Eog-Based Device Control Interface for Patients with Quadriplegia

Kuadripleji Hastaları İçin Eog Göz Sinyali ile Cihaz Kontrolü Arabirimi

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***Özetçe*—Felçli hastalar ve onların bakımından sorumlu kişilerin günlük hayatta yaşam standartları oldukça düşmektedir. Vücuttaki dört uzuv ve gövdenin felç olması anlamına gelen kuadripleji, en şiddetli felç durumu olarak bilinmektedir. Bu hastalar vücutlarında yalnızca gözlerini hareket ettirebildikleri ve kendi kendilerine ihtiyaçlarını gideremediklerinden, hem psikolojik hem fiziki olarak kısıtlanmaktadır. Bu çalışmada, hastanın göz hareketleriyle önündeki cihaz kontrol ara yüzünü kullanabilmesi ve böylece istediği cihaz veya cihazları kontrol edebilmesi için yeni bir sistem geliştirilmiştir. Bu şekilde hastaların bazı basit faaliyetleri yerine getirebilmesi ve hem hastanın hem de bakmakla yükümlü kişilerin yaşam standartlarının az da olsa iyileştirilmesi amaçlanmıştır. Yapılan denemeler sonucunda, tasarlanan sistem kullanılarak isteğe bağlı olarak önceden programlanmış cihazların çalışması başarılı bir şekilde kontrol edilebilmiştir.**

Anahtar Kelimeler—Felç, EOG, Cihaz kontrolü

***Abstract*—The life quality of the patients with plegia and their caregivers is drastically reduced in daily life. Quadriplegia, which means that four limbs and the body trunk are affected from the plegia, is known as the most severe type of plegia. Since patients with quadriplegia can only move their eyes in their bodies and cannot meet their needs themselves, this limits them both psychologically and physically. In this study, a new system is proposed to use the device control interface in front of the patient via their eye movements and hence to control a device (or devices) whichever they want. Therefore, an improvement in both the patient's and their caregivers' life qualities since the patients will be able to conduct some simple activities alone. As a result of the limited experiments, to turn on and turn off the pre-programmed devices are controlled using the proposed system successfully.**

Keywords- Plegia, EOG, Device control

I. INTRODUCTION

The word quadriplegia, which is of Latin origin, consists of the quad that means four, and plegia that refers not to move because the patients cannot move the four extremities in the body, including the trunk [1]. Quadriplegia prevents patients from daily activities [2,3]. That is, patients cannot satisfy their needs like toilets, nutrition, and cannot control devices in their rooms [4]. The most common problem for patients is that they need life-long caregivers to survive. This is also a tough process for their family [5]. Therefore, there is a nightmare not only physically but also psychologically for patients who are obligated to such a life [6].

In this study, which is presented to provide quadriplegia patients with some mobility within the room, it is aimed to see all the options in front of the patient and thus provide ease of use [7]. Moreover, the environment will be optimized for the patients with different types of need options to be added and the patients will be able to live in their room much more actively. Thereby, a great advantage will be supplied for both patients and their caregivers [6,7].

For this purpose, the patients will be able to see all the applications in the webserver created as a result of examining the EOG signals received from the patients and combining them with the software. They will be able to make a selection on the menu by moving their eyes, and thus patients will be able to fulfill some of their needs in the room or can inform the caregivers on some issues. Therefore, caregivers will be able to live their own lives more comfortably at home, and the patient's self-confidence will increase.

II. MATERIALS AND METHODS

A. *Single Channel EOG Acquisition Circuit*

The single-channel EOG circuit is obtained in seven stages in our design respectively [8]; instrumentation amplifier, low pass filter, high pass filter, gain amplifier, inverse amplifier, notch filter, and summing amplifier. This circuit was designed for a single-channel that expresses the right-left movement of the eye and another channel that expresses up-down movement and was combined for the project (Figure 1).

