Electrooculogram Based Wheelchair Control in Real-Time

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Abstract. The goal of this work is to provide solutions for needs of patients suffering from Amyotrophic Lateral Sclerosis (ALS), tetraplegic clinical conditions (e.g., the locked-in syndrome), paralysis or other progressive illnesses, disabled and/or elderly with acute disabilities in moving their whole bodies due to motor system disorders which prevent accurate and correct limb and facial muscular responses. We propose to establish an efficient alternative channel for communication and control based on Electrooculogram (EOG) that operates by the only muscular movement that these patients are capable of i.e., the eyeball movement. Ability to control some household devices, electric wheelchair, and computer with eye movement facility by elderly or severely disabled persons reduces their dependency on others. This not only improves their lives, but also makes them more self-assured and self-reliant. This paper describes the design and development of a Smart, Motorized, Bluetooth controlled Wheelchair for the physically differently abled people where their eyeball movements act as commands and controls the movements of the wheelchair. To test the performance of the system, four volunteers were asked to make 20 eye movements randomly per person and the direction of movement of wheelchair was observed for each movement. All the 80 eye movements made by the four volunteers were identified with 100% accuracy, generating the corresponding command, and moving the wheelchair in the desired direction.

Keywords: Electrooculogram · Motor disability · Wheelchair · Human-Machine Interface

1 Introduction

According to the statistics of World Health Organization (WHO) which has given projected estimates of neurological disorders up to 2030 [1], there has been an exponential increase in the number of patients afflicted by neurological disorders like Amyotrophic Lateral Sclerosis (ALS), tetraplegic clinical conditions (e.g., the locked-in syndrome),

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paralysis or other progressive illnesses worldwide. They have acute disabilities in moving their whole bodies due to motor system disorders which prevent accurate and correct limb and facial muscular responses. Establishing an effective alternative communication channel that does not require overt voice or hand movements makes life easier for these patients and so enhances their quality of life [2].

It is estimated that people aged 65 and above are one tenth (10%) of the world's population and is expected to increase to 16% in the coming 2 to 3 decades as per the United Nations report [3]. So, in addition to the patients mentioned above, such a communication channel would be useful in the case of the elderly and the handicapped also.

A sensible way to improve the communication channels between the surrounding environment and these patients to the full extent is to use all their residual abilities. The only muscular movement that they are capable of is the eyeball movement [4]. In general, monitoring, analysis, and recognition of eyeball movements constitute a crucial tool for activity recognition, diagnosing neurological diseases, biometrics, sleep stage analysis, detection of driver drowsiness and fatigue and many more applications. In addition to those, recognition of eye movements for the above-mentioned patients can be coded for human-computer interface or human-machine interface (HCI/HMI) [2, 4, 5, 21–23].

There are various types of eyeball movements like saccadic movements, smooth pursuit, vergence etc. Different techniques such as Electrooculography (EOG) [6, 7], Infrared Oculography (IROG), Dual Purkinje Image (DPI), Search Coils (SC) etc., are available for tracking eyeball movements, but they differ in terms of range, resolution, invasiveness, case of use and cost. Each of them is chosen depending on the intended application. However, for the present work, EOG was chosen because it provides an unobtrusive, inexpensive, and non-invasive means of recording eyeball movements, thereby causing minimal discomfort to the subject [8, 9]. Measurement of eyeball movement is a major application of the EOG.

After the recognition of the type of eye movement based on EOG signal, corresponding control and validation signals are generated for the HCI applications. These applications include control of some household devices [10], electric wheelchair [11–13], computer cursor [14], virtual keyboard [2, 15], writing a letter, sending E-mail, speaking and spell with eye movement facility for elderly or severely disabled persons. Thus, their dependency on others is reduced. This not only improves their lives, but also makes them more self-assured and self-reliant. This type of interface would not be confined to severely impaired people but could be used by anyone who can regulate their eye movements for games and other entertainment activities, to improve the quality of life.

2 Smart, Motorized, Bluetooth Controlled Wheelchair Hardware

The main components used in the design and development of a smart, motorized, Bluetooth controlled wheelchair in real-time are wheelchair, high torque motors (MY1016Z2), Amptek AT12–12 12V 12Ah lead-acid battery, sprocket and chain mechanism, HC-05 Bluetooth device, Arduino uno, BTS 7960 High Current 43 A H-Bridge motor drivers, SONGLE SRD-05V DC-SL-C 1-Channel power relay module, Arduino

IR (Infrared) obstacle avoidance sensor module. All these are integrated into a complete system to achieve the objective of this work.

