter/data telemetry reader that is physically incorporated into the prosthesis (**Fig. 1**). No percutaneous wires will cross the skin. A miniature coil, within the EMG sensor will serve the dual function of coupling power and bi-directional telemetry to the EMG sensor electronic circuitry. Each implantable myoelectric sensor will be addressable, and have provision for four different EMG amplifier gain settings. All of the EMG sensor circuitry will be contained within an application-specific integrated circuit (ASIC). The only component external to ASIC will be a blocking capacitor, placed in series with one of the EMG sensing electrodes, to act as a safety element. Each IMES will be packaged in a BION® II hermetic ceramic capsule provided by the Alfred E. Mann Foundation (AEMF)

(Valencia, CA). These capsules are small enough to permit injection through a 12-guage hypodermic needle.

Transfer of sensed EMG to the prosthesis controller will be performed by an external transcutaneous magnetic telemetry subsystem. The telemetry system will consist of compact custom electronics, a single antenna coil and be capable of handling up to sixteen IMES. EMG sample rate will be 1.2k samples per second with at least eight sensors operational at 10-bit accuracy per sample. The Exciter will operate at a carrier frequency of 1.6 – 2 MHz with a forward telemetry data rate of ~422kBPS, and a reverse telemetry data rate of ~105kBPS. The antenna coil will be laminated into a prosthetic interface (socket) such that when the prosthetic socket is donned this coil will encircle the IMES and be in an optimal geometry to inductively couple with these electrodes (**Fig 1**.)

One of the key issues for the potential success to the use of IMES is EMG signal independence. The primary measure of myoelectric signal independence is the amount of cross-talk. Traditionally, cross-talk is prevented from interfering with prosthesis operation by setting a threshold. The amputee must generate a signal greater than the threshold to operate the prosthesis. The threshold is set above the background noise and cross-talk from nearby muscles. The choice of implant EMG sites and the cross-talk level are closely related. There is little if any published work on the control of complex mechanisms by EMG from the kind of sites accessible to implants. To explore this issue and the issue of the overall technical feasibility of placing electronic sensors in a strong magnetic coupling field we performed preliminary experiments. A Proof-of-Concept system was built that demonstrated the technical feasibility of an implantable EMG sensing system using reverse telemetry to transmit sensed EMG and forward telemetry to transmit power and a single subject experiment was performed that demonstrated the independence of up to 7 channels of intra-muscular EMG data.

A. Proof-of-Concept System

To demonstrate the technical feasibility of an implantable EMG sensing system a Proof-of-Concept system was constructed that used an application-specific integrated circuit (ASIC) originally developed to telemeter inputs from strain gauge sensors embedded within conductive carbon panels commonly found on military aircraft and naval ships [funded by Office of Naval Research (ONR)]. See **Fig 2** for block diagram.

This Proof-of-Concept system was built to address whether or not the strong magnetic excitation required to power the system would interfere with the transduction or amplification of the small EMG signals. It was thought this interference might result from rectification artifacts at the EMG electrode sites, excessive induced AC voltages in the interconnecting leads and compromised amplifier performance due to input overload, bias shifts or other unforeseen interactions. The other issue was to ensure that practical modulation rates of the local magnetic field by the transponder were high enough to realize a sufficiently high sampling rate of the EMG signal.

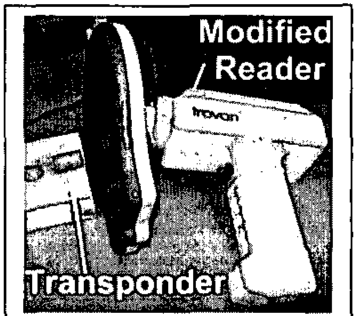

Fig. 3: Proof-of-Concept System

For this system the ASIC was packaged in a conventional 14-pin DIP package wired to a few external electronic components and placed within a ½"-diameter cylindrical plastic housing (Transponder in **Fig 3**). Although not implantable, this small-sized package included electrical terminals that could be connected to surface, or percutaneous EMG electrodes. The ONR transponder assembly is completely passive, i.e. it is powered by an external magnetic field produced by a remote transmitter/reader. Data is transmitted back from the transponder to the reader where it is decoded into a digital data stream.

