Design and Development of an EOG-based System to Control Electric Wheelchair for People Suffering from Quadriplegia or Quadriparesis

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***Abstract*—In this research, we have designed and developed an EOG-based Electric Wheelchair system for patients suffering from Quadriplegia or Quadriparesis or similar condition where a person is not only unable to walk but also unable to move fingers to press a button. The designed EOG recorder is used to capture intentional eye blink and eye movements (i.e. EOG signals) performed by the patient sitting in the Wheelchair. The recorded EOG signals are then processed in Arduino platform and converted to command signals to control the movement of the wheelchair in four directions (i.e. left, right, front and back) from four different EOG signals (i.e. left, right, up and down eye movements) along with start and stop commands from intentional eye blink signals. The electric wheelchair is also designed and implemented by converting a normal chair to wheelchair with necessary motors (2 DC brushed motors), wheels, and control circuitry along with the battery power supply. The EOG system is portable, wireless and user friendly which can be worn by the patient to control the wheelchair. Test experiment with subjects suggests that the proposed EOG system can detect different eye movements with an average accuracy of 90% in controlling the wheelchair. The overall cost of the developed system is around 20,000 BDT which is affordable. The proposed system has a huge potential to be used by our country's rural and middle-income people suffering from similar disability who can't afford commercially available expensive automated electric wheelchairs. This work can be further modified to use in other applications for the same type of patients such as EOG controlled mouse cursor for computer use. Thus this EOG-based human-machine interface applications can significantly enhance the quality of life for such middle-income or lower-middle income patients living in the developing countries such as Bangladesh.**

***Keywords*—EOG, Eye blink, Eye movement, Electric Wheelchair, Quadriplegia, Arduino, DC motor.**

I. Introduction

Quadriplegia is a form of paralysis caused by serious neurological disease or severe brain/spinal cord injury that results in the partial or total loss of use of all four limbs (both legs and arms) where the affected person lost both of his/her sensation and control [1]. On the other hand, Quadriparesis refers to a condition characterized by weakness (temporary or permanent) in all four limbs (both arms and both legs) which may be caused by an infection (e.g. polio) or by a neuromuscular disease (e.g. muscular dystrophy) or due to damage to the nervous system by an injury or another medical condition [2].

Electrical wheelchairs are for the people who cannot walk and to help them move around by their self. But traditional electrical wheelchairs are controlled by switch or joystick. So the technology is limited for those who are able to use their hand or finger. Research shows that almost 41% people find it difficult to use joysticks in electric wheelchair and there are people who are completely paralyzed and who cannot even move their fingers such as Quadriplegic patients. Quadriplegia is a form of paralysis caused by serious neurological disease or severe spinal cord injury that results in the partial or total loss of use of all four limbs (both legs and arms) where the affected person lost both of his/her sensation and control. The people suffering from Quadriplegia, Quadriparesis or similar diseases/disabilities are however able to move their eyes.

With the modern technology it is possible to do human and machine interfacing. Electroculargraphic signal (EOG) is a type of biomedical signal that can be used to interface with machine such as wheelchair [3-19]. EOG signal is produced by the potential difference between retina and cornea of the eye. Electrodes can detect the horizontal and vertical eye movements in the form of EOG signal. So whenever there will be an up-down eye movement or left-right eye movement there will be a change in the potential difference between the electrodes placed near the eyes. This changes are used to detect the eye-ball movement.

There are many research works found in the literature dealing with EOG-control wheelchair [3-19]. Few of them contributed only in the design of the EOG recording system [5, 13, 14], while some of them developed suitable algorithms to detect eye movements and to generate appropriate command signals to control the wheelchair [3, 12, 16] and some others demonstrated the movement of a robotic car with EOG signals mimicking the control of a wheelchair [4, 10, 11, 18, 19]. Some of them reported the design and development of the whole system with practical implementation and proper testing [7, 9, 15, 17]. Few others implemented the system by combined use both EOG and EMG to control the wheelchair [6, 8]. However, while designing such complete system, cost-effectiveness design for developing countries was either not considered or cost analysis was not presented. In addition to that, there is currently no EOG-controlled electric wheelchair available in the market.

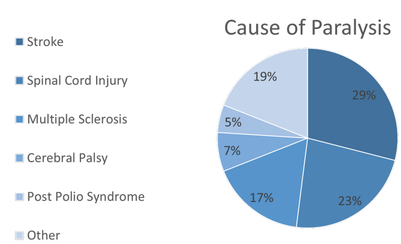

Fig. 1. Statistics for the different causes of paralysis all over the world (adopted from [2]).

