DOKUZ EYLÜL ÜNİVERSİTESİ MÜHENDİSLİK FAKÜLTESİ
FEN VE MÜHENDİSLİK DERGİSİ
Cilt/*Vol.*:17■ No/*Number*:2■Sayı/*Issue*:50■Sayfa/*Page*:84-94■ Mayıs 2015 / *May 2015*

Makale Gönderim Tarihi (Paper Received Date): 8 Mart 2015 Makale Kabul Tarihi (Paper Accepted Date): 15 Mayıs 2015

WIRELESS SURFACE ELECTROMYOGRAPHY DEVICE DESIGN FOR LUMBAR DISC HERNIATED PATIENTS

(LOMBER DİSK HERNİLİ HASTALAR İÇİN KABLOSUZ YÜZEY ELEKTROMİYOGRAFİ CİHAZ TASARIMI)

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ABSTRACT

A portable and wireless surface electromyography device was developed for tracking the regional muscular activities of lumbar disc herniated patients. Previous studies showed that there is relation between paraspinal muscular activities and lumbar disc herniation. These studies encouraged us to develop a novel wireless surface electromyography device to follow muscular activities of lumbar disc herniated patients. Using such kind of wireless system in lumbar disc herniation studies leads to follow muscular activities practically. The overall system would lead to make diagnosis of lumbar disc herniation with a novel approach. The developed system consists of four major stages; amplification, filtering, A/D conversion, and the wireless communication stages. Bluetooth technology is chosen for communication between the proposed device and the computer. The designed device can be fully controlled within MATLAB software, and measured data can be directly streamed to computer environment. As a demonstration of the developed system, we also did certain signal processing operations in MATLAB by using measured surface electromyography signals.

Keywords: Surface electromyography, Lumbar disc herniation, Embedded biomedical systems

ÖZ

Bel fıtıklı hastaların bölgesel kas faaliyetlerinin takibi amacıyla portatif ve kablosuz bir yüzey elektromiyografi cihazı geliştirilmiştir. Önceki çalışmalar paraspinal kas aktiviteleri ile bel fıtığı arasında ilişki olduğunu göstermektedir. Bu çalışmalar bel fıtıklı hastaların kas faaliyetlerini takip amacıyla yeni bir kablosuz yüzey elektromiyografi cihazı yapmaya teşvik etmiştir. Böyle kablosuz cihazın kullanımı bel fıtıklı hastaların kas akitivitelerini daha kolay takibini sağlayacaktır. Genel olarak sistem yeni bir yaklaşım ile bel fıtığı teşhisinin yapılabilmesinin önünü açabilecektir.Geliştirilen sistem kuvvetlendirme, filtreleme, analog-dijital dönüştürme ve kablosuz haberleşme olmak üzere dört ana kısımdan oluşmaktadır. Elde edilen cihaz ile bilgisayar arasındaki haberleşme için Bluetooth teknolojisi kullanılmıştır. Cihaz MATLAB yazılımı üzerinden kontrol edilebilmektedir ve doğrudan bilgisayar ortamına aktarılmaktadır. Geliştirilen sistem ile elde edilen yüzey elektromiyografi sinyalleri üzerinde MATLAB programıyla sinyal işleme de yapılmıştır.

Anahtar Kelimeler: *Yüzey elektromiyografi, Lomber disk hernisi, Gömülü biyomedikal sistemler*

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1. INTRODUCTION

Low back pain (LBP) is a quite common disease in societies. It's assumed that approximately 80% of adults could have any LBP disease at least one time in their life, which influences their daily activities. LBP is one of the biggest causes of work absenteeism in the USA. It is estimated that total annual cost of LBP and LBP originated productivity loss is about $50 billion for USA [1]. Lumbar disc herniation (LDH) is the predominant reason of LBP. LDH is a widespread disease in societies. It is a serious disease as causing pain and decreasing the workforce of individuals. The prevalence of this disease in some of European societies is about 1-3 % depending on age and sex [2].

