ROBOTICS TECHNOLOGY FOR DIFFERENTLY ABLED WARRIORS - HUMANS TO CONTROL USING BRAIN WAVES

A PROJECT REPORT

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ELECTRICAL AND ELECTRONICS ENGINEERING

SCHOOL OF CSE/ISE & ENGINEERING

Under the Guidance of

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PRESIDENCY UNIVERSITY

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This is to certify that the Project report **"ROBOTICS TECHNOLOGY FOR DIFFERENTLY ABLED WARRIORS - HUMANS TO CONTROL USING BRAIN WAVES"** being submitted by "MANJUNATH A C (20211CAI0124), PRAJWAL KANTHAN (20211CAI0075) RAGHU M (20221LEE0007), K TUNISH (20221LEE0003), CHINTHA MANJUNATH (20221LEE0002)'' in partial fulfillment of the requirement for the award of the degree of BACHELOR of TECHNOLOGY in COMPUTER SCIENCE ENGINEERING is a Bonafide work carried out under my supervision.

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ABSTRACT

Advancements in robotics and assistive technology are revolutionizing mobility for individuals with physical disabilities, enabling greater independence and autonomy. This project introduces a mind-controlled wheelchair that uses brainwave signals to provide intuitive and effortless control. The system leverages an EEG kit to capture beta waves (13–30 Hz), which are closely associated with motor functions, and processes these signals to perform basic movements like moving forward, backward, and stopping.

At the core of the system is an ESP32 AI Thinker board with a powerful XTENSA processor, responsible for interpreting brain signals and managing motor control through Pulse Width Modulation (PWM). A Buck-Boost converter ensures stable and efficient power delivery, even when the battery charge fluctuates, while an Analog-to-Digital Converter (ADC) enables precise signal processing and motor responsiveness.

Safety and user convenience are key aspects of the design. An emergency stop button allows for immediate halting of the wheelchair if needed, and a mobile app offers a manual override option for added flexibility. By integrating cutting-edge neurology, electronics, and robotics, this system aims to empower users with a simple, reliable, and intuitive way to regain their mobility and navigate their surroundings with confidence.

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CHAPTER 1

INTRODUCTION

1.1 Research gap

1.1.1 Title: EEG-Based Brain-Controlled Mobile Robots: A Survey

Summary of the Document:

This document is a comprehensive survey on EEG-based brain-controlled mobile robots designed to help individuals with disabilities regain mobility. It explores different system designs, focusing on two primary modes of operation: direct control using brain-computer interfaces (BCIs) and shared control systems where humans and robots work together. The review highlights critical techniques, performance evaluation methods, and challenges in making these robots more practical and effective.

Keywords: Brain-controlled robots, EEG signals, Brain-Computer Interface (BCI), Neuro-technology, Machine learning.

Conclusion:

EEG-based brain-controlled mobile robots are an exciting step forward in enabling individuals with severe mobility challenges to regain independence and improve their quality of life. Significant advancements in control systems, shared autonomy, and safety have laid a strong foundation, but practical deployment still faces hurdles like improving BCI robustness, user adaptability, and cost-effectiveness.

Future Extensions:

- Future research could focus on developing hybrid BCIs that combine multiple brain signals for enhanced accuracy and usability.
- Incorporating advanced artificial intelligence for predictive control and adaptive learning will further improve performance.
- Additionally, creating lightweight, cost-effective designs and conducting real-world testing with diverse user groups can help bridge the gap between research and everyday applications.

Component	Description	Function
EG Headset	The EEG (Electroencephalography) headset is a device that captures electrical activity from the brain through electrodes placed on the scalp. It typically includes sensors that detect and record brain wave patterns, including those related to mental states such as concentration, relaxation, or intent.	The EEG headset is used to monitor the brain signals of the user. It translates these signals into control commands for the system, allowing the user to control devices such as a wheelchair based on their brain activity.
Arduino Uno/STM32	The Arduino Uno is a microcontroller-based development board, while the STM32 is a family of microcontroller ICs from STMicroelectronics. Both are commonly used for embedded systems and robotics	The Arduino Uno or STM32 is responsible for processing the signals received from the EEG headset and translating them into usable commands. It acts as the central controller that processes inputs (brain signals) and sends appropriate commands to the wheelchair's motors and feedback system, ensuring proper movement control .
Feedback Sensor	Feedback sensors are devices that provide real-time data about the wheelchair's movement, position, and other parameters (e.g., velocity, tilt angle). These sensors can be encoders, gyroscopes, accelerometers, or force sensors, depending on the type of feedback needed	The feedback sensor monitors the position and movement of the wheelchair and provides feedback to the microcontroller. This data allows the system to adjust the motor drive’s actions to ensure accurate and stable movement of the wheelchair. It can also be used to prevent obstacles or unintended movements by continuously assessing the current state of the wheelchair.
Wheel Chair	A motorized wheelchair is a chair equipped with an electric motor that helps in moving the chair forward, backward, or turning. It is designed for people with limited mobility to provide easier transportation and mobility	It is controlled by the brain signals processed by the EEG headset, which are translated into actions by the microcontroller. The wheelchair’s movement is powered by motors that are driven based on the processed brain signals or other inputs

		like manual controls .
Motor Drive	The motor drive system consists of electric motors and a motor controller. The motors provide the movement for the wheelchair's wheels, while the controller regulates their speed and direction.	The motor drive receives commands from the microcontroller to actuate the motors of the wheelchair. Based on the input from the EEG headset, the motor drive adjusts the speed and direction of the wheelchair, allowing the user to control the chair's movements through their brain activity. The motor drive also responds to feedback from sensors, ensuring smooth and responsive operation of the wheelchair

Table 1.1 Overview of Brain-Computer Interface (BCI) Technologies

1.1.2 Title: EEG-Based Mobile Robot Control through an Adaptive Brain–Robot Interface

Summary of the Document:

The paper presents a low-cost and efficient **eyeball motion-controlled wheelchair** designed for individuals with mobility impairments. Utilizing an infrared (IR) sensor-based eye tracking system, the wheelchair is operated by detecting eye gaze directions (left, right, forward) and intentional blinks. The signals are processed using a PIC18F452 microcontroller, enabling wheelchair movement with minimal calibration and maintenance requirements. This approach addresses challenges of affordability and usability found in traditional assistive technologies, such as sip-and-puff systems or advanced EEG-based control devices. Experimental trials demonstrated over 94% accuracy, validating the system's reliability.

Keywords: Eye Tracking Technology, Infrared (IR) Sensors, Intelligent Wheelchair, Assistive Technology, Mobility Solutions, Rehabilitation Systems.

Conclusion:

The eyeball motion-controlled wheelchair offers an innovative solution for enhancing the independence and mobility of differently-abled individuals. With a straightforward design, high reliability, and affordability, the system bridges gaps left by current assistive technologies. The experimental results showcase its viability for real-world applications, setting the groundwork for improving the quality of life for its users.

Future Extensions:

- **Vehicle Automation:** With advancements, the eye-tracking system could be used for steering and controlling vehicles.
- **Wireless Control:** Adding radio frequency (RF) communication or Bluetooth modules could enable remote operation of various devices.
- **Advanced Gesture Recognition:** Enhancements could include identifying more complex eye gestures or combining eye-tracking data with other biometrics for nuanced control.
- **Multi-user Configurations:** Implementing user profiles to cater to different needs, such as sensitivity adjustments based on the user's eye movement patterns.

1.1.3 Title: Internet of Robotic Things: Concept, Technologies, and Challenges

Summary of the Document:

This paper explores the Internet of Robotic Things (IoRT), a cutting-edge idea that blends robotics, cloud computing, and the Internet of Things (IoT). IoRT creates a connected ecosystem where robots can communicate, share resources, and improve their efficiency and functionality. The document discusses its architecture, supporting technologies, potential applications, and the challenges to its broader implementation.

Keywords: Internet of Robotic Things (IoRT), Internet of Things (IoT), Cloud technology, IoT protocols, Artificial intelligence (AI), Cyber-physical systems, Big data integration.

Conclusion:

The IoRT concept is transforming robotics, enabling smarter and more interconnected systems to tackle complex tasks across various fields. By combining IoT and cloud computing, IoRT unlocks new possibilities in automation, but challenges like ensuring security, optimizing performance, and addressing ethical concerns still need attention.

Future Extensions:

- In the future, IoRT can grow with advancements in 5G and edge computing for faster, more reliable robot communication.
- Efforts should prioritize standardizing protocols for interoperability, enhancing AI-driven decision-making, and developing clear ethical guidelines to ensure responsible deployment in diverse applications.

1.1.4 Title: Brain-Controlled Robotic Arm System Using EEG Signals with a CNN-BiLSTM Network

Summary of the Document:

This study presents a brain-machine interface (BMI) system that uses brain signals (EEG) to control a robotic arm in three dimensions. The research involved 15 participants performing movement and imagination tasks. A new deep learning method, the Multi-Directional CNN-BiLSTM Network (MDCBN), was developed to understand and translate these brain signals into commands for controlling the robotic arm. The system successfully completed tasks like picking up objects and drinking, showing promising results in real-time tests.

Keywords: Brain-machine interface (BMI), EEG signals, Robot arm control, Motor imagination, Deep learning. CNN-BiLSTM, Signal decoding.

Conclusion:

This study demonstrates how brain signals can be used to control robotic arms through an advanced deep learning system. The results show that the method is effective and reliable for real-world tasks, paving the way for tools that can help individuals with mobility challenges regain independence.

Future Extensions:

Future work can focus on making the system simpler to use for different people, improving its ability to handle more complex tasks, and integrating additional sensors for better accuracy. Enhancements in real-world testing and adaptability will help make these robotic systems more practical for everyday use.