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Thus, motivated from the above mentioned background study, the purpose of this study was to develop an EOG based complete system to control electric wheelchair for people suffering from Quadriplegia or similar medical conditions. Both the EOG recording system and electric wheelchair (i.e. the whole system) have been designed, developed, implemented and tested successfully with low-cost which makes this work a complete unique package. To the best of our knowledge, no other research findings have yet been reported with similar amount of contributions.

II. Methods and Materials

The overall EOG based wheelchair control system block diagram is given in figure 2.

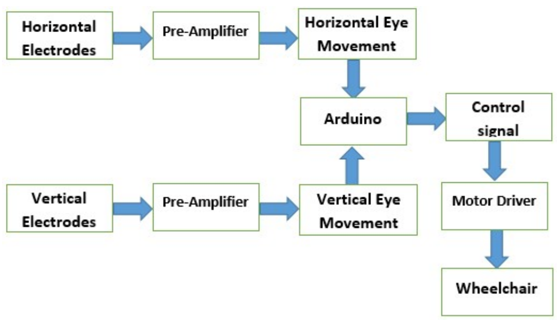

Fig. 2. Block diagram of the proposed EOG-based wheelchair control system

EOG signals are very weak picked up by the Ag-AgCl electrodes. The amplitude is in mili-volt range. So in order to detect any change in the signal, a pre-amplification is required. An instrumentation amplifier *AD620* is used in the circuit to amplify the signal. The frequency range of the EOG signal is between 0.1 to 20Hz. Therefore, to remove offset, power-line interferences, base-line drift, and other artifacts, the raw recorded signals picked up by the electrodes are passed through a n active high pass filter followed by an active low-pass filter with cut-off frequency of 0.1Hz and 20Hz respectively. The filtered signal was then fetched to the microcontroller (i.e. Arduino) where the eye movement was detected. For the power supply, rechargeable batteries were used.

A. Electrodes

In this work, Ag-CI electrodes were used. The electrodes are connected around the eyes. They were connected in a way that they can detect both horizontal and vertical eye movements. The electrode positions are shown in figure 3.

Fig. 3. Electrodes' position: two horizontal, two vertical and one reference

B. Amplifier

AD620 instrumentation amplifier were used amplify the signal and detect if there is any change in eye position. It's an affordable and highly accurate instrumentation amplifier. The amplification gain is set with a resistor which is externally connected with AD620. The rage of gain is from 1 to 1000. For this work, 500 gain was used. The equation to calculate the gain is

$$G = \frac{49.4k\Omega}{Rg} + 1 \qquad (1\alpha)$$

100Ω external resistor was used for this work. From this equation the gain calculated was almost 500.

$$G = \frac{49.4k\Omega}{100\Omega} + 1 = 495 \qquad (1\beta)$$

C. Arduino

Arduino is an open source electronic platform. In this work, Arduino has been used to detect the eye movement direction and to give the corresponding command to the wheelchair. The EOG signal is given to the analog pins of the Arduino then using ADC the signal is digitized. In the Arduino by detecting the amplitude and time duration, the position of the eye movement is determined. Moving average filter was used to filter the signal in Arduino. A flowchart diagram of the Arduino programming is given below (adopted from [15].

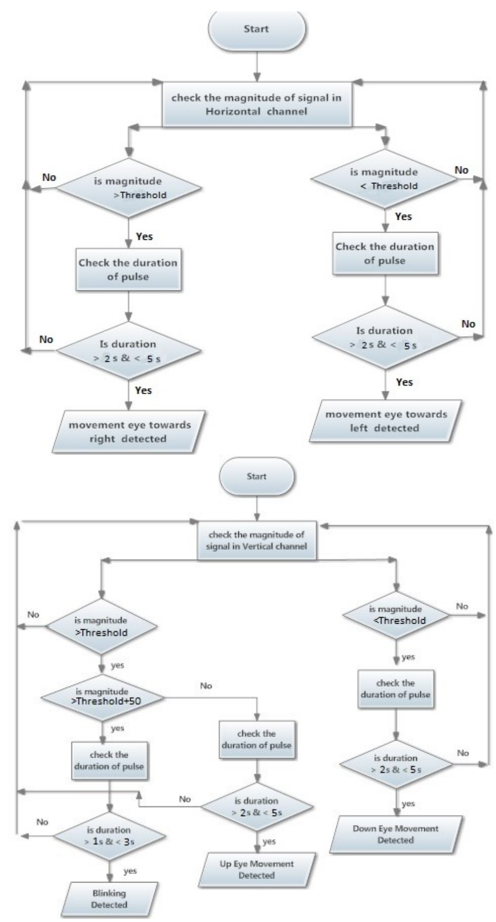

Fig. 4. Flowchart of the algorithms used to detect horizontal or left-right (Top) and vertical or up-down (Bottom) eye movements along with eye blinks in Arduino