In traditional LDH diagnosis, relatively more expensive method of magnetic resonance imaging is the most frequently applied monitoring technique. Computed tomography scan and myelography are also rarely used methods in LDH diagnosis [3]. Electromyography (EMG) is also rarely used in LDH, mostly to understand irritation situation of nerve roots.

There are many studies on the relation between paraspinal muscles and LDH. In these studies, a patient group and a control group were recruited. The paraspinal muscular activities of each group individuals were recorded during contracting and relaxing physical activities. The surface electromyography (SEMG) records of all individuals evaluated by using signal processing techniques. Comparison of these activity results showed that there were measurable differences in paraspinal muscular activities depending on whether that person has LDH or not. The following studies show the relationship between paraspinal muscular activity and LDH.

Çevikcan and Kara recruited 30 lumbar disc herniated patients in their patient group, and a group of 30 other people for the control group, all healthy without any low back pain evidence [4]. All 30 people in the patient group are confirmed to have LDH by clinicians with magnetic resonance imaging in the same hospital environment. All individuals' SEMG signals are measured at abdominal muscles and paraspinal muscles in two different physical situations. Then by using the Welch method, power spectral density (PSD) of SEMG signals measured at abdominal and paraspinal muscles are computed for both group members. When the amplitude levels and PSD results for some specific frequencies of SEMG records of patients and control group individuals were compared, significant differences were found. It is observed that the herniated people abdominal and paraspinal muscles have different levels of energy consumption in each physical position (contraction and relaxation) [4].

Çakar et al. designed a paraspinal muscular activity tracking system in their studies [5]. But, the hardware component of their system was not based on was not able to set its connectivity with computer wireless. This study is the continuation of these previous studies [5], [6].

Geisser used the flexion-relaxation phenomenon (FRP) which is a quantitative measurement tool used to evaluate the paraspinal muscles' condition [1]. They concluded that FRP, as an objective indicator of LBP, should be used as a supplementary method in musculoskeletal studies of LBP [1].

De Luca used the EMG spectral technique to evaluate the performance of back muscles [7]. His concept is based on a device and technique named as back analysis system, which is composed of four elements. In the analysis of SEMG signals, instead of calculation of amplitudes, a so called fatigue index from the frequency spectrum of the SEMG signal is computed. The SEMG signals were collected from six different locations at the back of each individual. Almost in each test group, he identified the low-back patients with an accuracy higher than 90% with his purely SEMG spectral variable based test. These results show that EMG spectral technique should provide information about the evaluation of the performance of back muscles [7].

Haig et al. evaluated the muscular activities during FRP to understand the relation between muscular activities and LBP [8]. This group could measure the FRP of a subject before and after the subject had a herniated nucleus pulposus during their study. They found that the FRP disappeared with disc herniation and returned to normal with the decrement of symptoms in the subject. Haig et. el proposed that the decrease in the range of motion, and loss of FRP was due to the herniated subject's increased paraspinal muscle activity during standing position [8].

In study of Jalovaara et al. LDH and other LBP suffering people were recruited and SEMG records were taken from all the people [9]. They used variance and t-test in the analysis of SEMG records to understand the association of SEMG with diseases. Their results showed that surface EMG should be used as a good tool for assessing pain in different LBP patients [9].

Ambroz et al. investigated that the usage of SEMG in assessment of chronic low back pain [10]. They recruited 30-persons of patients having chronic low back pain and 30 people for control group. Lumbar muscle activities of people are recorded during static and dynamic positions. The collected SEMG data are examined by using paired t-test. The results of this study showed that evaluation of paraspinal muscle activity of people during static and dynamic physical situations should be used to differentiate LBP people from others [10].

In this study, we aimed to design a wireless and physically minimized SEMG system that was special for SEMG studies in LDH disease. Such a wireless system in detection of muscular activities in lumbar disc herniation diseased patients makes it as a user friendly device. Ultimate goal of this study was improving the system to help medical staff to make decision about the diagnosis of herniation of the lumbar discs by evaluating the SEMG records of regional muscles.

