

PIC 32 MICROCONTROLLER BASED sEMG ACQUISITION SYSTEM AND PROCESSING USING WAVELET TRANSFORMS

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Abstract – In this paper, an embedded system platform is used for signal acquisition and processing. On a healthy male subject, the motor unit of the ring finger is marked. The surface Electromyographic (sEMG) signals and their corresponding skeletal muscle force signals are acquired using a PIC 32 microcontroller at a sampling rate of 2000 samples per second. The filtration is achieved by using a Wavelet transform Daubechies 44 filter at 5 levels of decomposition for sEMG and a Chebyshev Type-II filter for skeletal muscle force signals. The data is acquired through the Universal Asynchronous Receiver/Transmitter (UART) model of the PIC 33MX360F512L embedded test bed and is compared to data acquired with standard sEMG Delsys® Bagnoli 16 acquisition system.

Keywords: sEMG, Wavelet Transforms, Real-time Data Acquisition,

I. INTRODUCTION

The functioning human body is one of the most intricate systems available. Similarly, surface Electromyography (sEMG) signals are quite complex and challenging to analyze. Currently more than 2 million Americans have an amputation, and the number of amputees is increasing by approximately 185,000 per year [1]. Research related to upper extremity prostheses over the recent past has been focused on increasing function of the user coupled with reducing the psychological and emotional aftermath of dealing with limb loss. A robotic prosthetic hand should be autonomous, have a high level of functionality, comfort and be easy to use [2]. From [3, 4] it is clear that electromyography (EMG) signals have served as a strong model for prosthetic function. The EMG signal is a natural means of communication and can be recorded at the surface of the limb, which is known as surface EMG (sEMG).

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The sEMG is the result of the electrical activity during skeletal muscle contraction. It ranges between -5 and +5 mV. The sEMG signals are widely used for the position and force control of the hand prosthesis [5, 6]. Since the skeletal muscle force and the sEMG signals are directly proportional, an increase in force production results in increased sEMG activity. Therefore, the latter is used as a control input to realize force and motion control of a prosthetic hand. This makes the precise interpretation of the sEMG signal an essential task.

In the present research environment, embedded systems have become pervasive and as research advances, more and more functions of analog circuits are being realized by microcontrollers, Analog to Digital Converters (ADCs) and Digital to Analog Converters (DACs). In a modern control system, data acquisition, processing and control functions are performed by embedded systems. A well-designed embedded control which deals with widely varying operating conditions can realize excellent system performance. The embedded system should be designed carefully in order to have a robust, precise, fast and consistent performance.

In our previous work [7-9], we implemented a real-time embedded control system to control the force and motion of a prosthetic hand. The present work is a step ahead in the same direction where the authors explore the PIC 32 microcontroller as an embedded platform to simultaneously acquire the sEMG and skeletal muscle force. sEMG sensors are placed on the ring finger motor point of the dominant hand of a healthy subject and the subject is asked to squeeze a stress ball which has a force sensing resistor attached to it. The data is simultaneously captured using the PIC 32 embedded platform with MATLAB®/SIMULINK® real-time workshop (RTW) and regular NI LabVIEW™ data acquisition. Both sEMG and force data is captured at 2000 Hz. The sEMG signal is filtered using four different types of filters nonlinear Bayesian filters: Exponential, Poisson, and Half-Gaussian filter and wavelet transforms Daubechies 44 filter. The corresponding skeletal muscle force is filtered by a Chebyshev type-II filter [8]. Among these different types of filters the wavelet Daubechies 44 filter is giving the best results [10-15].