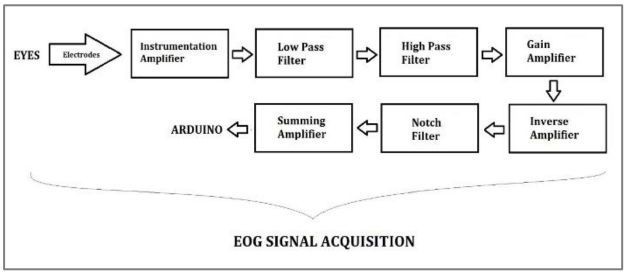

Figure 1. Block diagram of EOG Signal Acquisition Circuit

1) *Instrumentation Amplifier (INA)*

Since biopotential signals obtained from the body are quite small, it is necessary to increase the amplitude of the signals firstly. This process is occurred by using an instrumentation amplifier and it is also called preamplifier.

In our design, the INA121 integrated circuit which is Op-Amp based instrumentation was used. For gain, a trimmer potentiometer was placed between the 1^{st} and 8^{th} legs of the integrated circuit, and the desired amplitude values were achieved. For the power supply to INA121, Vcc^- which is -9V and Vcc^+ which is +9V was applied to 4th and 7th legs of IC respectively.

The gain was determined from the INA121 datasheet.

$$Gain = 1 + \frac{50k\Omega}{Rgain} \tag{1}$$

To increase the biopotential signal, the gain must be as high as possible. Therefore, R_{gain} was determined 75 Ω to achieve this, and gain resulted in 665.

2) *Active Low Pass Filter*

Since the signals received from the body contain all the signals in the body, filtering is required to obtain the desired signal specifically. The active low pass filter passes signals below a specific cut-off frequency, whereas it attenuates signals above the same cut-off frequency [9].

In our circuit, the cut-off frequency of the active low pass filter was determined as 33.8 Hz, since the EOG signals cover the signals below 50 Hz. The formula of the cut-off frequency is shown below:

$$fc = \frac{1}{2.\pi.R.C} \tag{2}$$

Where R2 is 1kΩ and C1 which value is 4.7µF.

In our design, the TL072 integrated circuit was used. For the power supply, Vcc^- which is -9V and Vcc^+ which is +9V was applied to 4th and 8th legs of IC respectively.

After processing with each part of the circuit, interference may occur on the signal. To prevent this, positive (+) end of the Op-Amps was connected to ground with a high-value resistor which is 1MΩ. This situation was applied to almost every party except active notch filter and summing amplifier.

The phase of the signal coming from the input changes 180° and the gain formula of the active low pass filter is shown below. Since the primary aim of the active low pass filter is filtering the signal, the Op-Amp's gain value was determined as 1. This situation is valid for active high pass filter. This formula is also used for active high pass filter, gain amplifier and inverse amplifier in EOG signal acquisition circuit design.

$$Gain = \frac{Vo}{Vin} = -\frac{Rf}{R1} \tag{3}$$

Where Rf and R1 are symbolized with R3 which value is 1kΩ and R2 which value is 1kΩ.

3) *Active High Pass Filter*

Since the EOG signals received from the body are within a specific frequency range, it is necessary to attenuate low-frequency signals as they can also contain noise. Therefore, a high pass filter was used for this process [10].

In our design, the cut-off frequency of the active high pass filter was determined as 1.03Hz, since the EOG signals cover the signals above 0.1Hz. The formula (2) was used, where R5 which is 33kΩ and C2 which is 4.7µF.

Since the power supply to IC is already done for the active low pass filter, there is no need to power supply again. This situation is the same for the inverse amplifier part and the summing amplifier part.

The formula (3) was used where R6 which is 33kΩ and R5 which is 33kΩ.

4) *Gain Amplifier*

The gain amplifier circuit is used to reach the signal generated by amplifying the received signal from the body to the desired signal amplitudes. The gain amplifier is the process of amplifying using Op-Amp. As a result of gain amplify operation, the input signal is multiplied by the gain, and output is obtained. The formula (3) was used where Rf and R1 are symbolized with respectively R9 which value is 220Ω and R8 which value is 22Ω. Therefore, the amplitude of the signal in the input amplifies 10 times in the output [10].

5) Inverting Amplifier

Since all the circuit parts used until now in the EOG signal acquisition are created with the inverting configuration circuit, the signal received from the body changes phase at each output. Therefore, it is necessary to capture the phase of the signal in the body to get the desired and correct EOG signal. For this, the phase difference was eliminated by using the inverse amplifier circuit. Since the primary aim of the inverse amplifier circuit is to eliminate the phase variation between input and output, the Op-Amp's gain value was determined as 1.

