Graded Muscle Contractions Determined by Temporal Recruitment

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***Abstract*—Electromyogram (EMG) signals have the potential to allow patients without total muscle controls to operate electronic or mechanical devices, such as a power wheelchair. A muscle contraction can be interpreted as a switching signal and its strength can determine the intended level. The purpose of this study is to implement an algorithm to accurately detect the strength of a muscle contraction. Muscle contraction strength can be increased by temporal or spatial recruitment. In this case, the graded muscle contraction is detected by the temporal recruitment, where the frequency of the EMG signal is evaluated. A nonlinear detection algorithm is used to define the duration of a contraction episode. The frequency of the spikes within the contraction episode is used to determine the contraction strength. The algorithm should be useful for designing myoelectrically controlled devices.**

***Keywords*—electromyogram; myoelectric control; graded muscle contraction; temporal recruitment; signal processing; nonlinear detection algorithm**

I. Introduction

Myoelectric controls have been widely used for prosthetics and assistive technology for several decades [1]. However, how to extract the maximum amount of information from the electromyogram (EMG) remains to be an important topic of on-going research. People with limited mobility can benefit from various devices that are operated by interpreting signals from muscle contractions. For example, a power wheelchair has the potential to be completely directed by the contractions of any muscles that produce reliable electrical signals, but not necessarily sufficient mechanical forces [2].

The strength of a muscle contraction can be increased via two types of recruitment: spatial recruitment and temporal recruitment [3]. Spatial recruitment is the increase in number of motor units in order to increase strength. This results in an electromyogram signal with greater amplitude. Temporal recruitment, or rate coding, is the increase in rate of action potentials in order to increase the strength of a contraction [1]. This results in an electromyogram signal with a greater frequency. This study developed a technique to grade muscle contractions into three levels; low, medium, and high. This is accomplished by 1) detecting a time interval of sustained contractions and 2) estimating the frequency of the firing of action potentials and quantifying it to three levels of contraction strength. The project has been implemented on an embedded system platform. The algorithms have been developed and coded in the C language.

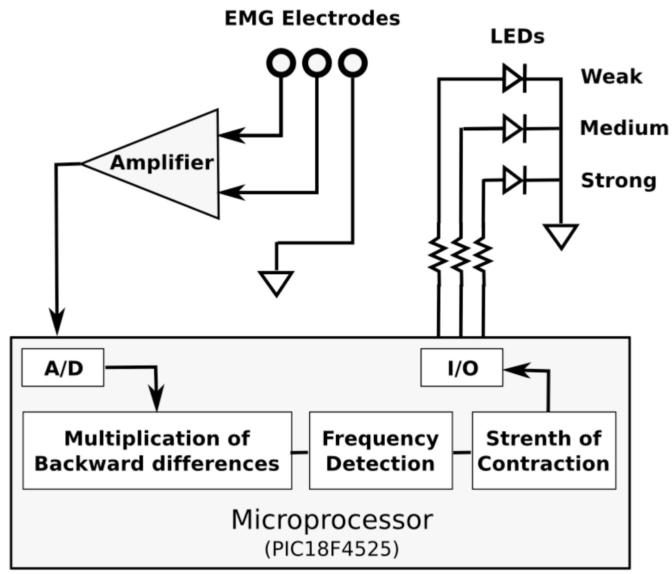

Fig. 1. Block diagram of the embedded system for quantifying the strength of muscle contractions

II. Methods

A. *Instrumentation*

The embedded system for EMG measurement was based on a previous project [4]. The electromyogram signal was attained by using three surface electrodes places on an individual. Two of electrodes are located on the forearm used to pick the muscle contraction. The third electrode is used a reference (ground) point for voltage. The electrodes are connected to leads that fed into an amplifier. The amplified electromyogram signal are then inputted to a microprocessor (PIC18F4525, Microchip, Chandler, AZ). To distinguish between the outputs from the PIC microprocessor, three LEDs are connected. Each LED corresponds to a different grade that will illuminate when each grade is detected. The different grades are strong, medium, and weak muscle contractions.