This paper is organized as follows: the present section is followed by the ‘Experimental Set-Up,’ then the ‘Signal Pre-Processing,’ ‘Methodology,’ ‘Results and Discussion,’ are presented. The paper is concluded with the section of ‘Conclusion and Future Work.’
II. EXPERIMENTAL SET-UP

Using a muscle stimulator (Richmar HV 1100) the motor point for the ring finger of the dominant hand of a healthy male subject is identified. Prior to affixing the sEMG sensors, the skin surface of the subject was prepared according to International Society of Electrophysiology and Kinesiology (ISEK) protocols. Different sets of experiments were conducted with DE 2.1 and DE 3.1 DELSYS® Bagnoli sEMG sensors. One sensor was placed on top of the motor point location and two sensors were placed next to the motor point. The subject was asked to squeeze the stress ball with the ring finger which has a 0.5 inch force sensing resistor from Interlink™ Electronics mounted on it. The sEMG and skeletal muscle force signals were acquired using the 16-channel DELSYS® Bagnoli sEMG and NI ELVIS™ respectively. Using a PIC 32 embedded platform. A similar experimental set-up was designed where the sEMG and the force data was acquired. In both the cases, data was captured at a sampling frequency of 2000Hz. Fig. 1 and 2 show the two experimental set-ups.

III. SIGNAL PRE-PROCESSING

From the authors’ previous research [16] shows that the Bayesian based filtering method yields the most suitable sEMG signals. These nonlinear filters extract a signal by significantly reduces the noise. The latent driving signal x results in the EMG which can be computed using an instantaneous conditional probability \( P(EMG | x) \), [17]. Research work in [16] describes the EMG signal as an amplitude-modulated zero mean Gaussian noise sequence. This estimation algorithm uses the model of the conditional probability of the rectified EMG signal \( emg = |EMG| \), [17].

Equation (1) gives an “Exponential Measurement Model” for the rectified EMG signal [17].

\[
P(emg|x) = \frac{\exp(-emg)}{x}.
\]

Equation (2) gives a “Poisson Measurement Model” for the rectified EMG signal [15].

\[
P(emg|x) \approx x^n \exp(-x).
\]

In equation (2) \( n \) is the number of events. Equation (3) presents the “Half-Gaussian measurement model” for the rectified EMG signal [17].

\[
P(emg|x) = \frac{2^{n} \exp(-\frac{emg^2}{2x})}{\sqrt{(2\pi x^2)}}.
\]

The model for the conditional probability of the rectified EMG is a filtered random process with a random rate. The likelihood function for the rate evolves in time according to the Fokker–Planck partial differential equation [16]. The discrete time Fokker–Planck Equation is given by Equation (4).

\[
p(x,t-\varepsilon) = \alpha * p(x-\varepsilon, t-1) + (1 - 2 * \alpha) * p(x, t-1) + \alpha * p(x+\varepsilon, t-1) + \beta + (1 - \beta) * p(x, t-1)
\]

In Equation (4) \( \alpha \) and \( \beta \) are two free parameters, where \( \alpha \) is the expected rate of gradual drift and \( \beta \) is the expected rate of sudden shift in the signal [17]. The latent driving signal \( x \) is discretized into bins of \( \varepsilon \). These free parameters of the nonlinear Half-Gaussian filter model are optimized by a simple elitism based Genetic Algorithm (GA). GA is an optimization algorithm which is based on observing nature and its corresponding processes to imitate solving complex problems, most often optimization or estimation problems, [18-20]. A wavelet transform is used with a Daubechies mother wavelet (filter). The order of the wavelet is chosen as 44 at 8 levels of decomposition [21]. Continuous wavelet transform of a signal is computed by [21],

\[
CWT(t,\omega) = \left( \frac{\omega}{\omega_0} \right)^{1/2} \int_{-\infty}^{\infty} s(t-\tau)d\tau
d\tau
= \{ s(t), \psi(t) \}
\]

The inner product of the signal \( s(t) \) and \( \psi \) \( L^2(R) \{0\} \) is the mother wavelet function. It must satisfy the following condition:

\[
0 < C_\psi = 2\pi \int_{-\infty}^{+\infty} \left| \Phi(\xi) \right| \frac{d\xi}{|\xi|} < +\infty
\]

Skeletal muscle force signal from FSR is filtered utilizing a Chebyshev type II low pass filter with a 550 Hz pass band frequency.