2.1 Wheelchair

In this work, a wheelchair is converted into a powerchair, such that propulsion is provided by batteries and electric engines. There are numerous different types of wheelchairs, each with its own controlling technique, control components, and innovation. The client controls the powerchairs mostly with a joystick or remote control located on the armrest or on the upper front of the seat. Head switches, jaw operated joysticks, taste and puff controllers, and other modified controls may allow customers who are unable to use a manual joystick to operate the wheelchair independently. Here, eyeball movement is used to control the wheelchair.

2.2 High Torque Motors (MY1016Z2)

MY1016Z2 24 V 250W 360 RPM Geared DC motor is a widely accepted reduction DC motor that is commonly used in better-quality scooters, bikes, and in a variety of projects such as Segway, e-cars, and robots such as All-terrain vehicle (ATV) robots, combat robots, and warbots. This motor comes with 9 Tooth sprocket [16] attached to it. In this work, 2 such motors are used, one for the right rear wheel and the other for the left rear wheel of the wheelchair.

2.3 Amptek AT12-12 12V 12Ah Lead Acid Battery

The Amptek AT12-12 12V 12Ah lead acid battery is used in this project to power the 2 MY1016Z2 24 V 250W 360 RPM Geared DC motors that are connected to right and left rear wheels of the wheelchair.

2.4 Sprocket and Chain Mechanism

The sprockets are welded to the rear wheels of the wheelchair and the motors are fixed on the wheelchair such that each one is parallel to the sprocket so that the chain doesn't trip. To convert the wheelchair into power wheelchair by adding motors and battery, sprocket-chain mechanism is established between the sprockets of the motors fixed to the wheelchair and the sprockets welded to the rear wheels of the wheelchair, so that motion and force can be transmitted from motors to the wheelchair converting it to power wheelchair. Figures 1 and 2 show this arrangement. All these are fitted to wheelchair in such a fashion that it is still foldable as shown in Fig. 3 providing the comfort of easy transportation in most of the vehicles thus increasing the options with regards to travel and overall flexibility of its users.

2.5 HC-05 - Bluetooth Module

The HC-05 [17] is a popular Bluetooth SPP (Serial Port Protocol) module that may be used to provide two-way (full-duplex) wireless serial communication setup functionality between two microcontrollers, such as an Arduino, or communicate with any Bluetooth-enabled device, such as a phone or laptop.

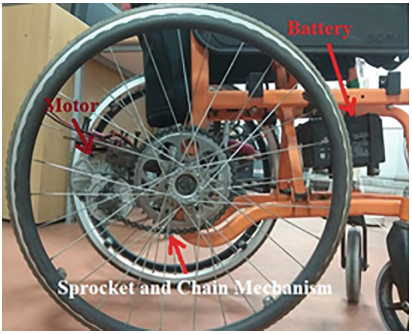

Fig. 1. Sprocket and Chain Mechanism

Fig. 2. Battery and Motors arrangement

2.6 Arduino Uno

The Arduino UNO is the generally utilized open-source microcontroller board created by Arduino.cc built on the ATmega328P microcontroller, which is a single-chip computer that has a CPU, RAM, flash memory, and input/output ports [18]. It has 14 digital pins and 6 analog pins. It is built to connect a variety of sensors, LEDs, motors, speakers, servos and other electronic devices directly to these pins, which can read in or output digital or analog voltages between 0 and 5 V.

2.7 BTS 7960 High Current 43 A H-Bridge Motor Drivers

The BTS 7960 is a fully integrated high current half bridge for motor drive applications [19]. The BTS 7960 is a cost-effective solution for Pulse Width Modulation (PWM) motor drives with high-current protection. In this work, 2 BTS 7960 High Current 43A H-Bridge motor drivers are used to control the two DC motors that are connected to the rear wheels of the wheelchair.