6) Active Notch Filter

One of the most important things to consider when obtaining signals from the body is to receive a noiseless signal. It is necessary to eliminate the power-line noise, which is one of the elements that can create noise. Therefore, an active notch filter was used.

The power-line noise is 50 HZ in our country, the cut-off frequency of the notch filter is approximately 48.3 Hz in our design to prevent noise. The formula (2) was used where R is R16 and R17 which values are 3.3kΩ, and C is C3 and C4 which values are 1µF.

7) Summing Amplifier

The summing amplifier provides the desired signal at the output of the summing amplifier by adding another input signal to the output of the active notch filter. Since it is a non-inverting configuration circuit, the gain formula has changed as follow:

$$Gain = 1 + \frac{Rf}{Ra} \tag{4}$$

Where Rf is feedback resistance and Ra is the input resistance. When the superposition theorem was applied to the positive (+) end of the Op-Amp, the output voltage formula is shaped as follows:

$$Vout = Gain\ x\ [\frac{R1\ x\ V1}{R1\ +R2} + \frac{R2\ x\ V2}{R1\ +\ R2}] \tag{5}$$

where R1 and R2 input resistors that are R18 and R19 respectively, V1 and V2 are input voltages, V1 is Vin and V2 is 3V respectively.

Because of the R1 equals to R2, the formula changes as:

$$Vout = \left(1 + \frac{Rf}{Ra}\right) x\ (\frac{V1 + V2}{2}) \tag{6}$$

and because of the Rf and Ra equal each other, the formula:

$$Vout = (V1 + V2) \text{ or } Vout = \ (Vin + 3V) \tag{7}$$

The summing amplifier operation is performed in order not to lose negative-valued EOG signals. The reason for making a 3V summing amplifier is that the signal coming from the notch filter circuit to input of this circuit took values between -3v and 2v.

As a next step, signals from the output of the Summing Amplifier must be connected to any analog pins on the Arduino board to be used in the Arduino Leonardo.

B. Ethernet Connection and Webserver

For the web server design, the Arduino board to be used was decided. One of the most important details in the study is that the patient will move the mouse cursor on the screen by using his eyes. Therefore, the Arduino Leonardo, allowing with the characteristic of ATmega32u4 to use the Mouse.h library to move the cursor was chosen. Also, the fact that this board is suitable for SPI communication.

The ENC28J60 was chosen as the Ethernet module to design web server (Figure 2). Then, the Ethernet network cable was connected to the ENC28J60 module and the modem [11]. The USB cable was connected to the Arduino board [12].

The Arduino IDE program required for coding via Arduino Leonardo was installed and run. After selecting the appropriate microcontroller and port, the codes were written.

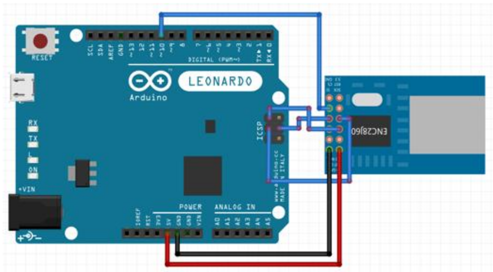

Figure 2. The Fritzing scheme of Arduino Leonardo and ENC28J60 Ethernet module

C. Mouse Cursor Control

This project aims to provide mobility to patients with quadriplegia, the ability to move the mouse cursor is required during operations on the webserver interface. Since the ATmega32u4 chip supports the Mouse.h library, codes for the movements of the cursor were written. So, we completed the code as shown in the Appendix section to control the mouse cursor based on the eye signals.

D. Device Control

To complete the project, the connections of the devices that can be controlled within the room were designed and built. In real room design, the devices will be combined with the relay which has an appropriate channel that will be selected according to the number of devices.

The alarm system was designed for the most urgent needs of the patient such as toilet, nutrition, or water. A blue bulb representing water, a red bulb representing nutrition, and a yellow bulb representing the toilet were chosen. Thanks to the colors evoke the meaning of bulbs, it will be easy for the caregiver to code the meanings to his head. Also, with a buzzer placed in the system, when the bulbs light up, the caregiver is warned even in another room.