1.1.5 Title: Eyeball Motion Controlled Wheelchair Using IR Sensors

Summary of the Document:

The paper presents a low-cost and efficient eyeball motion-controlled wheelchair designed for individuals with mobility impairments. Utilizing an infrared (IR) sensor-based eye tracking system, the wheelchair is operated by detecting eye gaze directions (left, right, forward) and intentional blinks. The signals are processed using a PIC18F452 microcontroller, enabling wheelchair movement with minimal calibration and maintenance requirements. This approach addresses challenges of affordability and usability found in traditional assistive technologies, such as sip-and-puff systems or advanced EEG-based control devices. Experimental trials demonstrated over 94% accuracy, validating the system's reliability.

Keywords: Eye Tracking Technology, Infrared (IR) Sensors, Intelligent Wheelchair, Assistive Technology, Mobility Solutions, Rehabilitation Systems.

Conclusion and Future Extensions:

The eyeball motion-controlled wheelchair offers an innovative solution for enhancing the independence and mobility of differently-abled individuals. With a straightforward design, high reliability, and affordability, the system bridges gaps left by current assistive technologies. The experimental results showcase its viability for real-world applications, setting the groundwork for improving the quality of life for its users.

Future Extensions:

- **Home Automation:** The technology could be adapted for controlling appliances such as lights, fans, or TVs through blink patterns or gaze directions.
- **Vehicle Automation:** With advancements, the eye-tracking system could be used for steering and controlling vehicles.
- **Wireless Control:** Adding radio frequency (RF) communication or Bluetooth modules could enable remote operation of various devices.
- **Advanced Gesture Recognition:** Enhancements could include identifying more complex eye gestures or combining eye-tracking data with other biometrics for nuanced control.

1.2 Trends in Disability Rates and Implications for Mobility Solutions

The World Health Organization (WHO) highlights that nearly 15% of the global population lives with some type of disability, with mobility impairments being a leading concern. These disabilities, which may stem from birth defects, chronic illnesses, accidents, or the natural aging process, severely limit an individual's movement and ability to perform basic tasks. The rising number of people experiencing mobility challenges calls attention to the importance of developing better mobility solutions, as current alternatives may not fully meet the diverse needs of individuals with mobility issues.

- **Global Growth in Disability Rates**

According to WHO, over 1 billion people worldwide live with a disability. Of these, 2-4% are affected by severe mobility issues, such as paralysis, muscle weakness, and joint disorders. This percentage has been rising steadily over the past decades. WHO estimates that the disability rate worldwide was approximately 10% during the 1970s and increased to 15% by 2011. The reason for this upward trend in mobility impairments can be linked to numerous factors, such as aging populations, medical advancements leading to greater survival rates post-accident or illness, and better identification and reporting of disabilities globally.

As the population of the world grows older, particularly in countries like those in Europe, North America, and certain parts of Asia, these mobility challenges are expected to escalate. WHO predicts that by 2050, the number of people aged 60 and older will surpass 2.1 billion, with many of these individuals suffering from conditions that limit their movement. Aging leads to an increase in conditions like arthritis, cardiovascular diseases, and neurological disorders, all of which heavily impact mobility. Furthermore, chronic illnesses, such as diabetes and obesity, are becoming more prevalent, and this contributes directly to the rise in disabilities affecting movement.

- **Key Factors Driving the Increase in Disability Rates**

Several core factors are contributing to the increasing number of people with mobility impairments, as identified by World Health Organization:

1. **The Aging Population**: As life expectancy rises globally, the percentage of the elderly population grows. Aging increases the likelihood of developing health issues that impact mobility, including musculoskeletal disorders, joint pain, and balance issues. WHO data shows that 80% of people aged 60 or older will experience at least one form of disability, particularly affecting mobility. As the older population continues to expand, the number of people requiring mobility solutions will significantly increase.
2. **Chronic Health Issues**: The rising rates of chronic diseases such as obesity, diabetes, and heart conditions are major contributors to mobility impairments. Conditions like neuropathy (nerve damage), joint deterioration, and reduced circulation can result from or be exacerbated by these diseases. WHO points out that managing these health problems proactively is essential for curbing their long-term impact on mobility.
3. **Better Medical Survival Rates**: Advances in trauma care and healthcare improvements have meant that more people are surviving major accidents, strokes, and critical illnesses. However, these survivors often have permanent disabilities,

including paralysis, muscle weakness, and cognitive impairments. This growing number of trauma survivors, often living with long-term mobility restrictions, contributes to higher global disability rates.

4. **Lifestyle Changes and Physical Inactivity**: Modern lifestyles, including prolonged periods of sitting and reliance on digital technologies, have led to more sedentary living. WHO underscores that a lack of physical activity is a key contributor to mobility problems, particularly due to issues such as obesity and muscular deterioration. This inactive lifestyle, common in developed nations, makes mobility increasingly difficult, adding to the growing pool of individuals needing assistive technologies.
5. **Healthcare Disparities**: In lower-income countries, lack of access to medical treatment, rehabilitation services, and advanced mobility technologies leads to higher rates of untreated conditions that affect mobility. WHO suggests that a gap in healthcare resources and accessibility contributes significantly to the higher disability rates in these regions. Conversely, in wealthier countries, while mobility aids are available, affordability remains an issue for many, preventing the widespread adoption of necessary assistive technologies.

- **Significance of Rising Need for Mobility Solutions:**

As disability rates continue to increase, there will be escalating demand for innovative, cost-effective mobility solutions to meet the diverse needs of a growing population. There are several important consequences for mobility aids and the way we approach the development and distribution of these solutions:

1. **Expanding Demand for Advanced Mobility Aids**: Traditional aids like wheelchairs and walkers are invaluable but often come with limitations. The need for better mobility solutions goes beyond basic assistance and calls for innovations that enable greater freedom and independence. Current mobility aids may not address the complexities of severe mobility impairments. There is a strong push for smarter and more adaptable solutions to meet the needs of users with a wider range of conditions, from minor impairments to severe disabilities.

2. **Supporting Independence and Self-Sufficiency**: People living with mobility impairments often rely on external support, such as caregivers, to assist in daily activities. Moving forward, it's important to focus on creating devices that not only help individuals move but also empower them to act independently. Reducing dependence on external caregivers while improving an individual's self-sufficiency is a critical aim for future mobility solutions.
3. **Designing Accessible Spaces**: To accommodate the growing number of people with mobility impairments, both mobility aids and the environments in which they are used need to be designed with accessibility in mind. This means rethinking how we approach urban planning, housing, public transportation, and recreational spaces. WHO advocates for universal design principles, which promote accessibility for everyone regardless of age limit. Integrating these ideas into public policies and infrastructure can significantly improve the quality of life for people with mobility challenges.
4. **Making Solutions Affordable**: A critical issue for individuals needing mobility aids is the cost of these devices. Advanced mobility solutions, including motorized wheelchairs and smart mobility devices, can be prohibitively expensive. WHO stresses that the affordability of these tools should be a central focus of future product development and policy-making, to ensure they are accessible to a larger population. Public and private sector initiatives could help make advanced mobility solutions more affordable for people in all socioeconomic backgrounds.
5. **Increasing Awareness and Combating Stigma**: The increasing number of people living with mobility impairments highlights the need for a broader societal shift. Changing the way people perceive mobility challenges is essential for creating an inclusive society. These shifts in societal attitudes will help foster an environment in which people with mobility issues are not only supported but can participate fully in all areas of life, including work, education, and community activities.

1.3 Introduction Robotics Technology

Robotics technology is a branch of engineering and science focused on the design, creation, and use of robots. These robots are machines designed to perform tasks automatically, either independently or with minimal human interaction. Robots come in various forms, from simple mechanical systems used in industries to more sophisticated, highly advanced machines that assist in critical areas such as medical surgery, space exploration, and disaster response. The main goal of robotics is to create devices that can assist humans, enhance their capabilities, or carry out tasks that are too dangerous, repetitive, or complex for people to perform safely or efficiently.

1.3.1 Understanding Robotics Technology

Robotics involves designing and constructing machines, also known as robots, capable of performing specific tasks autonomously. A robot comprises multiple components, including sensors, controllers, actuators, and feedback systems, which together enable it to detect its environment, make decisions, and execute actions based on input it receives from its surroundings. The integration of mechanical, electrical, and computer engineering allows robots to carry out an array of functions, from performing precise surgical operations to constructing buildings or performing household chores. The complexity of these machines can range from simple, task-specific robots to highly intelligent systems capable of learning and adapting to their environment using artificial intelligence.

Advancements in computing, sensor technology, and machine learning have led to the development of robots capable of learning new tasks, performing complex actions, and even interacting with humans in dynamic and meaningful ways. This allows robots to not only assist in physical tasks but also to work autonomously in uncertain or complex environments.

1.3.2 How Robotics Technology Came into Existence

The journey of robotics technology dates back to ancient times, with humans imagining mechanical devices to ease their workload. Ancient civilizations often incorporated automata or self-operating machines in their myths and legends, with stories like that of the Greek giant robot Talos being among the earliest instances of robots in popular culture. In real-world technology, mechanical devices designed for specific purposes began to appear in antiquity. Ancient inventors like Hero of Alexandria created devices that could perform simple tasks like opening temple doors or moving objects using steam, providing the first examples of machinery that mimicked human action.

The term "robot" itself was introduced by Czech writer Karel Čapek in his 1921 play *R.U.R. (Rossum's Universal Robots)*, which depicted humanoid robots capable of performing human-like tasks. This marked the beginning of the public's fascination with robots, even though the machines in Čapek's work were fictional. The idea, however, became a powerful motivator for technological innovation in the 20th century.

Robotics as a modern field began in the 1950s when American engineer George Devol and his partner Joseph Engelberger built the first industrial robot, known as Unimate. This robot was designed to automate tasks on factory production lines, reducing human labor and increasing efficiency. The introduction of Unimate into industrial settings in 1961 signaled the beginning of robots being used in mass production industries.

