

## Neuromotion: Brain Wave-Based Mobility System

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### Abstract

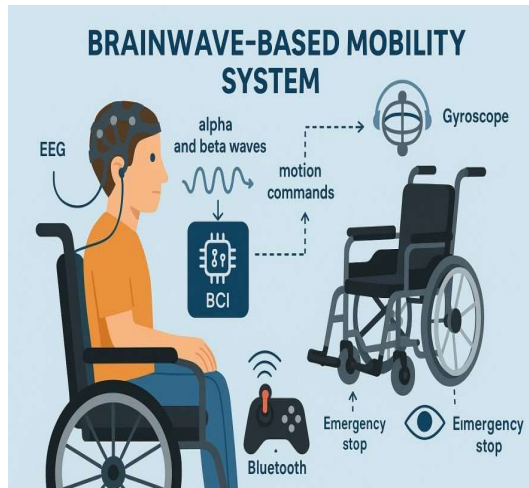
*Mobility impairments resulting from neurological disorders or severe physical disabilities significantly limit personal independence and reduce quality of life. Conventional wheelchairs generally rely on manual operation or joystick-based control, which may not be practical for individuals with restricted motor abilities. To overcome this limitation, the proposed Neuromotion system introduces a brainwave-controlled mobility solution based on Brain-Computer Interface (BCI) technology, enabling hands-free navigation. The system captures Electroencephalography (EEG) signals and identifies specific brainwave patterns, particularly alpha and beta rhythms, which are processed to generate motion commands. Directional control is further enhanced through a gyroscope that interprets head movements, while a triple eye-blink detection mechanism is implemented as an emergency stop feature. The hardware architecture includes a BioAmp EEG headset for signal acquisition, dual ESP modules for wireless communication—one dedicated to EEG data processing and the other (ESP8266) responsible for command reception and motor control—a motor driver module for operating the chassis, and an optional Bluetooth joystick for manual override. The software is developed using Embedded C/C++ and uploaded during initial configuration, after which the system operates autonomously without requiring continuous PC connectivity. Real-time feedback is supported through MATLAB visualization and onboard indicators. Experimental evaluation in controlled environments demonstrates reliable interpretation of brain signals and responsive mobility control. The proposed system offers a cost-effective assistive technology solution and establishes a foundation for future enhancements, including obstacle avoidance, machine learning-based signal classification, and integration with smart environments.*

**Keywords** — Brain-Computer Interface (BCI), EEG, Assistive Technology, Smart Wheelchair, Embedded Systems, ESP8266, BioAmp EEG, Head Movement Control, Eye Blink Detection, Wireless Communication, Rehabilitation Engineering, MATLAB, Motor Driver, Human-Computer Interaction.

### Introduction

Rapid advancements in assistive and rehabilitation technologies are significantly improving mobility solutions for individuals with severe physical disabilities. Conventional wheelchairs, while widely used, generally depend on manual propulsion or joystick-based control, which can be difficult or impossible for users with neuromuscular disorders or limited motor function. To address these limitations, Brain-Computer Interface (BCI) technology has emerged as a promising approach that enables individuals to control external devices using brain activity. By translating neural signals into actionable commands, BCI-based systems offer an alternative mode of interaction that does not rely on physical movement, thereby enhancing independence and accessibility for users with profound mobility impairments. The proposed system, titled *Neuromotion: Brain Wave-Based Mobility System*, presents an intelligent mobility platform controlled through brainwave signals. The system employs Electroencephalography (EEG) sensors to capture alpha and beta brainwave patterns, which are processed to initiate or halt the movement of a wheelchair or mobile chassis. Directional navigation is achieved through the integration of a gyroscope, which interprets head orientation or tilt to control turning movements. The architecture incorporates key hardware components such as EEG sensors, motor driver modules, a gyroscope, and an ESP32-based wireless communication unit. Brainwave data is processed in real time using embedded controllers, while tools such as MATLAB support signal visualization and analysis. To enhance operational safety, a triple eye-blink detection mechanism is implemented for emergency stopping, and an optional Bluetooth-enabled joystick provides manual override capability when required.