This paper presents the primary phase of complete LDH diagnosis system. The hardware components of developed system were clearly demonstrated. The collected signals were evaluated and processed with using MATLAB signal processing toolbox.

2. MATERIAL AND METHOD

The proposed system consists of five stages as shown in the block diagram given in Figure 1.

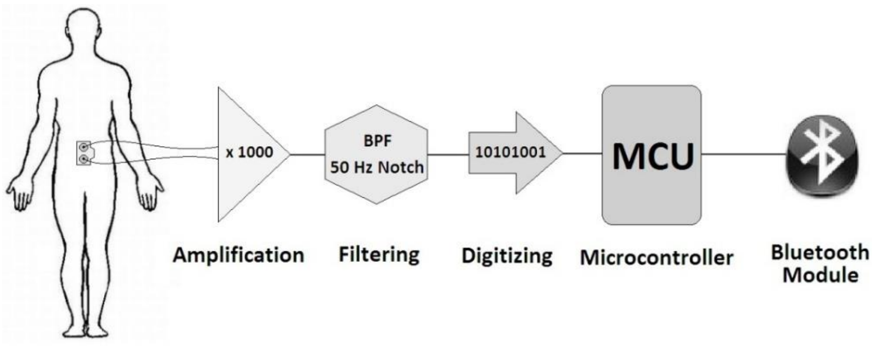

Figure 1. Block Diagram of System [11]

In the first stage, the raw SEMG signals are amplified by a predefined factor. Environmental disturbances and other noise effects are eliminated in the filtering stage. Subsequently, the analog signal is converted to digital form by using a high resolution analog to digital converter. A microcontroller is used to transfer the digitized data to the bluetooth module. At the final stage of the system, bluetooth module transmits the SEMG signals to personal computer. In the following figure, individual stages of the overall system are shown, and in the following subsections, each block is discussed in detail.

2.1. SEMG Amplifier

SEMG biopotential amplitudes range from hundreds of microvolts up to a few millivolts [12]. For amplification of low amplitude SEMG biopotential signals, an instrumentation amplifier (IA) of Analog Devices' AD620 is used as the core element of the amplification stage of the system. The gain of this low cost, low noise, low power and high accuracy IA can be adjusted by using just a single external resistor from 1 times to 10000 times. Because of these features AD620 is a very suitable IA for battery powered medical devices and applications [13]. The circuit diagram of amplification stage is shown in Figure 2.

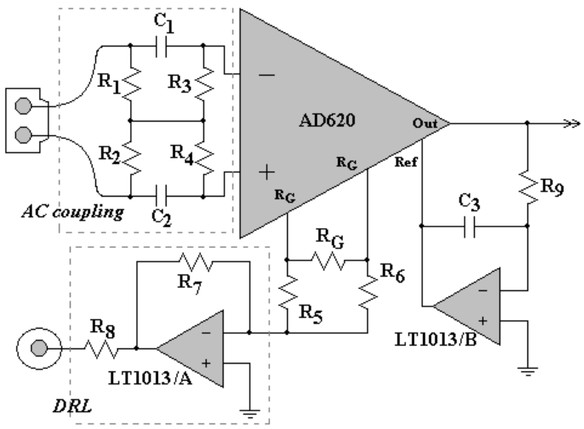

Figure 2. SEMG Amplifier [14]

AC coupling is an essential issue to decrease the effects of unwanted noise effects in biopotential measurements. In order to do this, SEMG signals should be directed to AD620 via a differential ac-coupling network. AD620 amplifies the differentially ac-coupled biopotentials and provides a differential output voltage which is converted to a single-ended voltage by the output terminal. Spinelli et al. suggests a novel ac-coupling circuit which doesn't have any connection with ground and obtains quite high common mode rejection ratio (CMRR). The ac-coupling circuit is based on a high pass filtering circuit in front of the amplifier. The biopotentials are ac-coupled to AD620's inputs through C1 and C2 capacitors. The component values of the ac-coupling network were chosen properly to achieve a large CMRR and to avoid any mismatches in poles and zeros of the filters [15].