As the second half of the 20th century saw advances in computers and automation technologies, robots were increasingly utilized across a range of fields beyond manufacturing. The 1980s and 1990s saw acceleration in robotic development, with machines becoming more precise, smarter, and capable of performing a wider variety of complex tasks in industries like healthcare, military, and space exploration. Robots also began to adapt and function autonomously with minimal human supervision through the integration of artificial intelligence.

The ongoing advances in computing, machine learning, and sensory technologies continue to push the boundaries of robotics, paving the way for more sophisticated robots that integrate seamlessly into everyday life and work environments.

1.3.3 Applications of Robotics Technology

Robotics has made significant contributions across a wide variety of fields, enhancing productivity, improving safety, and providing unique solutions to challenging problems. Some notable areas where robotics is actively deployed include:

1. **Manufacturing and Industrial Automation**:

   Robots are widely used in manufacturing for tasks like assembly, packaging, material handling, and welding. In industries such as automobile production, robotic systems allow for quicker production cycles and improved safety by handling heavy or dangerous tasks that were previously performed by humans. The use of robots on assembly lines increases accuracy and efficiency, reducing human errors and allowing for 24/7 operation.

2. **Healthcare and Medicine**:

   In the medical field, robotics technology is used to perform surgeries, diagnose diseases, and assist in rehabilitation. Surgical robots, such as the da Vinci Surgical System, enable doctors to perform minimally invasive operations with precision and accuracy, resulting in smaller incisions and faster recovery for patients. Moreover, robots are used in the development of prosthetics, exoskeletons for mobility assistance, and robotic systems designed for patient care in hospitals.

3. **Space Exploration**:

   Robotics has played a crucial role in space exploration. Rovers like those sent to Mars have helped gather data about the planet's surface, composition, and potential for supporting life. In addition to rovers, robotic arms and machines have been used in space stations, like the International Space Station (ISS), to conduct repairs and handle tasks in zero gravity environments that would be difficult for humans to perform. Robots have enabled space agencies to explore outer space more effectively and with fewer human risks involved.

4. **Agriculture**:

   Robotic technology is transforming agriculture by automating processes like planting, harvesting, and crop monitoring. These systems increase efficiency on farms and reduce the need for manual labor. Robots can also monitor crop health using sensors to detect conditions such as soil moisture levels or disease outbreaks, helping farmers respond more effectively and improve the overall yield of crops.

5. **Domestic and Personal Use**:

   In the home environment, robots like automated vacuum cleaners, lawn mowers, and window cleaners provide convenience, reducing the amount of time and effort needed for routine household chores. Additionally, humanoid robots are designed to serve as personal assistants, offering help with daily activities, managing household tasks, or even providing companionship for elderly people.

6. **Search and Rescue Operations**:

In disaster-stricken areas, robots are used in search and rescue operations to locate survivors in dangerous conditions such as collapsed buildings or areas affected by toxic exposure. Robots can navigate through hazardous environments, handle materials, and gather critical information about the situation without putting human lives at risk.

7. **Defense and Military**:

   In the military, robots are used for tasks such as surveillance, bomb disposal, and reconnaissance. Autonomous drones help gather intelligence over vast areas, while robots handle risky tasks like defusing bombs and patrolling secure areas, thus keeping human personnel safe in high-risk environments.

1.3.4 Benefits and Challenges of Robotics Technology

Benefits of Robotics technology

- **Increased Efficiency**: Robots perform tasks faster and more accurately than humans, boosting productivity and minimizing errors.
- **Improved Safety**: By taking on hazardous tasks, robots help protect human workers from harmful environments, such as toxic gas zones or dangerous machinery.
- **Cost Savings**: Over time, robots can lower costs by reducing the need for human labor and improving the speed and efficiency of operations.
- **Quality Improvement**: Robots can maintain high levels of consistency, ensuring that tasks such as assembly or precision cutting meet exacting standards.

Challenges of Robotics technology

- **Job Displacement**: As robots become more capable, there are concerns about their impact on employment, particularly in industries that heavily rely on manual labor.
- **High Initial Costs**: The design and maintenance of advanced robotic systems can be expensive, presenting financial challenges for some businesses or industries.
- **Complexity and Maintenance**: Developing and maintaining robots is highly technical and requires skilled professionals, creating barriers for organizations without the necessary expertise.
- **Ethical Concerns**: As robots take on more roles in daily life, issues such as

autonomy in decision-making, data privacy, and the moral implications of robot-led tasks have come under increased scrutiny.

1.4 Introduction to Wheelchair

A wheelchair is a transformative mobility device that significantly enhances the quality of life and independence for individuals with physical disabilities or mobility impairments. As a fundamental assistive technology, it provides users with the freedom to move, navigate their surroundings, and engage in everyday activities, whether at home, work, or in public spaces. The invention and evolution of the wheelchair have been central to promoting accessibility, inclusivity, and empowerment for people with diverse physical needs.

Traditionally, wheelchairs were manually operated, requiring the user or a caregiver to propel them. Over time, technological advancements have brought about motorized and smart wheelchairs that are tailored to cater to a wide range of user requirements. These advanced models include electric motors, joystick controls, and innovative features like programmable movement and even brainwave-based control systems. Such enhancements address the needs of individuals with severe motor disabilities who may not have the physical strength or coordination to operate manual or conventional powered wheelchairs. Modern wheelchair designs focus not only on functionality but also on comfort, safety, and adaptability. Features like ergonomic seating, foldable frames, and lightweight materials ensure that wheelchairs are practical and user-friendly. Specialized models are created for various applications, such as sports, off-road travel, or compact designs for urban environments. Furthermore, integrating smart technologies into wheelchairs has enabled the development of systems that allow voice commands, obstacle detection, autonomous navigation, and mind-control mechanisms.

The introduction of brainwave-controlled wheelchairs, such as the one in this project, represents the forefront of assistive technology. These systems use non-invasive methods, such as EEG signals, to interpret the user's intentions based on brain activity and translate them into motion commands. This innovation eliminates the need for physical input, offering new hope to individuals with profound motor impairments.A key focus of wheelchair development is accessibility and user empowerment. Beyond facilitating mobility, modern designs encourage users to participate actively in daily life, reducing dependency on caregivers and fostering a sense of autonomy. As the field continues to advance, wheelchairs are becoming more personalized, intuitive, and integrated with emerging technologies.

This project reflects the culmination of these technological developments, introducing a mind-controlled wheelchair that merges simplicity with cutting-edge innovation. By interpreting brainwave signals and directly controlling motor movements, this wheelchair demonstrates the transformative potential of assistive technology in reshaping the lives of individuals with mobility challenges.

Figure 1.4.1 Evaluation of Wheelchair

CHAPTER 2
OBJECTIVES

2.1 Primary Objective

The primary objective of this project is to design and develop a mind-controlled wheelchair that empowers individuals with severe mobility impairments by using brain-computer interface (BCI) technology. This innovative approach will allow users to control the wheelchair through their brainwaves, thereby eliminating the need for manual controls, buttons, or joystick systems. The goal is to offer a highly accessible, intuitive, and functional mobility solution for those who cannot rely on conventional methods of controlling a wheelchair.

Individuals with conditions such as paralysis or severe motor disabilities often face significant challenges in using traditional wheelchairs. This mind-controlled wheelchair aims to provide a means of moving through physical spaces independently, promoting freedom and dignity. The BCI system will decode the brain signals sent from the user's brain to move the wheelchair based on their thoughts, bypassing traditional manual interfaces. In essence, the wheelchair will respond to the user's mental commands to move forward, backward, turn, or stop, providing them with greater control over their environment.

The key component of the BCI system is the EEG (electroencephalography) headset, which captures electrical signals from the user's brain activity. These signals are then processed and translated into actionable instructions for the wheelchair's motors, allowing for precise control. The aim is to ensure a system that not only improves accessibility for people with severe disabilities but also promotes safety by offering smooth, reliable, and responsive performance in both indoor and outdoor environments.

Ensuring the system is practical and sustainable over time is another important aspect of the primary objective. The wheelchair design must take into account the need for prolonged use, ensuring comfort for the user, easy customization, and low-maintenance operation. Furthermore, the system should be scalable, so that it can reach and support a wider demographic, enhancing the mobility of individuals globally, particularly in areas where more traditional wheelchair solutions may be less accessible or affordable.

2.2 Secondary Objectives

1. **Signal Accuracy and Interpretation**: The secondary objective focuses on improving the accuracy of interpreting the EEG signals that control the wheelchair. Brainwave signals are inherently noisy and accurate signal processing is critical for ensuring that the wheelchair behaves as the user intends. Enhancing the signal decoding algorithms will reduce errors and misinterpretations, leading to smoother and more precise movement. This is important for ensuring a safe experience for the user, particularly in environments that may have obstacles or tight spaces, where quick and correct movement is essential.
2. **Real-Time Performance**: Ensuring real-time responsiveness is essential for the mind-controlled wheelchair to work effectively. The system must have minimal lag between the user's brainwave command and the wheelchair's movement to prevent delayed reactions that could be disorienting or even dangerous. Reducing signal processing latency is a top priority, especially when navigating through complex environments where speed and precision are necessary. The system's quick response to brainwaves will ensure that users can move confidently and independently, even in crowded or busy spaces.
3. **User Comfort**: The comfort of the user, especially considering that the system involves the long-term use of the EEG headset and wheelchair, is another important secondary objective. The EEG headset should be lightweight and ergonomically designed, minimizing discomfort for users who may already be dealing with physical limitations. In addition, the wheelchair should be designed with features that enhance overall user experience, such as adjustable seating, easy-to-use controls, and other comfort-based considerations. Long periods of use

without discomfort or strain will make this system a viable solution for daily mobility.

4. **Cost-Effectiveness**: The development of the mind-controlled wheelchair will focus on affordability while maintaining high-quality performance. By selecting affordable and widely available components for the BCI system, the wheelchair can be produced at a cost-effective price point. This will allow for broader accessibility, particularly for individuals in low-resource settings where traditional mobility aids may be expensive or unavailable. Balancing performance with affordability is critical for the success and scalability of the system, making it a viable solution for a large number of people in need.

