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Monitoring of upper-limb EMG signal activities using a low cost system: Towards a power-assist robotic arm

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ABSTRACT

Many human activities depend on upper-limb motion, which can be characterized and estimated using the activation levels of the electromyography (EMG) signal of the upper-limb muscles. Researchers are devoting much effort to investigating these activities during elbow extension and flexion. Also, a few studies have concluded with the development of a power-assisted arm. However, the systems introduced so far are expensive and there are long waiting lists of people requesting such systems. The aim of the present work is to develop a power-assist arm based on the EMG signal activities of the upper-limb, and this paper describes the first part of this study focusing on the monitoring of EMG signals during upper limb activities based on the development of a low-cost system. The relationship between elbow motion and the activity level of the biceps muscle is characterised and different relevant features are logged. The new low-cost system is then validated against the Biopack specialised biomedical measurement system.

Keywords: Biceps muscle, Elbow, Electromyography (EMG), Exoskeleton system, Low-cost controller, Power-assist, Upper-limb.

1. Introduction

The motion of the human body upper-limb is essential for many daily human activities, including eating, drinking, combing the hair and washing the face, etc. Disabled, injured or weak or elderly people sometimes find it difficult to move their upper-limbs to perform these activities. Many research studies are now focusing on how to assist with these problems, by seeking to understand the behaviour of human muscle signal activities [1, 2] during different operations [3, 4], and also via the development of power-assist robotic systems to support the daily operations of physically weak persons [1,5-7, 15,16]. It has been widely concluded that power-assist robotic systems can be operated using the EMG signal of human muscles since it reflects the activity levels of the muscles [13].

The EMG signal is an electrical signal that can be used to observe muscle contraction. Measurement can take place either by surface EMG, where electrodes are placed on the skin, or invasive EMG, where needle electrodes are inserted into the muscle fibre. The EMG signal is the sum of all the action potentials that occur around the electrode position, where muscle contraction causes an increase in its amplitude (0-10mV_{pk-pk}) or (0-1.5mV_{rms}). The usable energy of the EMG signal is in the frequency range of 0-500Hz, while its dominant energy is in the frequency range of 50-150Hz [9]. Fig. 1 is an example of the frequency spectrum of the EMG signal of the tibialis anterior muscle during a constant force isometric contraction.

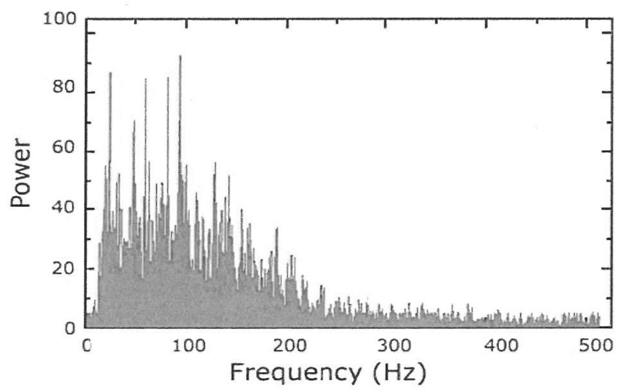

Figure 1. Frequency spectrum of the EMG signal [11]

The standard measurement technique for surface EMG uses three electrodes, namely: the reference, and two pick-up or recording electrodes. The reference (ground) electrode is placed on a neutral part of the body such as the bony part of the wrist to reduce noise and interference, while the two pick-up electrodes are placed over the muscle. These two electrodes signal is differentially amplified to cancel the noise as shown in Fig. 2, where m is the EMG signal and n is the undesired noise signal [10, 11].

The exoskeleton robot is a device, which can be worn as an orthotic device by the human operator [5]. It can be operated in different modes to achieve several applications, such as a power-assist device, human-amplifier, rehabilitation device, and haptic interface [5]. The skin surface EMG signals of the muscles can be used as input information for the controllers of the exoskeleton robot [4]. The EMG signals vary from person to person and may differ for the same motion even in the same person according to physical conditions such as tiredness [4]. Therefore, by characterising the EMG signals, a control method can be developed to operate a power-assisted robotic system based on the information extracted from the signals. Since the surface EMG signals can directly reflect the human motion intention, they can suffice as the only input required for the controller of the power-assisted robotic system, which could then assist physically weak persons without the need for any other equipment.

