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# Design and Implementation of Brain Controlled Electric Wheel Chair for Quadriplegic Persons

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*Abstract*—**Quadriplegia refers to a condition where the body experiences paralysis below the neck, affecting the trunk, legs, and arms. Globally, the World Health Organization (WHO) reports that around 5.4 million individuals are afflicted by quadriplegia. Offering secure and independent mobility to such a substantial population aligns with the United Nations' (UN) third sustainable development goal of promoting good health and well-being. Addressing this challenge demands innovative, and user-friendly solutions. To tackle this pressing issue, this paper introduces a hardware-based implementation of a brain-controlled electric wheelchair tailored for quadriplegic individuals. The proposed system comprises an electric wheelchair, an electroencephalogram (EEG) headset, a Bluetooth module (HC-05), a controller, and gear motors. The EEG headset captures brain signals, and transmits them to the controller via Bluetooth. The controller communicates with motor drivers, propelling the wheelchair in desired directions: left, right, forward, or backward-based on the extracted brain signal information. For a comprehensive solution catering to a wider audience of individuals with disabilities, the manuscript also uses joystick-controlled wheelchair, a cost-effective option for those with leg impairments. The implemented solution stands out for its speed, user-friendliness, and safety, incorporating a collision avoidance system to ensure user well-being.**

*Index Terms*—**Brain Control, Electric wheel chair, EEG headset, Quadriplegia.**

## I. INTRODUCTION

Quadriplegia primarily arises from spinal cord damage, often occurring within the cervical vertebrae (specifically, the C1-C7 sections closest to the skull). Individuals effected by quadriplegia encounter significant mobility challenges and rely entirely on the assistance of others for their movement. Unfortunately, they often experience discrimination, being viewed more as a burden to society rather than a valuable part of it, leading to feelings of rejection. Through the utilization of wheelchairs, those with quadriplegia can regain a sense of independence and self-directed movement. The global population of quadriplegic individuals who have experienced complete loss of mobility is considerable. Research indicates that each year, approximately 5.4 million people worldwide contend with quadriplegia [1]. To provide a secure and independent mobility to such people is a major issue. They need a continuous assistance which demands smart engineering solutions. To address this issue, alternative and effective options for user friendly wheelchairs are of pivotal importance. In order to help disabled people, different types of devices are available that operate using various inputs for example joystick [2,3] and voice [4,5] etc. However, these solutions are not useful for Quadriplegic users and mostly these solutions lack in obstacle avoidance interface; that may lead to harmful outcomes and accidental situations.

Even though such people are disabled, they have strong operational brains. To provide the movement opportunities to such people, brain can be utilized freely to control the wheelchairs using their thoughts. So, the only way to help these users is to establish a direct communication with brain. This direct communication is possible only using brain computer interface (BCI) which acquires and process brain signals to extract useful specific features and then these signals are translated as commands to operate and control different devices [6,7]. There are various techniques to acquire electrical signals from the brain generated to command physical responses of human body part. These methods include magnetoencephalography (MEG), electroencephalography (EEG), functional near-infrared spectroscopy (FNIR), electrocorticography (ECoG), and functional magnetic resonance imaging (fMRI) etc. [1].

MEG is a non-invasive neuro-imaging method that detects the brain's magnetic fields, offering precise insights into neural activity. MEG systems are expensive and complex, limiting

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their availability and accessibility for research and clinical use [13]. FNIRS is a non-invasive neuro-imaging method that gauges changes in brain blood oxygen levels using near-infrared light. It tracks neural activity through variations in blood flow. FNIRS has limitations in depth of brain penetration and sensitivity to motion artifacts and is more expensive [14].

ECoG involves placing electrodes on the brain's surface, offering detailed neural activity for research, surgical planning, and epilepsy study. It is invasive due to surgery, limiting its use to specific clinical and research situations [15]. EEG is a technique used for visualizing and recordings the electrical signals during the brain activities [9]. EEG technology is used in most of the BCI operations. The major reason for the selection of EEG is its non-invasiveness, low cost and portability [13, 14]. It is actually visualization of electric impulses produced in brain along the scalp during different actions of the body [4]. Each action or thought generates a specific and unique brain signal, which may differ from person to person. EEG signals obtained from brain has different frequencies and amplitudes according to which they are classified into five different EEG bands [5] as shown in the Figure 1.