By combining neurotechnology, embedded systems, and intelligent sensing, the proposed solution aims to redefine assistive mobility systems. The integration of non-invasive EEG acquisition, real-time processing, and wireless control enables hands-free operation while maintaining reliability and safety. This approach not only improves autonomy and dignity for individuals with mobility challenges but also opens new avenues for innovation in healthcare, rehabilitation engineering, and smart assistive devices.



**Fig 1: Brainwave-Controlled Wheelchair**

### Objectives

The objectives of the proposed system focus on developing a reliable and efficient brainwave-controlled mobility platform using non-invasive EEG technology. The system aims to acquire brain signals using a BioAmp EEG headset and process alpha and beta wave patterns to initiate movement. A gyroscope-based mechanism is implemented to enable head-controlled directional steering, while a triple eye-blink detection feature ensures safety through emergency stopping. Wireless communication is established using two ESP modules, where one module processes EEG data and the second module, based on ESP8266, controls the motorized chassis. The design ensures that a personal computer is required only during initial code uploading, allowing the system to operate autonomously afterward. Furthermore, the project emphasizes real-time performance, low power consumption, user-friendly operation, and suitability for assistive mobility and rehabilitation applications.

### Literature Survey

Over the last decade, Brain-Computer Interface (BCI) technology has gained considerable attention as an alternative control mechanism for individuals with severe motor impairments. These systems enable users to interact with external devices through neural signals, thereby reducing reliance on physical movement. Conventional wheelchairs typically depend on manual operation or joystick-based navigation, which becomes impractical for individuals affected by conditions such as spinal cord injuries, amyotrophic lateral sclerosis, or cerebral palsy. Electroencephalography (EEG)-based BCIs, which are non-invasive and relatively cost-effective, have emerged as a widely adopted solution. These systems analyze brainwave patterns, particularly alpha and beta frequency bands, associated with relaxation, concentration, and motor intent. By translating these signals into control

commands, assistive mobility devices can be operated without direct physical input. However, early implementations were largely dependent on personal computers, required extensive user training for motor imagery tasks, and often suffered from poor signal quality and latency issues, which limited their real-time performance and portability.

### Motivation

Mobility limitations significantly affect the independence and quality of life of individuals with neurological and muscular disorders. Although various assistive mobility systems have been developed, many existing solutions remain expensive, complex, or dependent on continuous computer interfaces, making them unsuitable for everyday use. This project is motivated by the need for a hands-free, intuitive, and non-invasive mobility aid that enhances user autonomy. By combining EEG-based brainwave interpretation with gyroscope-based head movement control, the proposed system aims to eliminate physical input requirements while maintaining real-time responsiveness. The inclusion of wireless communication and emergency control mechanisms further improves usability and safety. The overall objective is to contribute to assistive robotics and smart healthcare by providing an accessible and affordable mobility solution.

### Problem Statement

Individuals with severe motor disabilities often face significant challenges in operating conventional wheelchairs due to limited physical control. Although EEG-based BCI systems offer an alternative, many existing designs rely on costly hardware, bulky setups, or complex training procedures. Additionally, several systems lack intuitive navigation methods and emergency stop features, which may compromise user safety. There is therefore a need for a user-friendly, low-cost, and portable mobility solution that supports real-time control through brainwave signals and head motion. Such a system should function wirelessly, operate without continuous PC connectivity, and incorporate safety mechanisms to ensure reliable performance. The proposed Neuomotion system addresses these requirements by integrating EEG-based control, gyroscope-based steering, wireless ESP communication, and an emergency triple eye-blink detection feature.