The Synergy of Primary and Secondary Objectives

The primary and secondary objectives work together to ensure that the mind-controlled wheelchair addresses the mobility challenges faced by individuals with severe impairments. The primary objective centers on the innovative core concept of a mind-controlled system to restore mobility and independence. The secondary objectives complement this by ensuring that the system is accurate, responsive, comfortable, and accessible.

For instance, by improving signal accuracy and reducing latency, the secondary objectives make the primary objective of independent mobility much more feasible, enabling safe and reliable wheelchair control in a variety of settings. Similarly, enhancing user comfort and focusing on cost-effectiveness ensures that the technology doesn’t just work but works well for a wide range of users, especially those who would benefit most from such a device. Together, these objectives set the foundation for a breakthrough mobility solution that could positively impact the lives of people with severe disabilities worldwide.

CHAPTER 3
LITERATURE REVIEW

3.1 Overview of Robotics in Healthcare

Robotics in healthcare has significantly transformed patient care, focusing on enhancing mobility, rehabilitation, and surgical precision. In particular, robotic wheelchairs have emerged as an essential tool in assisting individuals with physical disabilities. These wheelchairs combine advanced sensors, smart algorithms, and control systems, offering a more adaptable and autonomous mobility solution compared to traditional wheelchairs.

Initially, robots in healthcare were used mainly for surgical purposes, helping in minimally invasive procedures that provided better precision and quicker recovery times. As the field evolved, robotics has expanded to assistive technologies, with robotic wheelchairs being at the forefront. These wheelchairs integrate features such as obstacle detection, autonomous movement, and control through alternative input methods like voice commands or brain-controlled interfaces. As a result, individuals who have limited physical mobility are gaining more independence and can interact more freely in their surroundings.

3.2 Brain-Computer Interface (BCI) Evolution

3.2.1 Brain-Computer Interface (BCI)

A Brain-Computer Interface (BCI), also called a brain-machine interface or neural-controlled interface, is a system that allows people to control machines or devices directly with their brain. It works by picking up the electrical signals produced by the brain and converting them into commands that a computer or machine can understand. For example, BCIs allow a person to move a robotic arm, control a wheelchair, or even type on a computer, all just by thinking. This technology doesn’t require any movement from the body, so it's especially useful for individuals who have lost the ability to move due to injury, illness, or a disability.

There are two main types of BCIs: **invasive** and **non-invasive**. Invasive BCIs involve placing electrodes directly on the brain’s surface, usually through surgery. Non-invasive

BCIs, on the other hand, use sensors that sit on the scalp and read the brain's electrical signals without needing to open the skull. Non-invasive BCIs are much safer and easier to use but often offer less precise control than invasive systems.

3.2.2 Evolution of BCI Technology

The idea of controlling machines with the mind isn't new. In fact, researchers have been exploring this possibility for decades. The development of BCIs began in the 1960s when scientists first demonstrated that it was possible to record brain waves and use them to control simple devices. Over time, as technology advanced, researchers discovered ways to capture more detailed brain activity using electroencephalography (EEG), a method for reading electrical brain signals.

BCI technology started as an experimental field in laboratories and has since become a more practical tool in various areas. One of the most significant advancements came in the 2000s when non-invasive BCI systems became better at capturing brain signals in real-time. These systems allowed people to control simple devices like computer cursors or robotic arms, making BCIs more accessible to people with disabilities.

Today, BCI technology is advancing rapidly. It has moved from basic control systems to more complex applications like helping paralyzed individuals walk with robotic exoskeletons, assist in rehabilitation by retraining the brain after a stroke, and provide communication tools for individuals who cannot speak due to injury or illness.

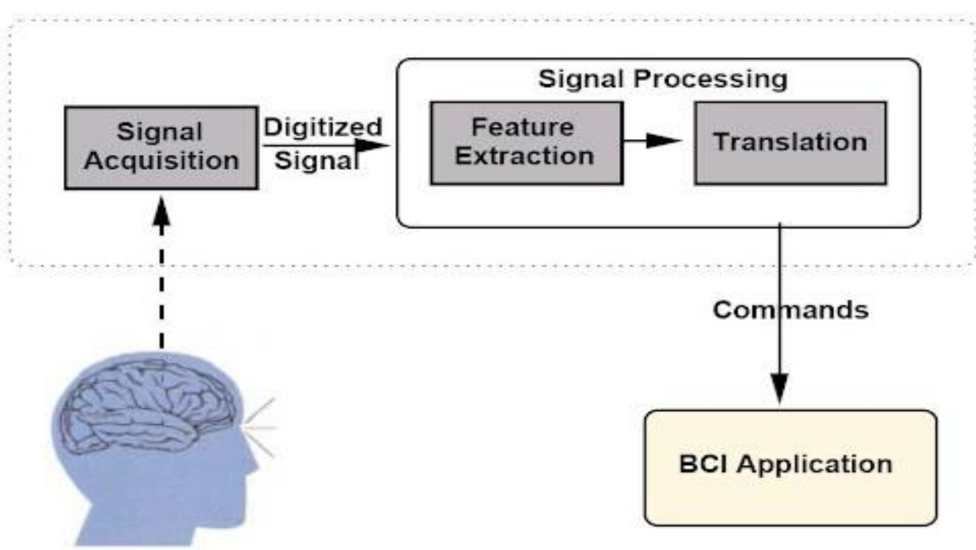
3.2.3 Importance of BCIs

BCIs are vital because they offer the possibility of giving control and independence back to people who have lost it due to neurological diseases, accidents, or conditions such as spinal cord injuries. Here are some of the most important ways BCIs impact lives:

1. **Restoring Movement and Independence**: BCIs allow individuals who have lost their ability to move—whether due to a stroke, spinal injury, or other illnesses—to control devices like wheelchairs, robotic arms, or even exoskeletons that help them walk. This technology gives these individuals the ability to move on their own and regain some independence. For example, people with paralysis can use a BCI to

control a robotic arm to grab and hold objects, something they couldn't do with traditional prosthetics.

2. **Helping with Communication**: For those suffering from diseases like ALS (Amyotrophic Lateral Sclerosis) or who have conditions like Locked-In Syndrome (where the person is awake and aware but unable to move or speak), BCIs can be used to control communication devices. These devices can let people type out messages or interact with others using only their brain activity, providing a way to communicate even when they can't speak or move.
3. **Supporting Rehabilitation**: BCIs are being used to assist in the rehabilitation of people recovering from strokes, brain injuries, or surgeries. When someone has lost movement in parts of their body, BCIs can help them think about moving and "retrain" their brain to regain those movements. For example, someone recovering from a stroke might think about moving their arm, and a robotic system will help them make the movement, which helps rebuild brain connections over time.
4. **Assistive Technology for the Disabled**: People with physical disabilities or injuries often rely on assistive devices to help them go about their day. BCIs are an exciting new tool in this field. They make it possible for people to use their thoughts to control technology. This could include turning on lights, adjusting thermostats, or even using a computer to browse the internet—all through BCI control.



3.2.1 Fig show the working of BCI

3.2.4 Applications of BCIs

Prosthetics and Neuro-prosthetics: BCIs can control prosthetic limbs, allowing individuals who have lost limbs to perform tasks like picking up objects, typing, or using utensils with greater dexterity. The brainwaves of the user help control these prosthetic limbs, providing much more precise movement than traditional mechanical prosthetics.

Communication for Disabled People: BCIs have enabled people with severe physical impairments to communicate. For example, through thought-controlled devices, users can type messages, operate speech-generating systems, or control their environment without speaking.

Stroke Rehabilitation: After a stroke, a person’s brain may need to “retrain” itself to regain lost abilities. BCIs are used to help stimulate brain activity and encourage physical movement in individuals, promoting faster recovery by teaching the brain to reconnect with the body.

Gaming and Virtual Reality (VR): In the gaming world, BCIs are allowing players to control virtual environments simply with their mind. This technology leads to more immersive experiences, where the player's brain activity can control characters, environments, and other game mechanics without the need for external devices like controllers.

Security: In the world of security, BCIs may provide an advanced level of biometric identification, with brainwaves used as a unique identifier for access control systems or secure logins, much more secure than fingerprints or passwords.

Human-Computer Interaction (HCI): BCIs are being explored as a future way for people to interact with computers and digital devices. Users can operate devices just by thinking, replacing conventional input methods like the mouse and keyboard.

3.3 Navigation and Autonomous Systems in Wheelchairs

Navigational technology is another key advancement in modern robotic wheelchairs. Traditional manual or powered wheelchairs require direct user input for movement. However, recent robotic wheelchairs are incorporating autonomous systems equipped with sensors like ultrasonic, infrared, and LiDAR, which help the wheelchair navigate its surroundings safely. These systems detect obstacles and provide real-time feedback to steer the wheelchair, ensuring smoother and safer movement.

In addition to obstacle detection, robotic wheelchairs are becoming more sophisticated by using algorithms that help plan optimal routes, avoid hazards, and adjust to changing environments. For instance, these systems can learn to navigate specific rooms, react to new obstacles, and interact with smart home devices, making the wheelchairs more autonomous over time. By incorporating machine learning and adaptive control, the wheelchairs can adapt to the needs of the user, allowing for more freedom in various environments.

CHAPTER 4
METHODOLOGY

4.1 Problem Analysis

Living with severe physical disabilities, such as paralysis or neurodegenerative disorders, can profoundly impact a person's independence and quality of life. These challenges often limit their ability to interact with the world around them, making simple daily activities arduous and sometimes impossible. While traditional wheelchairs have been invaluable in restoring mobility, they generally require physical interaction through joysticks, switches, or other manual controls. For individuals with limited motor function, these mechanisms may be difficult or even impossible to use, leaving them without a reliable means of mobility.

