Wheelchair Control System based on Gyroscope of Wearable Tool for the Disabled

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Abstract. A wheelchair control system based on Gyroscope of wearable tool can serve the disabled, especially in helping them move freely. The recent evolution of new technology means that unassisted, free movement has become possible. For this purpose, human–machine interface hands-free command of an electric-powered wheelchair can be achieved. In this paper, an electroencephalogram instrument, namely the EMOTIV Insight, was implemented in a human–computer interface to acquire the user’s head motion signals. The system can be operated based on the user’s head motions to carry out motion orders and control the motor of the wheelchair. The proposed system consists of an EMOTIV Insight brain-based gyroscope to sense head tilt, a DC motor driver to control wheelchair speed and directions, an eclectic-powered wheelchair, microcontroller, and laptop. We implemented the system in practice and tested it on smooth and rough surfaces in indoor/outdoor settings. The experimental results were greatly encouraging: disabled users were able to drive the wheelchair without any limitations. We obtained a significant average response time of 2 seconds. In addition, the system had accuracy, sensitivity, and specificity of 99%, 99.16%, and 98.83%, respectively.

Keywords: accuracy, Arduino, DC motor driver, EMOTIV Insight, response time, ultrasonic, wheelchair

1. Introduction
The increasing numbers of the elderly in society, and the increasing number of accidents, wars, and disabled people are the main reason for developing special control techniques. Quadriplegic (QP) or tetraplegic (TP) patients are people who have lost the ability to move their upper and lower limbs due to spinal cord injury but are able to perform complete head motions. People with C4 neurological stage injuries can breathe almost naturally; nevertheless, they still require assistance. Accordingly, they can typically make head and neck motions. Therefore, an electric-powered wheelchair (EPW) that uses neck movement is effective for people with such injury. Thus, users who cannot utilize a traditional joystick in their daily motion and activities require an intelligent control unit. The present EPW are mostly joystick-driven and cannot fully meet the needs of the disabled and the elderly. Smart EPW have become a natural replacement for standard wheelchairs as an aid for the elderly and people with mobility issues. There was a need to develop EPW with smart commands to match the wide variety of applications in assistive technology (AT).
Many kinds of research involving several techniques for operating EPW without utilizing the classic joystick tool have been published. Numerous sophisticated devices and human–machine interfaces
(HMI) have been proposed. These include vision-based methods [1]; speech identification [2]; gestures [3]; head control [4]; tongue drive system (TDS) [5]; and bio-signal-based control such as electromyography (EMG) [6], electrooculography (EOG) [7], or electroencephalography (EEG) control [8]. For example, a motion control model for an EPW that uses eye gaze activity could be used as a human–computer interface (HCI) in an unknown environment using two cameras [9]. In addition, an EPW can be equipped with four types of sensors, a standard webcam, an RGBD camera, a laser range finder, and an inertial measurement unit (IMU) sensor [10]. Moreover, a wearable EOG measurement model used in HCIs/HMIs has been developed. An algorithm classified for only four directional eye motions and tested with four subjects with about 91.25% accuracy has also been proposed [11]. EPW can be voice-operated as well; therefore, many researchers have developed and built models and prototypes for improving such EPW. A smart wheelchair with a speech control system and an ultrasound (obstacle detection unit) has been established. One limitation encountered in such research is that the DC motor holds a maximum weight of 50 kg [12]. Subsequently, three distinct control methods: speech, hand gesture, and joystick, have been implemented in the intelligent wheelchair (IW). Wheelchair users can use these methods to drive their wheelchairs [13]. There is also a wheelchair that includes a navigation system that uses an accelerometer and a magnetometer. The model has an obstacle avoidance model consisting of four ultrasonic sensors, in addition to a real-time location monitoring tool that utilizes RFID (radio-frequency identification) to track the wheelchair inside a building. Moreover, a speech guidance system aids the visually impaired [14]. Furthermore, an EPW that incorporates hand motions in three perpendicular positions identified by a MEMS (microelectromechanical systems) accelerometer and conveyed to a personal computer through Bluetooth wireless technology has been proposed [15].

Certain authors have established an EPW with head motions possibilities, utilizing an IMU to capture gestures from the user’s head and to move an EPW [16]. Two control systems design have been proposed; the first input is a speech controller system and the second is the control device for head orientation. It utilizes the user’s head motions around the x-, y-, and z-axes to control wheelchair motion in all directions [17]. A robotic wheelchair was developed for QP users, with mobility assistance performed using head movements. A controller uses the signal for navigation and enables wheelchair travel. Ultrasonic sensors assist with avoiding obstacles by using the data collected during navigation [18]. A simple simulator program for assisting with wheelchair design has been proposed. G-code has been used in applications for controlling 3D wheelchair design in computer numerical control (CNC) systems. The computer simulation could be notified of potential issues with any design mistakes. It enabled the performance of tasks, command scheme experimentation, and structure evaluation [19]. The TDS is an AT that enables disabled users to use voluntary tongue movements to operate their computers, smartphones, and wheelchairs [20].