### Hardware and Software Requirements

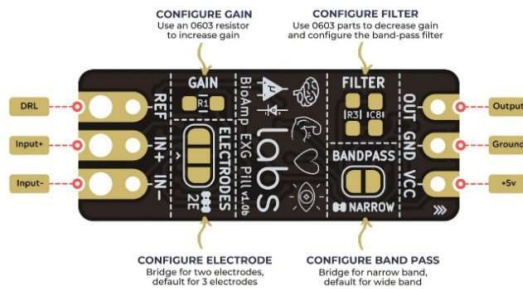
This describes the hardware and software components utilized in the development of the Neuomotion system. The selected components enable accurate acquisition of brainwave signals, reliable wireless communication, and real-time control of the assistive mobility platform. The integration of these modules forms a brainwave-driven mobility solution designed to assist

individuals with limited motor abilities. Each component is chosen based on performance, compatibility, power efficiency, and ease of integration to ensure stable and responsive system operation.

### Hardware Components

#### EEG Headset (BioAmp)

The BioAmp EEG headset is a non-invasive sensing device used to capture brain signals from the scalp. It primarily detects alpha and beta wave activity, which are associated with attention levels and motor intention. The acquired signals are transmitted to the processing unit for interpretation and control command generation.



**Fig 2: BioAmp EEG Headset**

#### ESP8266 Modules

Two ESP8266 microcontroller modules are employed to establish wireless communication within the system.

- **ESP8266 (Unit 1):** Receives EEG data from the BioAmp headset, processes the signals, and transmits control commands wirelessly.
- **ESP8266 (Unit 2):** Receives commands from Unit 1 and controls the motor driver for mobility execution.

#### DC Motors and Chassis

DC motors are used to drive the wheels of the mobility platform. The motors receive control signals from the motor driver to execute movement commands. The chassis acts as the mechanical base that supports all system components and ensures stability during operation.

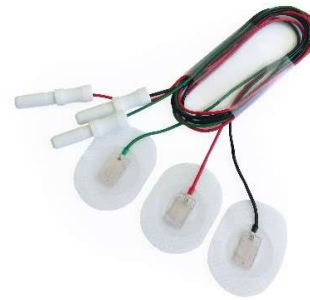


**Fig 3: Chassis**

#### Gel Electrodes

Gel electrodes are wet-type electrodes used for EEG signal acquisition. Conductive gel is applied between the electrode and the scalp to reduce

impedance and improve signal quality. This enhances the accuracy of brainwave detection.



**Fig 4 Gel Electrodes**

#### 3.2.7 Bluetooth Joystick (Manual Override)

A Bluetooth joystick is incorporated as a backup control mechanism. In case EEG-based control becomes unavailable, the joystick allows manual operation by the user or caregiver, ensuring system reliability.

#### Software Tools and Platforms

##### Arduino IDE

The Arduino Integrated Development Environment (IDE) is used to develop and upload firmware to both ESP8266 modules. It handles signal processing, communication, and control logic implementation.



**Fig 5 Arduino IDE**

##### 3.3.2 MATLAB

MATLAB is used for offline analysis and visualization of EEG signals during development. It assists in identifying alpha and beta wave patterns and optimizing signal processing parameters.



**Fig 6: MATLAB Interface**

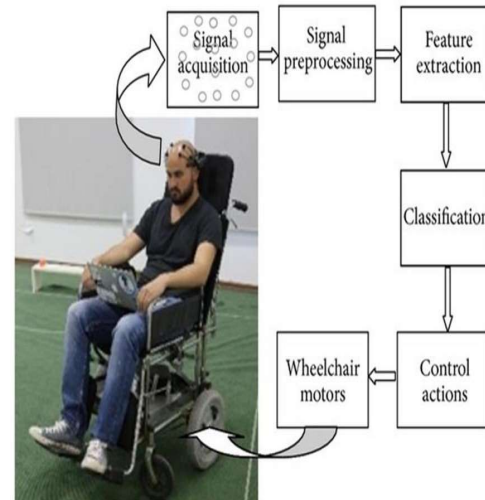
#### NeuroMotion – Brain Wave-Based Mobility System

NeuroMotion is a hands-free assistive mobility system developed to support individuals with severe motor disabilities. The system utilizes a non-invasive electroencephalography (EEG) headset to capture brainwave activity, specifically alpha (8–13