The Proof-of-Concept Reader, was implemented using a commercially available Trovan® radio-frequency-identification (RFID) transponder reader (Reader in **Fig. 3**) that was modified to decode the data from the ONR transponder. The modified reader operated at 130kHz. The intent of using available technology for preliminary studies, in the form of the ONR transponder and the Trovan® reader, was to confirm the electrical feasibility of the proposed EMG telemetry system.

In a single subject experiment to demonstrate the Proof-of-concept system, a commercially available surface myoelectrode was connected to the modified ONR transponder and placed over the forearm flexors. The subject then elicited a signal by flexing the wrist. This signal was captured by porting it over a TCP/IP connection to a telnet connection that streamed the data to a file for further signal processing. For the purposes of this demonstration the data was de-trended and graphed (**Fig. 4**). This process of

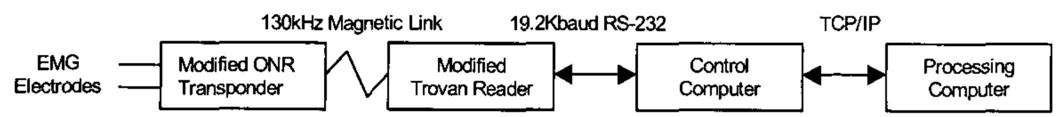

Fig. 2: Proof-of-Concept System Block Diagram

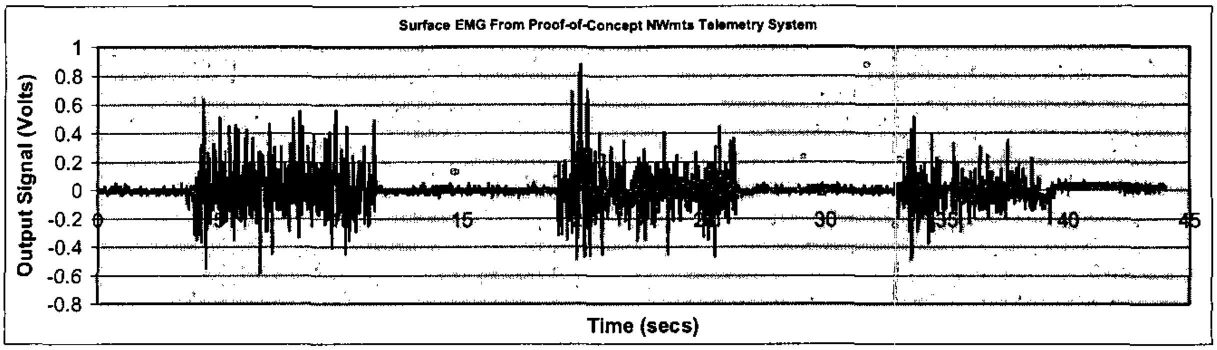

Fig. 4: Graph of zero-mean (de-trended) EMG data recorded using the Proof-of-Concept system. The signal was ported to a file via a TCP/IP connection in real-time while a subject performed voluntary contractions of the forearm flexors.

eliciting EMG signals was repeated with the forearm of the subject remote from the reader coil and again with the forearm next to the reader coil. The purpose of the latter test was to make sure the system would still read with the arm in the field and to see if the presence of myoelectrodes in the magnetic field would cause the reader any problems. In all instances EMG signals could be obtained.

The Proof-of-Concept did not address packaging issues pertaining to implementation in a form suitable for clinical prosthesis use. The challenge is not that an implantable myoelectric sensor using reverse telemetry can be built – indeed this preliminary work shows that it can. Rather, the engineering challenge is whether the external reader coil can be built in a form physically small enough and light enough that it can be incorporated into a prosthesis. The other issue raised by this work was the issue of power consumption. The litz-wire of the external reader coil is bulky and requires high currents to power the implants, adding both heat and weight to the arm prosthesis. Both of these are issues that have yet to be addressed and are part of our onging work.