Other researchers have used bio-signal-based controls, such as that used in a design for controlling a 4-wheel omnidirectional wheelchair utilizing intention-based myoelectric signals, with about 98.9% accuracy [21]. Furthermore, wireless brain–computer interface BCI (WBCI) and a commercial EEG headset have been used to control home and medical devices such as a light bulb, a fan, and EPW for dependent users [22]. Moreover, a special IW navigation method has been described. Using a camera detector and eight ultrasonic sensors, the proposed model prevents collisions with various obstacles. The experimental findings showed that the proposed navigation systems shown accuracy about 98.3% in outdoor settings and obstacle-avoiding paths with accuracy about 92% indoors and outdoors [23]. However, each development has limitations that prevent it from being used in daily life. For example, joystick control requires complete dexterous control of the upper limbs [24]. Speech recognition systems have become widely available on computers and smartphones, but they are not efficient for cursor or wheelchair navigation. In addition, as speech recognition is sensitive to acoustics, it is unreliable in noisy environments [25]. BCI is useful for users with high levels of paralysis, but is subject to motion artifacts and interference, and cannot be easily adapted to daily activities [26]. EMG control helps the disabled access computers or navigate EPW; on the other hand, the number of commands is limited and long-term use can cause muscle fatigue [27]. The eye tracker is efficient for controlling a mouse cursor on a computer screen. However, as it requires a camera in front of the user’s face, it can block the line.
of sight, rendering it unhelpful for mobile settings [28]. Head motions are the most popular AT, where TP and QP users can use it for driving EPW. Moreover, they are affordable and simple [29].

In the present paper, we describe a means of overcoming the limitations in the previously presented solutions: a HMI that provides hands-free command of an EPW based on an EMOTIV Insight EEG sensor that can sense brain signals, which was implemented in practice. It involves nine states dependent on head motion: forward, turn right slow, turn right fast, turn left slow, turn left fast, stop, rotate left or right, and reverse. Our research work different from other previous studies by adopting more than one speed of moving and more than one direction to control the wheelchair, and calculated wheel rotation radius, which they used to know the dimension of corridors and doors. Furthermore, it has six states for motor speed and four states for the wheel rotation radius. It is important to note that once the HMI is in operation, the user does not need to maintain a particular pose. Thus, user fatigue can often be reduced significantly. Fifteen men and women aged between 20 and 70 years examined this system. Nearly all handled the command headset effectively and indicated happiness and satisfaction with this system. The research findings strategy involved a brief training program, continuous real-time control, and obstacle avoidance.

Our research contributes are implementation of a wheelchair control system (WCS) that can achieve all possible movements for the disabled, such as forward, turn right, turn left, rotate, reverse, and stop. Besides, make the WCS suitable for indoor and outdoor conditions by providing multiple states of speed and ensuring that the turning radius is suitable for indoor and outdoor use. The response time of the program for the system and response time between instructions, plus the response time of the driver as well as the response time of the motor to perform the order is up to 2 seconds.

2. Methodology
The proposed system comprises an EMOTIV Insight headset worn by the user, and the data (head motion) are transferred wirelessly to the computer for analysis. The data are processed by a microcontroller (Arduino UNO) and are used for managing and controlling the instructions for speed and direction. These instructions are relayed to a DC motor driver to control the wheelchair’s motor and move the EPW according to orders from the user. Figure 1 presents a block diagram of the WCS, including all input and output parts. The framework was designed keeping in view the demands of future development, and can be simply modified by adding and replacing the input or output parts.

![Figure 1. Block diagram of the WCS.](image-url)
2.1. Head movement detection unit
We used the EMOTIV Insight headset gyroscope to capture head motions and send them to a dongle transceiver module. The system used the EMOTIV headset because it has a high response speed, it cancels the cables that uncomforted the user (wireless technology), easy to control as well as wear on the head, and the user does not have to maintain the head posture after the command is executed. The EMOTIV Insight designed for everyday use with fully optimized to produce clean, robust signals anytime and anywhere. Besides, the dongle transceiver is a small component of hardware that links to the port of another device to provide useful features. In addition, it is used to connect the software with the device and it has two light-emitting diode (LED) (power and connect the Emotiv Insight). It is the main component of the process that is used specifically for transmitting and receiving data; the data cannot be obtained without it. As shown in Figure 2, the EMOTIV Insight measures EEG activation from five saline electrodes [30]. The electrodes are organized according to the 10/20 system, and their locations are AF3, AF4, T7, T8, and Pz. In addition, we used an EMOTIV software development kit (cortex) involving an application programming interface (API) to program the system (Figure 3).

