Design and Development of Low Cost Biceps Tendonitis Physiotherapy Monitoring System using Surface EMG Electrodes for Automated Rehabilitation

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LIST OF ABBREVIATIONS

EMG	Electromyogram
EEG	Electroencephalogram
MEG	Megneto-encephalogram
GSR	Galvanic Skin Respone
ECG	Electrocardiogram
HRV	Heart Rate Variability
MUAP	Motor Unit Action Potential
AAPB	Association for Applied Psychophysiology and Biofeedback
BCIA	Biofeedback Certification Institution of America
ISNR	International Society for Neurofeedback and Research
NCS	Nerve Conduction Studies
SENIAM	Surface EMG for Non-Invasive Assessment of Muscle
DAQ	Data Acquisition
ADC	Analog to Digital Converter
WLAN	Wireless Local Area Network
EHW	Evolvable Hardware
fEMG	Facial EMG
SEMG	Surface EMG Electrodes
PGA	Programmable Amplifier's Gain
ROM	Range of Movement

Rekabentuk dan Pembangunan Sistem Pemantauan Fisioterapi Biceps Tendonitis Kos Rendah Menggunakan Elektrod Permukaan EMG untuk Pemulihan Automatik

ABSTRAK

Signal Electromyogram (EMG) adalah satu signal berbentuk potensi yang diukur dengan elektrod yang dilampirkan pada kulit apabila terdapat pengecutan otot. Isyarat ini adalah berguna dalam kajian kinesiology, penyelidikan bioperubatan, penggunaan klinikal, fisioterapi dan diagnosis ketidafungsian otot. Walau bagaimanapun, sistem perolehan yang terdapat di pasaran semasa adalah mahal dan bersaiz besar. Oleh itu, penyelidikan ini cuba untuk mereka bentuk dan membangunkan sistem perolehan and pemantauan kos rendah EMG bagi fisioterapi bisep tendonitis. Sistem perolehan yang dibangunkan mengunakan EMG elektrod permukaan untuk mengesan signal EMG. Dalam reka bentuk litar EMG perolehan, signal EMG diperkuatkan dalam dua peringkat kepada skala yang sesuai untuk dilihat. Gangguan frekuensi 50Hz yang wujud daripada pembekal kuasa adalah dihapuskan dengan satu IC hybrid penapis takuk. Kemudian, pembetulan dan modul low pass akan menukarkan signal EMG kepada bentuk gelombang linear envelope. Isyarat ini kemudiannya sampel oleh modul pemprosesan isyarat. Linear envelope analog signal EMG disampel menjadi 24 bit data digital. Satu algoritma dibangunkan untuk menghantar data digital ke dalam komputer. Data digital EMG tersebut akan dikumpul and disambungkan semula dan dipaparkan mengunakan perisian skop dalam komputer. Dalam usaha untuk menguji sistem kami, 20 subjek adalah diminta untuk melaksanakan satu set latihan pemulihan dan signal EMG telah direkodkan. Keputusan yang dipungut daripada sistem pemerolehan EMG yang dibangunkan dibanding dengan bacaan perolehi dari produk komersial. Perbandingan ini memberi ralat purata ±0.05mV dalam bacaan. Oleh itu, yang dicadangkan direka disifatkan sebagai memuaskan.

