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ORIGINAL RESEARCH

EOG acquisition system based on ATmega AVR microcontroller

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Abstract

This paper presents a hardware and software of an electrooculogram (EOG) acquisition system based on ATmega AVR microcontroller for the acquisition of vertical and horizontal eye movements. The presented system is used to acquire a dataset of eye movements for volunteers. This system gives two channels representing vertical and horizontal EOG signals. The frequency range of the EOG signal is known to be 0.1 to 10 Hz, and hence this frequency range is isolated with a High-Pass Filter (HPF) with a cutoff frequency of 0.1 Hz followed by a Low-Pass Filter (LPF) with a cutoff frequency of 10 Hz. The EOG acquisition system is interfaced with an ATmega AVR microcontroller to acquire a dataset that can be used for controlling hardware such as Light Emitting Diodes (LEDs), wheelchair, and robot arm. The presented system is composed of EOG signal acquisition, Ag/AgCl electrodes, analog-to-digital converter through Arduino Mega 2560 board microcontroller unit, trainer board, laptop, keypad, and Liquid Crystal Display (LCD). The eye movement is detected by measuring the potential difference between cornea and retina using five Ag–Agcl disposable electrodes. Different volunteers of different ages at different times have been treated with the presented system to obtain data. Classified vertical and horizontal EOG signals and the basic eye movements e.g., open eye, left, right, up, and down can be used to control robots and wheelchairs for rehabilitation purposes.

Keywords EOG · ATmega AVR microcontrollers · Horizontal eye movements · Vertical eye movements · Human Computer Interface (HCI)

1 Introduction

Research in the field of Human Computer Interface (HCI) can greatly improve life quality, for the people with severe disabilities, suffering from spinal injuries, joint deformities, muscle spasms, Amyotrophic Lateral Sclerosis (ALS), etc. These patients have difficulties to achieve their goals, because they have no control over their muscles, voluntarily. They are still conscious, however, and can control eye movements. Several devices are used to record human eye activities, but most of them have their limitations (Qi and Alias 2018).

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Electroculography (EOG), Infrared Oculography (IROG), Infrared Video System (IRVS), Search Coil (SC), Purkinje Dual Purkinje Image (DPI) and Optical Eye Tracking System (OETS) are different techniques that can be implemented based on eye movement detection (Young et al. 1975; Deng et al. 2010). Compared to other bioelectrical signals, the EOG signal offers the advantages of high amplitude, low frequency and easy reception and transmission of information with high activity (Lee et al. 2017)

The EOG has turned out to be the simplest technique to measure eye movement directions. It is easy to create EOG systems with surface electrodes around the orifice and modify them in real time. An EOG system allows us to predict the presence of a disease in a simple and economic way. The symptoms of some diseases are characterized in a simple and cost-effective way by eye movements (Banerjee et al. 2014).

The EOG can be used to determine eye movements by measuring the potential difference between the front and back of the eyeball. There is a direct relationship between eye movements and EOG signal amplitude (Choudhury et al. 2005). On the other hand, EOG could be a good engineering tool for detecting the electrical activities produced by the human eye that further acts as an electrical dipole. Hence, positive, and negative electrodes are used to capture the retina and cornea potential difference. With a series of gel-based electrodes located around the eye, the EOG detects non-invasive electrical activities induced by the Corneo-Retinal Potential (CRP) (Bulling et al. 2011; Barbara et al. 2019).

The EOG potential is generated by electrical signals produced during different horizontal and vertical movements of the eye, such as blinking, staring, and anger (Ma et al. 2015). The EOG signal amplitude and frequency range from 15 to 3500 microvolts and 0 to 100 Hz, respectively. Its unique voltage range and easiness of detection makes the EOG signal ideal to be used as an input signal for different applications (Deng et al. 2010; Barea et al. 2002).

The EOG signals are essential for scientists and physicians, because they offer a wealth of information on neuropathology. Without hand movements or speech for HCI, the EOG is an efficient alternative. In Human-to-Machine Interfacing (HMI) applications such as computer control and wheelchairs, the EOG signals are widely used, as both programs allow people with disabilities to navigate and manage their computer applications (Samann and Hadi 2018). Thus, the EOG signal is a suitable candidate for eye-movement-based systems. Indeed, several HCI applications using EOG have been proposed, including control of electric wheelchair (Barea et al. 2002), control of mobile robot (Bulling et al. 2011), recognition of eye writing (Usakli et al. 2009; Wissel and Palaniappan 2013), recognition of activity (Bulling et al. 2011), etc.

Therefore, in this work, we are motivated to introduce hardware and software of an EOG acquisition system based on ATmega AVR microcontrollers for the acquisition of vertical and horizontal eye movements. The main contribution of this work is the introduction of a method for EOG signal acquisition. It includes both hardware and software for the acquisition of eye movement signals for horizontal and vertical directions, such as open eye, left, right, up, and down. The proposed system is used to acquire a dataset of eye movements for volunteers. It is composed of Ag/AgCl electrodes, analog-to-digital converter through Arduino Mega 2560 board microcontroller unit, trainer board, laptop, keypad, and LCD.

The eye movement is detected by measuring the potential difference between cornea and retina using five Ag–Agcl disposable electrodes. ATmega AVR microcontroller serializes the EOG data for calibration and provides a threshold reference point, which is used for controlling the hardware. Different volunteers of different ages at different times have been treated with the proposed system to obtain data. The results obtained prove that the proposed system provides an effective tool for obtaining digital data that researchers can use to help the disabled to perform various tasks.

The rest of the paper is structured as follows. Section 2 shows the previous related works. Section 3 shows the fundamentals of eye movement signals (EOG signals). In Sect. 4, the experimental design, materials, and methods used to build the proposed system are discussed. Section 5 presents the methodology of the proposed system. Section 6 gives the experimental setup that has been discussed. Section 7 presents the experimental results. Section 8 presents a comparison with recent related works in addition to the links of the dataset and program of the proposed system. Finally, Sect. 9 gives the concluding remarks.

2 Previous related works

In the literature, a researcher in this field can find a variety of studies using different signal acquisition devices and functional graphical user interfaces in the context of EOG-based HCI. Reviewing the relevant literature, most of the research has focused either on the hardware stage or the software stage. Some related work is presented below.

In Manousos Klados et al. (2016), the authors presented a semi-simulated EOG dataset. The EOG signals were obtained from the subjects, during an eyes-opened condition, using two electrodes placed above and below the left eye and the other two on the outer canthi of the two eyes. This process gave rise to two bipolar signals, namely vertical-EOG (VEOG) which is equal to the upper minus lower EOG electrode recordings, and horizontal EOG (HEOG) which is equal to the left minus right EOG electrode recordings.

These EOG signals were band-pass filtered at 0.5–5 Hz. The VEOG signals were used to detect all the blink segments (start–peak–end). The data are available for downloading without any restrictions using this URL: https://data.mendeley.com/datasets/wb6yvr725d/1.

In Wilming et al. (2017), the authors presented a dataset of eye-movement recordings that contains more than 2.7 million fixation locations from 949 observers on more than 1000 images from different categories. This dataset was collected from 23 different studies conducted at the Institute of Cognitive Science at Osnabrück University and the University Medical Center in Hamburg-Eppendorf. Trained personnel recorded all studies under standard conditions with homogeneous equipment and parameter settings. All studies allowed for free eye movements and differed in the age range of participants (~ 7–80 years).

In Fuhl and Kasneci (2018), the authors presented a dataset of eye movements. The dataset consists of over 800,000 gaze points recorded during car riding in the real world and the simulator. In total, the eye movements of 19 subjects were obtained. In this dataset, there are several data sources such as eyelid closure, pupil center, optical vector, and a vector into the pupil center starting from the centers of the eye corners. These different data sources are analyzed and evaluated individually as well as in combination with respect to their goodness of fit for eye movement classification.

In Barbara et al. (2020), the authors recorded the EOG data using the g.tec USBamp bio signal amplifier (g.tec medical engineering GmbH, Austria) with a sampling frequency of 256 Hz. The data is bandpass filtered between 0 and 30 Hz, and a 50-Hz notch filter is also applied. This dataset comprises EOG data recorded for six healthy participants. A total of 600 saccades of random ocular displacement and 300 blink events were recorded for each subject. These eye movements were recorded using a standard EOG electrode configuration, comprising two horizontal aligned electrodes mounted adjacent to the lateral canthi and two other electrodes, which are vertically aligned with the right eye. A ground ('G') electrode and a reference ('R') electrode were also attached on the forehead and behind the left ear, respectively.