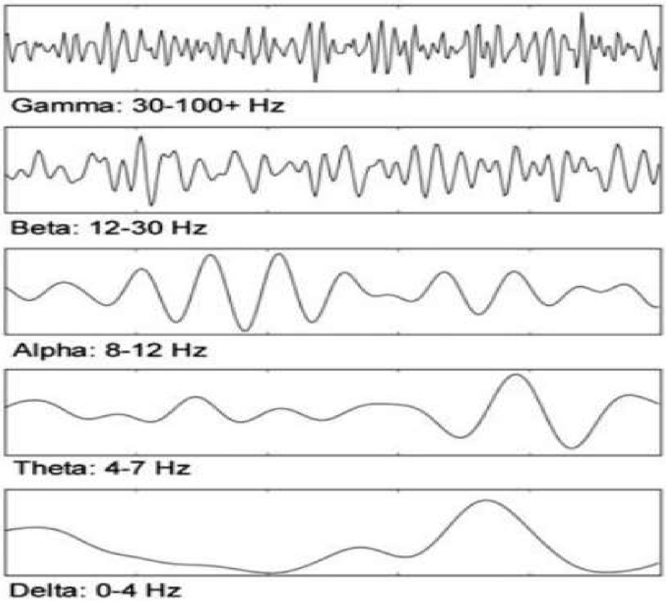

Fig. 1: EEG Wave Forms

The Delta waves, ranging from 0 to 4 Hz, are prominent during deep sleep and unconsciousness, reflecting the brain's lowest levels of activity. Theta waves, in the 4 to 8 Hz range, emerge during light sleep, deep relaxation, and meditative states, often linked to creative and insightful thinking. Alpha waves, spanning 8 to 13 Hz, signify an awake yet calm and relaxed state, often observed when the eyes are closed and the mind is idle. Beta waves, extending from 12 to 30 Hz, dominate during active and alert mental engagement, such as problem-solving and decision-making. Finally, the gamma waves, ranging from 30 to 100+ Hz, are associated with intricate cognitive processes, heightened perception, and the integration of information from various brain regions, playing a role in overall consciousness and complex thinking patterns [19].

In order to record the brain activity in the form of electrical signal releasing from brain, EEG sensor called EEG Electrodes are used by the researchers [12]. These electrodes can be classified as invasive or non-invasive [20]. In non-invasive type we put electrodes just on the scalp, no surgery is required for this but in invasive type we need a surgery [16]. Generally, non-invasive electrodes are being used because no surgery is required. Non-invassive EEG electrodes are further divided into wet or dry electrodes [12]. Wet electrodes mean it need some gel before placing it on scalp while in dry electrode no gel is required.

Recently some built-in brain signal recording sensors are introduced [9]. There are many wired and wireless EEG devices which are portable that can be easily available in the market, i.e., Muse, Emotiv EPOC, OpenBCI, Mattel Mindflex, Enobio, OpenEEG and Neurosky Mindwave [4]. We select Neurosky Mindwave [17] because it is cheap, easily available and easy to use.

While the inaugural showcase of the initial electric-powered wheelchair took place in 1929, its patenting and widespread accessibility didn't materialize until 1952. The distribution of mobility devices was predominantly overseen by Invacare, a prominent company with roots dating back to the late 19th century. Progress in the latter half of the 20th century was centered on tailoring weight and frame designs to individual needs. Particularly noteworthy is the 'Quickie,' which emerged in 1979, introducing lightweight materials and a distinctive visual appeal. Additionally, the 'Hall's Racing Wheelchair,' exhibited at the Museum of Modern Art (MoMA) in 1986, garnered recognition for its innovative design [18-22].

This article presents the hardware implementation of a brain-controlled electric wheelchair, operated by the brain activity of individuals with quadriplegia. This innovative implementation offers these individuals the ability to navigate independently in their daily lives. The wheelchair is designed for comfort, cost-effectiveness, and security with an obstacle avoidance system. To provide a comprehensive solution, we also integrate a joystick-controlled wheelchair option.

The wheelchair's operation is governed by a dual-position switch: "master" and "slave." The master setting signifies the brain-controlled mode (BCM), allowing quadriplegic users to control the chair using their brain signals. Conversely, the slave position activates the joystick-controlled mode (JCM), catering to individuals with leg disabilities. It's important to note that both modes are designed to address the distinct needs of these two user categories.

For the sake of completeness, we present both operational modes within a unified solution, although they might not be physically integrated into a single chair. These modes operate independently, granting users the flexibility to seamlessly switch control of the smart wheelchair between modes as needed. Furthermore, an obstacle avoidance safety mechanism based on ultrasonic sensors is incorporated into both modes. This additional layer of safety enhances the overall security of the wheelchair, safeguarding users from unforeseen or accidental situations.