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ABSTRACT

Electromyogram signal (EMG) is an electrical potential signal generated from EMG electrodes attached on the skin when there is a contraction of muscles. These signals are useful in kinesiology study, biomedical research, clinical usage, physiotherapy and muscle dysfunction diagnosis. However, current acquisition systems that are available in the market are expensive and bulky. Therefore, this research attempts to design and develop a low cost EMG acquisition system for monitoring biceps tendonitis physiotherapy. The proposed EMG acquisition system uses surface EMG electrodes for EMG signal detection. In the design of the EMG acquisition circuit, the EMG signal is amplified in two stages to convert it into an observable scale. The inherent noise acquired from the power line of 50Hz frequency is eliminated with a single hybrid IC notch filter. Then, the rectification and low pass filter modules will convert the EMG signal to a linear envelop waveform. This signal is then sampled by a signal processing module. The analogue linear envelop EMG signal is sampled into a 24 bit digital data. An algorithm is developed and coded to send the digital data into the computer. The digital EMG data is then reassembled and displayed using a software scope on the computer. In order to test the system, 20 subjects are requested to perform a set of rehabilitation exercise and the EMG signals were recorded. The results collected from this proposed EMG acquisition system is compared with the readings obtain from a commercial product. This comparison gives an average error of ±0.05mV in the readings. Hence, the proposed designed is deemed to be satisfactory.

CHAPTER 1

Introduction

1.1 Overview

Biosignal is a signal produce from human body that can be used to quantify the physiological process of a living organism and also used to measure and monitor a biological being. Normally, it is referred to as a bioelectrical signal. Bioelectrical signals are produced by the sum of electrical potential difference across a specialized tissue, organ, or cell system such as the nervous system. Among all biosignals, the well known types are electroencephalogram (EEG), magneto-encephalogram (MEG), galvanic skin response (GSR), electrocardiogram (ECG), electromyogram (EMG) and heart rate variability (HRV). In recent years, more and more researchers are interested in developing this technology.

Recently, the trend in the development of this technology is going towards integrating the biosignal with electronic devices and mechanical components. This integration creates a helping hand for the disable people, which can improve their living quality and comfort. There are some commercial products which are already in the market, like the peacemaker for heart problems, intelligent prosthesis for arm amputees, camera based vision for blind people and medical robots used in surgical rooms.

Electromyogram signal (also known as EMG signal) is collected from the human body as the muscle fiber contracts. Muscle fibers are arranged in groups and each group of muscle fiber is under the control of a single motor neuron (Jurkat et al., 2005). A motor neuron and the group of muscle fibers innervated by its axon constitute a functional unit that is known as the motor unit (W. W. Campbell, 1999). These muscle fibers, which are polarized with the muscle fiber cell are electropositive outside and electronegative inside during its nature state. Hence, a potential different exists inside the muscle fibers. During muscle contraction, the exchange of ions across the muscle fibers when innervated by the recruited motor unit will cause a small electrical current which is known as action potential. For a particular motor unit, this electric current is referred to as the motor unit action potential (MUAP) (S. Day). The aggregated electric signal generated from all the MUAPs in an area of detection is referred to as the myoelectric signal, which is also called electromyogram (EMG). Signal propagation precedes muscle movement by around 10ms to 100ms (B. Gerdle, 1999).

Although a lot of research has been done in this field in the past decade, some disarrays regarding the EMG signal still remains. To convert the raw EMG signal into an applicable signal, an acquisition system is required. However, commercial acquisitions in the current market are bulky and expensive. Hence, there still a room to develop a portable and low cost acquisition system. This thesis, will present the basic knowledge of EMG, development details of a low cost acquisition system and some pre-processing techniques of EMG signal to obtain useful data.

1.2 Motivation

EMG signals are not only used for physiological and biomedical study. It also has applications in medical surgery, rehabilitation, sport science, ergonomics, and robotics. However, commercial EMG acquisition systems is available in the market are very expensive price. Hence, only those who are wealthy or an organization such as a hospital, physiotherapy lab or a rehabilitation center can afford to purchase this system.

The prices of some EMG acquisition systems available in the market are summarized in Table 1.1. The high prices indicate that there is an opportunity to develop a low cost EMG acquisition system that can be affordable by many people.

Table 1.1: EMG acquisition system price list.