D. Battery

In order to give power to the amplifier 3.7V, a rechargeable Li-Po battery is used and to power up the Arduino, 9V batteries were used.

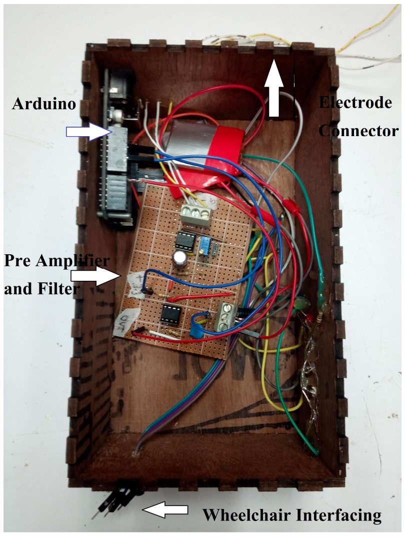

Fig. 5. Setup of the EOG recording system: Pre-amplifier circuit, Arduino, Batteries and Electrodes

E. Wheelchair

Conventional manual wheelchairs are widely used among disabled people though these doesn't fulfill their needs and cut their independence as ordinary hand powered wheelchairs draws the user's energy and sometimes the user has to depend on other person for pushing the wheelchair. A segment of the disabled community finds it difficult or impossible to use wheelchairs dependently. An electric wheelchair can reduce these problems a lot as the user will be independent and faster. As an electric wheelchair is not affordable for many families in our country, the main challenge is to develop a smart electric wheelchair using local technology and in minimum cost for the mobility impaired people.

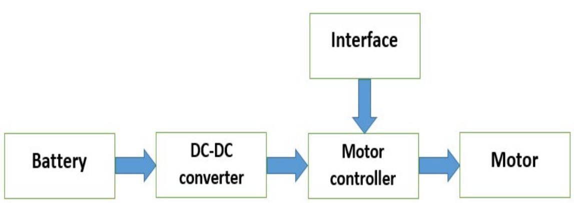

Fig. 6. Block diagram of the electric wheelchair

F. Electric Wheelchair

- Motor

Permanent magnet brushed DC motor is as it is cheaper and available. Alternate power supply can drive the motor clockwise or anti clockwise. Two My1016z2 motor (24v, 250w) is used to drive the wheelchair. Each motor has a capacity of carrying maximum 80 kg and maximum speed is 20km/h. A gear box is attached with a gear ratio of 1:9.78. Without gear box the motor has 3850 RPM with no load and 3000 RPM in rated load and torque is 0.80 N.M.

- Wheels

The specifications of wheels used in our electric wheelchair are given in table 1.

TABLE I. WHEEL SPECIFICATIONS

	Drive wheel	**Caster wheel**
Diameter	10 inch	4 inch
Weight capacity	600 Kg	200 Kg
Material	Solid rubber	Plastic
Bearing diameter	1 inch	-

- Control circuit

Generally motors are rotated clockwise or anti clockwise using H-bridge method. It takes 4 switches for one H-bridge. IGBTs/transistors or different types of switches are used to make H-bridge. But in this electric wheelchair relay is used to reduce the cost. In this control circuit one motor is controlled using just 2 relays so it takes 4 relays to control both motor without any possibilities of short circuit.