In the following two sections, we present the design and implementation of brain controlled and joystick controlled electric wheelchair.

## II. BRAIN CONTROLLED ELECTRIC WHEELCHAIR

In this section, we introduce the Brain Control Mode as shown in Figures 2 and 3, a primary control of the proposed system specifically designed for individuals with quadriplegia. This mode encompasses the acquisition of EEG data from specific brain points using the Brainlink Lite EEG headset. To visualize the EEG signals transmitted from the brain, we utilize an Android-based smartphone. The Android app employed for this purpose is developed using the Neurosky development toolkit, which is freely available. This app is designed to effectively gauge the intensity of attention and the strength of eye blinks. It establishes a wireless connection with the EEG headset via Bluetooth communication protocol, enabling the receipt and analysis of EEG signals.

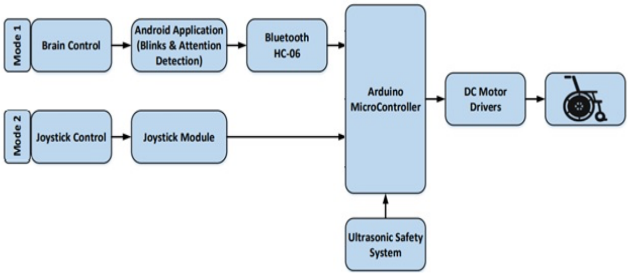

Fig. 2: Block Diagram of Purposed Dual Mode Electric Wheelchair

The core components of the system include the headset, wheelchair frame, Arduino microcontroller, and movement-controlling motors. The headset establishes a Bluetooth connection with the microcontroller, facilitating the direct transmission of data from the headset to an Android application for signal analysis before relaying it to the microcontroller. The HC-05 Bluetooth module serves as the intermediary interface between the headset and the Arduino microcontroller. The movement-controlling motors are governed by motor drivers, which interpret instructions from the microcontroller.

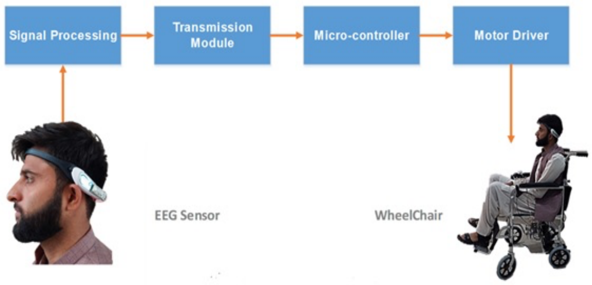

Fig. 3: Block Diagram of the Brain Control Electric Wheelchair

The overarching objective of this system is to capture EEG signals from the brain and interpret them according to the user's intentions to drive the movements of the wheelchair.

### A. *EEG signals Acquisition*

The system employs a wireless headset known as the Brain link EEG headset (depicted in Figure 4) for capturing brain signals. This implementation contributes to the cost-effectiveness of the smart wheelchair, enabling four-dimensional operation encompassing right, left, forward, and backward movements.

Fig. 4. Neurosky Headset

For the acquisition of brain activity signals and the identification of mental states such as eye blinks and attentiveness, we utilize the frontal lobe's, i.e., FP1 and FP2 positions shown in Figure 5. This is the electrode placement point.

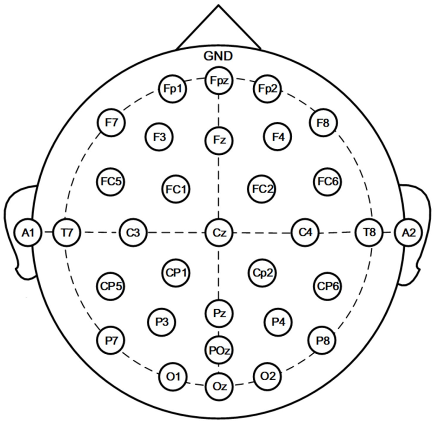

Fig. 5. Position of Electrode placement [18]

For the acquisition of brain activity signals and the identification of mental states such as eye blinks and attentiveness, we utilize the frontal lobe's, i.e., FP1 and FP2 positions shown in Figure 5. This is the electrode placement point. Brain signals acquired using EEG headset from FP1 and FP2 positions are transmitted by the Bluetooth module which are then analyzed and processed at the android smart phone which contains a customized algorithm for this purpose. Overall circuit for the hardware implementation of the BCW mode is presented in Figure 6.