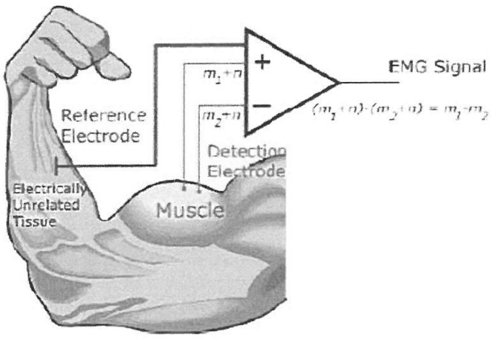

Figure 2. EMG differential amplifier configuration [11]

The human upper-limb consists of several degrees of freedom (DOF) [14], including: 3DOF in the shoulder joint, 2DOF in the elbow joint and 2DOF in the wrist joint. The upper-limb's basic motions are [8]: shoulder vertical flexion/extension, shoulder adduction/abduction, shoulder horizontal flexion/extension, shoulder internal/external rotation, elbow flexion/extension, forearm supination/ pronation, wrist flexion/extension, and wrist ulnar/radial deviation. The upper-limb motions used in daily activities are combinations of these basic motions. The human upper limb is activated by many muscles, some of which are bi-articular and others uni-articular, and agonist-antagonist muscles activate the shoulder, elbow and wrist. This paper considers the flexion and extension motions of the elbow.

This work aims to develop a power-assist system based on the EMG signal of human upper-limb activities to help elderly, injured and physically weak persons. This paper describes the first part of this ongoing research study, focusing on characterising the EMG signals using a low-cost measurement system as a key step in developing a complete controller for the upper-limb power-assist robotic system. Extensive experiments are conducted to characterise the EMG from the biceps muscle at different loads and angles during elbow flexion and extension and to extract the signal's useful features. The measured EMG signal was figured out to determine the relationships between the extracted features, arm angle and load.

2. Monitoring of EMG signal activities

2.1. Using the Biopack DAC System

The measurement process using the Biopack system illustrated in Fig. 3 was achieved in four steps. First the surface EMG signals were detected using Ag\AgCl EMG surface electrodes adhering to the skin surface above the muscles with a separation of 1cm, after the electrode and skin had been thoroughly cleaned using alcoholic liquid [11]. Then a reference electrode was attached to skin covering electrically unrelated tissue such as bone.

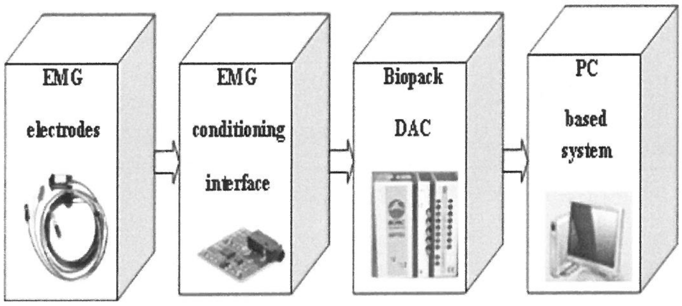

Figure 3. Monitoring the EMG signal activities using the Bioback measurement system

Then a small form factor electromyography signal conditioning interface was used to provide the signal to the Biopack DAC. This EMG interface card has an adjustable gain and improved ruggedness such that the amplified, rectified, and smoothed EMG signals (envelope EMG) are fed to a general DAC analog-to-digital converter (ADC) (not an EMG module) [12]. The output samples from the Biopack were analysed using the Matlab program to extract the indicating features and represent them graphically.

2.2. Using a Low Cost System

The next phase was to develop a low-cost system using a low-cost processor and the envelope EMG. Such processor has less sampling time, which is sufficient for the low frequency envelope EMG. The Atmel ATMega microcontroller board is used as a DAC system, shown in Fig. 4, instead of the expensive Biopack DAC. Here measurement is also achieved in four steps. The surface EMG signals are detected using Ag\AgCl EMG surface electrodes adhering to the skin surface of the muscles with a separation of 1cm. Then the electromyography signal is fed to the EMG signal conditioning board to be amplified, rectified, and smoothed, and subsequently sent to the Atmel ATMega microcontroller board ADC. The output samples from the microcontroller were analysed using an online LabVIEW program to extract the useful features, log them and graphically represent them.