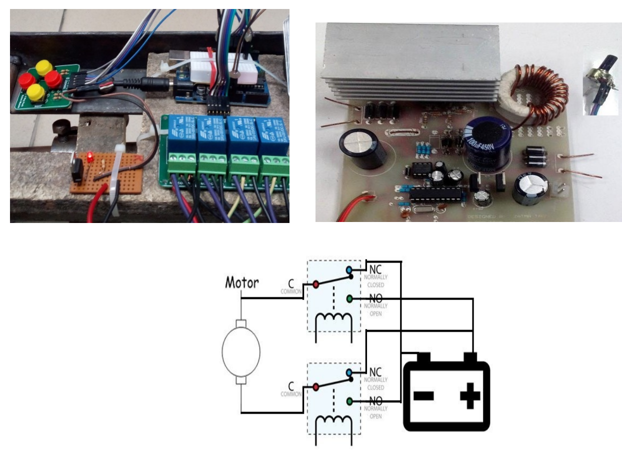

Fig. 7. Relay connection with battery and DC-DC Synchronous buck converter

After receiving signals, a microcontroller (Arduino Uno) will send trip signal to the relay module. The relay module will get power from a DC-DC synchronous buck converter which will take power from battery. The DC-DC converter is used for soft start and to adjust speed. User can adjust motors speed using a potentiometer.

- Battery

To power up the circuits and motors, a 12V 30ah electric bike maintenance free battery is used as it is available in market.

- Dimension of the wheelchair:
    - ❖ Height: Total height: 2' 11"
    - ❖ Ground to seat height: 1' 10"
    - ❖ Width: Front width: 2' 3"
    - ❖ Back width: 1' 8.5"
    - ❖ Footrest width: 1' 8"
    - ❖ Seat width: 1' 5"
    - ❖ Length: Lower frame length: 1' 11"

- ❖ Footrest length: 10”, Total length: 2’ 9”
- ❖ Total weight of the wheelchair is 30 Kg Carrying capacity is up to 200 Kg

Fig. 8. Final prototype of the electric wheelchair

Fig. 9. Experiment with the subject for controlling the movement of the wheelchair with his eye movement.

III. RESULTS

The EOG signal was recorded both in oscilloscope and in pc using Arduino. The signals were quite accurate. At first using the signals we have successfully turned LED on and off.

The LEDs were turned on as long the subject kept looking left and right. And the LEDs were turned off when the subject was neutral.

The blinks were also been detected. The blink signal looks like a spike. And from the intentional and unintentional blinks were easy to detect. The intentional blinks were strong so the amplitude of the signal is also high and on the other hand the unintentional blink is weak so the signals amplitude were less than intentional blinks amplitude.

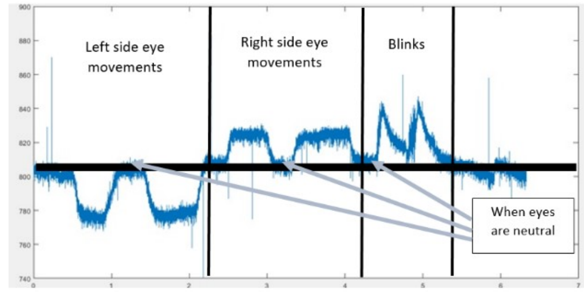

Fig. 10. Recorded EOG signals plotted in MATLAB by interfacing with PC through Arduino.

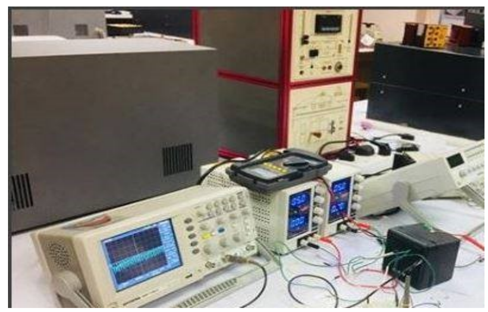

Fig. 11. Testing of EOG recorder

All four signals (left, right, up and down) were detected successfully and fetched to the controller of the wheelchair.

TABLE II. AVERAGE ACCURACY (%) FROM MOVEMENT OF WHEELCHAIR FOR 4 DIFFERENT DIRECTIONS AFTER 5 TRIALS FOR EACH SUBJECT EXPERIMENTED WITH TOTAL OF 5 SUBJECTS

Average Accuracy (%) after 5 Trials for Each Subject						
Direction of Movement	**S-1**	**S-2**	**S-3**	**S-4**	**S-5**	**Average Accuracy (%) per Direction**
Right	80	100	80	100	100	**92**
Left	100	80	100	100	80	**92**
Front	80	100	100	100	80	**92**
Back	100	80	80	60	100	**84**
Average Accuracy (%) per Subject	**90**	**90**	**90**	**90**	**90**	**90** / **90**

A. *Performance analysis of the wheelchair*

The advantage of this electric wheelchair is, it takes a soft start every time, which means it starts drawing power from minimum to maximum slowly in a certain time. Maximum power consumption of this wheelchair is 39.36W (4.8V, 8.2A) which occurs at the beginning to give starting torque. But average power consumption is 26W (6.5V, 4A).