Hz) and beta (13–30 Hz) frequency bands, which are commonly associated with relaxation, concentration, and motor intention. These signals are processed in real time and translated into control commands that drive a mobile platform, allowing users to navigate without relying on physical interaction. By eliminating the need for manual controls, the system provides an intuitive and accessible solution for individuals with limited mobility. Directional navigation within NeuroMotion is achieved through a gyroscope sensor that detects head movements. Tilting the head to the left or right enables steering, thereby providing a natural and responsive method for directional control. To ensure operational safety, the system incorporates a triple eye-blink detection mechanism that immediately stops the platform when triggered. This safety feature minimizes the risk of unintended movement and enhances user confidence during daily use. Wireless communication between the EEG headset and the mobility chassis is facilitated by dual ESP8266 microcontrollers, allowing real-time data transfer without the need for a computer interface. Once configured, the system operates as a portable standalone unit. Additionally, a Bluetooth joystick is integrated as a manual override option, enabling caregivers or users to control the system in situations where EEG signals are weak or unavailable. The overall design emphasizes affordability, portability, and scalability, making NeuroMotion suitable for home environments, hospitals, and rehabilitation centers.

#### Signal-to-Motion Working Model

The NeuroMotion system operates by converting brain signals into motion through a structured signal-processing pipeline. The process begins with signal acquisition, where EEG electrodes placed on the user's scalp detect electrical activity generated by brain functions. These raw signals primarily include alpha and beta waves, which reflect mental states related to attention and intentional movement. Since EEG signals are inherently weak and susceptible to interference, the captured data undergoes preprocessing to remove noise and artifacts caused by eye movements, muscle activity, and environmental electrical disturbances. Filtering and amplification techniques are applied at this stage to improve signal clarity and reliability.



**Fig 7: Architecture of Brain-Controlled Mobility System**

Following preprocessing, the system performs feature extraction to identify meaningful characteristics within the EEG signals. Parameters such as frequency components, amplitude variations, and energy distribution are analyzed to determine patterns corresponding to user intent. Techniques like Fast Fourier Transform (FFT) or similar frequency-domain methods may be used to isolate relevant features. The extracted features are then passed to a classification stage, where decision logic interprets the user's mental state. This stage determines whether the user intends to move forward, turn, or stop. Based on the classification output, control commands are generated and transmitted to the motor driver circuit. The motor driver then activates the DC motors attached to the mobility chassis, producing the desired movement. Through this sequence—acquisition, preprocessing, feature extraction, classification, and actuation—the system effectively translates brain activity into physical motion, enabling hands-free navigation.

#### Working Methodology

The working methodology of the NeuroMotion system integrates brain signal interpretation with head-motion-based navigation to enable real-time assistive mobility. The operation begins with a non-invasive EEG headset positioned on the user's scalp to capture electrical signals generated by neural activity. The BioAmp module amplifies these signals and applies basic filtering to remove unwanted noise. The processed signals are then analyzed to identify alpha and beta wave patterns associated with attention and motor intent. Feature extraction techniques evaluate frequency content and amplitude variations to determine meaningful command indicators.

Simultaneously, a gyroscope sensor mounted on the wearable setup detects head orientation and tilt. These measurements provide an additional control input, allowing users to steer the platform

intuitively. For example, tilting the head forward may correspond to forward movement, while left or right tilts determine turning directions. Both EEG-based commands and gyroscope data are processed by a central microcontroller, such as an ESP8266, which integrates the inputs and generates appropriate motor control signals. These signals are transmitted to the motor driver circuit, which controls the rotation of the DC motors attached to the mobility chassis.

### Results

The NeuroMotion system was implemented and evaluated under multiple simulated operating conditions to assess its capability in detecting brainwave activity and translating it into real-time mobility commands. During system initialization, all hardware modules—including the EEG headset, ESP8266 microcontrollers, gyroscope sensor, and motor driver—were successfully powered and synchronized. The serial interface confirmed operational readiness, indicating that communication between the processing and control units was established correctly. This initial validation ensured that the integrated hardware architecture functioned as intended before further testing. Experimental observations demonstrated that the EEG headset was able to capture alpha and beta brainwave patterns with acceptable consistency. When alpha wave activity became dominant, the system interpreted the signal as a forward movement command, resulting in smooth motion of the mobility platform. Conversely, increased beta wave activity was mapped to a stop condition, and the system halted the motors accordingly. Directional control using head tilt was evaluated through the MPU6050 gyroscope sensor.