### B. *Design Flow of BCW*

In this section, we elucidate the functionality of the brain-controlled electric wheelchair. The design process is visually represented in Figure 7, which expounds on the wheelchair's operation. Control over the wheelchair's movements is vested in the user's attention and eye blinks. A predetermined sequence of movement instructions is chronologically fed to the microcontroller at 1.5-second intervals, concurrently displayed on the LED direction panel. To designate a movement direction, the user can execute two consecutive eye blinks. Following direction selection, the user must then intensify their level of attention. When the attention level attains a specific threshold, set at 100 in this instance, the wheelchair commences movement in the designated direction.

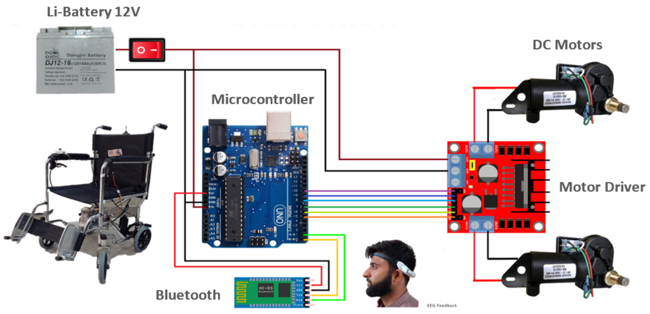

Fig. 6. Circuit Diagram of Brain Controlled System

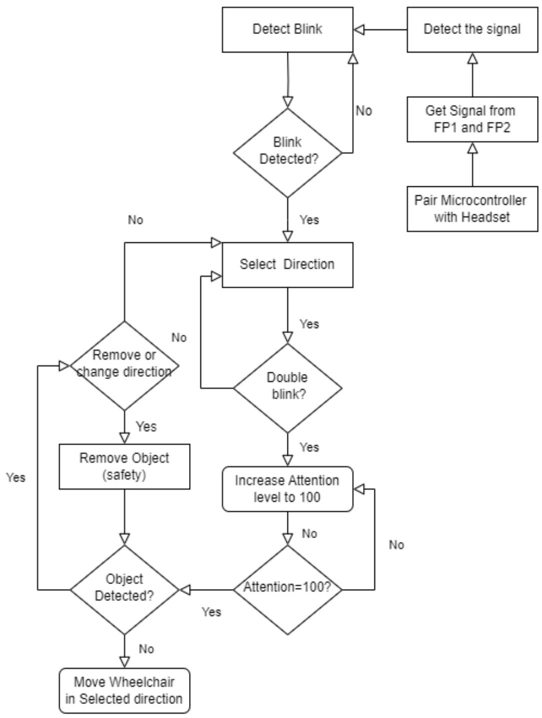

Fig. 7. Flow Diagram of the BCW

The wheelchair operates within four distinctive states: standby mode, command mode, focus mode, and running state. Initially, the wheelchair remains in standby mode until an eye blink is detected. Upon achieving the threshold value, the wheelchair transitions to command mode. Here, sequential data for four directions initiates a cyclic sequence. Each direction is displayed for 1.5 seconds, and if the user does not choose a direction, the wheelchair reverts to standby mode. By executing two eye blinks, the user can select a specific direction from the sequential data, transitioning the wheelchair into focus mode. Within focus mode, the user elevates their attention level. Once the attention/focus level surpasses 100, the mode shifts to the "Running" state, prompting the wheelchair to initiate movement in the specified direction.

### C. *Experimental Testing*

An extensive trials were conducted to assess the wheelchair's performance. The feasibility of the wheelchair is evaluated with three subjects, each participating in the experiment.

The analysis of the wheelchair's brain-controlled mode performance across different subjects reveals noteworthy results. Among the directional categories, the highest accuracy, reaching 89%, was attained in the forward and right directions. Impressively, the left and backward directions exhibited accuracies of approximately 92% and 94% respectively.

## III. JOYSTICK CONTROL ELECTRIC WHEELCHAIR

In addition to the primary control of the wheelchair using the EEG headset, the wheelchair also integrates a secondary control system based on a joystick. This secondary control employs a Dual Axis XY Joystick Module, which interfaces with DC motors through the Arduino Uno microcontroller to manage specific movements. This module has the capacity to transmit five distinct commands to the microcontroller based on its X and Y values, encompassing forward, backward, right, left, and stop motions. The transmission of directional signals from the joystick to the controller is facilitated through wired connections. The arrangement of the joystick in tandem with the microcontroller is visually depicted in Figure 8.