Fig. 3. Foldable Wheelchair

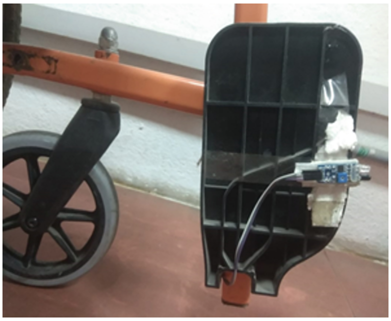

Fig. 4. IR sensor placement beneath one of the footplates of the wheelchair

2.8 SONGLE SRD-05V DC-SL-C 1-Channel Power Relay

A 5v relay is an automatic switch that is commonly used in an automatic control circuit and to control a high-current using a low-current signal. The SONGLE SRD-05V DC-SL-C Single Channel Power Relay module is used in this project. It is generally used to manage high voltage, current loads like solenoid valves, motor, AC load & lamps.

2.9 Arduino IR (Infrared) Obstacle Avoidance Sensor

The Arduino IR Obstacle Avoidance sensor module is a general-purpose proximity sensor [20]. Here we use it for obstacle detection. The detection range of the sensor can be obtained by adjusting potentiometer. The IR sensor is placed beneath one of the footplates of wheelchair as shown in Fig. 4.

3 Proposed Methodology for Motorized Bluetooth Controlled Wheelchair

The block diagram of proposed methodology for Smart Motorized Bluetooth controlled Wheelchair using eye movements consists of 2 parts, one is a EOG Acquisition, Classification and Command Generation system (Bluetooth transmitter side) and the other is a Control Circuit Board for Wheelchair Mobility (Bluetooth Receiver side) and are as shown in Figs. 5 and 6 respectively.

3.1 EOG Acquisition, Classification and Command Generation

The EOG acquisition was done using ADInstruments Hardware such as PL3516 Power Lab 16/35 and FE238 Octal Bio Amp as well as ADInstruments Software LabChart 8.0. A written consent from all the subjects was taken on their willingness to be a part of the experiment. The study procedure and conceivable risks involved were precisely disclosed to every participant. Here, while acquiring and sampling of the EOG signals of the subject using the wheelchair at the LabChart software, using LabChart's advanced scripting streaming of live EOG data from LabChart to MATLAB was done. This provides the ability to display and classify the EOG signals as well as generate the commands corresponding to the type of eye movement in real-time, which will enable us to control the wheelchair also in real-time.

For this purpose, LabChart Package demonstrating this capability is installed. It will create a tab called 'MATLAB Sampling' in LabChart's Welcome Center which consists of several MATLAB m-script files like MATLAB_Sampling, RegisterLCEvents, LCCallBacks and doOnNewSamples, required for live data streaming.

Double click the 'MATLAB_Sampling.m' file. This opens MATLAB and show the source code for that file. Open a document in LabChart ready for sampling. Run the MATLAB_Sampling.m file in MATLAB. When LabChart starts sampling, the latest live data from the horizontal and vertical channels of EOG signal are plotted in MATLAB as it is being sampled. The.m files are tailored by incorporating another m-script file "identify_movements_bluetooth", to meet our requirement of identification of type of eye movements and generation of Bluetooth commands based on the type of eye movement.

Here, the identification of eye movements is based on the amplitudes and duration of peaks in both horizontal and vertical channels. The variables 'hmaxpeak', 'hminpeak', 'hmaxthresh', 'hminthresh', 'hmaxtime' and 'hmintime' are used to represent maximum

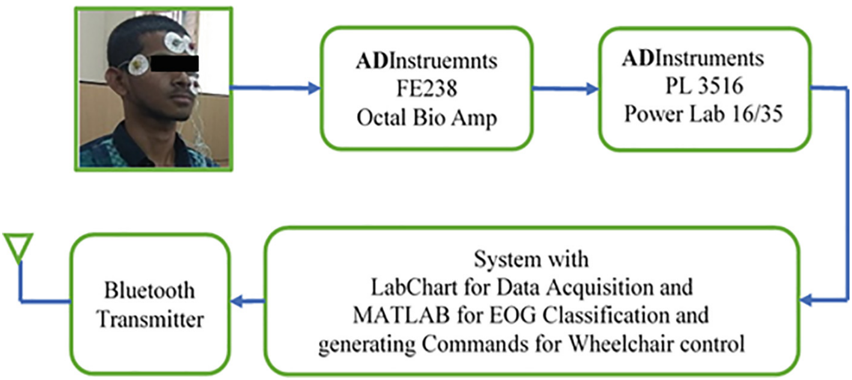

Fig. 5. Block Diagram of EOG Acquisition, Classification and Command Generation (Bluetooth Transmitter side)