Although, the ac-coupling circuit removes dc input voltages, there should be offset voltages sourcing from IA. Furthermore, any changes in electrode contact, temperature change on skin and unwanted electrochemical processes at the electrodes generate dc and very low frequency harmonics which have disturbance effects on the biopotential of interest [16]. For the suppression of dc and low frequency noise components, the output voltage of IA should be feed back to the reference terminal of IA through an integrator [17].

The gain of SEMG amplifier is adjusted to 1000 times with using external resistor RG. Resistors R5 and R6 those correspondingly connected to RG average the collected voltage to sense common mode voltage.

A driven right leg (DRL) circuit is generally used in biopotential measurement applications to increase the common mode voltage rejection. DRL is based on a system that senses the patient's common mode voltage and reapplies the inverted common mode voltage in a reversed phase [18]. The output of DRL is reapplied with a monopolar electrode to the tissue of patient which is electrically unrelated with the place of measurement. DRL circuit greatly increases the CMRR [19].

2.2. Filtering

The SEMG frequency spectrum ranges from 10-20 Hz up to 500-600 Hz [12]. A filtering block is used to suppress noise signals which are outside this frequency band. Because of this, an analog filtering stage is used following the SEMG biopotential amplifier. The analog filtering block consists of a high-pass filter with 10 Hz of cut-off frequency, low-pass filter with 550 Hz of cut off frequency and a 50 Hz of notch filter. The high-pass filter is necessary to remove the unwanted DC offset, which is generated by the half-cell potentials of the surface electrodes. It would also cause saturation, if it isn't suppressed carefully. Moreover, high-pass filter removes the unwanted signals such as motion artifacts. The low-pass filter is necessary to remove unwanted noise beyond the bandwidth of interest, which could cause the reduction of signal to noise ratio. The low-pass filter helps to avoid aliasing effect of the wideband background noise [19].

Both of high and low pass filters are designed with Sallen-Key filter topology. The Butterworth filter response is selected because of it has quite flat response in passband and stopband. In addition, the smoothness in stop band and passband is ripple free [16].

In some of the publications, it is not advised to use analog notch filters in SEMG instrumentation those placed in applications such the shape of the SEMG signal is of interest. Other reasons of avoidance using notch filters are disappearing of 50 Hz and close frequency components of SEMG signal and the phase rotation effect of analog notch filters [20].

However, it is not very important if SEMG amplitude and/or power of SEMG are of interest [21].

In our application, the interference effect of the power line was quite obvious in laboratory measurements. Moreover, in our application, the power of SEMG signal is more important rather than the shape of SEMG biopotentials. In that case, a 50 Hz of notch filter is used in our system.

2.3. Analog to Digital Conversion and Data Transfer

For the analog to digital conversion process, 16-bit of high resolution analog to digital converter (ADC) named as ADS7813 of Texas Instruments has been chosen. This is a successive approximation type ADC that offers 20 μs of maximum conversion time and maximum 35 mW of power dissipation. The serial interface supported converter should be configured with wide range analog input voltages. The Serial Peripheral Interface (SPI) compatibility of ADS7813 makes it useful with serial interface compatible applications [22]. The timing diagram given in the component datasheet is used in data conversion process.

The digitized data is transferred to the computer via a Bluetooth module. Class 2 type Bluetooth module of Bluegiga Technologies has Bluetooth 2.0 and enhanced data rates those provide three times faster data rates compared to Bluetooth 1.2 [23]. WT12 has an embedded firmware that runs on RISC processor of module. iWRAP named firmware lets users to access Bluetooth functionality with using simple ASCII commands. For the configuration of WT12 with ASCII commands, the module should be connected to the PC over a serial link.

High performance and widely available microcontroller of Microchip´s PIC18F452 is used to establish the communication between ADS7813 and Bluetooth module. PIC18F452 establishes its communication with ADS7813 via SPI module with three pins. The microcontroller offers various clock rates those are user programmable. This lets users to reach a maximum data rate of 10 Mbps with 40 MHz oscillator. The communication between the microcontroller and Bluetooth module is established with universal asynchronous receiver transmitter (UART) communication protocol that both of these components support. The UART module of WT12 supports minimum 1200 baud rate and maximum 3 Mbaud rates and PIC18F452 can reach 2 Mhz of maximum baud rate with a 25 Mhz of crystal. The baud rate in UART communication between WT12 and PIC18F452 is configured as 200900 baud [24].