B. Independance of Multiple Intra-Muscular EMGs:

To explore the questions of intra-muscular signal independence and the ability to voluntarily elicit a particular signal channel independently from the rest, another single subject experiment was performed in which seven channels of intra-muscular EMG were obtained from different muscles in the forearm. The muscles chosen were based on the desire to be able to independently control a two degree-of-freedom (DOF) wrist, and 3 DOF prosthetic hand [2]. Working on the theory that the use of implantable electrodes will allow all hand and wrist functions to be controlled simultaneously the following muscles were chosen: Supinator and pronator teres to give wrist rotation, flexor carpi ulnaris and extensor carpi ulnaris to give wrist flexion and extension, flexor pollicis longus and extensor pollicis to control a thumb, and flexor digitorum sublimas and extensor digitorum communicus for finger opening and closing. Using a clinical electromyography text [3] an initial location for each muscle was found and two percutaneous fine-wire intra-muscular electrodes, spaced about 15 mm apart, were placed in the target muscle on either side of this location. Anticipating our future implantable device, this spacing was chosen to mimic that of the electrode spacing of the *Alfred E. Mann Foundation (Valencia, CA)* BIONII® package. An 8 channel Noraxon Corp., (Phoenix, AZ) telemeter Telemyo 8 system (Sample rate 1400 Hz/channel, 10 Hz highpass cutoff, 500 Hz lowpass cutoff, gain of 2000) was used to collect the EMG data. Once all the percutaneous fine-wire electrodes were located the subject was instructed to elicit a response, six times, from each electrode site independent of the other sites and to hold that response for 5 seconds.

In the actual experiment only seven of the eight proposed channels were obtained. Also, the second electrode for the differential recording of the supinator failed to function properly so only a single-ended supinator recording was obtained. However, we were able to locate and acquire data for six ½ differential EMG channels. The results are shown in **Fig. 5.** The charts show mean RMS voltage (computed over 64 samples/point) of six medium level contractions, held for five seconds, for all channels with respect to the commanded channel. In all cases the commanded channel could be elicited at a substantially greater level than the other channels. However, the RMS voltage seen on some of the other channels is non-trivial compared to the commanded channel. The signals seen on the other channels are due to a combination of co-activation and/or cross-talk.

From the perspective of our fuzzy logic controller this is not necessarily a problem. The automatic rule generation takes into consideration RMS voltage levels for each channel and generates a rule to classify this combination of signals as being associated with the desired function. So while a simple "Crisp" threshold might be problematic, a controller running onset detection and pattern recognition/classification should be a lot more robust.

Consequently, the results demonstrate the ability to locate multiple implant sites that are sufficiently independent to enable multifunction control. Further, it was possible to voluntarily elicit each site using dedicated control motions.