In Christoph Reichert et al. (2020), the authors recorded the EOG, while participants were looking at a cross which they were asked to track with their gaze, and which changed its position every 1,250 ms. The position displacement relative to the center varied from 1 to 7 degrees horizontally, and in 30% of the trials, there was an additional displacement of the cross by 2 degrees, vertically. Three times the cross was replaced by a circle, and the participants were asked to perform an eye blink immediately. In total, 40 gaze shifts and three blinks were performed in an unpredictable order, resulting in approximately 1 min of EOG calibration. This procedure provided calibrated data that characterize the strength of EOG signals as a function of gaze shift angle. These data were used to evaluate the degree of unintentional eye movement during BCI control.

In Andres Jaramillo-Gonzalez et al. (2021), the authors presented a dataset that contains recordings of EEG and EOG from four advanced locked-in states (LIS) patients suffering from amyotrophic lateral sclerosis (ALS). Data were recorded for four patients during a variable range of visits (from 2 to 10). Each visit comprised 3.22 ± 1.21 days and consisted of 5.57 ± 2.61 sessions recorded per day. The dataset provides an insight into the progression of ALS and presents a valuable opportunity to design and improve assistive and alternative communication technologies and BCIs. It might also help redefine the course of progression in ALS, thereby improving clinical judgment and treatment.

The main contributions of our research work are listed below as follows:

1. An EOG acquisition system is designed to take actually the signals of eye movements in practice. It is also designed on the proteus program.
2. The signal taken is converted into digital data through the ATmega AVR microcontroller. It can be used for classification in several applications.
3. The EOG acquisition system acquires digital signals with the help of a trainer board, which contains 13 LEDs that represent all directions of eye movements, regularly.
4. The keypad is used to control the course of the program and carry out what is required to take data from the volunteer.
5. The Liquid Crystal Display (LCD) is used to allow easy interaction with the proposed program.
6. Parallax Data Acquisition (PLX-DAQ) tool is used and linked with the ATmega AVR microcontroller in the proposed system to record all readings in both horizontal and vertical directions.
7. The data is stored in an excel sheet by linking and adjusting both the port used and the speed of transmission (baud rate = 9600 bps). The data are taken for volunteers at different times, ages, and conditions, not just from the designer himself.
8. The researcher in this field can use the proposed system and follow the steps in the flowchart mentioned to take a large amount of digital data, as much as possible to design a system that helps the disabled for their applications.

3 Fundamentals of eye movement signals (EOG signals)

The EOG is a technique for measuring the standing potential of human cornea-retina between the leading and trailing edges of the human eye movements. When there is an active nerve in the retina, a potential difference of 10 to 30 mV

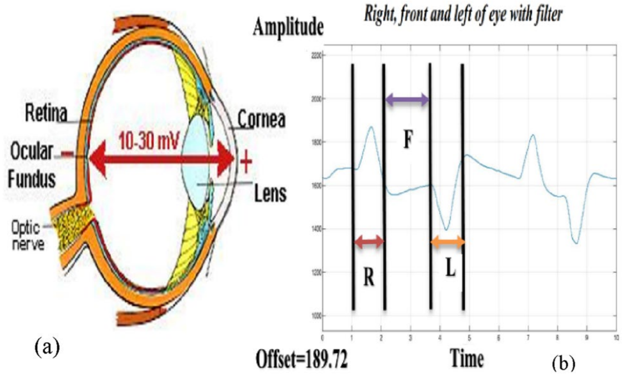


Fig. 1 Basic principles of eye movement signals: **a** Eyeball anatomy, **b** Pulse of eye movement filtered: Pulse of Right (R), Pulse of Front (F) and Pulse of Left (L)

compared to the front of the eye exists, as shown in Fig. 1a (Champaty et al. 2014).

This difference in voltage between the cornea and the retina is due to the wonderful active presence of the nervous system in the retina of the anterior part of the eyeball. This can be seen as a steady electrical dipole with negative and positive poles on the retina and the cornea, respectively. (See Fig. 1b). The resulting signal is called electrocologram (EOG) (Lv et al. 2018).

The EOG signal normally consists of 2 pulses. The first pulse represents the beginning of the EOG signal, and the second pulse reveals the stop of the signal. Properties of different human eye movements are mentioned in Table 1.

When the eyeball moves to the right, the front, and the left or to the top, the front, the bottom and the center, the positive and the negative pulses are produced, respectively, in the vertical or horizontal channel (see Fig. 1b).

4 Experimental design, materials, and methods

4.1 Dataset description

This section describes the dataset of eye movements in vertical and horizontal directions. These data are digital data taken for volunteers through the proposed system by placing electrodes on the volunteer's face in a certain way and then taking movements from the eye. The obtained signals are very small-magnitude analog signals. These signals are amplified. Then, they are filtered and converted into digital format, through the ATmega AVR microcontroller, and then sent to the computer for storage.

Table 1 Properties of different human eye movements

Eyeball movements	First pulse	Second pulse	Pulse duration (ms)
Right	Positive	Negative	400–600
Left	Negative	Positive	400–600
Up	Positive	Negative	400–600
Down	Negative	Positive	400–600

The signals are stored and dealt with easily, because they are digital for each movement of the eye and are used later for the different applications related to the disabled. In this presented work, we take data through the proposed system for volunteers ranging in age from 20 to 32 years at different times and circumstances. Volunteers sit on chairs. The height of the chair is about 55 cm from the ground. The height of the trainer board is 86 cm above the ground. The researchers can use these data for a variety of purposes for medical applications to help the handicapped.

4.2 System configuration

The vertical and horizontal acquisition system of EOG signals for HCI based on ATmega AVR microcontroller consists of hardware and software interfaces. The block diagram of the acquisition and recording system using EOG and ATmega AVR microcontroller is shown in Fig. 2. This system includes volunteer, EOG, ATmega AVR microcontroller, trainer board, LCD, keypad, and laptop. The step-by-step method is described below.

4.2.1 Volunteer

A volunteer is a person, who gives the signals in both horizontal and vertical directions (e.g., closed eye, open eye, left, right, up, and down) by placing the electrodes on his face as shown in Fig. 3.

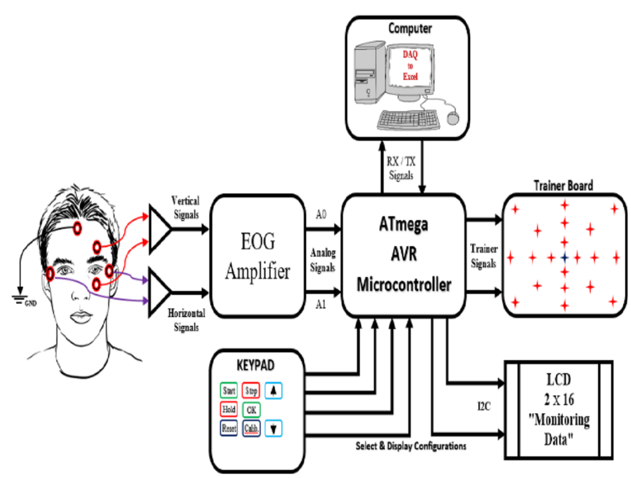


Fig. 2 Block diagram of the system configuration

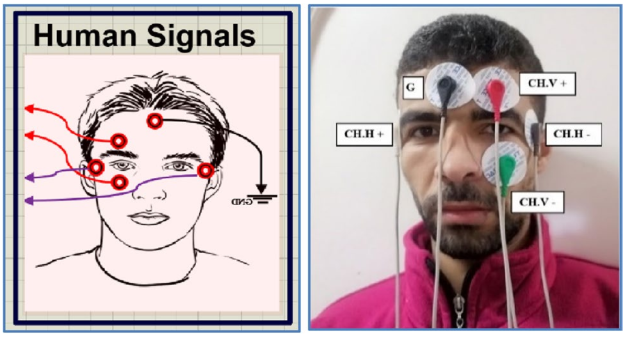


Fig. 3 Electrode placement and configuration

Figure 3 shows the placement of five surface electrodes around the eye. The vertical band is obtained in the upper left and lower parts (Ch. V + and Ch. V-) of the left eye. Two eyes move simultaneously in a vertical direction.

Therefore, only the right eye is used for vertical signals. A horizontal connection is made with two electrodes to the right and left of the external electrical socket (Ch.H + and Ch.H–). The reference electrode is placed on the forehead (G).