![Figure 2. Emotiv Insight headset.](image1)

![Figure 3. Cortex application programming interface [31].](image2)
2.2. Algorithm of control unit

The personal computer and the microcontroller were selected to form the basis of the system. All conditions of the input/output items for the system are covered. The microcontroller receives the head signals from the personal computer, which is used as an adapter between the microcontroller and the headset. The acquired signals are processed in the Arduino programming using a specific algorithm. The order instructions acquired by the microcontroller control the motion and direction of the wheelchair. An algorithm is used to control the system using Microsoft Visual C++. Figure 4 depicts the flowchart of the system.

![Flowchart of the WCS](image)

**Figure 4.** Flowchart of the WCS.

2.3. Wheelchair and motor driver unit

The WCS uses an EPW manufactured by IMC [32]. It has the following characteristics: 120-kg carrying capacity, 24 V–200 W double motor, adjustable armrests, adjustable footrests, foldable backrest, and demountable skeletal system. Thus, it can be modified and adjusted according to any demands or changes. The motor velocity is controlled using pulse width modulation (PWM). Here, we used a 100 A dual-channel H-bridge DC motor drive module, a high-power motor that controls the velocity of the
wheelchair [33]. It is highly integrated, very beautiful, very small, and the drive module measures 82 mm × 70 mm. Figure 5 shows the wheelchair of the WCS in different postures.

![Wheelchair in different postures](image)

**Figure 5.** The wheelchair of the WCS.

### 3. System Performance Evaluation

The performance quality of the system was derived from three statistical analyses, namely, sensitivity, specificity, and accuracy [34].

Sensitivity (SN) refers to the ability of the system in to perform all orders, as shown in Equation (1).

\[
SN = \frac{TP}{TP+FN} \times 100\% \quad (1)
\]

Specificity (SP) refers to the ability of the system to detect the following orders, as shown in Equation (2).

\[
SP = \frac{TN}{TN+FP} \times 100\% \quad (2)
\]

True positive (TP) indicates that the system detects the order and the command is issued; false positive (FP) indicates that the system detects the order and the command is not issued; true negative (TN) indicates that the system does not detect the order so the command is not issued, and false negative (FN) indicates that the system does not detect the order and the command is issued.

Accuracy (AC) refers to the overall ability of the system to carry out the orders, as shown in Equation (3).

\[
AC = \frac{TP+TN}{Pn+Nn} \times 100\% \quad (3)
\]

where Pn and Nn denote the number of positive and negative attempts, respectively.

The proposed velocity depends on the rotations per minute (RPM) of the wheel and the PWM. Furthermore, the wheel rotation radius must be found to determine the space needed for each turn. Figure 6 illustrates the rotation radius of the wheels. The velocity system, time, and rotation radius were calculated using the following equations [35]:

\[
V = \frac{d}{T} \quad (4)
\]
\[ T = \frac{60}{\frac{\text{RPM}}{V_2 \times \text{sh.}}} \]  
\[ R_2 = \frac{V_1 - V_2}{V_1 - V_2} \]  
\[ R_1 = R_2 + \text{Sh.} \]  
\[ CF = 2 \times \pi \times D \]

where \( V \) = wheel velocity, \( d \) = distance, \( T \) = time, \( R_1 \) = rotation radius of the first wheel, \( R_2 \) = rotation radius of the second wheel, \( \text{Sh.} \) = shaft between the wheels, \( CF \) = wheel circumference, \( D \) = wheel diameter, \( V_1 \) = velocity of the first wheel, and \( V_2 \) = velocity of the second wheel.

**Figure 6.** Rotation radius of the wheels [35].

### 4. Results and discussion

The proposed WCS uses a control method dependent on head motions that used the signals acquired by two-axis of the gyroscope in the EMOTIV sensor to identify head motions without using a camera. The user makes a specific head motion according to the user interface program, e.g., up, down, right, and left, to execute a control order (forward, stop, rotate, reverse, turn right, turn left). Figure 7 shows the proposed graphical user interface (GUI). One lighted arrow shows that the wheelchair turns at low speed; two lighted arrows show that the wheelchair turns at high speed.

**Figure 7.** GUI of the WCS based on Microsoft Visual C# program.
To demonstrate the performance of the model, the response time is used to indicate the proportion of total period to head tilt. In addition, the sensitivity, specificity, and accuracy are used as a statistics performance to evaluate the system and how useful it is. Table 1 and Table 2 show the experimental evaluations. The test findings indicate that users can control direction based on their own head tilt technique. The classification models (TP, FP, TN, and FN) were evaluated in elderly and young subjects, i.e., the participants were aged 20–70 years and comprised both men and women. Fifteen participants tested the system, and each order was repeated 100 times to review the results and accuracy requirement. The average response time, sensitivity, specificity, and accuracy was 1-2 seconds, 99.16%, 98.83%, and 99%, respectively. Besides, Table 3, represent the results of sensitivity, specificity, and accuracy for subject 1-15 with the average of all subjects. Table 4 presents the velocity and the wheel rotation radius based on the equations.

