An Electromyogram Simulator for Myoelectric Prosthesis Testing

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***Abstract*—Myoelectric prostheses use the naturally occurring surface electromyogram (EMG) produced by extant muscle tissue to provide amputees control of artificial limbs. Design and testing of these devices is currently performed using function generators or the healthy EMG signal of the tester. However, these methods of testing either do not provide data representative of the intended usage or are inconvenient to the tester, respectively. In this paper, we present a simple and portable prototype device which simulates the surface EMG signal in order to test myoelectric prostheses with a currently unavailable level of precision.**

I. Introduction

The device presented in this paper, the "EMG simulator," has been developed for Liberating Technologies Incorporated (LTI), a Massachusetts-based manufacturer of myoelectric prosthetic devices. Myoelectric prostheses use the surface electromyogram (EMG) signal produced by muscle tissue (often extant muscle tissue at or near the locus of amputation) as their primary mechanism of user control. Usage of the surface EMG as a control signal provides this class of prosthetics with the advantage of being relatively intuitive to control and cosmetically appealing. However, the amplitude of the surface EMG varies significantly between subjects. Myoelectric prostheses must therefore be tuned for each user.

Because of the level of fine-tuning required by each prosthetic device, diagnosing and repairing malfunctions can be extremely difficult. This problem is compounded by the lack of an accurate and physiologically realistic source of test signals for direct application to the electrodes within a prosthetic socket. Currently, testing is performed by using either a commercially available function generator or the EMG signal of a human tester. These methods of testing have the respective disadvantages of being either physiologically unrealistic or restrictive to the tester.

In this paper we present a device for the testing of myoelectric prostheses, the EMG simulator. In Section II we present the engineering requirements for the design of the device. In Section III we present the approximation of the surface EMG as a band-limited Gaussian signal. Section IV discusses the algorithm used in the generation of such a signal, as well as the methods involved in delivering the signal to the prosthesis electrodes. Section V presents a review of the device and its application.

II. Design Parameters

The EMG simulator was designed to be a handheld and battery-powered device capable of interfacing with the wide array of electrodes used by LTI-supported prostheses. It incorporated two independent channels of output signal in order to interface with two different electrodes on a given prosthesis. The output signal was within the range of most surface EMG signals (1 μV_{pp} to 10 mV_{pp}) with additive sinusoidal power line interference (1 μV_{pp} to 10 mV_{pp}) of frequency selectable by the user (50 or 60 Hz). Additionally, three different modes of operation were specified for the device: A manual operation mode in which EMG amplitude levels are adjustable by knobs, a "ramp" mode in which EMG amplitudes were modulated by a linear ramp function, and a "pulse" mode in which EMG amplitudes were modulated by a square-wave with user selectable duty cycle. In each of these modes, power-line noise amplitude and EMG amplitude were selectable by the user.

III. The EMG as a Gaussian Signal

Because the EMG simulator was designed to be a handheld device, its computational power was limited. Due to this limitation, physiologically realistic simulations of the EMG (i.e., simulations which take into account the contributions of individual action potentials in the muscle fiber) were unfeasible. Previous work by Clancy and Hogan [1] suggests that the statistical distribution of an EMG falls in the realm of the Gaussian and Laplacian distributions. Because Gaussian signals can be generated with relative ease, we decided to approximate the EMG as a Gaussian signal.

The EMG signal originates with the action potentials of individual motor neurons, which are organized along with the respective innervated muscles into motor units. When excited, each motor unit produces a spike-shaped action potential, each of which is similar in shape when recorded at the skin surface (albeit differing in peak amplitude). During typical contraction, the inter-pulse intervals between successive action potentials can be realistically modeled as being statistically independent of each other and of the firing times of surrounding motor units [2]. Thus, action potentials emanating from motor units can be modeled as independent and identically distributed (IID) random variables.

