Eye-Gesture Controlled Intelligent Wheelchair using Electro-Oculography

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Abstract: This paper describes the design and implementation of an eye-gesture controlled electric wheelchair using the technique of Electro-Oculography. This is designed to be used as an intelligent mobility aid for the paralyzed which has features such as tilt detection, obstacle sensing, avoidance and path re-routing. The design employs an embedded control module that processes the bio-electric signals generated by the eye movements to actuate real world events. A microcontroller is used in place of a laptop computer, as the decision making entity, thereby making this an affordable solution. Various safety features are integrated using the control module to make a robust and optimized model.

Keywords: Electro-oculography, eye-gaze tracking, obstacle detection, paralysis, path re-routing, wheelchair

1 INTRODUCTION

Victims of severe paralysis, amputees and other physically challenged are unfairly deprived of an acceptable standard of life. Spinal cord injuries (SCI) and Progressive Motor Neuron Diseases (PMND) could cause a condition known as Quadriplegia which leads to loss of muscle functionality below the neck due to which the subjects are constantly dependant on others for their mobility. In such cases, ocular control is either not affected or affected last. Keeping in mind these constraints in muscle control and disease progression, a cost effective solution is developed in order to assure victims of paralysis a greater degree of independence and better quality of life. The idea involves the design and implementation of an eye-gesture controlled electric wheelchair using the bio-medical technique of Electro-Oculography (EOG).

Of the several methods exist to detect eye-gestures, the physiologies of EOG are better understood. It is simpler to complete the acquisition, feature extraction and analysis of EOG signals [2]. Therefore, EOG based approach is more suited for this application in terms of dependability, accuracy and cost.

Several designs of an EOG based wheelchair have been proposed [3,4]. These designs make use of a laptop computer as the processing and control centre. Other systems that do not employ a laptop have also been proposed but such methods lack intelligence in terms of the systems' awareness of the environment. This paper proposes a modular design of an EOG based Human-Wheelchair interface which incorporates an obstacle detection, avoidance and path re-routing algorithm for reliable navigation using simple and effective ultrasonic range sensors to acquire sensorial information from the ambiance for reliable navigation. Integration of tilt detection into the algorithm is also imperative in order to address the problem of the assembly toppling over at a critical tilt point considering the fact that the user may need to manoeuvre through uneven terrain.

Since the target group comprises of those who require constant medical supervision, Patient Health Monitoring Systems become an indispensable part of the mobility aid. This makes for a well-rounded, complete system that not only assists the user in safe, collision-free mobility but also keeps track of his/her vital statistics, generates alerts and notifications which effect arrival of timely medical attention when required. The intelligence algorithm along with Patient health Monitoring Systems seek to achieve increased reliability and safety.

2 DESIGN AND IMPLEMENTATION

This paper presents an EOG based wheelchair with active collision avoidance and tilt detection. The system architecture has four major parts:

(2.1) EOG signal acquisition
(2.2) Signal conditioning module
(2.3) Wheelchair mechatronics and sensor system
(2.4) Control module and Intelligence Algorithm

Fig. 1 shows the proposed system architecture, and these major parts are illustrated as follows.

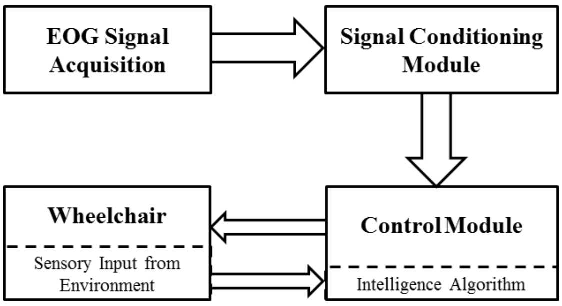

Fig. 1: System Architecture

2.1 EOG Signal Acquisition

Electrooculography (EOG/E.O.G.) is a technique for measuring the resting potential of the retina. The resulting signal is called the electro-oculogram. The main applications are in ophthalmological diagnosis and in recording eye movements. The eye, a seat of resting potential, acts as a dipole in which the anterior pole (cornea of the eye) is positive and the posterior pole (retina of the eye) is negative. This difference in potential can be explained by the metabolic activities in the eye which can be measured by means of EOG. The EOG signal has a magnitude in the range of 100µV to 1000µV with a frequency range of 0 to 30Hz [4].