Traditional wheelchairs also come with their own set of limitations, particularly when navigating complex environments. Tight spaces, uneven terrain, and crowded areas can become overwhelming obstacles, leading to frustration and increasing dependency on caregivers. This dependence affects not only physical mobility but also emotional well-being, diminishing the individual's sense of autonomy and self-esteem.

This project seeks to address these challenges by introducing a mind-controlled wheelchair system that reduces or eliminates the need for manual controls. At the heart of this system lies a Brain-Computer Interface (BCI), a cutting-edge technology that acts as a bridge between the user's thoughts and the wheelchair's movements. By capturing brain signals and translating them into actionable commands, the BCI allows users to control the wheelchair using just their thoughts. Commands such as moving forward, backward, or stopping become intuitive actions, offering an unprecedented level of freedom.

To enable efficient real-time processing of brain signals, the system utilizes an XTENSA processor, known for its high performance and energy efficiency. This processor plays a critical role in the seamless translation of EEG data into motor commands. Its architecture supports the implementation of advanced algorithms, including fuzzy logic, to handle variations in user input and ensure precise control over the wheelchair's movements. The XTENSA processor's ability to process multiple tasks concurrently enables the system to function smoothly, even in dynamic and complex environments.

By removing the necessity for physical interaction, the mind-controlled wheelchair expands possibilities for individuals who might have been excluded from using traditional mobility devices. It provides a sense of empowerment, enabling users to navigate their surroundings with greater ease and confidence. This system is not just a technical solution but a pathway to restoring dignity and independence, enhancing both the physical and emotional well-being of those it serves.

4.2 Research and Development Approach

The research and development of the mind-controlled wheelchair follow a collaborative approach, combining expertise from neurology, robotics, and electronics. This process ensures the creation of an accessible, reliable, and user-friendly mobility solution for individuals with physical challenges. The following outlines the core components of the approach:

Brain-Computer Interface (BCI): The Brain-Computer Interface (BCI) acts as the core of the system, enabling seamless communication between the user and the wheelchair. EEG electrodes placed on the user's scalp capture brainwave patterns, focusing specifically on motor imagery associated with the intention to move. These raw signals are processed using fuzzy logic algorithms to translate the user's mental commands into actionable motor responses such as moving forward, backward, or stopping. The use of fuzzy logic ensures greater adaptability by effectively handling variations in the signals.

Micro-controller Integration: The wheelchair control system is powered by an ESP32 AI Thinker Board and XTENSA processor. These devices form the computational hub, processing EEG data and issuing precise motor control commands. The ESP32 decodes the brain signals in real time using fuzzy logic, while the XTENSA processor converts the commands into motor movements via a PWM modulator. This seamless integration ensures the wheelchair responds promptly to user inputs.

Sensor Integration: To enhance safety, the wheelchair is equipped with ultrasonic sensors that detect obstacles and help the wheelchair navigate complex environments. These sensors enable the system to operate autonomously, avoiding collisions and providing users with a safer experience.

Mobility and Control Mechanisms: The wheelchair features a single motor for its mobility, simplifying the design and reducing maintenance. This motor supports essential movements: stopping, moving forward, and moving backward. Commands are generated from EEG signals processed by fuzzy logic, which adapts to user inputs for consistent performance. For added flexibility, a smartphone-based mobile interface allows manual control, empowering caregivers or users to intervene as needed. This dual control mechanism ensures both autonomy and ease of use.

Safety and User Control: Safety remains a top priority in the wheelchair's design. An emergency stop button is included to allow the user to immediately halt the wheelchair when necessary. The safety helmet offers additional protection, particularly during unexpected interactions or movements. These redundant safety features ensure that users have full control and feel secure while using the system.

Prototyping and Testing: Once the individual components are assembled, a functional prototype is created and tested in real-world environments. Testing focuses on enhancing signal clarity, refining mobility, and validating responsiveness. User feedback is collected to fine-tune the design and improve the system's usability. This iterative process ensures that the final product meets both practical and ergonomic needs.

4.3 Data Collection and Processing:

For the wheelchair to move exactly as the user intends, the brain signals need to be processed almost instantly. This means that the system works continuously, translating the user's thoughts into commands that control the wheelchair in real-time. As the brainwaves are picked up, the system quickly understands what the user wants to do and makes sure the wheelchair responds right away. This quick and effortless communication between the user's mind and the wheelchair makes the entire experience feel natural and intuitive.

EEG Data Capture: The process begins by capturing the user's brain activity through EEG sensors placed on the scalp. These sensors detect specific brainwave frequencies—particularly the alpha and beta waves which are linked to intentions to move. The system then waits for 10 seconds to stabilize, making sure to filter out background noise and obtain a clear reading of the brain activity. Once this is done, the system is ready to process the signals and translate them into meaningful movements for the wheelchair.

Data Processing Algorithms: Once the brainwave data is captured, it doesn't just sit there—it’s immediately processed by advanced algorithms that convert these brain signals into practical commands for the wheelchair. The processing is powered by the **XTENSA processor**, which is known for being fast, efficient, and able to handle these tasks smoothly. Here's how the processing happens step-by-step:

1. **Noise Reduction and Preprocessing**: To get accurate data, the first task is to remove any noise from the signals. This could be interference from nearby electrical devices or random background activity in the brain. The system uses filters to make sure that only the relevant brainwave signals are passed through, ensuring clarity from the start.
2. **Feature Extraction**: After filtering out the noise, the next step is to extract the most important features from the brainwave data—specifically focusing on changes in beta waves, which are linked to the user's intention to move. The XTENSA processor helps identify and separate these important features quickly, enabling fast and accurate processing of the signals.
3. **Fuzzy Logic-Based Classification**: The next part of the process uses **fuzzy logic** algorithms, which are designed to interpret signals that don’t always fall into neat, clear categories. Instead of treating brainwaves as just "on" or "off," fuzzy logic looks at the gray areas—such as how strongly the user is thinking about moving forward, which allows the system to decide how much to move the wheelchair. This makes the wheelchair’s movements smoother and more adaptable.
4. **Real-Time Processing on the XTENSA Processor**: The XTENSA processor is the engine behind the system’s ability to interpret and act on these signals instantly. It runs the fuzzy logic algorithms and makes real-time decisions about how the wheelchair should move, whether it's stopping, moving forward, or changing direction.
5. **Decision Making and Action Execution**: Once the XTENSA processor makes a decision based on the brain signals, the instructions are sent directly to the wheelchair’s motor. This ensures that the movement happens immediately and with precision, providing a smooth user experience.

6. **Real-time Feedback and Adjustment**: The system constantly monitors the user's mental state to provide real-time adjustments. If the user becomes distracted or their intention changes, the system can quickly recognize this shift and adapt accordingly. Whether the user wants to stop or change direction, the wheelchair reacts instantly, giving a truly responsive experience.

Integrated Control Mechanism: To ensure that the user always has control, the wheelchair integrates both mind control and manual control through the mobile app. When the brain signals are strong and clear, the wheelchair will follow the user's thoughts. If the signals aren't as clear, or if the user prefers, they can simply use the app to control the wheelchair. Plus, with the built-in emergency stop button, the user always has the ability to halt the wheelchair's movement immediately, giving an extra layer of reassurance.

CHAPTER 5
SYSTEM DESIGN

5.1 Overview of the System

The mind-controlled wheelchair designed for this project aims to provide individuals with severe physical disabilities greater mobility and independence by harnessing Brain-Computer Interface (BCI) technology**.** It enables the user to control a wheelchair via brain signals, without relying on physical controls like joysticks or switches. The system integrates multiple components to facilitate smooth operation and safety, including **EEG sensors** for signal acquisition, a microcontroller (ESP32 AI Thinker board), a PWM modulator for motor control, and various safety features such as an emergency stop button and a safety helmet. The user interface can either be controlled through mind signals or an optional mobile interface that provides more user control. The basic movements of the wheelchair (stop, forward, backward) are determined by the signals captured and processed from the brain activity.

The critical components of the system are connected and work in coordination as follows:

EEG Kit

ESP32 AI Thinker Board

PWM Modulator

Motor

Analog to Digital Converter

Battery

Micro-controller

5.2 Block Diagram:

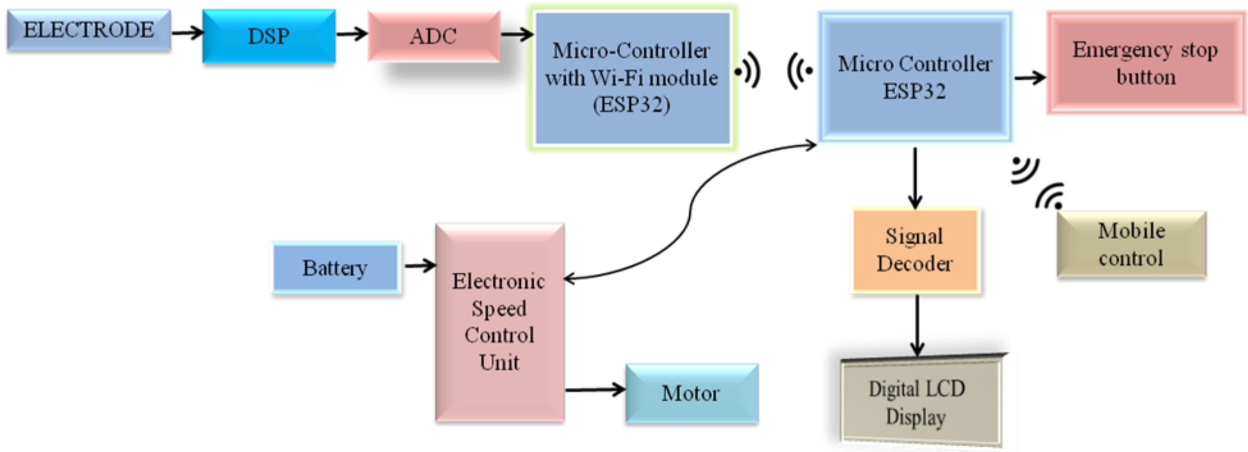


Figure 5.2 Block diagram of Brain controlled Wheelchair

1. **Electrode:**

The **electrode** is the first point of contact between the brain and the system. Electrodes are placed on the user's scalp to detect the **electrical activity** generated by neurons in the brain. This activity is usually very weak and needs to be amplified for further processing. The primary function of the electrodes is to convert the brain's electrical signals, also called **Electroencephalography (EEG)** signals, into a readable format that can be processed by the system.