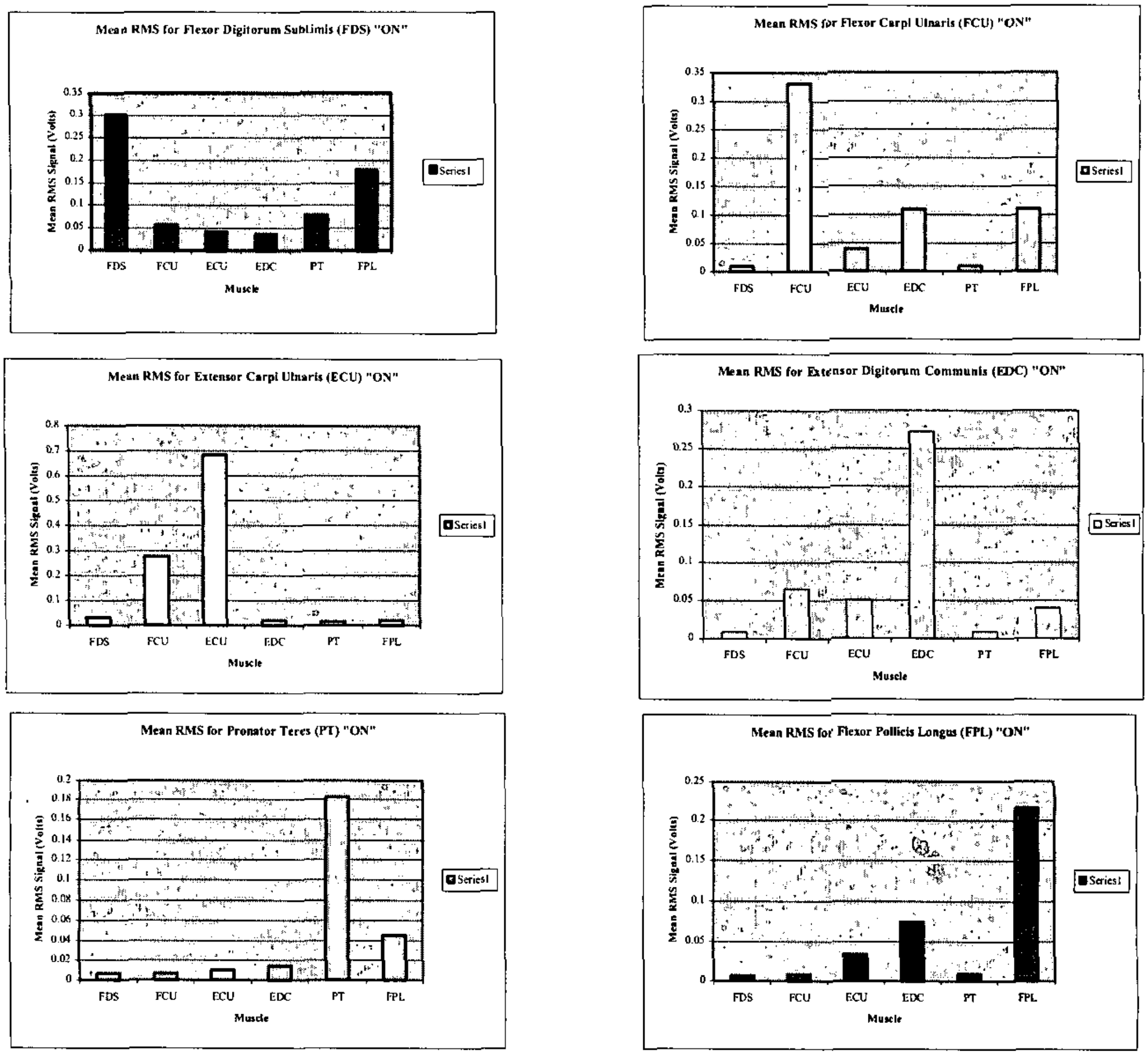

Fig. 5: Results of the percutaneous fine-wire intra-muscular experiments.

III. Conclusion

The appeal of implanted myoelectric sensors (IMES) for EMG control is that the EMG can be measured at its source providing relatively cross-talk free signals that can be treated as independent control sites. Therefore the number of degrees-of-freedom that can be simultaneously controlled and coordinated in an externally powered prosthesis will be greater than with surface EMG or mechanical control sites. Not only will superficial muscles become more distinguishable, but deeper muscles can also be used as additional control sites.

Our preliminary work demonstrates that the idea is both physiologically and technically feasible. The percutaneous fine-wire experiments demonstrated that sufficient signal independence can be obtained on multiple channels and that these signals can be voluntarily controlled. The Proof-of-concept system demonstrated the technical feasibility of using reverse telemetry to pass EMG data out of the body and went a long way towards starting the actual design of the intended system.

Acknowledgment:

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