The sensor accurately detected left and right head movements, enabling intuitive steering of the mobility platform. The system successfully translated these orientation changes into corresponding motor commands. Wireless communication between the two ESP8266 modules functioned without noticeable latency, confirming stable data transfer between the wearable EEG unit and the mobile chassis. The system operated independently without requiring a continuous computer connection, validating its standalone capability. In scenarios where EEG signals were weak or temporarily unavailable, the Bluetooth joystick override allowed manual control of the platform. This fallback mechanism ensured uninterrupted operation and improved system reliability. The collected EEG and electrooculography (EOG) data were visualized to analyze signal characteristics. The waveform plots obtained from frontal electrode positions showed distinct peaks corresponding to voluntary eye-blink events. The synchronized patterns across multiple channels confirmed reliable blink detection. These signal characteristics were essential for implementing the triple eye-blink emergency stop feature. Additionally, the hardware prototype consisting of a four-wheeled chassis integrated with an L298N motor driver and ESP8266 controller demonstrated stable mobility. The wireless commands transmitted from the wearable unit were correctly interpreted, allowing forward motion, directional turns, and stopping actions. The overall hardware setup validated the feasibility of translating brainwave signals into real-world mobility control.

Collected Brain Wave Data

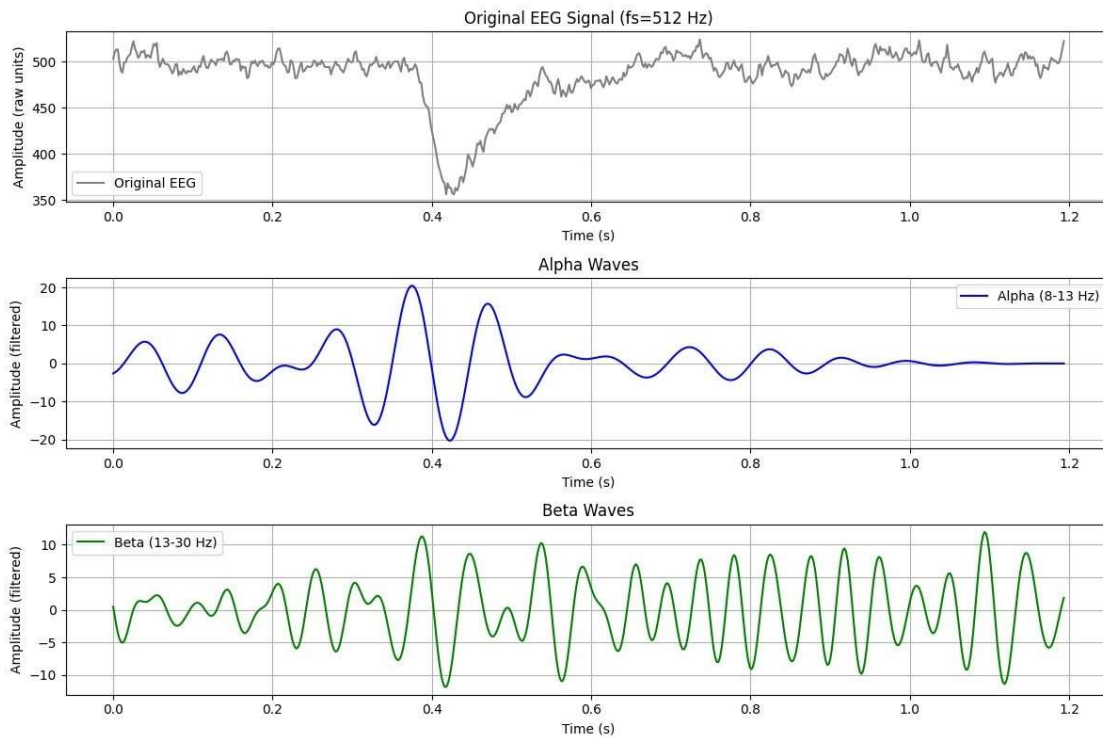
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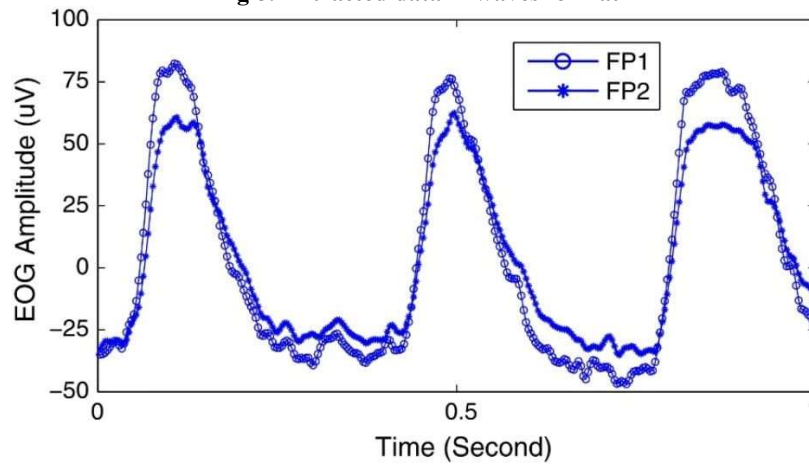
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**Fig 8: Extracted data in waves format**