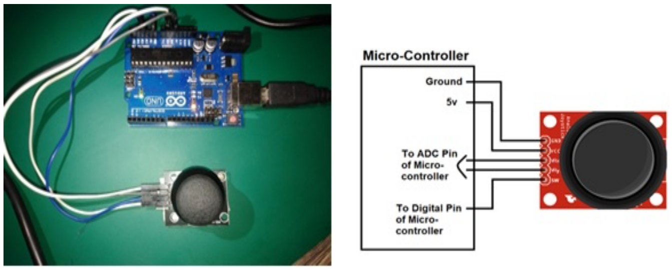

Fig. 8. Joystick Wire Configuration

### A. *Design Flow of JCW*

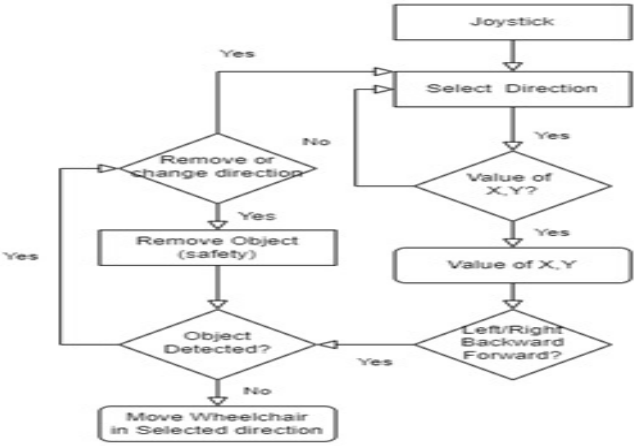

Fig. 9. Flow Diagram

Similarly, in the case of the Joystick-controlled wheelchair depicted in Figure 9, we interpret specific X and Y values to determine the intended action. When X: 512 and Y: 519, the wheelchair remains stationary. If X: 508 and Y: 0, the wheelchair moves forward. With X: 512 and Y: 1023, the wheelchair moves backward. For X: 1023 and Y: 517, the wheelchair veers right. Conversely, when X: 0 and Y: 519, the wheelchair initiates a leftward movement.

### *B. Experimental Testing of JCW*

To evaluate the performance of the joystick-controlled wheelchair, a series of trials were conducted for each directional command. This validation testing was carried out with three healthy subjects. The performance assessment of the wheelchair when operated in joystick mode demonstrates an exceptional accuracy rate of 100%.

### *C. Collision Avoidance in Electric Wheelchair*

In both the brain-controlled and joystick-controlled wheelchairs, if an obstacle obstruct the wheelchair's path, it will come to a halt and remain stationary until the obstacle is cleared. Ensuring the safety of an electric wheelchair is of paramount importance. The primary objective is to safeguard the user by minimizing collision risks. To achieve this, the wheelchair is equipped with two front-mounted ultrasonic sensors designed to detect obstacles. The functionality of these sensors relies on ultrasonic waves. Essentially, a sensor emits ultrasonic waves towards a target, and subsequently, the reflected beams are received by the same sensor. By measuring the time taken for the waves to be transmitted and received, this data is translated into a distance measurement. This measured distance serves as a crucial element in our safety system, helping to avert collisions with obstacles. To implement this, a distance threshold is set within the microcontroller. When the sensor detects that the distance to an obstacle has breached this threshold, an integrated buzzer is activated. This action both alerts the user and triggers a high-priority interrupt, thereby halting the movement of the wheelchair instantly. This proactive approach significantly enhances the safety of the user and prevents potential collisions.

## IV. CONCLUSION

An affordable and dependable BCI-driven dual-mode wheelchair is developed, utilizing NeuroSky's EEG headset for signal acquisition from the brain's frontal lobe (FP1 position). Control is executed through Blink Strength and Attention data from the headset. The wheelchair sequentially receives directional data, spacing 1.5 seconds apart, necessitating a double blink for user-specific direction selection indicated by LEDs. Following direction choice, attention escalation to a pre-set 100-threshold triggers motor driver communication, directing wheelchair movement. The Brain-controlled wheelchair achieves an average accuracy of 91%. A safety system is seamlessly integrated, featuring two front-placed ultrasonic sensors per side for obstacle detection within a 2-meter range. Detected obstacles promptly signal the microcontroller for instant wheelchair halt, ensuring user safety. Complementing the EEG headset-based primary control, the wheelchair boasts a joystick-based secondary control. Integrated with the safety system, this mode augments reliability and user security, achieving an impeccable accuracy of 100%.

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