Then, the design of the fan and bedside lamp occurred. To use for the control of the curtain and patient bed, the DC motor system were designed also.

III. RESULTS

This project was designed to move the mouse cursor with eye movements of patients with quadriplegia, and thus to control the devices in the patient room through the webserver. For this, suitable values were determined, an electronic circuit was developed (Figures 3 and 4). The electrodes are placed and the circuit was connected to the volunteers (Figure 5). In order to achieve a two-channel EOG, we used two circuits.

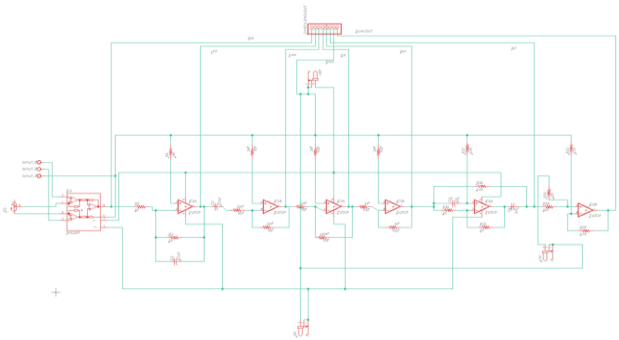

Figure 3. The design of the single-channel EOG circuit

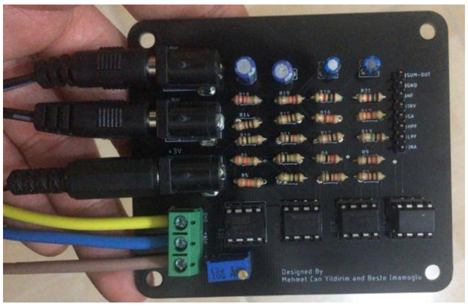

Figure 4. The single-channel EOG circuit card

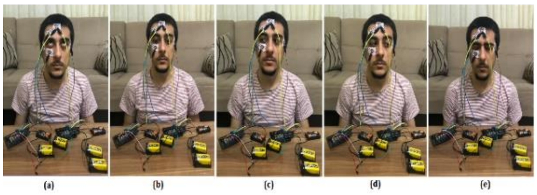

Figure 5. The placement of electrodes on the face to obtain eye movements for (a) up, (b) down, (c) right, (d) left, (e) click operation

A webserver was designed by using the ENC28J60 Ethernet module. Therefore, the design shown in Figure 3 was seen, and the control of devices can be performed.

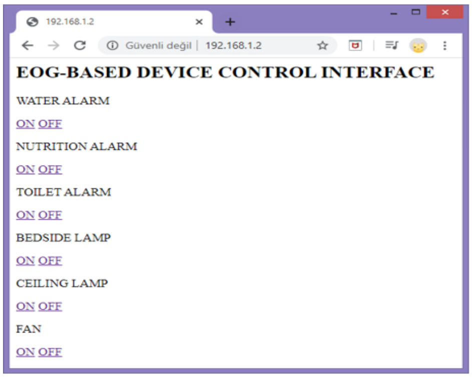

Figure 3. The design of the webserver interface

The control of the mouse cursor was provided in the presence of the Mouse.h library. As a result of the Arduino code, the movement of the mouse cursor on the webserver with the eye movements was performed to right-left and up-down. Also, the click operation of the mouse was obtained.

IV. CONCLUSION

In this project, we designed a system for patients with quadriplegia who cannot move any part of their body except eyes. To summarize the system simply, it can be said that this system will enable patients to control the devices in the room by making selections on the screen in front of them with eye movements.

The project was completed with some missing points. Firstly, instead of a good-looking webserver that allows all the desired devices, a simple-looking webserver capable of controlling six devices had to be used due to the limited memory of the Arduino board.

As a future aspect, a more useful webserver can be designed by solving the memory problem of the Arduino board. For this, the design must be loaded into the SD card and connected to Arduino. Also, eye tracking which is a more ergonomic system can be preferred rather than the EOG circuit. In cases where the patients are children, more colorful design can be made in which the devices are expressed with visuals instead of the text.

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