System Name	Price in USD
TECA Synergy T2X EMG System	8999.00
Nihon Kohden Neuropak M1 MEB-9200 EMG / EP System	13,995.00
Cadwell Sierra Wave EMG Machine	15,995.00
FlexComp Infiniti - 10 Channel System	6500.00

On the other hand, as the numbers of muscle dysfunctional patients increase a dedicated and portable EMG monitoring system can provide the physiotherapy patient a comfortable rehabilitation session. In this research, a biceps tendonitis monitoring system is concern in the development of an EMG acquisition system. Besides, with a dedicated system patient can perform rehabilitation without making appointments with physiotherapists. Hence, there is a need to develop an EMG acquisition system which can provide an alternative rehabilitation methods to physiotherapy patients.

Moreover, for disabled people the application of EMG is very useful in their daily activities. Based on a study, the human brain continues to generate a nerve impulse such that even a paralyzed person can produce a distinct EMG signal by self-effort (Walker et al., 1998). Therefore, an efficient EMG signal acquisition system is needed to collect the signal and enhance possible development of applications based on EMG. Meanwhile, the available acquisition systems in the market are built only to collect multiple types of biosignals without any specification purpose. In addition, these multiple acquisition systems are bulky. Therefore, a light weight and small size portable acquisition system is preferred to better aid human.

1.3 Problem Statement

EMG signal can be informative, but it is easily influenced due to its nature. It consists of shortcoming uncertainty and uncertain values (Klasser and Okeson, 2006). Most of the biosignals such as EMG, EEG, and ECG have very low amplitude levels. Therefore, the nature of EMG signals can be a challenging problem in the acquisition stage.

The important factor to be concerned about in the development of an EMG acquisition system is the method to preserve the fidelity of the EMG signal from the acquisition process. Any disturbance from frequency, power line radiation, motion artifacts or ambient noise will influence the degree of fidelity of EMG signal. Therefore, it is important for the acquisition system to collect and process the EMG signal properly.

Besides, there are many additional factors, which must be considered such as, type of electrodes, electrode placement, skin impedance and circuit wiring, which may affect the reliability of the collected EMG signal. Therefore, more attention must be given to the design process of the acquisition system.

1.4 Scope

The aim of this research is to develop an acquisition system to collect EMG signals from the biceps muscles. We are focusing in eliciting EMG response through voluntary contraction of the biceps brachii muscle. Raw EMG signal collected from the muscle is unable to provide any information without further processing. Therefore, some pre-processing steps are performed in the developed acquisition system to obtain useful data.

To this end, the scope of this research is as follows:

- There are several electrodes available in the market that can be categorized as invasive and non-invasive electrodes. Surface EMG non-invasive type electrodes are used in this research. This is chosen because surface EMG electrodes do not require any professional training to handle it and the subject will free from discomfort when attached to the electrode.
- Muscles exist in most parts of the human body. However, only the biceps brachii muscle will be of interest in this study. It is conveniently accessed and recognized for sensor placement.
- The biceps brachii muscle is located at the upper arm and it is responsible for elbow flexion and forearm rotation. Therefore, throughout this research, elbow flexion is selected activity to be carried out during the experiments for the biceps beachii muscle.
- In this study, standard off the shelf electronic components will be used to develop the low cost acquisition system in order to produce an EMG signal which can be used for further advance digital signal processing.

1.5 Objectives and Methodology

The objectives of the research are as follows:

- To design and develop a low cost EMG acquisition system for automated physiotherapy monitoring of patients with biceps tendonitis.

- To evaluate the developed EMG acquisition system against a commercial product using different types of action performed by the biceps brachii muscle.

These objectives will be achieved with the following methodology:

- Determination of design parameters for the proposed EMG acquisition system.
- Development of signal processing modules for the acquisition platform using off the shelf electronic components.
- Testing the various signal processing modules and assemble them to built a complete EMG acquisition platform.
- Obtain data from proper exercise protocols by using the developed EMG acquisition system.
- Comparison of collected data collection between the developed acquisition system with a commercial product to evaluate the propose system.