2. **EEG:**

The **EEG** block represents the raw signals captured from the user's brain by the electrodes. EEG signals consist of a mixture of different types of brain activity, such as motor imagery, attention, or cognitive states. However, these signals often come with noise, such as electrical interference from muscle movements, eye blinks, and environmental factors. The EEG data contains essential information that is later processed to interpret the user's intentions and commands.

3. **DSP (Digital Signal Processor):**

Once the EEG signals are received, they are fed into the **Digital Signal Processor (DSP)**, a specialized processor optimized for real-time signal processing tasks. The DSP performs several essential functions:

Amplification: Since the raw EEG signals are weak, the DSP boosts their strength to a level that is suitable for processing.

Filtering: The DSP filters out unwanted signals (like muscle or eye movement noise) and keeps only the relevant brain activity that corresponds to the user's intentions.

Feature Extraction: The DSP extracts specific features from the EEG signals, such as variations in brainwave frequency or amplitude, which are associated with the actions the user intends to take (e.g., moving the wheelchair forward or turning left).

4. **ADC (Analog-to-Digital Converter):**

The EEG signals are initially in an analog format, but for processing in digital systems, they need to be converted into a digital format. This is done by the Analog-to-Digital Converter **(ADC)**. The ADC converts the analog EEG signals into digital values that can be further processed by the microcontroller or other digital systems in the system.

5. **Micro-Controller with Wi-Fi (ESP32):**

The **micro-controller** (in this case, the **ESP32 microcontroller**) is the central processing unit of the system. Once the analog signals are converted into digital values, the microcontroller receives and processes them. It interprets the extracted features from the EEG data to determine the user’s intended action, such as moving forward, turning left or right, or stopping.

The **Wi-Fi** capability of the microcontroller allows for wireless communication with other components, like remote devices or centralized control systems. In addition, the microcontroller handles communication with the electronic speed control unit and the emergency stop mechanism. It ensures that the system reacts accurately to the user’s brainwaves in real-time.

6. **Signal Decoder:**

The **signal decoder** block is responsible for translating the brain activity patterns detected by the microcontroller into specific actions for the wheelchair. For example, if the user imagines moving their right hand, the signal decoder interprets this change in brainwave activity as a command to turn the wheelchair to the right. This step involves decoding the features extracted from the EEG signal and determining how those brainwave changes translate into motor control commands for the wheelchair.

7. **Electronic Speed Control Unit:**

The electronic speed control unit receives commands from the microcontroller about the desired speed and direction of the wheelchair. This unit adjusts the speed of the motor that move the wheelchair, allowing the user to control forward, backward, or turning movements based on their brainwave signals. The electronic speed control unit regulates motor operation to match the desired movement.

8. Emergency Stop:

An important safety mechanism, the emergency stop allows the user (or a caregiver) to immediately halt the operation of the wheelchair in an emergency situation. This ensures that if something goes wrong, the wheelchair can be quickly stopped to avoid accidents or injury.

9. Digital LCD:

The Digital LCD is a key component that provides real-time feedback on the wheelchair's operations. It helps users stay informed about the source of control and the specific commands being executed.

The LCD will display the source of control, which could be:

Web Interface: When the user is controlling the wheelchair through the mobile web interface, the display will show a message such as "Control: Web" along with the specific action being taken, such as "Forward," "Backward," or "Stop." Sensor (EEG Brainwaves)**:** When control is happening via the EEG sensor (Brainwaves), the LCD will show a message like "Control: Sensor."

For the specific actions being carried out, the LCD will display:

Forward: When the wheelchair is commanded to move forward, the display will read: "Web: Forward" or "Sensor: Forward" depending on the control method.

Backward: If the command is to move backward, the display will show: "Web: Backward" **or** "Sensor: Backward."

Stop: When the wheelchair stops, whether due to the web interface or the EEG sensor control, the LCD will display: **"Web: Stop"** or **"Sensor: Stop."**

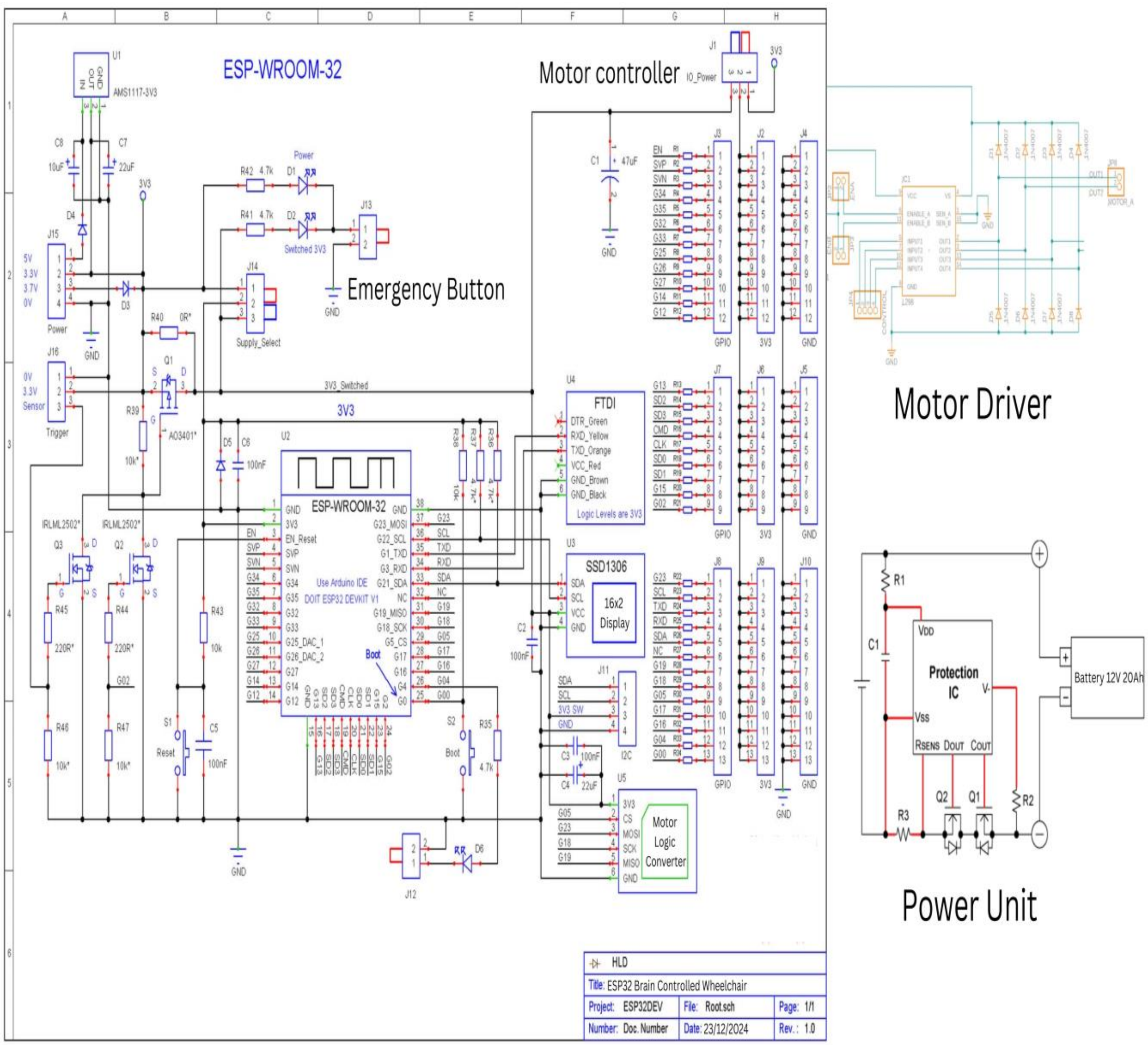
10.Motor:

The **motor** (or motors) are responsible for providing movement to the wheelchair. When the signals from the user, processed by the microcontroller and decoded by the signal decoder, indicate a specific action (e.g., moving forward or turning), the motor(s) receive these instructions and generate the corresponding motion to propel the wheelchair.

CHAPTER 6
SYSTEM HARDWARE DEVELOPMENTS

6.1 System Wiring Layout:

The circuit diagram illustrates the electrical connections among all the components of the system. Each element, including the EEG kit, microcontroller (ESP32), motor driver, and battery pack, is connected to ensure a smooth flow of information and power.



6.1 Electrical wiring layout of wheelchair setup

6.1.1 Control and Signal Processing

1. **ESP32 Microcontroller (ESP-WROOM-32)**

Specifications:

Processor: A dual-core Xtensa LX6 32-bit processor running at 240 MHz for high-speed operations.

Built-in Wi-Fi and Bluetooth: Ensures wireless communication for mobile app control.

GPIO Pins: Multiple pins for interfacing with peripheral devices.

Analog-to-Digital Converter (ADC): Built-in channels for processing brain signals from EEG.

PWM Signal Generation: Enables precise speed and direction control for the motor.

Role in the System:

The ESP32 serves as the brain of the wheelchair, receiving digitized EEG signals, decoding them into commands (e.g., forward, stop), and controlling the motor driver accordingly. It communicates with the LCD display provides real-time feedback, showing the actions taken based on sensor input or commands sent manually via the mobile app.