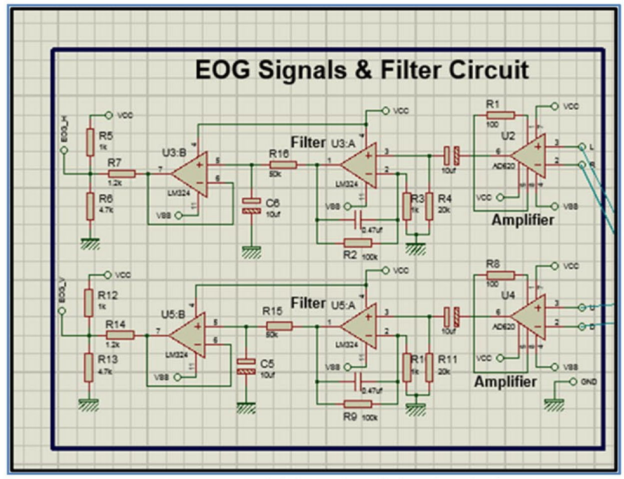
4.2.2 EOG signal acquisition circuit

Electrooculogram (EOG) is a bio-signal produced by the potential difference between the retina and the eye cornea in both horizontal and vertical directions by iris movement (Deng et al. 2010). The potential difference is generated, because the metabolic rate of the retina is higher than that of the cornea. In this way, the eye is modeled as an electrical dipole, and this dipole moves with the movement of eyeball (Estrany et al. 2008).

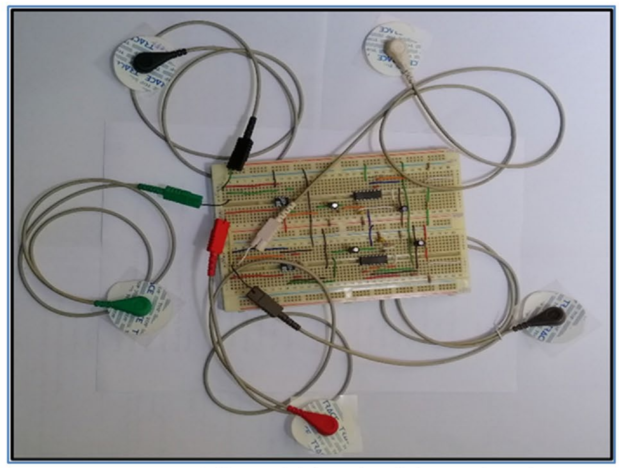
Normally, the EOG signal has a differential potential of 0.05–3.5 mV in amplitude and a frequency range of 0.1-20 Hz. For HCI applications, this EOG signal can be used to transfer information between humans and machines. Many strategies have already been introduced to implement the HCI system based on EOG signal (Estrany et al. 2009).

The EOG signal acquisition circuits, as shown in Figs. 4a, b and c consist of the Ag/AgCl electrodes that are used to detect the EOG signal by placing the electrodes close to the face and using AD620 instrumentation amplifier, signal filtering, voltage follower, shift stage, and analog-to-digital conversion in Arduino Mega 2560 board microcontroller unit.

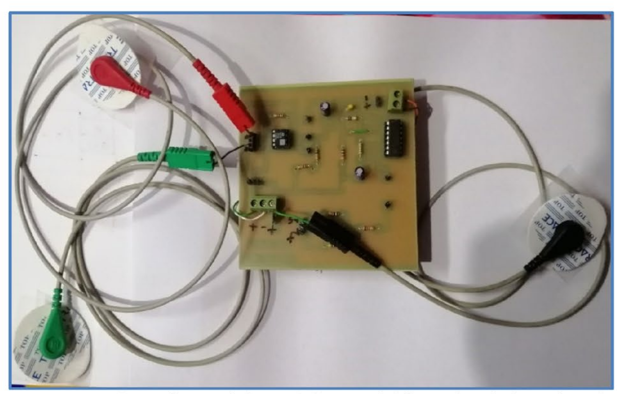
The eye movement is detected by measuring the potential difference between cornea and retina using five Ag–Agcl disposable electrodes. The frequency range of the EOG signal is known to be 0.1 to 10 Hz, and hence this frequency range is taken using HPF and LPF to obtain an accurate EOG signal. The analog output of the EOG signal from



a EOG acquisition circuit in simulation.



b EOG acquisition circuit in test board.



c One channel for EOG acquisition circuit in printed circuit board.

Fig. 4 **a** EOG acquisition circuit in simulation. **b** EOG acquisition circuit in test board. **c** One channel for EOG acquisition circuit in printed circuit board the filter is converted into a digital signal using an Arduino Mega 2560 board microcontroller on A0 and A1 for vertical and horizontal directions.

4.2.3 ATmega AVR Microcontroller

An analog EOG signal is transferred to the Arduino through serial communication, where the EOG signal is converted into a digital signal. This digital data is transferred to the computer calibration and classification stage with the C programming language in the Arduino program.

The Arduino ATMega 2560 board microcontroller shown in Fig. 5 was used. The speed of the serial communication is 9600 bps, taking 320 samples per second. A larger sampling rate can be achieved by choosing a high baud rate or clock speed (Samann and Hadi 2018). It is important to isolate the signal acquisition circuit from the AC mains for reducing noise and power line interference. A virtual ground of 3.3 V is used as a reference of the instrumentation amplifier, which converts the bipolar EOG signal to unipolar format. Simply, the AVR microcontroller unit is connected to a computer with a Universal Serial Bus (USB) cable and AC-to-DC adapter or battery to get started.

The following items are linked to the ATmega AVR microcontroller:

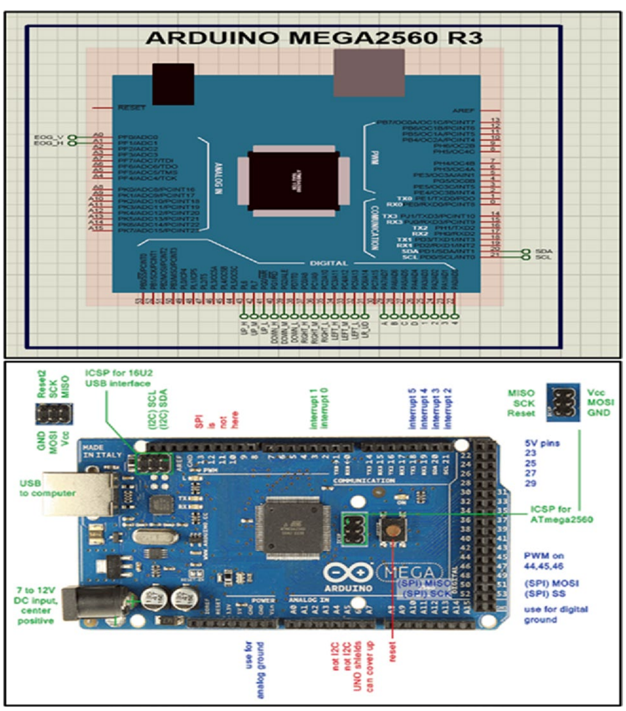
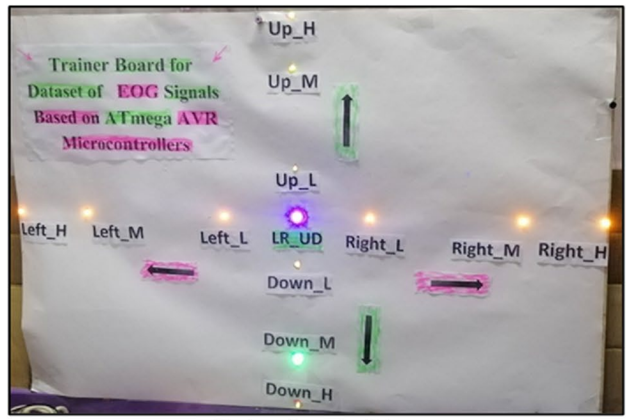
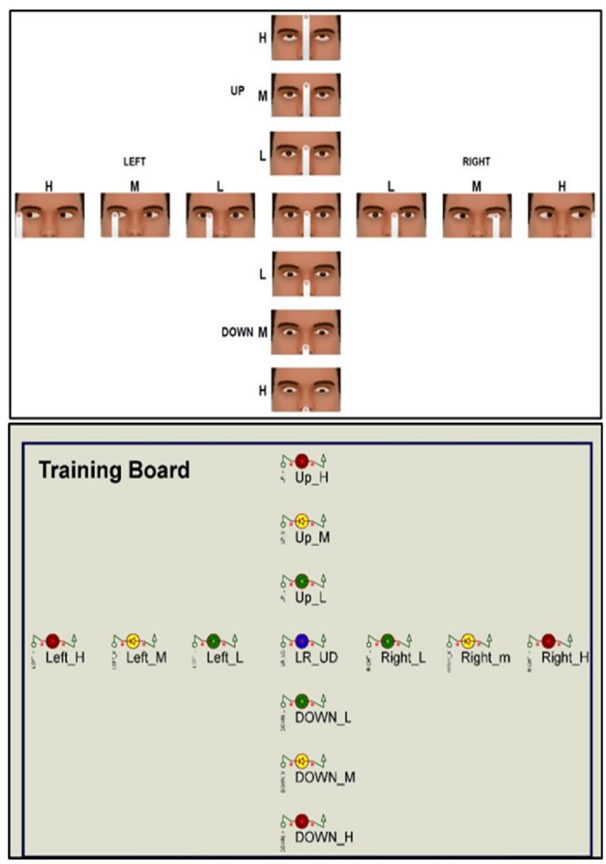