1.6 Expected Research Output

The expected outcome of this research is an in house built EMG acquisition system which is capable to collect good quality EMG signals for biceps brachii muscle and digitally display it on a computer software. Finally, the developed EMG acquisition system is also expected to have similar output reading compare to the commercial acquisition system.

1.7 Thesis Outline

In this chapter, an overview of the general idea of this research is presented. Following this, the scope, problem statements, objectives, research methodology, and the expected outputs of this research are mentioned briefly.

Basic knowledge of EMG signals, types of biofeedback, and the commonly used biofeedback sensors are described in chapter 2. Besides this, biofeedback acquisition systems are discussed and categorized into commercialized and non-commercialized acquisition systems. Later in this chapter, some existing applications of EMG are also presented.

Next, the design and development of the low cost EMG acquisition system is described by stages in chapter 3. The methodology and the components used for developing the acquisition circuit are detailed in this chapter. Furthermore, additional details on component calculations, signal flow, parameter settings, data conversion and chip coding are described in this chapter.

In chapter 4, experiments are conducted to test the developed acquisition platform. The design protocol of each experiment conducted is mentioned in this chapter. The results of the conducted experiment are analyzed and discussed in this chapter. In addition, a comparison of the developed acquisition platform with a commercialized instrument is also presented in this chapter.

Finally, this research thesis will be concluded in chapter 5 with the summary of the thesis and the recommendations for future work.

bvCHAPTER 2

Literature Review

2.1 Introduction

This chapter presents the literature review done in this research to gain an in-depth knowledge about biofeedback acquisition systems. The knowledge of existing technology is important for the proper design and development of a biofeedback acquisition system. Introduction to biofeedback and some common types of biofeedback are briefly discussed in the beginning of this chapter. Different types of electrodes used for various biofeedback signals are also presented.

Following this, commercial and non-commercial acquisition systems used to collect EMG signals will be presented. The components used in developing this type of biofeedback acquisition system will be the focus in this section. Besides this, the different modules generally used to process the signal in this biofeedback acquisition system are briefly described.

Existing applications of the developed biofeedback system is present at the end of this chapter. Various commercial and research applications pertaining to the investigated acquisition system is discussed. The areas of application for these existing acquisition systems are discussed. This will help to illustrate the potential applications of the acquisition system developed in this project.

2.2 Biofeedback and Biosensors

2.2.1 Biofeedback

The human body produces feedback through the nerve system to indicate the change that happens in the surrounding area and on our physical body. Biofeedback, also known as biosignal is the process of providing an individual with physiological data that the patient might be unaware of (Deidre Donaldson and Dennis Russo, 2005). According to three professional biofeedback organizations in year 2008 which are the Association for Applied Psychophysiology and Biofeedback (AAPB), Biofeedback Certification Institution of America (BCIA), and the International Society for Neurofeedback and Research (ISNR) defined the term biofeedback as follow (AAPB, 2008):

"*Biofeedback is a process that enables an individual to learn how the change physiological activity in the purpose of improving health and performance. A precise instrument is used to measure the physiological activity such as brainwave, heart function, breathing, muscle activities and skin temperature. These instrument rapidly and accurately 'feedback' the information to the user. The presentation of this information often in conjunction with the changes in thinking, emotions, and behavior supports the desired physiological changes.*"

In the middle of the 20th century, groups of psychologists interested in operant conditioning were the first who introduced the term of 'Biofeedback' in their study on enabling conscious regulation of a body function by mental control (J. Haslam, 2007). In recent years, biofeedback has been introduced to a variety of clinical problems such as vasoconstrictive syndromes (Green & Green, 1989) (Thompson et al., 1992), Gsatrointestinal disorders (Leahy, Clayman et al., 1998) (Whitehead, 1992), attention-deficit hyperactivity disorder (Baumgaertel, 1999) (Lubar, Swartwood et al., 1995), and rehabilitation (Miller and Chang, 1999) (Richards and Pohl, 1999). As technology improves, products with biofeedback has been introduced for people with disabilities such as grasp recognition which is an advanced application for prosthetic hand control (Ferguson S., 2002), unvoiced speech recognition (Manabe H., 2003) and control of upper limb prosthesis (M. Troncossi, R. Caminati et al., 2010).