B. *Peak Detection*

The strength of a muscle contraction can be increased by spatial recruitment and by temporal recruitment. It has been proven that temporal recruitment is easier to reconstruct [3]. Using this theory, it is more effective to interpret the strength of a muscle contraction by finding the frequency of an EMG signal instead of the amplitude of an EMG signal.

In order to detect the EMG signal, the multiplication of backwards differences (MOBD) algorithm was used [5]. The MOBD is an estimate of the derivative of a digital signal. The derivative of the EMG signal allows the peaks to be easily detected. The frequency of the signal is determined by the number of peaks that are detected over a 250 ms window. To determine the MOBD, the current EMG value is subtracted by the previous value. Let d_0 be the current value of the backwards difference.

$$d_0 = emg_0 - emg_1 \qquad (1)$$

To detect the peaks of the signal, the absolute values of the current and previous two differences are dividing by eight [1]. Let d_1 and d_2 be the previous values of the backwards difference and M be the current result from the MOBD algorithm.

$$M = \frac{|d_0||d_1||d_2|}{8} \qquad (2)$$

C. *Frequency Calculation*

The frequency of the peaks is directly related to the strength of the contraction. The frequencies used to determine the strength of the contraction were theoretically derived. The frequency of the action potentials is directly proportional to the frequency of the EMG signal.

The frequency of activation is estimated within a 250 ms window. The 250 ms window was chosen as a compromise between the robustness of the frequency estimation and the response time of the system. An increase of this time window would increase the robustness but at the sacrifice of slowness of the system's response. Each peak is counted over 250 ms and recorded. The relationship over this time frame allows the program to observe enough to determine the difference between a weak, medium, and strong contraction. A higher frequency corresponds to a stronger muscle contraction.

III. Results

The constructed device was able to execute the accurate detection of a weak, medium, or strong muscle contraction. It determines the frequency of the electromyogram signal and translates it to a grade: weak, medium, or strong. An LED corresponding to a grade illuminates when the different grades are detected. Figure 2 shows a typical result that the user made sequential contractions from weak, to medium and to strong. The LEDs were indicative of the contraction strength.

IV. Discussion

To obtain graded contraction strength from EMG, a technique and device implementing this technique has been

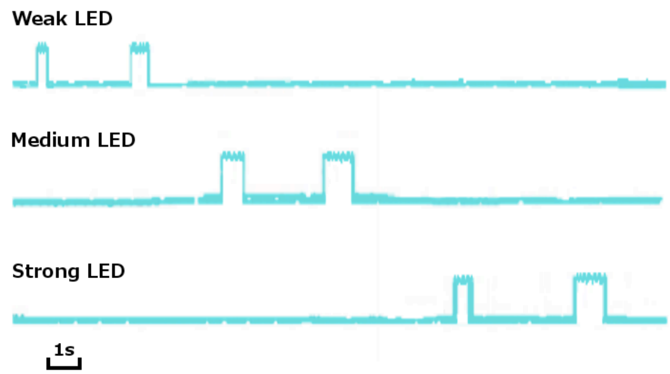

Fig. 2. Oscilloscope display of the on/off signals for the LEDs showing the weak, medium, and strong contractions, as the user sequentially increased the strength of muscle contractions.

developed to estimate the frequency of the muscle contracts instead of measuring the amplitude of the peaks. It has been researched by Safavynia and Ting, who found that measuring the frequency of the peaks rather than the amplitude of S the peaks is a more reliable and accurate depiction of the graded potential [3]. For future work, muscle fatigue should be taken into consideration. Over the course of a muscle contraction, the signal decreases quickly with time due to muscle fatigue. Muscle fatigue is unavoidable and fatigue will alter the results of the graded potential. When the muscle fatigues, the muscle weakens because there are less motor neurons contracting and as a result, the amplitude and the frequency will decrease with time.

The study has demonstrated an effective algorithm for quantifying the muscle contraction strength. The algorithm can be implemented in real time with a low-cost embedded processor. The ability to accurately detect graded muscle contractions can be applied to devices such as powered wheelchairs, prosthetic limbs, as well as other assistive technology devices.

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