Fig. 5 Arduino Mega 2560 board microcontroller (https://www.pngegg.com/en/png-izset)

- Keypad
- LiquidCrystal_I2C display (LCD address to 0 × 27 for 16-chars and 2-line display)
- Trainer board
- Laptop (It has PLX-DAQ and Arduino program)



a Trainer board of the system.



b Trainer board in simulation of the system.

Fig. 6 **a** Trainer board of the system. **b** Trainer board in simulation of the system

4.2.4 Trainer board

The trainer board is placed in front of the volunteer in order to make the signals correct in both the horizontal and vertical directions. This board allows different directions as shown in Figs. 6a and b.

Through this trainer board, which contains 13 LEDs, each LED indicates a specific direction including horizontal and vertical directions. The LR_UD LED in the middle indicates the front direction.

In the right direction, the three LEDs indicate the close, middle, and extreme (Right_L, Right_M, and Right_H) of the right direction. In the left direction, the three LEDs indicate the close, middle, and extreme (Left_L, Left_M, and Left_H) of the left direction. On other hand, three LEDs are used for the up direction (Up_L, Up_M, and Up_H) and three for the down direction (Down_L, Down_M, and Down_H).

Ten signs are taken for each LED in the trainer board, and then the average is taken for these signs. The values of these signs are recorded on the computer. The program is linked to excel through data acquisition (PLX-DAQ) by defining the port of ATmega AVR microcontroller and setting the baud rate as 9600 bps.

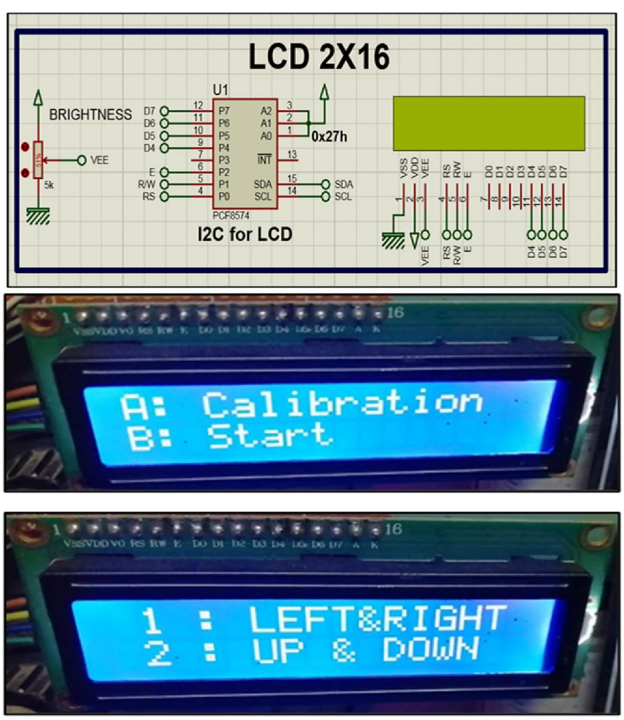


Fig. 7 LiquidCrystal_I2C display (LCD display)

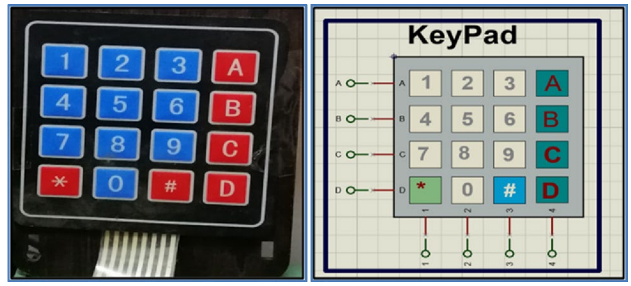


Fig. 8 Keypad used in the system

4.2.5 LiquidCrystal_I2C display (LCD display)

The LCD shown in the Fig. 7 is used. It is linked to the ATmega AVR microcontroller to allow each trainee, user, and designer of the program to follow the program execution in order to easily deal with the proposed system.

4.2.6 Keypad

The keypad shown in Fig. 8 was used. It is linked to the ATmega AVR microcontroller. The keypad allows both the trainee, the user, and the designer to control the program. Each key in the keypad performs a specific function in the program, such as choosing the direction of eye movement. In addition, it is possible to return to the main menu of the program and repeat the process again from the beginning in the case of new volunteers. The buttons in Fig. 8 are used according to Table 2.

4.2.7 Data acquisition for excel (PLX-DAQ)

Data acquisition (PLX-DAQ) is used and linked to the ATmega AVR microcontroller in the proposed system. It is used to record all readings in both horizontal and vertical directions in an excel sheet. The data is stored by defining the port used and setting the speed of transmission (baud rate) to 9600 as shown in the Fig. 9. The data of the trainees are obtained and recorded by time and date.

5 Methodology

The flowchart of the proposed system is shown in Fig. 10. It is composed of twelve main parts. The flowchart of calibration in the proposed system is shown in Fig. 11. It is composed of six main parts.

In Fig. 10, the AVR microcontroller is initialized with the definition of the variables, and functions of input and output terminals. The LCD is connected to the AVR

Table 2 Functions of buttons in the keypad of the system

No	Button	Use
1	A	Calibration
2	B	Start main program
3	C	Restart
4	#	LCD clear and goto main process
5	*	LCD clear and goto calibration (For next step)
6	D	LCD clear and break (For next step)
7	1	LCD clear and goto horizontal direction of eye movements (Left & Right)
8	2	LCD clear and goto vertical direction of eye movements (Up & Down)
9	3	LCD clear and goto test mode selection
10	4	LCD clear and goto horizontal direction (Left & Right) in test mode selection
11	5	LCD clear and goto test all directions in test mode selection
12	6	LCD clear and goto vertical direction (Up & Down) in test mode selection

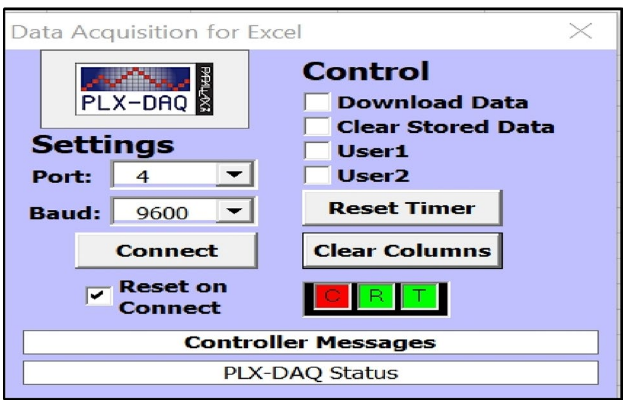


Fig. 9 Data acquisition for excel (PLX-DAQ)

microcontroller to show the commands. In addition, the keypad is used to choose the appropriate command. The serial port is initialized and linked to the data acquisition (PLX-DAQ). When the program is run, the LCD is opened, and it waits for the response from a keypad to choose one of the two options as shown in Fig. 12a. If the button A is chosen from a keypad, the LCD waits for the response from the keypad to choose one of the two options as shown in Fig. 12b.

For the representation of the signals for each direction including left, right, up, and down directions, we have different categories. For example, for the left direction, these categories are close (Left_L), medium (Left_M) and extreme (Left_H). Different realizations (ten readings of digital data) for the three signals acquired for the left categories are averaged to represent the left signal. A similar treatment is performed for all directions, as shown in Fig. 13a and b.