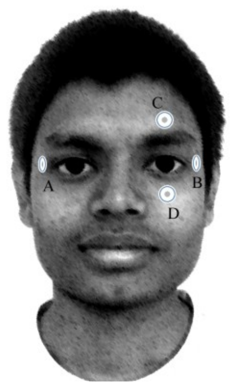

Fig. 2: Electrode Placement

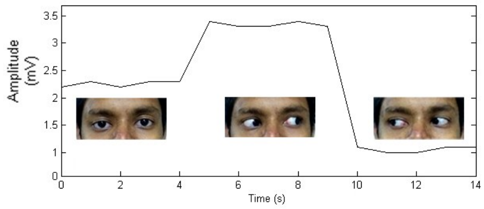

Fig. 3: EOG Horizontal Differential Signal

Silver-Silver Chloride (Ag-AgCl) electrodes are placed on the corners (lateral canthi) of both the eyes to capture the change in EOG signal for lateral eye motion. When the subject's gaze is to the left, the positive end of the dipole the eye comes closer to the electrode on the left canthus and the negative end to the right canthus.

The vice-versa is observed for the eyes looking towards the right. This is portrayed in Figure 3. In a similar manner, electrodes placed above and below the eyes of the subject can be used to record change in EOG signal for eye-ball motion in the vertical direction (Figure 4). Ideally the difference in potential should be proportional to the sine of the angle the eye produces with respect to the central axis.

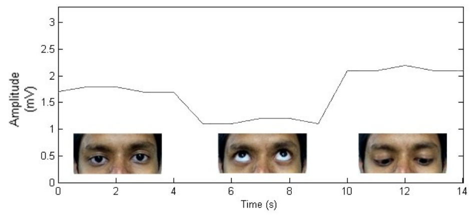

Fig. 4: EOG Vertical Differential Signal

2.2 Signal Conditioning Module

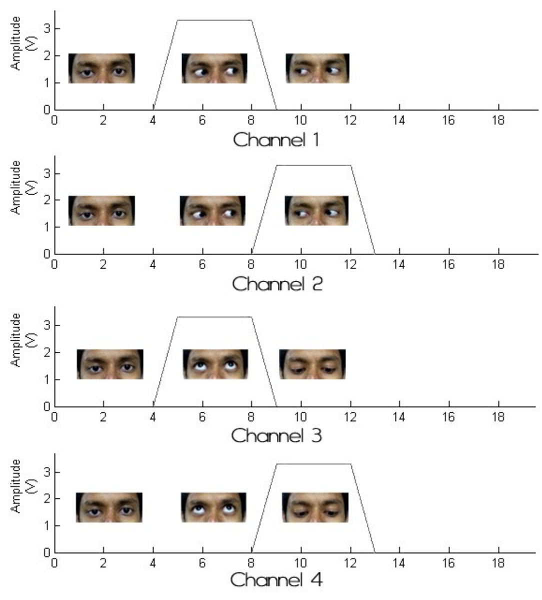

Fig. 5: Digital Input to Microcontroller

The EOG signal is a low voltage range bio-potential signal which can be easily corrupted by noise in the ambiance. It therefore is passed through a signal conditioning module to extract the horizontal and vertical gaze direction.

The signal processing module consists of amplification in two stages using instrumentation amplifiers (AD620) with a gain of 100 and 10 respectively. Noise is cancelled out using a low pass filter of cut off frequency 30Hz. The DC drift is removed using a high pass filter of cut-off frequency 0.16 Hz. A divider circuit is used using high-speed switching diodes and op-amps in inverting and non-inverting stages to achieve four separate channels of signal, one each for up, down, left and right [4].