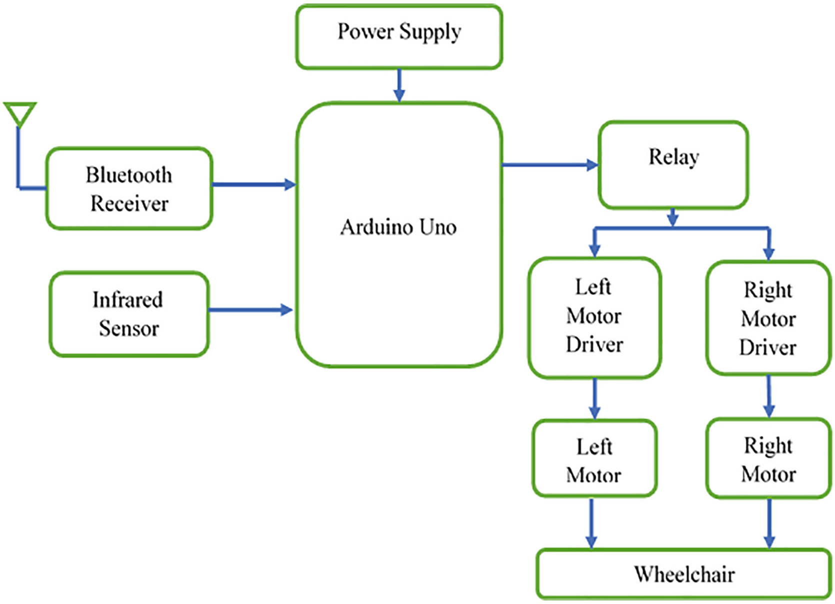

Fig. 6. Block Diagram of Control Circuit Board for Wheelchair Mobility (Bluetooth Receiver side)

positive peak, minimum negative peak, maximum positive threshold, minimum negative threshold, maximum positive peak time and minimum negative peak time of peaks in the horizontal channel. Similarly, The variables 'vmaxpeak', 'vminpeak', 'vmaxthresh', 'vminthresh', 'vmaxtime' and 'vmintime' are used to represent maximum positive peak, minimum negative peak, maximum positive threshold, minimum negative threshold, maximum positive peak time and minimum negative peak time of peaks in the vertical channel.

If the signal in the vertical channel is almost in line with the base line and the signal in the horizontal channel detects a positive peak followed by a negative peak, then it is a right movement of eyes. Similarly in such a case, if the horizontal channel detects a negative peak followed by a positive peak, then it is a left movement of eyes. That is if 'hmaxpeak' is greater than 'hmaxthresh' and 'hminpeak' is less than 'hminthresh' and if 'hmaxtime' is less than 'hmintime' and 'hmintime – hmaxtime' is less than 750 ms, then it is a right movement of eyes. Instead, if 'hmaxtime' is greater than 'hmintime' and 'hmaxtime – hmintime' is less than 750 ms, then it is a left movement of eyes.

If the signal in the horizontal channel is almost in line with the base line and the signal in the vertical channel detects a positive peak followed by a negative peak, then it is a upward movement of eyes. But if the positive peak is comparatively high and the negative peak is comparatively low, then it is blink movement of eyes. Similarly in such a case, if the vertical channel detects a negative peak followed by a positive peak, then it is a downward movement of eyes. That is if 'vmaxpeak' is greater than 'vmaxthresh' and 'vminpeak' is less than 'vminthresh' and if 'vmaxtime' is less than 'vmintime', 'vmintime – vmaxtime' is less than 750 ms, and 'vmaxpeak' + 'vminpeak' > 79 mV

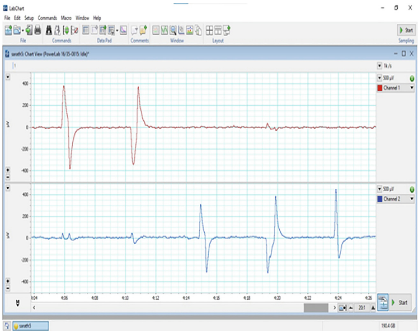

Fig. 7. Sample recording of 5 basic movements of eye of a subject

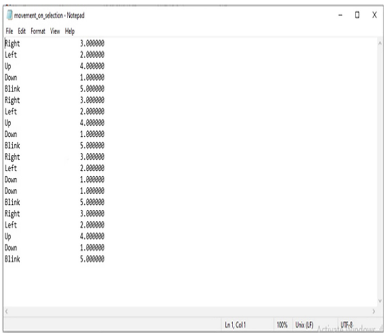

Fig. 8. Generated Commands based on the type of eye movement identified

then it is a blink movement of eyes, otherwise it is a upward movement of eyes. Instead, if 'vmaxtime' is greater than 'vmintime' and 'vmaxtime – vmintime' is less than 750 ms, then it is a downward movement of eyes.