IV. METHODOLOGY

The acquisition and transmission of the sEMG signals are done by using Analog Input (ADC Module) and the UART module of the PIC 32. The outputs from the DELSYS® Bagnoli system are connected to the analog input channels of the PIC 32 micro controller. In this work the signal from the...
motor unit (middle sensor) is acquired and pre-processed. A C code is generated by a dsPIC block set for the PIC32 from SIMULINK®. The dsPIC block set generates a ‘.hex’ file, and this file is imported by MPLAB® to program the PIC32. The sEMG and the corresponding skeletal muscle force data is read by using analog Input module. There is an internal analog to digital converter (ADC) in the PIC 32. It has a 10-bit resolution so that it can differentiate up to 1024 different voltages, usually in the range of 0 to 3.3 volts, and it gives 3mV resolution. The signals from the microcontroller are transmitted to the PC through the UART module in the PIC32 using serial communication. In this design, a virtual ‘com port’ is created to feed the data via USB cable to the computer. The signals from the ports are read by MATLAB®.

Fig 2 depicts the acquisition system using the PIC 32 microcontroller

![PIC 32 and Embedded Platform](image)

**V. RESULTS AND DISCUSSION**

Surface Electromyography (sEMG) and the corresponding skeletal muscle force data was acquired from the microcontroller through UART channel 2 of the PIC32MX360F512L by a virtual com port via USB at 57600 baud rate. The data from the microcontroller was converted into uint16 data before it was transmitted through the UART. The PIC32 microcontroller is running at 80 million instructions per second (MIPS) with its phase lock loop (PLL) activated. It was running at an external clock frequency of 8 MHz with internal scaling enabled. Fig. 3a shows the sEMG signal acquired by the proposed acquisition system using DE 2.1 electrodes. Fig3b. shows the filtered sEMG signal using a wavelet transform Daubechies 44 filter. Fig. 4a and 4b shows the raw EMG and wavelet transform based Daubechies 44 filtered sEMG signals at 5 levels of decomposition acquired by the proposed acquisition system using DE 3.1 electrodes.

The following experiment was repeated several times to check the consistency and the accuracy of the proposed acquisition system. Fig. 5 and 6 show the validation for the proposed acquisition system for repeated experiments using DE 2.1 and DE 3.1 electrodes.

![Fig. 2. Experimental Set-Up with PIC 32 Embedded Platforms and DELSYS® EMG System.](image)

![Fig. 3a. Unfiltered sEMG Signal from the Proposed Acquisition System Using DE 2.1 Electrodes, 3b. Filtered sEMG signal with Wavelet Daubechies 44 Filter](image)

![Fig. 4a. Unfiltered sEMG Signal from the Proposed Acquisition System Using DE 3.1 Electrodes, 4b. Filtered sEMG signal with Wavelet Daubechies 44 Filter](image)

![Fig. 5a. Unfiltered sEMG Signal from the Proposed Acquisition System Using DE 2.1 Electrodes, 5b. Filtered sEMG signal with Wavelet Daubechies 44 Filter](image)
The sEMG signals and the corresponding skeletal muscle force acquired from the standard acquisition system are given in Fig. 7a, 7b and 7c. Since the sEMG is a random signal corrupted with noise it is hard to achieve the same correlation every time. This proposed acquisition and filtering system is working better than the Half-Gaussian filtering that was previously developed by the authors [22].

VI. CONCLUSION AND FUTURE WORK

In this paper, a real-time sEMG acquisition and processing system was designed for the control of a prosthetic hand prototype. The proposed design shows the same performance when compared with the standard EMG acquisition system. The DE 2.1 electrodes are giving good results when compared to the DE 3.1 electrodes of the Delsys® Bangnoli 16 system. This proposed acquisition system miniaturizes the size and helps the transmission of the data from the microcontroller to the computer. This helps the user to compare the accuracy, precision and real-time performance of the acquisition system.

For future work, we are planning to implement a real-time online model-based force estimation along with controller design for position and force control, based on this embedded platform [22]. It will also be interesting to do the wavelet Daubechies 44 filtration online instead of post processing. Finally, we expand this sEMG acquisition to all the five fingers of the prosthetic hand prototype.

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