Therefore eye gaze direction will be detected as a pulse which can be effectively considered a digital HIGH. The absence of such a pulse can be considered a digital LOW. This in effect renders the use of an Analog to Digital converter unnecessary. The output of the signal conditioning module is shown in figure 5.

2.3 Wheelchair and Sensory Input from Environment

The eye-gaze direction and speed control directives form the wheelchair motion commands that are generated by the EOG and signal processing modules are supplied to the microcontroller.

In most cases, an inconsistency exists between the goal direction and the direction of the wheelchair. This is caused due to the presence of obstacles in the motion path and the inability of the driver to navigate past them. Therefore, ultrasonic obstacle detection sensors are strategically placed on the wheelchair body, as shown in figure 6, to sense obstacles and thus aid in manoeuvring around them.

The sensory information is then sent to a microcontroller in the wheelchair which has an obstacle avoidance algorithm programmed. The final decision made by the microcontroller by a combination of eye- commands and sensory input is then sent to the DC motor drives.

As mentioned earlier, the speed of the wheelchair is set based on vertical eye-gaze. Pulse width modulation (PWM) technique is used to change and control the speed of the motors. The PWM signal is generated by the microcontroller placed on the wheelchair.

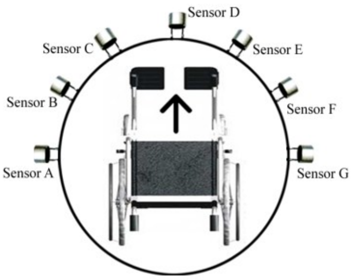

Fig. 6: Sensor placement on wheelchair

PID controllers are used to achieve linear and hence smoother turns.

2.4 Control Module and Intelligence Algorithm

The control module is split into two parts, the User Instruction Processor (UIP) and the Drive Control Module (DCM), each with its own microcontroller. Full duplex wireless communication exists between the two processors.

The microcontroller on the UIP accepts four-channel digital input from the divider module. It can be inferred from figure 5 that a digital HIGH pulse cannot be detected simultaneously in channels 1 and 2 (horizontal) or channels 3 and 4 (vertical). But a combination of horizontal and vertical motion can be detected along with pure horizontal or vertical gestures. This directly implies the UIPs capability of detecting 8 different positions of the eye ball. These various gestures can be used individually or as a combination of two or more, to generate simple or complex patterns.

Let up, down, right and left gaze directions correspond to North (N), South (S), East (E) and West (W) respectively and no pulse correspond to C (for centre). Simple eye gestures such N, S, E and W can be used to perform functions that need immediate execution such as stopping/braking and turning. For example, if the UIP receives a W signal, it makes the drive control decision that will cause a left turn. Similarly, a right turn is executed for E. Most importantly the wheelchair can be stopped/braked immediately for an S pulse. This allows immediate addressing of a user generated braking command.

A sequence of gestures that use combinations such as NW, NE, SW and SE along with N, S, E and W can be used to perform other functions that do not require quick response from the system. For instance, an N pulse followed by NE can be used to increase wheelchair speed and an N pulse followed by NW can be used to reduce wheelchair speed. This method of speed control can be pictured as sliding along a horizontal speed control bar. Also, powering on the system can be done using the following sequence: N-NE-E-SE-S-SW-W-NW-N-C. This pattern resembles a power button on any common household device. Drive control using such patterns are very intuitive and therefore make wheelchair control easy to learn and execute.

A Patient Health Monitoring system is interfaced to the UIP microcontroller which handles patient health stats data as a secondary function. Health monitoring systems are an integral part of the system since members of the target group sometimes require continuous medical supervision.

The drive control decisions made by the UIP are first encoded and then communicated to the DCM wirelessly. Wireless transmission is used to reduce wire clutter and increase modularity of the design. The DCM uses these decisions and sensory input data from the ultrasonic sensors placed on the wheelchair to make the final drive control decision using the intelligence algorithm that resides in the DCM microcontroller.