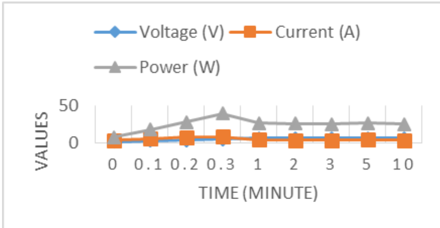

Fig. 12. Operating voltage, current and power curve

IV. Discussion

This project was designed for the Quadriplegia affected people but the wheelchair can also be used by the people who have the use of their hands but can't walk. The application of this project is to control the wheelchair by using EOG signal. But the EOG device in this project have more applications. The EOG can be used to control mouse and the keyboard of the computer as well. This overall project was designed and developed by using available resources. And this project was cost effective as well. There is not a single commercially available wheelchair that can be controlled by eye movement. There are EOG devices (in the form of EEG headsets) and electrical wheelchair available separately but they are very expensive. For example, the available EEG device (single-channel electrode positioned near eye which can also detect EOG signals) costs \$100 or 8500 Tk. (minimum). While the available electric wheelchair costs 1,15,000 Tk. (minimum). However, those two commercially available products (EOG recorder and electric wheelchair) can't be interfaced as they are from two different manufacturers as well as the blueprint of their system design or circuit schematic are not open-sourced. Compare to those products, this system is less costly and affordable. The wheelchair and the EOG device both were designed, developed and interfaced using locally available resources.

TABLE III. Approximated Cost of the Components Used in Our Proposed System

Components Used	Quantity	Unit Price (BDT)	Total Cost (BDT)	Remarks
Arduino UNO	01	600.00	600.00	
EOG Electrodes	05	10.00	50.00	Disposable / One time use
AD620	02	180.00	360.00	
9V Battery	02	30.00	60.00	
Electric Wheelchair	-	-	18,000.00	Including motors, wheels, batteries, controllers, dc-dc converters, etc.
Other components	1 set	Lump sum	500.00	Resistors, Capacitors, Connectors, ICs, Jumpers, etc.
Total Cost of the Overall System Approx. **19,570 TK!**				<20,000 Taka!!! Much lower compared to > 1 Lac Taka worth commercial Electric Wheelchair only (without EOG-based control feature)

There are still few things that were not yet covered. This system was tested on healthy subjects. So in order to understand if this will help the Quadriplegia affected people or not, subjects are required to test the system who are suffering from Quadriplegia or similar disabilities. And the feedback of the subject will help to improve the system in future. And this project is not yet user-friendly as the device is not wireless in its current form.

We have attempted an approximated cost analysis for the whole system and it is obvious from below table that it can be made within 20,000 BDT: 2000 BDT for EOG Recorder and 18,000 for Electric Wheelchair.

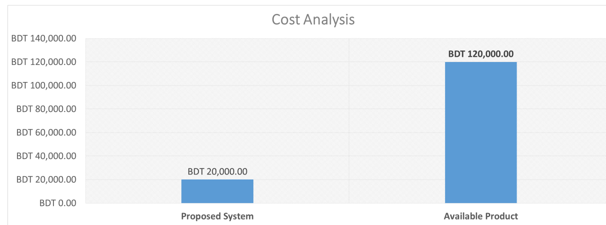

Fig. 13. Estimated cost comparison between our proposed system and commercial products (if available in near future).

Already this system is affordable. But if this project gets logistic and financial support then the system can be further improved and commercialized. And by commercial production of this system, the cost will be further reduced which will be an asset to the people in need of Bangladesh and similar .

V. Conclusion

The EOG based wheelchair is controlled by eye movement. The people suffering from Quadriplegia or similar condition will be able to move around by only moving their eyes. The controlling is very easy and the signal recording and detection has achieved reasonable accuracy. The system is not very difficult to get used to. With a little practice they will be able to get use to the device and will be able to control wheelchair with ease. This work can be further modified to use in other applications for the same type of patients such as EOG controlled mouse cursor for computer use [20].

In future we would like to make the EOG device wireless, add more adjustments to make it user-friendly. We would also test the whole system with people in-need as part of clinical trial and then correct all other issues that will be found by the feedback from our subjects.

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