Each LED for each category lights for three seconds until the eye responds to the signal, and then the signal is moved to the next category. The sampling is preferred in a relatively dark location to prevent disturbance of eye signals. Finally, all data are exported to the data acquisition (PLX-DAQ) through the serial port of the control unit. Then, the digital data are saved with the name of each category in the excel sheet.

After the data are recorded and saved through data acquisition (PLX-DAQ), two options can be used to complete the sequence of the program, loading pre-calibrated values or calibrating new data. In order to allow calibration, a program starts to run the training board in the same sequence to start a new calibration.

6 Experimental setup

6.1 Software

Figure 14 shows the experimental software setup for the proposed system using Proteus 8 professional simulation program. This figure shows the six main parts of the proposed simulation system, as follows:

- *Human signal acquisition:* In this stage, sensors are fixed on the human face to capture signals in the horizontal and vertical directions (e.g., closed eye, open eye, left, right, up, and down) by placing the electrodes on the face.
- *Training Board:* It is used to simulate the direction that the volunteer looks at in order to record EOG signals.
- *EOG acquisition circuit:* EOG signal can be used to transfer information between humans and machines. The EOG circuit shown in Fig. 14 has two channels (horizontal and vertical). Each channel consists of an AD620 instrumentation amplifier with a gain of 495. The gain of the AD620-IA depends on the resistance *Rg* in Eq. (1).

$$Gain = \frac{49.4k\Omega}{Rg} + 1 \tag{1}$$

where the gain resistance $(Rg) = 100\Omega$

$$Gain = \frac{49.4k\Omega}{100} + 1 = 495$$

Signal filtering is performed to remove unwanted interference and keep the EOG signal in the 0.1 to 10 Hz frequency range, after the first amplification stage. The HPF cut-off

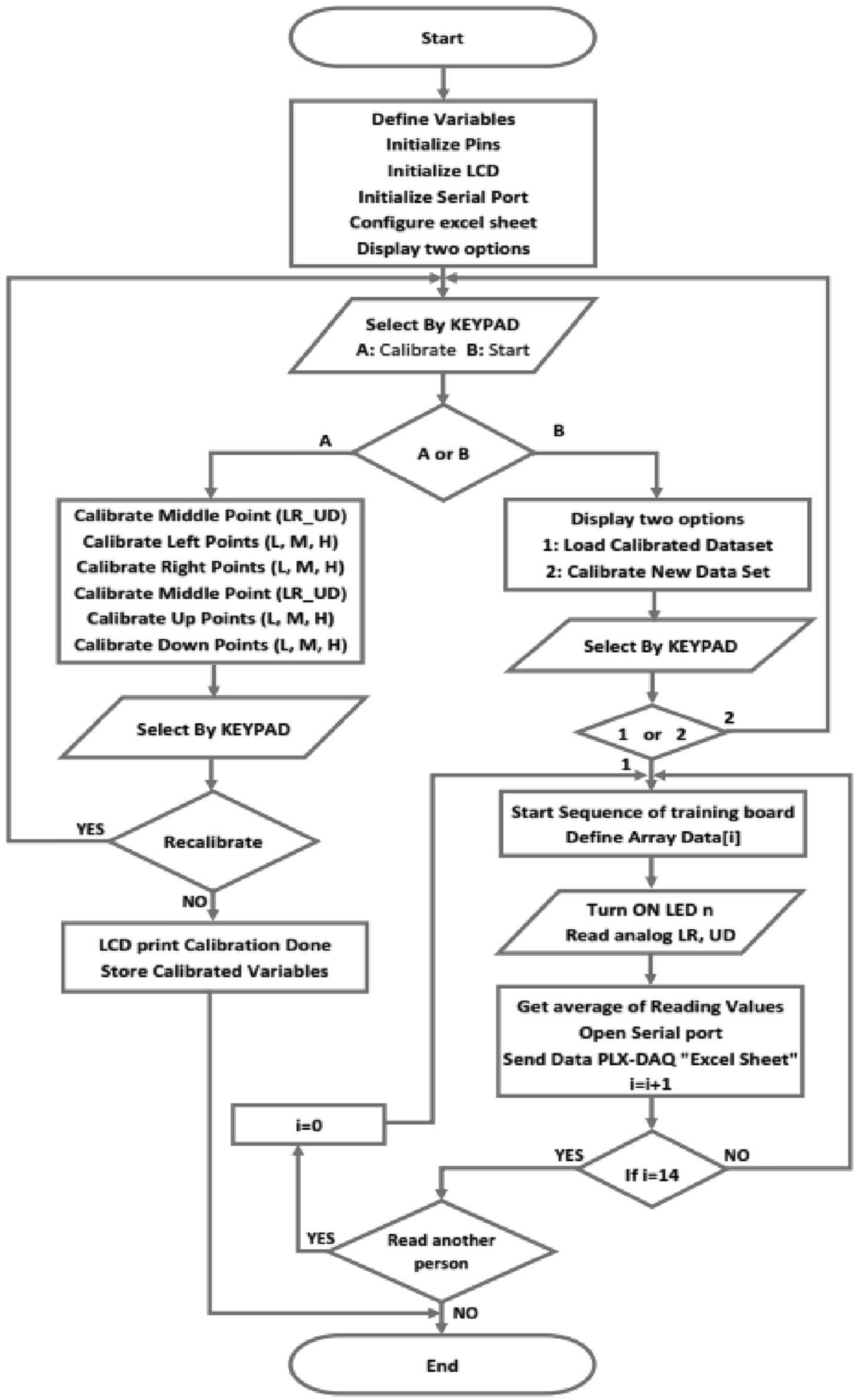


Fig. 10 Flowchart of the proposed system

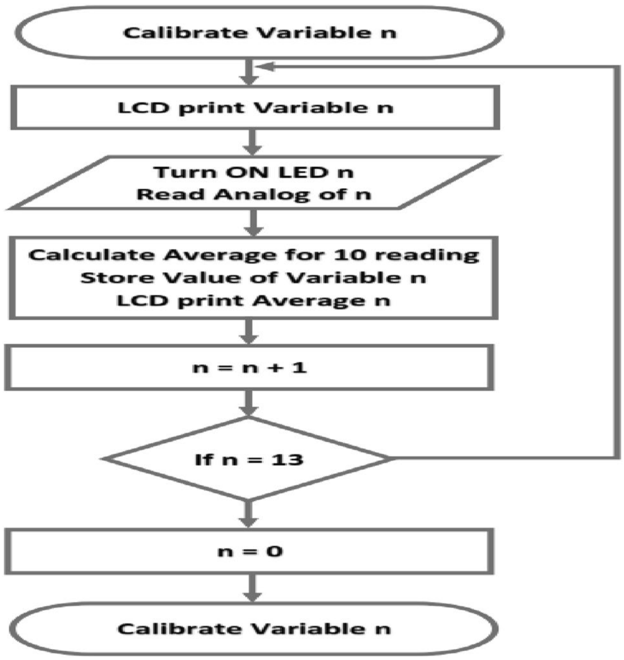
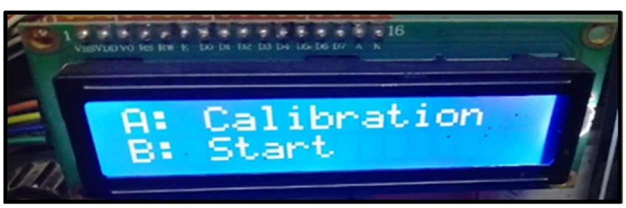


Fig. 11 Flowchart of calibration



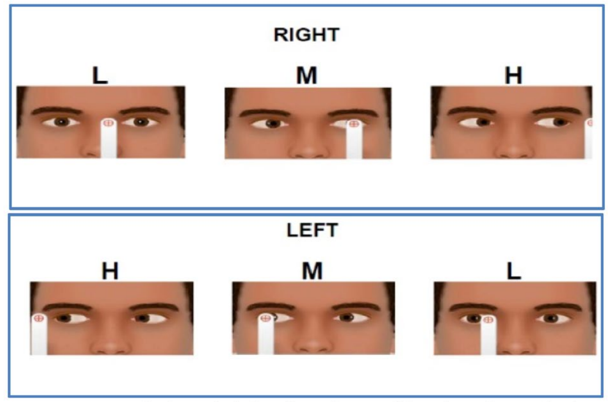
a Two options of the proposed system.

b Two options of calibration.