The amplitudes and duration of peaks in horizontal and vertical channels corresponding to right, left, up, down and blink movements of eyes, as shown in Fig. 7, varies from person to person. Therefore the identification of eye movements can be customized to the person using the wheelchair by identifying the amplitudes and duration ranges of the peaks of that person in horizontal and vertical channels. Likewise, the experimentation was done, and we could control the wheelchair successfully.

Once an eye movement is identified, depending on the type of eye movement i.e. right, left, up, down and blink movement of eyes, the commands such as "3", "2", "4", "1" and "5" are generated respectively as shown in Fig. 8 and transmitted to the control circuit board developed for controlling the wheelchair via Bluetooth communication.

3.2 Control Circuit Board for Wheelchair Mobility

The heart of the control circuit board is Arduino Uno. Here it is powered by a 6F22 Long-Life 9V Hi-Watt Zinc Carbon HW Battery. The HC05 Bluetooth module is connected to the Arduino Uno board. The command it receives via Bluetooth communication from

EOG acquisition, classification and command generation system is given to the Arduino Uno.

The control input pins RPWM and LPWM of both the BTS7960 High Current 43A H-Bridge motor drivers are given to pin 13, 12, 11 and 10 of Arduino Uno respectively. If the RPWM is set HIGH and LPWM is set LOW for a motor driver, then the motor connected to it will rotate in the clockwise direction. If the RPWM is set LOW and LPWM is set HIGH for a motor driver, then the motor connected to it will rotate in the anticlockwise direction. If both RPWM and LPWM are set LOW for a motor driver, then the motor connected to it will stop rotating. The Arduino Uno is programmed for the RPWM and LPWM pins of the left and right motor drivers as shown in the Table 1 to move the wheelchair either in forward, backward, right or left directions or even to stop it.

The pins R_IS (5) and L_IS (6) of motor driver are unconnected. The pins R_EN (3) and VCC (7) of motor driver are connected to 5 V supply, whereas pin GND (8) is connected to ground. The pin L_EN (4) of both the motor drivers together is given to the NC (Normally Closed) pin of the SONGLE SRD-05V DC-SL-C 1-Channel Power Relay Module. The COM (Common) pin of the Relay is connected to 5 V supply. Thus, the Relay is connected to the load i.e. wheelchair in the Normally Closed (NC) mode and therefore based on the eye movement and the corresponding command generated, the wheelchair moves either in forward, backward, right or left directions or even stops.

Here, an Arduino IR Obstacle Avoidance sensor module is also included in the design, and it aids in the detection of obstacles in the wheelchair's path that may obstruct its progress. As soon as the obstacle is detected by the IR sensor, it produces an output, which is given as input to the 'Signal' pin of the Relay module, thus enabling it to break the electrical connection between COM pin and NC pin of the Relay, otherwise which it will be operated in the NC mode. Because of this, pin L_EN (4) of both the motor drivers go LOW and eventually stops the wheelchair as soon as the obstacle is detected.

Table 1. RPWM and LPWM pins of Motor Driver for Mobility of Wheelchair

Pin 1 and Pin 2 of Motor Driver	Left Motor Driver	Right Motor Driver	Movement of Wheelchair
RPWM(1)	HIGH	HIGH	Forward
LPWM(2)	LOW	LOW	
RPWM(1)	LOW	LOW	Backward
LPWM(2)	HIGH	HIGH	
RPWM(1)	HIGH	LOW	Right
LPWM(2)	LOW	LOW	
RPWM(1)	LOW	HIGH	Left
LPWM(2)	LOW	LOW	
RPWM(1)	LOW	LOW	Stop
LPWM(2)	LOW	LOW	

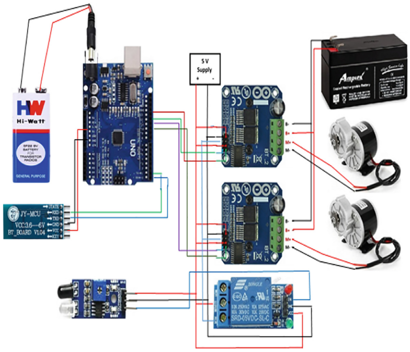

Fig. 9. Connection Diagram of Control Circuit Board for Wheelchair mobility

Fig. 10. Control Circuit board in a pocket stitched at the backrest of wheelchair

The connection diagram of the control circuit board is shown in Fig. 9. The developed control circuit board is placed in a pocket stitched at the back of backrest of the wheelchair as shown in Fig. 10.