The central limit theorem states that the sum of a sufficiently large number of IID random variables follows a Gaussian distribution. The voltage at an EMG electrode can be modeled as the sum of a large number of IID asynchronous motor unit action potential firings. Thus, it can be approximated as a Gaussian process. In practice, however, the EMG signal is band-limited to

978-1-4244-6924-6/10/$26.00 ©2010 IEEE

between 20 and 400 Hz due to the constraints imposed on the signal bandwidth by action potential shapes and firing patterns.

IV. Implementation

The hardware implementation of the prototype EMG simulator consisted of a commercially available microcontroller unit (MCU) development board from Olimex, Inc. (LPC-MT-2138) used in conjunction with a custom auxiliary electronics board housing the analog output stage of the device. Successful implementation of the device required three signal stages: digital signal generation, digital-to-analog conversion, and analog signal delivery.

Digital Signal Generation

The output signal, which consisted of a band- limited Gaussian signal, a multiplicative modulation of the Gaussian signal (depending on the mode of operation) and 50/60 Hz additive line interference was produced digitally on the MCU. A linear congruential 32-bit random number generator described in [3] was used to produce uniform random numbers. A new random 32-bit number R[n] was generated from the prior random number S[n] via the relation

$$R[n] = 1664525 \cdot S[n] + 1013904223 \quad (1)$$

This type of random number generator relies on the fact that C variables return to zero upon overflow, thus an addition and multiplication (no modulo operation) are all that is required.

In order to produce the band-limited Gaussian signal, the random number R[n] was shifted to signed format by subtracting the mean value and passed through a 4^{th} order FIR digital band-pass filter (F_S = 900 Hz, F_L = 20 Hz, F_H = 200 Hz) implemented with integer coefficients. Depending on the operating mode, this signal was then multiplied by a modulation function to produce the EMG signal. After the EMG signal was generated, a sine-wave of either 50 or 60 Hz (depending on user input) was added. Each channel required the production of two separate outputs, with the second including the additional step of inverting the EMG signal before the addition of the sine-wave in order to present the bipolar electrode on the prosthesis with the normal EMG at one terminal and an inverted EMG at the other terminal, for reasons discussed in the section on signal delivery.

Digital-to-Analog Conversion

After the output signal was generated in 32-bit signed integer format, it was converted to unsigned 16-bit format by level-shifting and integer division. This 16-bit signal was then transmitted via serial peripheral interface (SPI) to a 16-bit digital to analog converter (DAC) on the auxiliary electronics board. A 16-bit resolution was necessitated by the dynamic range of the output signal, $2\mu V_{pp}$ to $40mV_{pp}$, a ratio of 20,000. While technically a 15-bit DAC (32,768 quantization levels) would be sufficient in this case, 16-bit DACs are cheaper and easier to find due to their widespread use in industry.

Signal Delivery

Two analog signals were produced for each channel, with one having a negated EMG signal (but not a negated 50/60 Hz sinusoidal noise component) with respect to the other. In this manner the bipolar electrode was presented with a common-mode 50/60 Hz noise component and a differential EMG component.

A concern in the delivery of the signal was that the small voltages involved (μV range) would be too corrupted by noise to be recognizable at the electrode after being transmitted via a copper wire. To counteract electromagnetic interference, the cabling from the output electronics to the prosthesis utilized a shielded cable (connected to the battery reference of the EMG simulator).

V. Conclusion

The EMG simulator was designed to produce a physiologically realistic yet precisely controllable EMG signal for the testing of myoelectric prosthetic devices. Although it does not produce a true EMG signal (i.e., the sum of action potential spikes), it produces one which is approximately equivalent, a band-limited Gaussian signal. User selectable modes of operation allow for both manual and semi-automated testing with full control of output parameters. The simulator provides a test signal for use by prosthesis designers that is improved in both precision and realism over the current state of the art.

Acknowledgement

The authors would like to thank Liberating Technologies, Inc. for sponsoring and partially funding the development of the EMG simulator. In particular, we thank Todd Farrell, Bill Hanson, and Bob Quinzani of LTI for their technical feedback throughout the design process. S. Patrick, J. Meklenburg, and S. Jung completed this work as an undergraduate project at Worcester Polytechnic Institute under the supervision of Y. Mendelson and E.A. Clancy.

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