In general, biofeedback consists of different types of biosignal that can be obtained from our human body. Various biosignals that can provide the information from different parts of our body are listed as follows.

a) Electromyogram (EMG)

An electromyogram (EMG) also known as nerve conduction studies, measures the electrical activity of muscle contraction and how well and how fast the nerves can send electrical signals. EMG signal is measured using an instrument called an electromyograph, to produce a record called an electromyogram. An electromyograph detects the electric potential generated by muscle cells when these cells are electrically or neurologically activated. EMG signals are normally used in the muscle rehabilitation process, like paralysis, which has resulted from a stroke, incomplete spinal cord lesions, or cerebral palsy.

b) Electroencephalography (EEG)

An electroencephalography (EEG) records electrical activity along the scalp. EEG measures the voltage of fluctuations resulting from ionic current flows within the neurons of the brain. In clinical contexts, EEG refers to the recording of the brain's spontaneous electrical activity over a short period. All the activity is recorded by using multiple electrodes placed on the scalp. EEG is used to monitor for epileptic activity and creates a clear irregularity on a typical EEG study. EEG is also used in the analysis of encephalopathies and coma patients.

c) **Galvanic skin response (GSR)**

Galvanic skin response (GSR) signals are also known as psycho galvanic reflex (PGR), skin conductance response (SCR) and electrodermal response (EDR). GSR is a way of measuring the electrical conductance of the skin. GSR signal is the changes in the electrical properties of a person's skin caused by an interaction between the environmental events and the individual psychological state. In behavior therapy, it is used to measure physiological reactions such as fear.

d) **Hemoencephalography(HEG)**

Hemoencephalography (HEG) feedback is a type of brain imaging technology that indirectly measures neuronal activity of the brain. This technique uses the functional infrared sensors to generate the thermal image of the brain. HEG is normally applied in the study of blood flow in the brain by voluntarily controlling blood flow or oxygenation in specifically chosen areas of the brain.

e) **Electrocardiography (ECG)**

Electrocardiography (ECG) signals also known as elektrokardiogramm (EKG) in German is used to measures the heart's electrical activity. ECG signal is used to help evaluate its function and identify any problems that might exist. In clinical applications, ECG signal is to determine the rate and regularity of heartbeats, heart size, position of the heart's chambers and the heart damage condition.

2.2.2 EMG Biosensors

A sensor is a device that detects a change in a physical stimulus and turns it into a signal, which can be measured or recorded. Since various types of biofeedback signal can be obtained from different parts of our body, so different types of sensor are required. Table 2.1 shows the different types of electrodes that can be used to detect biofeedback signals. All the sensors shown in Table 2.1 produce an output base on potential differentce. Therefore, these sensors are also known as biopotential electrodes.

There are several types of electrodes used for EMG signal detection; wire electrodes, needle electrodes and surface electrodes. Wire and needle electrodes are invasive type of electrode. These invasive electrodes are useful for accessing individual motor unit and muscles in deeper layers under the skin. However, handling of these invasive electrodes requires a qualified professional user with appropriate skills.

Invasive electrodes such as the needle electrode are also known as the intramuscular electrode (IEMG). Generally, it is used to study a specific muscle and distinguish the motor units. Occasionally, this type of electrode is used in Nerve Conduction Studies (NCS). Nowadays, nearly all needle electrodes are disposable and used on the same patient. Needle electrodes can be classified into monopolar, bipolar or concentric. Monopolar needles are typically less expensive, less painful, and less electrically stable than the bipolar electrodes.