2.4. Connectivity and Software

The Bluetooth communication compatible computer inquiries for the SEMG system to make a new connection with it. When the pairing is established over a radio frequency communication (RFCOMM) channel, an emulated virtual serial port is formed in computer. Hereby, the interfaced system is ready to transfer the data to computer.

The organization of the microcontroller is configured with PicBasic PRO compiler and the whole system establishes its connectivity to the computer with MATLAB software. MATLAB offers a serial port input/output interface to access to peripheral devices directly. Figure 3 shows the relation between PicBasic PRO compiler and MATLAB. The microcontroller waits for the start SPI communication with ADS7813 command coming from computer. If the start command is received, the compiler branches to SPI communication loop and the analog to digital conversion process starts. The process takes about maximum 20 µs. When the conversion is over, 16-bit word data is read via SPI protocol. The most significant byte of the word is read first. Subsequently, the word is transferred to WT12 via UART protocol. After the transfer is over, the compiler gets back to the beginning of SPI communication start subroutine. This data traffic lasts till receiving the appropriate end communication command from MATLAB. The end communication command is defined as an interrupt in compiler. When this interrupt is recognized, the compiler branches to end communication subroutine and gets back to the beginning of main loop.

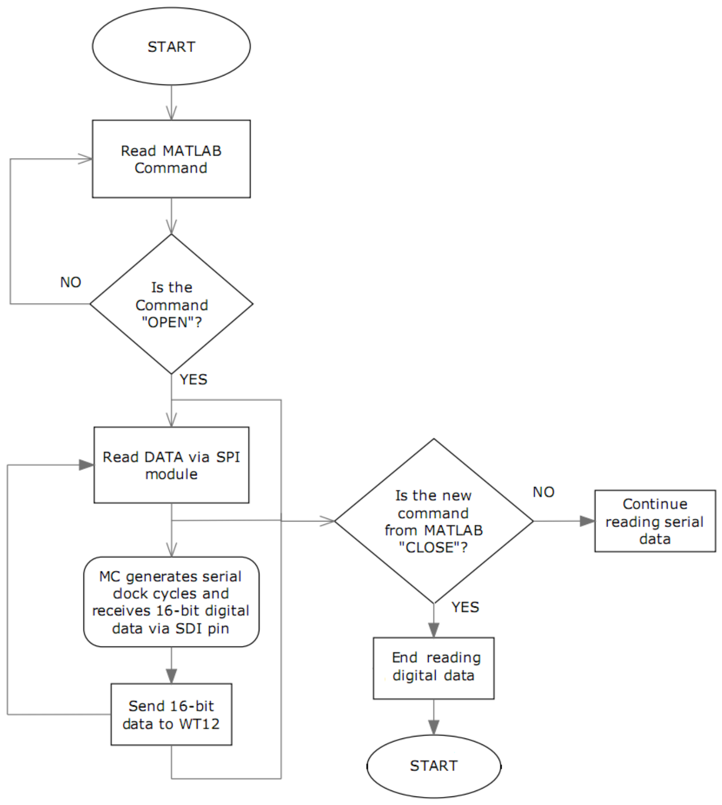

Figure 3. Flowchart of the microcontroller [13]

3. RESULTS AND DISCUSSION

The system was tested with a volunteer healthy male. The records were taken from right multifidus muscle of subject. The bipolar electrode was located to area of interest after cleaning the skin surface with an alcohol based cleaner. The reference electrode was attached to the left wrist.

The subject was asked to perform some physical activities. Standing subject flexed forward. The flexion motion lasted till the torso becomes perpendicular to the lower extremities of subject. This position took about a couple of seconds. The subject stayed in this position for a while. Then, the relaxation backward motion was performed. This motion also took about a few seconds.