**Fig 9: Triple Eye Blinking**

**Conclusion**

The NeuroMotion system demonstrates the practical application of brain-computer interface technology for enabling hands-free mobility in individuals with severe motor impairments. By utilizing non-invasive EEG signals—particularly alpha and beta frequency bands—and combining them with head-motion detection through a gyroscope sensor, the system effectively interprets user intent and converts it into movement commands. The implementation of dual ESP8266 microcontrollers enabled reliable wireless communication between the wearable EEG unit and the mobility platform, eliminating dependence on a continuous computer interface.

This design improved portability and allowed the system to function as a standalone assistive solution. Safety and reliability were enhanced through the integration of a triple eye-blink emergency stop mechanism and a Bluetooth joystick override. These features ensured that the system remained controllable even under uncertain signal conditions. The modular hardware architecture and use of open-source development tools further contributed to flexibility and ease of replication. Experimental evaluation confirmed that the prototype successfully provided real-time navigation based on brainwave input and head movements. Beyond technical functionality, the system promotes independence

and improves quality of life for users by restoring a degree of autonomous mobility. The NeuroMotion project highlights the interdisciplinary nature of assistive technology by combining neuroscience, embedded systems, and wireless communication into a unified solution. Overall, the developed system represents a meaningful step toward accessible, intelligent mobility assistance driven by cognitive input.

#### Future Scope

Although the NeuroMotion prototype demonstrated effective performance, several enhancements can further improve its capabilities. Future work may involve integrating the system with smart healthcare platforms to enable remote monitoring of EEG signals and system usage data by caregivers or medical professionals. Incorporating machine learning or deep learning techniques for brain signal classification could significantly improve accuracy and allow recognition of more complex commands. Emotion-aware adaptive control may also be explored, enabling the system to respond dynamically to user mental states such as stress or relaxation.

Additional improvements could include the development of a multimodal interface combining EEG input with voice commands, eye tracking, or gesture recognition for increased flexibility. A dedicated mobile application and cloud-based dashboard could provide real-time visualization of signals, battery status, and movement logs. Hardware optimization through compact and ergonomic redesign would enhance user comfort during long-term use. The inclusion of sensors such as ultrasonic, infrared, or LiDAR could enable semi-autonomous navigation with obstacle detection and avoidance. Furthermore, the architecture of NeuroMotion can be extended beyond mobility systems to applications such as robotic arm control, smart home automation, and remote robotic operations. These advancements would transform the system into a more intelligent and adaptive assistive platform for a wider range of users and environments.

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