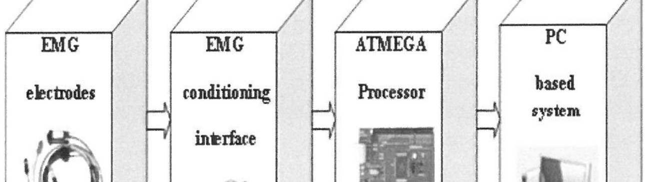

Figure 4. Monitoring the EMG signal activities using a low-cost measurement system

3. System validation

3.1. Validation of the Use of envelope EMG rather than Raw EMG

In order to study the characteristics of the EMG signal, several experiments were performed with a 28 year-old healthy male under test. During the experiments, elbow flexion and extension motions were performed at four angles (0°, 30°, 90°, 150°), as shown in Fig. 5 and at different loads (2, 4, 6 kg), and the experiments were repeated with all loads at each angle as follows: at angle 0°, each load was carried individually by the person under test and the EMG of the biceps muscle was recorded for 20s for each load and without motion. Then at each aforementioned angle (30°, 90°, 150°), the person under test moved his elbow from the initial position (angle 0°) to the desired angle and vice versa for 20 seconds and the EMG activities were recorded.

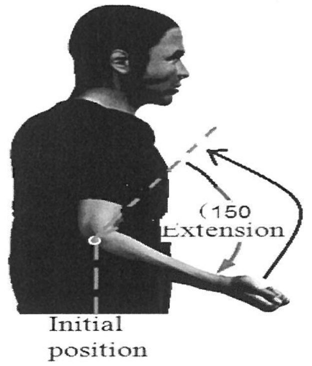

Figure 5. Elbow motion angles from 0 to 150 degree [11]

The EMG signals were recorded in each experiment and saved using the Biopack DAC with a sampling rate of 10 kHz (hence it was only used as an ADC), and the saved data was treated using the Matlab program to calculate the desired features: the RMS (root-mean-square) level of a vector X can be calculated as given in Equation 1; while the STD (standard deviation) of a data vector X can be calculated using Equation 2;.

$$X_{RMS} = \sqrt{\frac{1}{N}\sum_{n=1}^{N}|X_n|^2} \tag{1}$$

where, N is the total number of samples.

$$STD = \left(\frac{1}{n-1}\sum_{i=1}^{n}(x_{i-\bar{x}})^2\right)^{1/2} \tag{2}$$

$$STD = \left(\frac{1}{n}\sum_{i=1}^{n}(x_{i-}\bar{x})^2\right)^{1/2} \tag{3}$$

where, $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$

and n is the number of elements in the sample. The two forms of the STD equations are different only in $n - 1$ versus n in the divisor. Figures 6 and 7 represent the relationship between the RMS and the STD of the EMG signals at different loads and angles.

It is worth noting that these experiments were repeated using the Biopack EMG module with the following specifications (gain = 500, 5 kHz, LPF, 1 Hz HPF) in order to validate the previous results, as shown in Fig. 8. It is evident that the two Biopack setups provided the same RMS and STD trend at different loads and angles.

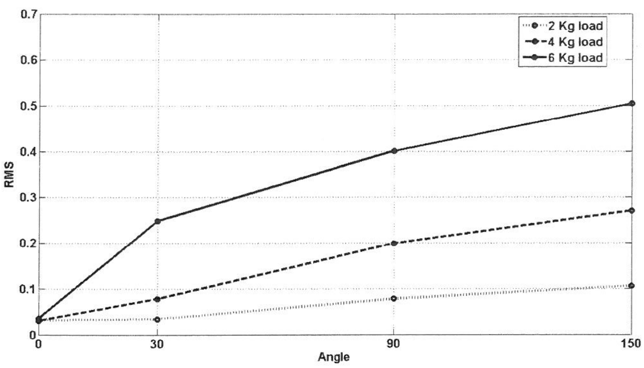

Figure 6. The RMS of EMG using the muscle sensor kit and the Biopack

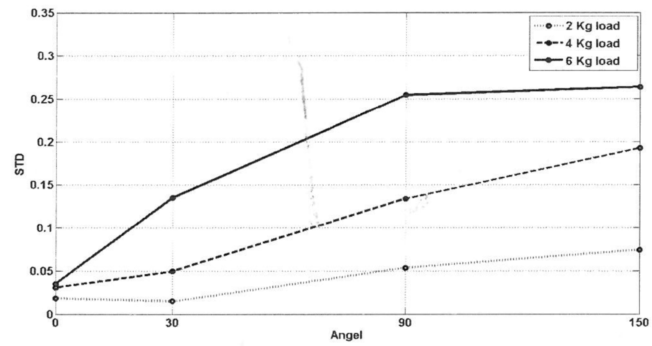

Figure 7. The STD of EMG using the muscle sensor kit the Biopack

3.2. Validation of the developed low-cost system

The EMG signals from the microcontroller were processed and the RMS feature along with the other extracted features were instantaneously calculated, logged and presented using the online LabView program. Also, it is evident that this low-cost system provided the same RMS trend at the different loads and angles if compared with those of the two Biopack setups, despite the differences in values of the RMS feature at the same load and the angle between the three setups. This is mainly related to the effect of the different power sources of the EMG interface card during the experiments with three setups. However, in the final system validation this should not occur since the setup will include the permanent power source.