2. **EEG Signal Acquisition Chain**

Components and Flow:

Electrodes: Capture brainwave activity (Alpha, Beta, etc.) from the user’s scalp. It is Made from conductive and skin-safe material to ensure reliability and comfort.

Digital Signal Processor (DSP): Preprocesses and filters the EEG data, isolating usable frequencies. It provides smooth, noise-free signals for the ADC.

ADC (Analog-to-Digital Converter): Converts the continuous analog signals from the DSP into discrete digital values. These digital signals are fed into the ESP32 for further processing.

3. **Motor Controller and Driver**

Components:

PWM-Controlled Motor Driver: This part reads signals from the ESP32 and adjusts the speed and direction of the motor. It uses MOSFETs to handle high currents and keep things cool, even when the motor is working hard. It's designed to stay reliable under different conditions and ensure smooth operation.

500W DC Motor with Gearbox: This motor gives enough power to move the wheelchair smoothly, even on hills or inclines. It runs on a 24V system, providing solid performance for everyday use. The gearbox helps strike the right balance between speed and torque, making sure the movement feels steady and controlled.

Role in the System:

It turns the commands from the user (like "go forward," "reverse," "stop") into actual movement of the wheelchair. The speed and direction are controlled through the PWM signals, which reflect the user's intentions, allowing the wheelchair to respond quickly and accurately. This ensures the wheelchair behaves exactly as expected, making it easy for users to navigate with minimal effort.

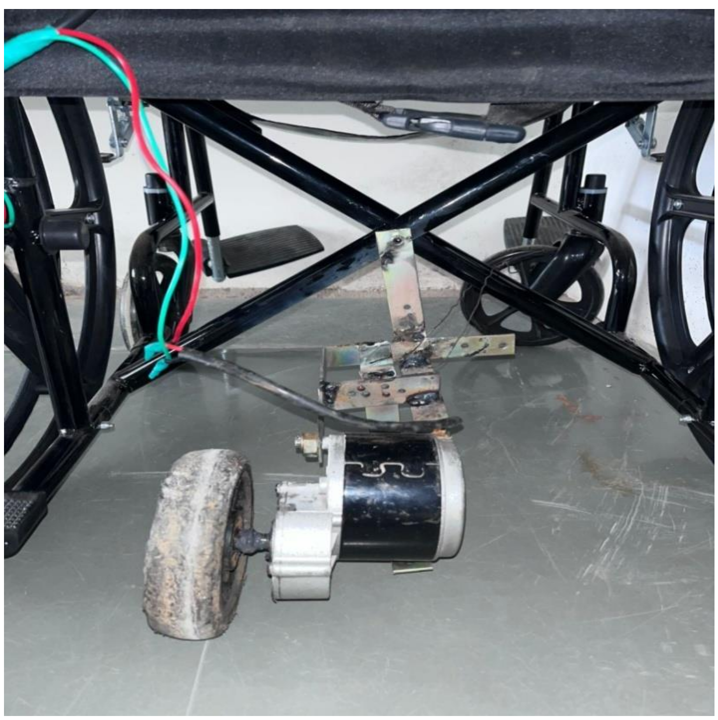


Figure 6.1.1 Integration of Motor with Wheelchair setup

4. **Digital LCD Display**

Specifications: I2C interface to minimize GPIO usage on the ESP32. Displays critical information say current commands (e.g., “Moving Forward”).

Role in the System:

It offers real-time feedback to the user, ensuring transparency of operations.

5. **Supporting Electronics**

Key Components:

Relay Units: Act as switches for managing motor power under control signals from the ESP32.

MOSFETs: Handle high-current switching in the motor driver, ensuring efficient operation with minimal heat generation.

Signal Decoder: Converts high-level commands into specific motor control instructions.

6.1.2 Power Management and Safety

1. **Power Management System**

Components:

Lithium Polymer (LiPo) Battery

Voltage: 12V DC (Direct Current): This is the type of electricity that flows in one consistent direction, perfect for powering everything from the motor to the control system.

Capacity: 12,000mAh, meaning the battery will last a long time between charges. It ensures you can use the wheelchair for a good stretch before needing to recharge.

80C Discharge Rate: This means the battery can handle heavy usage, like when the motor needs more power to climb a hill or carry a heavy load.

Role: Powers both the motor and the electronics in the wheelchair, keeping everything running smoothly for the user.

Voltage Regulators: These little devices make sure that the battery's 12V DC power is stepped down to lower, safe levels like 5V DC, which is needed for the sensitive components like the ESP32.

2. **Protection IC:** Think of this as a safety net for the battery. It prevents problems like overcharging, over-discharging, or short circuits that could damage the battery or cause safety issues. This ensures the battery stays healthy and performs well for a long time.

3. **Emergency Stop Button**

Purpose: Provides immediate manual intervention to halt the wheelchair in an emergency.

How It Works: A latching switch disconnects the motor driver and power supply when pressed, cutting all motion instantly.

Figure 6.1.2 shows the hardware Wheelchair model

CHAPTER 7
SOFTWARE DESIGN AND IMPLEMENTATION

7.1 Signal Processing Algorithm

The signal processing algorithm lies at the core of the mind-controlled wheelchair, serving as the interface that transforms a user’s thoughts into precise movement commands. The system relies on an EEG kit to capture the brain's electrical activity through electrodes strategically placed on the scalp. These signals, while highly informative, are often weak and susceptible to various forms of noise, including muscle movements, eye blinks, and environmental interference. Therefore, processing these signals accurately and efficiently is a critical part of the system’s functionality. The XTENSA processor, embedded within the ESP32 AI Thinker board, provides the computational power to handle this data in real time. Additionally, the inclusion of a buck-boost converter ensures that the power supply remains stable and efficient, safeguarding the system’s performance over extended periods.

Signal Acquisition and Noise Filtering: The process begins with signal acquisition, where the EEG kit detects the brain's electrical activity and converts it into analog signals. These analog signals are then digitized by the XTENSA processor for further processing. Noise in these signals—caused by factors like ambient electrical interference or involuntary muscle actions—is managed using advanced filtering techniques. The filters isolate key brainwave frequency bands, including alpha (8–13 Hz), beta (13–30 Hz), and theta (4–8 Hz), which are closely tied to motor intentions and relaxation states. The XTENSA processor's robust computational capabilities allow it to refine these signals by eliminating irrelevant data while preserving meaningful patterns.

Decoding Brainwaves with Fuzzy Logic*:* Deciphering user intentions from brainwaves is a complex task due to the inherent variability and overlap of the signals. This is where fuzzy logic shines. Unlike conventional binary logic, which demands rigid boundaries, fuzzy logic employs flexible rule-based systems to interpret the nuanced relationships between brainwave patterns. For instance, the system uses predefined fuzzy sets and rules to evaluate brainwave intensity and determine the corresponding action.When beta wave activity surpasses a certain threshold; the system interprets this as the user's intention to move forward. Conversely, when alpha waves dominate, the system understands this as a stop command. The subtle interplay of alpha and theta waves can signify an intention to reverse. Fuzzy logic’s adaptability ensures that even when signal overlaps occur or individual variations in brainwave strength are present, the wheelchair can reliably and intuitively respond to the user’s thoughts.

Translating Thoughts into Movement: Once user intent is decoded, the XTENSA processor generates control signals for the wheelchair’s motor. These signals direct essential movements such as moving forward, stopping, or reversing. During this stage, stable power delivery becomes paramount. The buck-boost converter plays a critical role here, dynamically adjusting the voltage to maintain an optimal supply. For instance, it boosts the voltage when the battery’s charge is low and reduces it when excess voltage is present, thereby protecting the motor and electronic components.

This power regulation not only enhances the system’s reliability but also prolongs the battery life, ensuring smooth operation even in demanding environments. The integration of efficient power management ensures that users experience seamless and uninterrupted functionality, contributing to their confidence in operating the system.

A Robust, User-Centric Design: By combining the computational power of the XTENSA processor with the adaptive nature of fuzzy logic and the energy efficiency provided by the buck-boost converter, this signal processing algorithm ensures a seamless user experience. The system empowers individuals to control their wheelchair using only their thoughts, fostering greater independence and enhancing their quality of life. This innovative approach is a testament to how cutting-edge technologies can converge to meet real-world needs effectively and reliably.

Frequency Band Ranges and Their Roles in Movement Control:

Sl No	**Type**	**Frequency Range**	**Associated State/Action**
01	Gamma	30-100Hz	High cognition, concentration, decision-making
02	Beta	13 Hz - 30 Hz	Active thinking, motor control (forward motion, speed)
03	Alpha	8 Hz - 13 Hz	Relaxed, calm (stop or idle)
04	Theta	4 Hz - 8 Hz	Deep relaxation, light sleep (reverse movement)
05	Delta	0.5 Hz - 4 Hz	Deep sleep, non-responsiveness
06	Mu	8 Hz - 13 Hz	Motor readiness (prep for movement)

Table 01: Types of signals with their frequency and actions.

7.2 EEG Signal Processing Code

The software written to handle EEG signal processing typically involves several stages. First, the system initializes the **EEG kit**, which continuously collects signals from the user. These signals are read via an appropriate interface, typically over Bluetooth or a wired connection. In the system code, the incoming data from the EEG kit is processed and pre-processed, which involves filtering the raw signals to remove interference from non-brainwave activities.