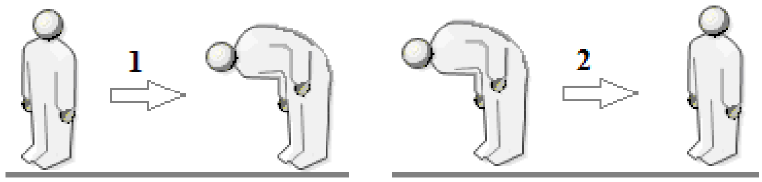

Figure 4. Flex forward and relax backward motions

Figure 4 shows the performed physical activities. The time domain signal plot during this physical activity is shown in Figure 5. The recorded SEMG biopotentials were analyzed with Welch's method. Welch's method was used to find the PSD plots of recorded biopotentials [25].

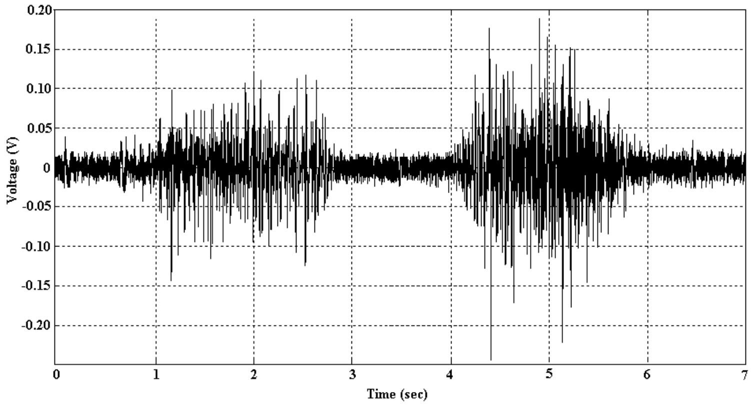

Figure 5. Muscular Activity of Right-Multifidus Muscle [13]

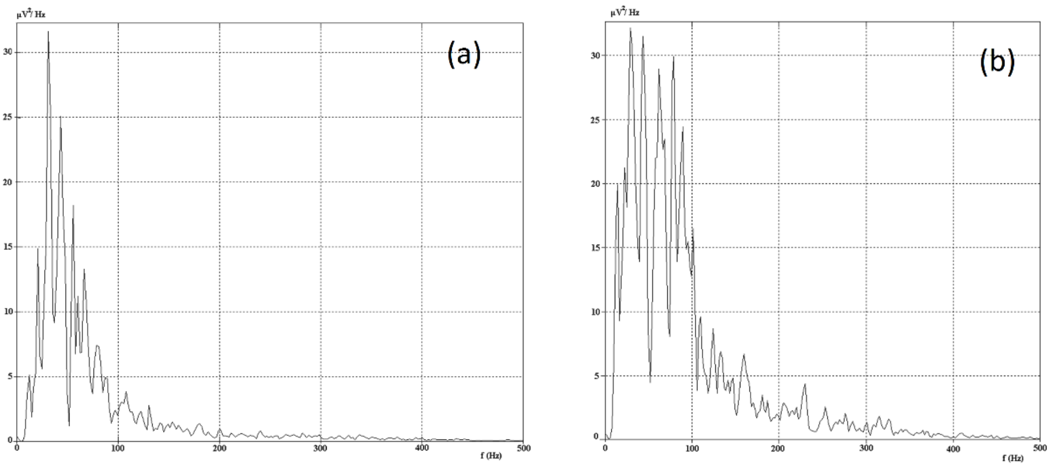

Figure 6. PSD plots when the subject was (a) flexing forward, (b) relaxing backward [13]

We used MATLAB software for the analysis of SEMG biopotentials. A user-friendly software is going to be designed for our application. The main goal of this study was the design of portable SEMG based LDH diagnosis system. The present constraints of this study don't include collection of SEMG data from herniated people and comparison of diseased people data with healthy people data. In the next future, it is aimed to make a clinical study to test the efficiency of the system.

NOTE: This study was presented in one national and two international congresses [5, 6, 11].

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