4 Results and Discussion

Design and development of a smart, motorized, Bluetooth controlled wheelchair using EOG in real-time has been successfully implemented. The classification of eyeball movements is done using MATLAB Programming in a laptop having Bluetooth and the commands such as "3", "2", "4", "1" and "5" are generated based on the right, left, up, down and blink movements of eye respectively. These commands are transferred to the Bluetooth module connected to the Arduino board using which the direction of the wheelchair is controlled. For example, when the user makes 'up' movement of eye, the command "4" is generated at the laptop by the EOG Acquisition, Classification and Command Generation (Bluetooth Transmitter side) system and it is transferred to the Arduino of the Control Circuit Board for Wheelchair Mobility (Bluetooth Receiver side) via Bluetooth communication and based on the Arduino programming the wheelchair will move

Table 2. Type of Eye Movement, Command Generated and Direction of Movement of Wheelchair

Type of Eye Movement	Command Generated	Direction of Movement of Wheelchair
Upward	**"4"**	Forward
Downward	**"1"**	Backward
Right	**"3"**	Right
Left	**"2"**	Left
Blink	**"5"**	Stop

in forward direction. Similarly, if the user makes down, right, and left movements of eyes, the commands "1", "3", and "2" will be generated respectively and when these commands are communicated to the Arduino controlling the wheelchair via Bluetooth, then the wheelchair will be moving in backward, right, and left direction respectively. For the blink movement of eye, the command is "5" for which the wheelchair stops moving. IR sensor is also included in the design which aids in detecting obstacles in the wheelchair's path that may obstruct its progress.

The Table 2 shows the type of eye movement done by the user using this smart, motorized, Bluetooth controlled wheelchair using EOG, the corresponding command that is generated and the corresponding direction of movement of wheelchair. But as per the design, if any obstacle is detected by the IR Sensor, then the wheelchair stops immediately irrespectively of the type of eye movement from the user. To test the accuracy, performance, and effectiveness of the system, four volunteers were asked to become a part of testing of this system. Each volunteer was asked to make 20 eye movements randomly and the direction of movement of wheelchair is observed for each movement. All the 80 eye movements made by the four volunteers were identified with 100% accuracy, generating the corresponding command, and moving the wheelchair in the desired direction.

5 Conclusions and Future Scope

This work elaborated the design and development of smart motorized Bluetooth controlled wheelchair using eye movements. The system has been tested and validated. It worked properly and moved perfectly as per the command given by the user. This system provided solution for mobility needs of patients suffering from ALS, tetraplegic clinical conditions (e.g., the locked-in syndrome), paralysis or other progressive illnesses, disabled and/or elderly with acute disabilities in moving their whole bodies due to motor system disorders which prevent accurate and correct limb and facial muscular responses. It makes their mobility easier as well as reduces their dependency on others for that. The developed system is very useful for household applications in which a disabled person can move in the house without the assistance of others. The detection of any obstacle in the path by the IR sensor successfully triggers the Relay to break the electric connection, which is otherwise NC (Normally Closed), stopping the wheelchair immediately. This designed and developed smart, motorized, Bluetooth controlled wheelchair using EOG signals in real-time assists differently abled and elderly people in becoming self-sufficient.

The generalization of the results obtained in this research work can be done by the application of these techniques on a still larger database. This will facilitate the study of the effect of age, gender, and environment on the eye movement recognition. ADInstruments Hardware and Software was used in this research study for EOG signal acquisition. The signal processing was carried out using MATLAB on a PC. Now it is being proposed to develop the necessary hardware and software for this specific purpose so that a dedicated system for wheelchair can be deployed. Wheelchair with these features stands good chances of commercialization and portability. Efforts are being made in this direction. The weight-speed trade-off of the developed system also need to be evaluated as the body weight differs from subject to subject. Similarly, the work has to be extended to control some household devices as well as computer with eye movement for these people. This not only improves their lives, but also makes them more self-assured and self-reliant.

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