The system tests were performed in the park and corridor of the Electrical Engineering Technical College. Evaluation of the initial scheme with head tilt tools was effective. Specific experiments were performed in different environments (Figure 8). Figure 9 depicts curves for the navigation cases for two scenarios A and B in the park of Electrical Engineering Technical College taking from google map.

Table 1. Experimental evaluation for subject 1.

| Subject 1 | Forward | Stop | Reverse (backward) | Turn right | Turn left | Rotate |
|-----------|---------|------|-------------------|------------|-----------|--------|
| attempts  | 100     | 100  | 100               | 100        | 100       | 100    |
| TP        | 99      | 99   | 99                | 99         | 99        | 100    |
| FN        | 1       | 1    | 1                 | 1          | 1         | 0      |
| Sensitivity (%) | 99 | 99 | 99 | 99 | 99 | 100 |

TP: True positive; FN: False negative

Table 2. Experimental evaluation for subject 1.

| Subject 1 | Forward | Stop | Reverse (backward) | Turn right | Turn left | Rotate |
|-----------|---------|------|-------------------|------------|-----------|--------|
| attempts  | 100     | 100  | 100               | 100        | 100       | 100    |
| TN        | 99      | 99   | 98                | 99         | 99        | 99     |
| FP        | 1       | 1    | 2                 | 1          | 1         | 1      |
| Specificity (%) | 99 | 99 | 98 | 99 | 99 | 99 |

TN: True negative; FP: False positive
Table 3. Experimental performance evaluation of the WCS.

| Subject | Sensitivity (%) | Specificity (%) | Accuracy (%) |
|---------|----------------|----------------|--------------|
| 1       | 98             | 97             | 97.5         |
| 2       | 100            | 99             | 99.5         |
| 3       | 97             | 100            | 98.5         |
| 4       | 99             | 100            | 99.5         |
| 5       | 100            | 99             | 99.5         |
| 6       | 99             | 100            | 99.5         |
| 7       | 99             | 99             | 99           |
| 8       | 100            | 97             | 98.5         |
| 9       | 100            | 100            | 100          |
| 10      | 99             | 99             | 99           |
| 11      | 99             | 97             | 98           |
| 12      | 97             | 100            | 99.5         |
| 13      | 100            | 97             | 98.5         |
| 14      | 99             | 99             | 99           |
| 15      | 100            | 99             | 99.5         |
| Average | 99.06          | 98.8           | 99           |

Table 4. The velocity and rotation radius of the system.

| PWM 1 | PWM 2 | RPM 1 | RPM 2 | T1 (s) | T2 (s) | D (m) | V1 (m/s) | V2 (m/s) | Sh. (m) | R1 (m) | R2 (m) |
|-------|-------|-------|-------|--------|--------|-------|----------|----------|---------|--------|--------|
| 50    | 50    | 30    | 30    | 2      | 2      | 1.0048| 0.5      | 0.5      | 0.55    | ---    | ---    |
| 60    | 40    | 36    | 24    | 1.6    | 2.5    | 1.0048| 0.6      | 0.4      | 0.55    | 1.7    | 1.1    |
| 70    | 30    | 42    | 18    | 1.4    | 3.3    | 1.0048| 0.7      | 0.3      | 0.55    | 1      | 0.4    |
| 40    | 40    | 24    | 24    | 2.5    | 2.5    | 1.0048| 0.4      | 0.4      | 0.55    | ---    | ----   |

PWM: Pulse width modulation; T: Time; D: Distance; V: Velocity; Sh.: Shaft between wheels; R: Rotation radius of the wheel.

Figure 8. Experiments in various environments (a) smooth surface, (b) rough surface.
5. Conclusions
In this paper, a head movement system is proposed for hands-free manipulation of an EPW. One of the important objectives of this work is to provide a more stable system with real ability that is effective for QP and disabled users. It utilizes head motions to capture the information acquired from an EMOTIV Insight headset. The system’s control method stems from the fact that velocity will be based on the required movement via nine control commands. The user does not have to maintain the head movement after the command is executed. The experimental findings indicate that the proposed WCS is secure, reliable, and suitable for wheelchair control. The system is indicted as secure because it achieves many tests based on several experiments in the Electrical Engineering Technical College for 15 participates that examine the wheelchair control system in an indoor/outdoor situations and for smooth and rough surfaces. The findings indicate a good, acceptable response time with a maximum time of almost 2 seconds. The velocity algorithm was evaluated using an EPW that has been tested with excellent results, with command accuracy of about 99%. Future work will focus on implementing a method for avoiding obstacles and orienting the wheelchair.

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