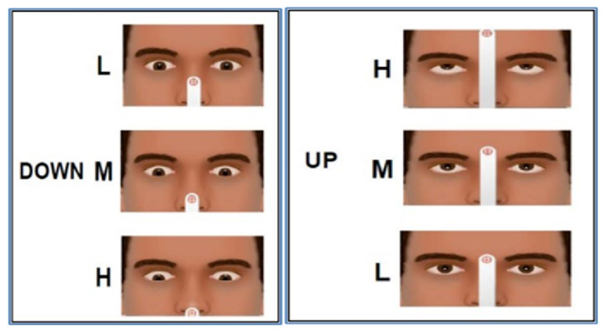
Fig. 12 **a** Two options of the proposed system. **b** Two options of calibration

frequency is set to 0.1 Hz and the LPF cut-off frequency is set to 10 Hz. The cut-off frequency of the filter is determined by Eq. (2).

$$f_c = \frac{1}{2\pi RC} \tag{2}$$



a left and right direction calibration through three levels (low, medium, and high).



b Up and down direction calibration through three levels (low, medium, and high).

Fig. 13 **a** left and right direction calibration through three levels (low, medium, and high). **b** Up and down direction calibration through three levels (low, medium, and high)

A buffer amplifier is used for matching to connect a high-source-impedance system to a low-impedance system. A level shifter is used to raise the signal level, because there are no negative potentials at the output.

- *ATmega AVR microcontroller:* Analog EOG data on A0 and A1 for vertical and horizontal directions are transferred to the Arduino, where the EOG signal is converted into a digital signal. This digital signal is transferred to the computer and stored by the data acquisition (PLX-DAQ).
- *LiquidCrystal_I2C display* (*LCD display*)*:* The LCD is used to allow each of the trainee, user, and designer of the program to follow the program execution.
- *Keypad:* The keypad allows both the trainee, the user, and the designer to control the program.

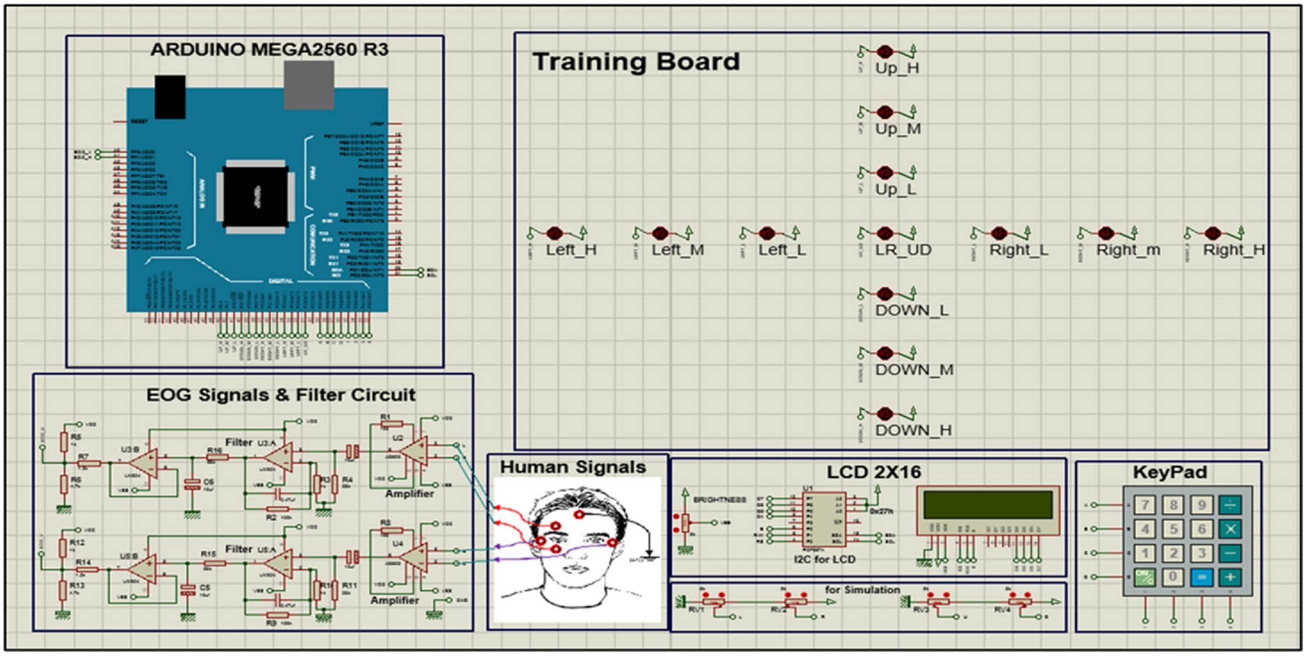


Fig. 14 Experimental software setup of the proposed system using Proteus 8 professional simulation program

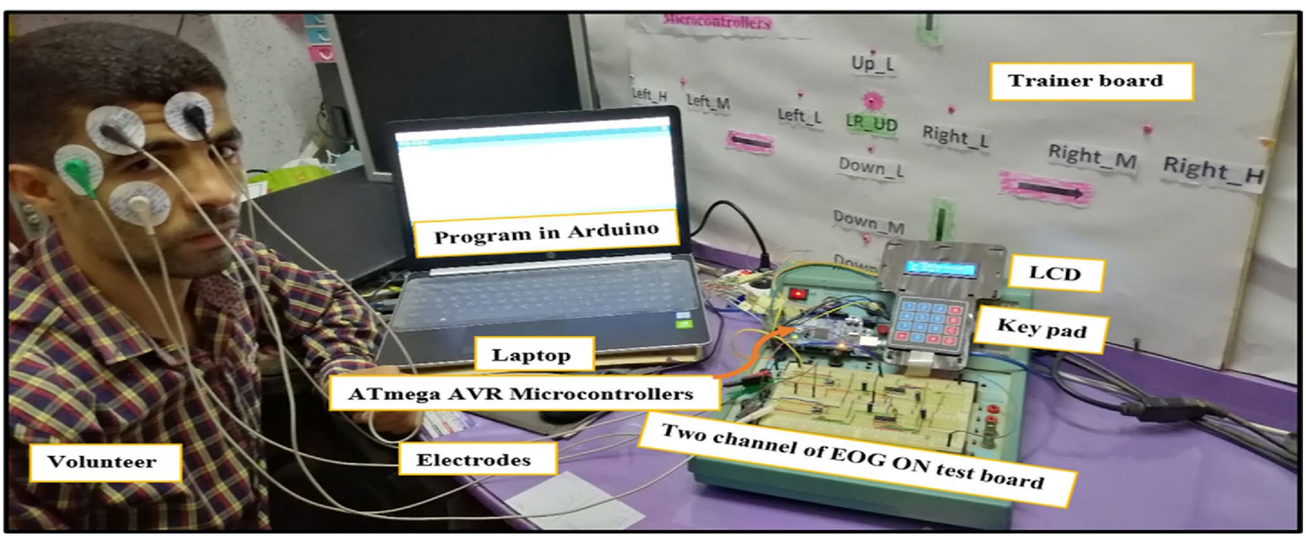


Fig. 15 Hardware experimental setup of the proposed system

Fig. 16 Some volunteers involved in the experiments for the system

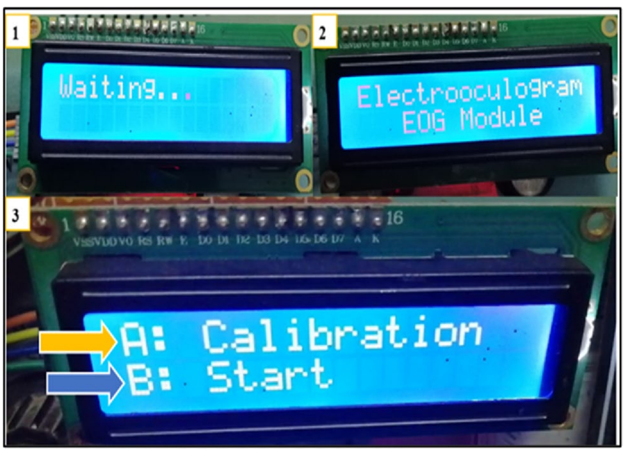


Fig. 17 Starting the experiments on LCD of the system

Fig. 18 Selection between horizontal and vertical eye movement signals on the LCD of the system

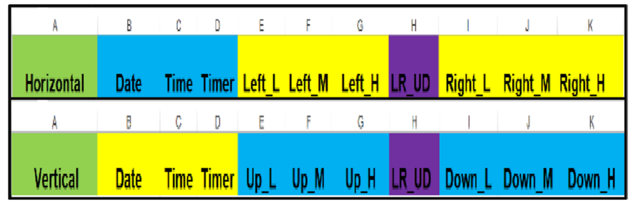


Fig. 19 Horizontal and vertical eye movement output excel sheet, when starting recording of the signals for the system

6.2 Hardware

Figure 15 shows the experimental hardware of the proposed system. This acquisition system based on ATmega AVR microcontroller is used to acquire a dataset of eye movements for volunteers. It is composed of Ag / AgCl electrodes placed on the face of the volunteer, analog-to-digital converter through Arduino Mega 2560 board microcontroller unit, trainer board that includes of LEDs, data acquisition (PLX-DAQ) on laptop, keypad, power supply (IDL-600 ANALOG LAB unit) and LCD. By following the sequence of the flowchart shown in Fig. 10 in the presented acquisition system, the data are acquired and stored on the laptop.