The intelligence algorithm works on the principle that the drive control decisions made by the UIP are always followed by the wheelchair until an obstacle is detected. Until such a time, the intelligence algorithm works in a transparent mode. The moment an obstacle is sensed by the ultrasonic sensors, the wheelchair is stopped immediately. Let us consider two cases: stationary obstacle and a moving obstacle.

In the case of a stationary obstacle, the wheelchair is firstly stopped. The outputs of all the sensors remain the same as the instant when the wheelchair was stopped even after some time has elapsed. The intelligence algorithm takes the constancy of the sensor outputs to classify the obstacle as stationary. The system now switches to the wall follower mode and generates an auditory alert, a beep for instance that notifies the user of the need for a "wall-follower direction" and remains in a wait state. In the wall follower mode, wheelchair speed control is not necessary and therefore the corresponding control gestures can be used to input wall-follower direction i.e., N followed by NW for left and N followed NE for right. Once the user inputs the desired direction of motion, the wheelchair turns toward the specified direction and navigates around the obstacle in the wall follower mode. To keep the wheelchair in this mode the user looks straight forward (C signal). In case the user needs to break away from the obstacle at any chosen time, he looks away from the obstacle, to the right or left, thus producing a W or E signal respectively which causes the wheelchair to turn away in that direction. This effectively aids the user in navigating around any stationary obstacle and also gives him/her maximum possible control.

A special case of a stationary obstacle is a dead-end. For the system to recognize a dead-end, the minimum requirement is that sensors B, C, D, E and F (figure 6) all output digital high at the same time. In such a situation, the only option of navigation is motion in reverse. Since wheelchair motion in reverse is not advisable for safety reasons, this obstacle is handled by making the wheelchair execute a 180° turn on the spot. Now the control is handed back to the user for further commandeering.

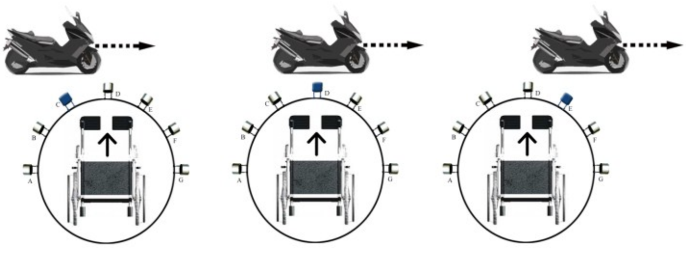

Fig. 7: Moving Obstacle

Now, let us consider a moving obstacle. When an obstacle is detected the wheelchair is immediately halted. The DCM waits to check if the sensor outputs remain the same even after some predefined time period. In this case the sensor outputs do not remain constant but change as the obstacle moves by. In figure 7, when the moving obstacle is first detected sensor C generates a digital HIGH signal as the obstacle is within its pre-set minimum distance. Then the obstacle moves to the right eliciting an active high from sensors D and E sequentially. The intelligence algorithm classifies such an obstacle that causes changing sensor output to be a moving obstacle. In such a case, the wheelchair is halted until the obstacle is beyond the minimum distance setting of all the sensors and is then allowed to move.

A gyroscope is interfaced with the DCM for wheelchair tilt detection. When the user drives through uneven terrain or on a ramp, there is a possibility of the wheelchair toppling over at a critical tilt point. The gyroscope is used to detect tilt angle which is supplied to the DCM microcontroller for processing. When the wheelchair reaches a predefined safe tilt limit, an auditory alert is generated warning the user of the imminent danger of toppling over so as to enable him to take corrective measures and the UIP is informed of this safe tilt limit breach wirelessly.

A GSM modem is also interfaced to the UIP. When the user cannot manoeuver through a region without external help due to excessive tilt or in case the wheelchair has toppled over, an alert in sent via text message to a pre-selected individual who can come to the user's aid. The same can be done to alert the user's doctor/nurse when the Health Monitoring system indicates that the user is in need of medical attention.