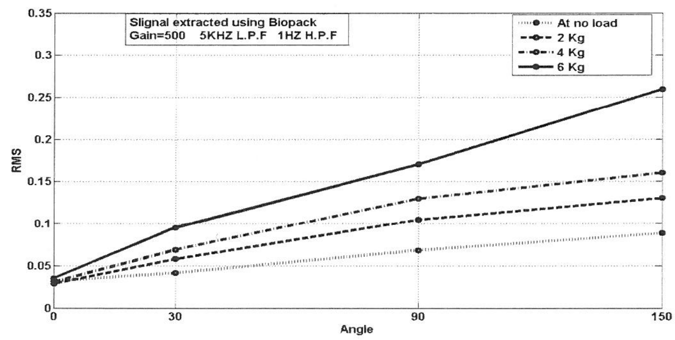

Figure 8. The RMS of the EMG signal using the Biopack EMG module

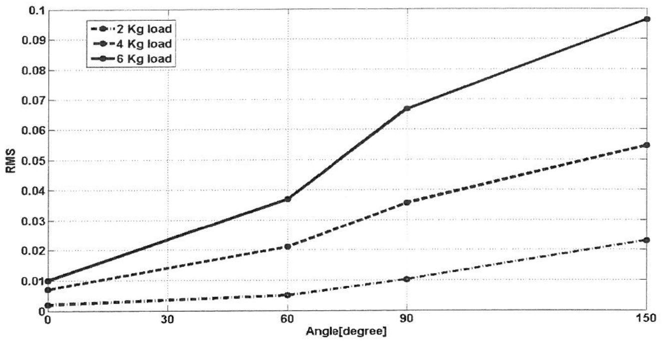

Figure 9. The RMS of the EMG signal using the muscle sensor kit and the low-cost microcontroller

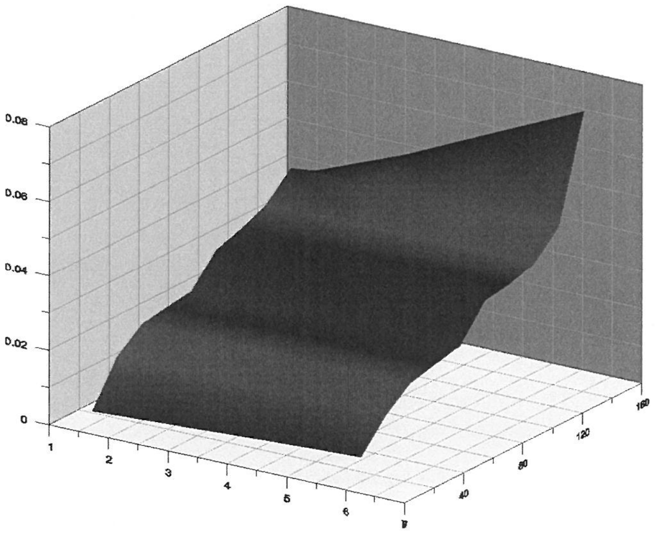

Figure 10. 3D surface diagram representing the relation between the EMG signal, load and arm angle

The 3D surface diagram representing the relationship between the three variables; EMG signal, load and angle has been studied in order to show the effect of both loads and arm angles on the EMG signal as shown in Fig. 10. It is evident that the load has much effect than the angle of the arm on the EMG signal activities, and at higher load values the effect of angle increase will have much higher EMG signal activities than of which at the smaller load values.

4. Conclusions

The biceps muscle activities during elbow flexion and extension have been studied using different three system setups in order to develop a prediction function which can be employed to estimate human upper-limb motions based on the EMG signals of muscles. The relationship between upper limb motion and the activity levels of the biceps were analysed using different extracted features, and the RMS feature was an indicative variable. Also, the 3D surface diagram representing the relationship between the EMG signal, loads and arm angles showed that the load has much effect than the angle on the EMG signal activities, and at higher loads the effect of angle increase will have much higher EMG signal activities than of which at the smaller loads. The analysis proven that the low-cost system developed is capable of being used in the development of a power-assist robotic arm system. The developed system is a successful key step in the development of the upper-limb exoskeleton robot.

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