Figure 16 shows some volunteers participating in our work to conduct experiments, and take eye data and readings with the experimental setup of the proposed system.

7 Experimental results

In the presented work, the first channel of the EOG circuit was connected to pin A0 and the second channel to pin A1 on the ATmega AVR microcontroller to train the volunteers on both horizontal and vertical eye movement signals. When the program is set on the ATmega AVR microcontroller, the message on the LCD of the presented system is shown in Fig. 17.

After that, the system is connected to the computer via the data acquisition (PLX-DAQ) by selecting port (4) and setting the transmission speed (baud rate = 9600 bps). Then, we press A (calibration) on the keypad and select between horizontal eye movement (Left and Right) and vertical eye movement (UP and Down) signals as shown in Fig. 18.

After the channel selection (horizontal or vertical eye movement) and the linking process to record the readings of the volunteer, we make a connection to the data acquisition (PLX-DAQ) excel sheet. Figure 19 shows the output excel sheet, when starting the recording of the selected eye movement signals.

Tables 3 and 4 show the readings and recordings of horizontal eye movement (Left and Right) output excel sheet

Table 3 Horizontal eye movement (Left and Right) output excel sheet for the first volunteer

Date	Time	Timer	L	Left_L	Left_M	Left_H	R	Right_L	Right_M	Right_H
10/12/2020	02:49:28	9.980469	633							
10/12/2020	02:49:30	11.33984		764						
10/12/2020	02:49:31	12.70703			782					
10/12/2020	02:49:32	14.0625				840				
10/12/2020	02:49:36	17.42578					622			
10/12/2020	02:49:37	18.78516						650		
10/12/2020	02:49:39	20.14844							703	
10/12/2020	02:49:40	21.51172								720

Table 4 Horizontal eye movement (Left and Right) output excel sheet for the second volunteer

Date	Time	Timer	L	Left_L	Left_M	Left_H	R	Right_L	Right_M	Right_H
10/12/2020	02:52:36	197.9258	849							
10/12/2020	02:52:38	199.2891		690						
10/12/2020	02:52:39	200.6523			716					
10/12/2020	02:52:40	202.0117				833				
10/12/2020	02:52:44	205.375					636			
10/12/2020	02:52:45	206.7344						566		
10/12/2020	02:52:47	208.0977							604	
10/12/2020	02:52:48	209.4688								833

Table 5 Vertical eye movement (UP, Down and LR_UD) output excel sheet for the first volunteer

Date	Time	Timer	U	Up_L	Up_M	Up_H	D	Down_L	Down_M	Down_H	LR_UD
10/12/2020	02:50:23	64.35938	376								
10/12/2020	02:50:24	65.71875		401							
10/12/2020	02:50:26	67.08594			458						
10/12/2020	02:50:27	68.44531				523					
10/12/2020	02:50:30	71.80469					0				
10/12/2020	02:50:32	73.17188						546			
10/12/2020	02:50:33	74.53125							548		
10/12/2020	02:50:34	75.89453								590	
10/12/2020	02:50:34	75.95703									376

Table 6 Vertical eye movement (UP, Down and LR_UD) output excel sheet for the second volunteer

Date	Time	Timer	U	Up_L	Up_M	Up_H	D	Down_L	Down_M	Down_H	LR_UD
10/12/2020	02:51:17	118.3047	558								
10/12/2020	02:51:18	119.6758		519							
10/12/2020	02:51:19	121.0352			541						
10/12/2020	02:51:21	122.3984				557					
10/12/2020	02:51:24	125.7578					0				
10/12/2020	02:51:26	127.1172						571			
10/12/2020	02:51:27	128.4805							590		
10/12/2020	02:51:28	129.8398								645	
10/12/2020	02:51:28	129.9023									451

Fig. 20 Horizontal and vertical eye movement output data for the system

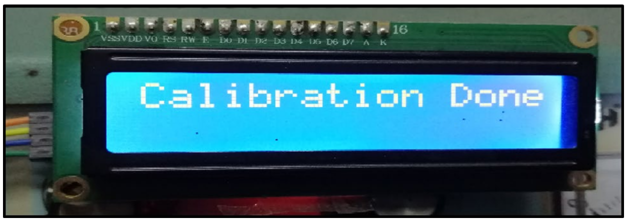


Fig. 21 End of calibration in the system

Table 7 Samples of readings and recordings of the digital data for the horizontal and vertical eye movement signals

Horizontal EOG	Vertical EOG
990	1023
895	990
866	895
764	866
562	877
285	870
114	837
54	819
24	285
0	114
28	24
85	0
142	21
213	85
279	142
357	270
424	520
562	560

for the first and second volunteers, respectively. Likewise, Tables 5 and 6 show the readings and recordings of vertical eye movement (Up, Down, and LR_UD) output excel sheet for the first and second volunteers, respectively. The number of samples ranges from 0 to 1024 as shown in Fig. 20.

After completing the training process for the vertical and horizontal eye movement directions, the message in Fig. 21 (calibration done) appears indicating that the training process

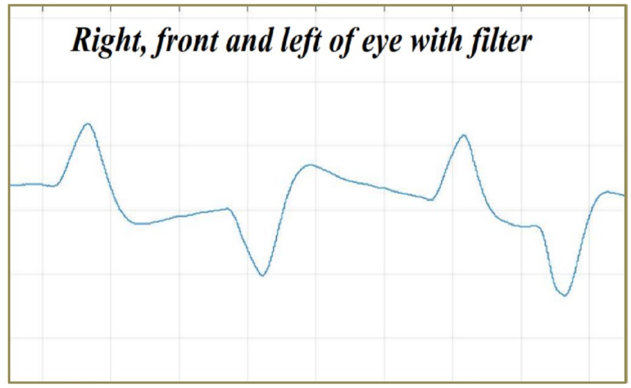


Fig. 22 Horizontal eye movement (Left, Right and LR_UD) output signal for the volunteer in the system

ended calibration and recording of the dataset in an excel sheet. To take readings and data for a new volunteer, we press the C key on the keypad to begin a new process for new volunteer.

Table 7 shows samples of readings and recordings of the digital data for the horizontal and vertical eye movement signals taken for the volunteer, in addition to Fig. 22 of the resulting graph.

By looking at the readings in Tables 2, 3, 4 and 5, we find that 10 readings are taken for each of the 13 LEDs on the trainer board, then the average is taken for each LED, separately. The readings are taken for the volunteers and the average is calculated through the Eq. (3). The code is shown under this equation:

$$average = \frac{\sum_{i=1}^{n} x_i}{n} \tag{3}$$

```
For (; ;)
{
    Digital Write (led _LR_UD, LOW);
For (i =0; i< No_Read; i++)
   {
Analog_Display ();    LRvalues[i] =x; delay (Del);
   }
i=0;
For (i=0; i< No_Read; i++)
       {     Average=average+ LRvalues[i];        }
             Average=average/No_Read;
             L=average;
             Serial.print ("DATA, DATE, TIME, TIMER, ");
             Serial.print (L); Clear Index ();
             Digital Write (led _ LR_UD, HIGH);      }
```

For the right side, after different readings are taken, the average of the right direction is taken and R is given as shown in Tables 8 and 9. In addition, for the left direction, L is given, for the up direction, U is given, and for the down direction, D is given.