The complete functional block diagram of this design is illustrated in Figure 8.

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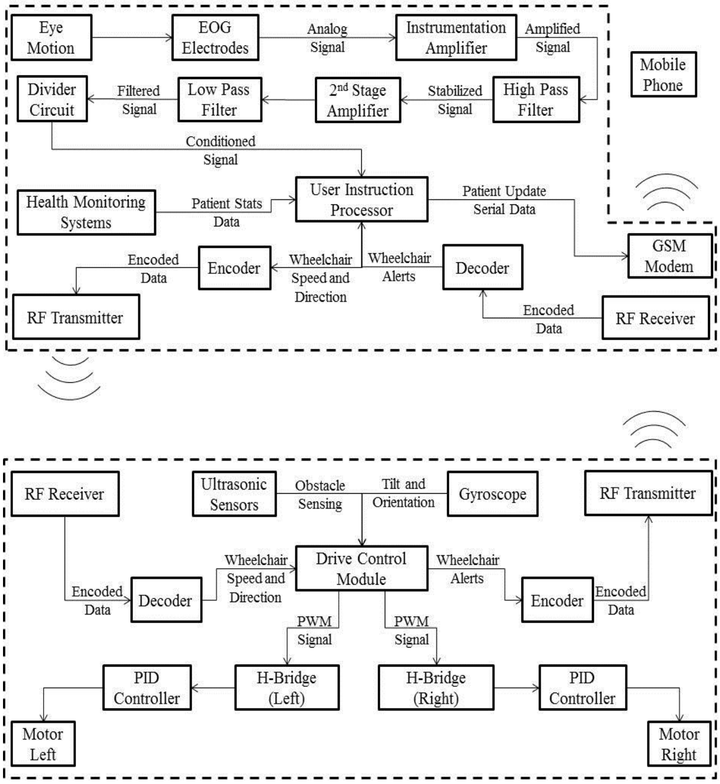

Figure 8: Complete Functional Block Diagram

3 PROPOSED MODEL

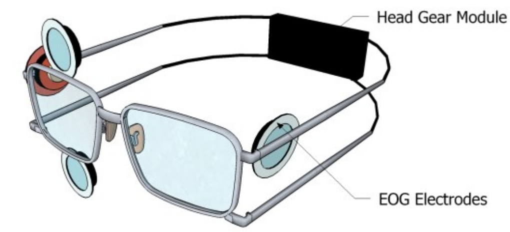

Figure 9: Proposed Head Gear

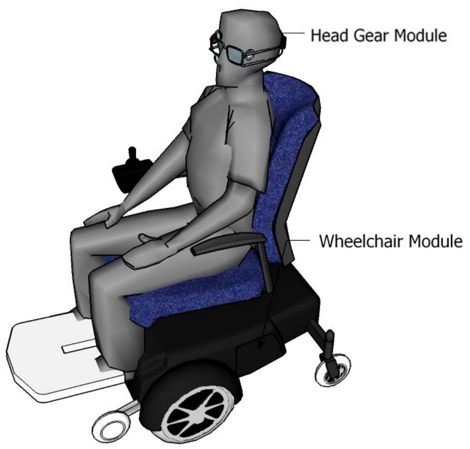

Figure 10: Proposed Wheelchair

4 CONCLUSION

This paper presents a method of eye gesture based wheelchair control using Electro-Oculography. User commands for wheelchair control are obtained from the EOG signal using the signal conditioning module. The extracted commands are processed through the intelligence algorithm that also takes into account ambient obstacle proximity detected by the wheelchair ultrasonic sensors to generate improved collision free drive control. This wheelchair is designed to be an intuitive and cost effective control method. A proof of concept has been successfully developed where the direction of motion of a wireless robot has been controlled using eye gestures (figure 11).

Figure 11: Proof of concept - Control Module (L) and Wireless robot (R)

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