Table 8 Part of the dataset for the horizontal eye movements (Left and Right)

No vol	L	Left_L	Left_M	Left_H	R	Right_L	Right_M	Right_H
1	633	764	782	840	622	650	703	720
2	849	690	716	833	636	566	604	833
3	453	504	552	556	414	468	502	521
4	654	671	673	677	678	679	682	684
5	827	896	916	921	921	917	922	924
6	596	657	664	664	663	661	664	665
7	558	509	525	560	546	555	580	603
8	654	742	744	756	778	752	765	774

Table 9 Part of the dataset for the vertical eye movements (Up, Down and LR_UD)

No vol	U	Up_L	Up_M	Up_H	D	Down_L	Down_M	Down_H	LR_UD
1	376	401	458	523	0	546	548	590	376
2	558	541	519	557	0	571	590	645	451
3	556	521	530	536	0	552	556	558	446
4	674	665	668	729	0	656	658	662	507
5	680	550	562	563	0	548	552	571	612
6	788	770	795	844	0	828	872	883	542
7	721	706	731	746	0	767	770	772	660
8	539	512	520	528	0	481	523	569	556

8 Comparison with recent related works

In this section, the presented EOG acquisition system is compared to some recent related works. We observe that most acquisition systems, to acquire the datasets of eye movements, depend on Electroencephalography (EEG). On the other hand, the presented system acquires data based on EOG only. The number of electrodes used to record eye movements is less than that for the EEG.

In addition, the EOG is easy to design and implement. It is different from the EEG circuit. It has horizontal and vertical channels. After obtaining the signals for eye movements through the presented system in all directions, the signals are converted into digital data through ATmega AVR microcontroller. Then, the digital data are stored to allow researchers in this field to deal with this data easily to be used in various applications in order to help the disabled.

In the contrary, most of the research on this topic depends on data taken with MATLAB and saved in the form of analog signals as for the data in the link https://data.mendeley.com/datasets/wb6yvr725d/1. On the other hand, the data in the presented system is in digital format.

The links of the dataset and program of the presented system are given below.

The dataset is included with the paper in the following link

https://techedubsuedu-my.sharepoint.com/:f:/g/personal/dr_abdelgawad_techedu_bsu_edu_eg/EiSpc8_UAaZBmQqzB6NCJUoBHYYkeVxbpwGjWBUIoF_hIw?e=E17D80

The program of the proposed system is included with paper in the following link

https://techedubsuedu-my.sharepoint.com/:f:/g/personal/dr_abdelgawad_techedu_bsu_edu_eg/EsC38Ye00kREsf-aYAlHmX8Bbo-4CZRK8lFrn1XWpPWvjg?e=I8IzA2

9 Conclusions and future work

The presented work illustrated hardware and software of an EOG acquisition system based on ATmega AVR microcontroller for the acquisition of vertical and horizontal eye movements, such as open eye (LR_UD), left, right, up and down. The EOG acquisition system is interfaced with an

ATmega AVR microcontroller in order to acquire a dataset of eye movements for volunteers. These signals are successfully acquired using the presented system in digital format. Subsequent classification can be implemented to classify the horizontal and vertical dataset. This trend can help the disabled in wheelchair regulation, rehabilitation aids and other applications by simply moving their eyes.

In the future, we will extend the proposed work to collect the largest possible number of eye movement signals. Different samples will be taken for different groups and different ages of women and men. These ages are considered to study the change in the eye signals for different groups. The database can be collected according to the directions of eye movements. The feature extraction and the different high-efficiency classifiers can be used to distinguish signals and compare between classifiers.

The proposed algorithm can be designed and implemented based on MATLAB and Arduino to help the disabled for efficiently performing their tasks in their daily life. It is possible to use the obtained signals to control different applications, like home control (room lighting—television control), wheelchair control, wireless control using Bluetooth with microcontrollers, NRF radio signals, and communication with infrared signals.

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Data availability Data links are included.

References

Banerjee A, Pal M, Shreyasi Datta DN, Tibarewala AK (2014) Eye movement sequence analysis using electrooculogram to assist autistic children. Biomed Sig Proces Cont 14:134–140

Barbara N, Camilleri TA, Camilleri KP (2019) EOG-based eye movement detection and gaze estimation for an asynchronous virtual keyboard. Biomed Signal Process Control 47:159–167

Barbara N, Camilleri TA, Camilleri KP (2020) a comparison of EOG baseline drift mitigation techniques. Biomed Sig Proce Cont. 57:1–9

Barea R, Boquete L, Mazo M, Lopez E (2002) System for assisted mobility using eye movements based on electrooculography. In IEEE Trans Neural Syst Rehabil Eng 10(4):209–218

Bulling A, Ward JA, Gellersen H, Troster G (2011) Eye movement analysis for Activity recognition using electrooculography. IEEE Trans Pattern Anal Mach Intell 33:741–753

Champaty B, Jose J et al (2014) Development of Eog based human machine interface control system for motorized wheelchair. In: 2014 Annual international conference on emerging research areas magnetics. Machines and Drives, pp 1–7. https://doi.org/10.1109/AICERA.2014.6908256

Choudhury SR, Venkataramanan S, Harshal B, Nemade HB, Sahambi JS (2005) Design and development of a novel EOG bio potential amplifier. IJBEM 7:271–274

Deng LY, Hsu C-L, Lin T-C, Tuan J-S, Chang S-M (2010) EOG-based human-computer interface system development. Expert Syst Applicat 37:3337–3343

Estrany B, Fuster P, Garcia A, Luo Y (2008) Human computer interface by EOG tracking. In Proc Stinternat Conf Pervas Technol Relat Assist Environm 10:1389694

Estrany B, Fuster P, Garcia A, Luo Y (2009) EOG signal processing and analysis for controlling computer by eye movements. In: Proceedings of the 2nd international conference on pervasive technologies related to assistive environments https://doi.org/10.1145/1579114.1579132

Fuhl W, Kasneci E (2018) A multimodal eye movement dataset and a multimodal eye movement segmentation analysis. Associat Comput Mach. https://doi.org/10.1145/1122445.1122456,pp1-12

Jaramillo-Gonzalez A, Shizhe W, Tonin A, Ardali MK, Birbaumer N, Chaudhary U (2021) a dataset of EEG and EOG from an auditory EOG-based communication system for patients in locked-in state. In Scientific Data. https://doi.org/10.1038/s41597-020-00789-4

Klados MA, Bamidis PD (2016) a semi-simulated EEG/EOG dataset for the comparison of EOG artifact rejection techniques. In Data in Brief. 8:1004–1006

Lee K-R, Chang W-D, Kim S, Im C-H (2017) Real-time eye-writing recognition using electrooculogram. IEEE Trans Neural Syst Rehabil Eng 22:40–51

Lv Z, Wang Y, Zhang C, Gao X, Wu X (2018) An ICA-based spatial filtering approach to saccadic EOG signal recognition. Biomed Signal Cont 43:9–17

Ma J, Zhang Y, Cichocki A, Matsuno F (2015) A novel eog/eeg Hybrid human machine interface adopting eye movements and erps: application to robot control. In IEEE Trans Biomed Eng. 62(3):876–889

Qi LJ, Alias N (2018) Comparison of ANN and SVM for classification of eye movements in EOG signals. Int Conf Data Inf IOP. Conf Series J Phys Conf Series 971:565–568

Reichert C, Ceja IFT, Sweeney-Reed CM, Heinze H-J et al (2020) Impact of Stimulus Features on the Performance of a Gaze-Independent Brain-Computer Interface Based on Covert Spatial Attention Shifts. In Front Neurosci. https://doi.org/10.3389/fnins.2020.591777

Samann FE, Hadi MS (2018) Human to television interface for disabled people based on EOG. In J Univ Duhok. 21:53–64

Usakli AB et al (2009) On the use of electrooculogram for efficient human computer interfaces. Computat Intel Neurosci. 11:1–6

Wilming N, Onat S, Ossandon JP, Açık A, Kietzmann TC, Kaspar K et al (2017) Data descriptor an extensive dataset of eye movements during viewing of complex images. In Scientificdata. https://doi.org/10.1038/sdata.2016.126

Wissel T, Palaniappan R (2013) Considerations on strategies to improve EOG signal analysis investigations into living systems. Artif Life Real-World Solut. https://doi.org/10.4018/978-1-4666-3890-7.ch017

Young LR, Sheena D (1975) Survey of eye movement recording methods In Behav Res Method. Instrum 11:397–429