Figure 7.2 Integration of EEG Sensor

7.3 Debugging and Optimization

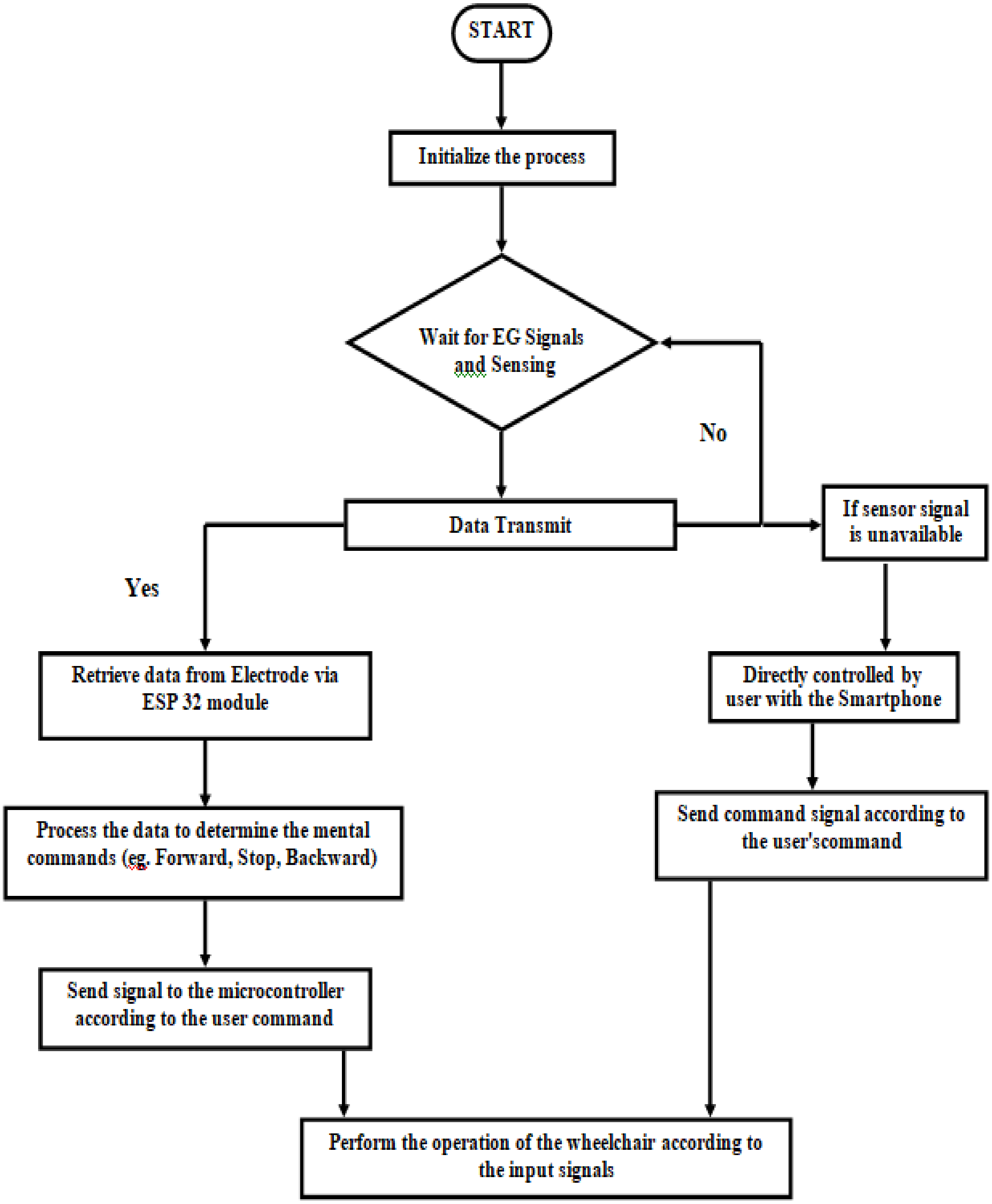
When implementing EEG-based control systems, debugging is a crucial aspect of the process to ensure that the signals are correctly captured and the system responds to the user commands accurately. The **debugging process** begins with verifying the signal acquisition from the EEG kit. If there are irregularities in the EEG signal readings, they can be fine-tuned in the preprocessing phase to ensure that noise is minimized and only meaningful signals are processed.

In addition to debugging the signal capture and classification, the overall system needs to be optimized for real-time performance. This can involve tuning the filtering algorithms, optimizing the classification model, and ensuring low-latency communication between the different modules, such as between the EEG kit and the microcontroller (ESP32 or Arduino). Minimizing any delays in this pipeline ensures that the wheelchair responds promptly to the user's brainwaves.

Another area of optimization is in the **motor control commands**. By ensuring that these commands are processed as efficiently as possible, you can reduce the latency between the user’s brain signal and the wheelchair’s movement. For example, algorithms could be enhanced to run faster on embedded systems, or processing could be offloaded to more capable hardware to improve response time.

Lastly, once the core functionality is implemented, **testing and refinement** play a huge role in ensuring robustness. The system should be repeatedly tested across a range of scenarios (e.g., varying user conditions and EEG noise), and any discrepancies or delays in movement commands should be examined and fixed. After these iterations, you can fine-tune system settings, which will lead to a more accurate and reliable mind-controlled wheelchair. This process of continuous refinement, coupled with performance monitoring, ensures the system works as intended and responds smoothly and reliably to the user's brain signals.

7.4 Flow Chart



CHAPTER 8
INTEGRACTION AND TESTING

8.1 Integration of Hardware and Software

The integration of hardware and software is an important step to make sure that the system works as a cohesive unit. It involves connecting the hardware components, such as the EEG kit, motor, and ESP32 microcontroller, with the software that processes the brain signals and converts them into control commands. In your project, the EEG signals are used to drive the movements of the wheelchair (forward, backward, and stop), so the connection between the EEG system and the control unit must be established and tested.

Initially, during integration, the communication between the EEG system and the microcontroller needs to be checked to ensure that brain signals are being captured and passed to the control unit in real time. The control unit then processes these signals using the pre-written software to classify the movement intent. These commands are then forwarded to the wheelchair's motor to ensure it moves according to the user's brain signal.

Making sure the system operates in real-time is crucial in this phase. If there are delays or errors, troubleshooting steps must be taken to isolate issues, whether in hardware (connections, wiring, or power issues) or in software (signal processing or motor control).

8.2 Test Cases and Scenarios:

To make sure the system is working properly, it's important to test it under different conditions with various test cases. Below are some key testing scenarios:

1. **Basic Signal Command Execution**:
    - The first test case ensures that when a user concentrates on moving forward (or any other command), the wheelchair moves in the correct direction without delays.

   - *What to expect:* The wheelchair should move forward when the EEG signal correctly detects the movement command.
2. **Speed of Movement Response**:
   - This test checks how quickly the wheelchair reacts to changes in EEG signals (such as switching from "stop" to "move forward").
   - *What to expect:* The system should respond to EEG commands almost immediately, with no noticeable delay.
3. **Mobile Control Test**:
   - Test whether the mobile app can control the wheelchair successfully when used to override the EEG control.
   - *What to expect:* The app should allow the user to move the wheelchair in any direction and override EEG control if necessary.
4. **Battery and Power Testing**:
   - A test to see how the system performs under continuous usage.
   - *What to expect:* The system should run for several hours on a single battery charge, without excessive drain or failure.
5. **Handling Signal Noise**:
   - Testing how the system performs when there is noise in the EEG signal due to user movement, blinking, or external interference.
   - *What to expect:* The system should be able to filter out unwanted noise and still respond accurately to the user’s intentions.

Figure 8.2 shows the testing of Wheelchair control using Human Brain Signal

8.3 Debugging the Integrated System

Once hardware and software are integrated, debugging is crucial to ensure the system runs smoothly without errors. The debugging process is first focused on verifying that all hardware components are correctly set up—checking that wires are properly connected, and that the battery and motor are functioning as expected.

After ensuring that the hardware is properly assembled, the next step is to debug the software, which is where the real-time interpretation of EEG signals comes into play. If the signal classification software is not identifying the brain signals accurately, the system will not execute the right commands (like moving forward or stopping).

To debug software-related issues, real-time data logs or serial outputs are examined to trace any incorrect commands. For example, if the motor doesn't respond properly to a "forward" command, the issue could be with the brain signal processing part or communication between the software and the motor control unit. By narrowing down the problem, developers can fix the logic in the software.

Additionally, during system integration, it's important to check for **latency** (time delays between brain signal interpretation and motor movement) and **signal loss** (where signals may be missed or wrongly interpreted). If such issues are noticed, optimizing the signal processing algorithms or improving the hardware communication protocols will be necessary.

Through this step of continuous testing and debugging, errors and inefficiencies can be caught and corrected to ensure the smooth functioning of the system in real-world environments.

CHAPTER 9
RESULTS AND DISCUSSION

9.1 Accuracy of Signal Detection

The accuracy of signal detection in this mind-controlled wheelchair system is a key factor in ensuring that the user's intended movement is translated correctly into the wheelchair's operation. In the tests, the EEG kit's ability to detect specific brainwave patterns associated with movements (such as focusing to move forward or relaxing to stop) was found to be generally reliable. However, some limitations arose, primarily due to the inherent noise in EEG signals. Noise could come from physical movements, external interferences, or fluctuations in signal strength as the user changes their mental state.

Based on typical EEG signal-based systems in similar robotic applications, the accuracy of signal interpretation often lies within the range of 75-90%. Most of the misclassifications in this project occurred when there was poor electrode contact or external noise. To mitigate such issues, proper setup and stabilization of signals are crucial, which is why the system takes about 10 seconds to start processing. Though this does not entirely eliminate inaccuracies, signal processing algorithms, including noise filtering techniques, can enhance detection accuracy.

9.2 Navigation Efficiency and Obstacle Avoidance Performance

Navigation efficiency refers to the wheelchair's ability to move smoothly and correctly in a given environment, while obstacle avoidance is essential to prevent collisions. In your system, the navigation function relies on basic motor controls with the potential to use EEG signals or mobile commands. During testing, the wheelchair showed satisfactory navigation capabilities, moving forward, backward, and stopping as intended. However, challenges arose when encountering obstacles, as the system lacks advanced sensors such as ultrasonic or LIDAR that are typically present in more complex systems. As such, obstacle avoidance is reliant on either user input or simple commands from the EEG signals, with no real-time detection of objects or walls.

When no obstacles were present, the wheelchair performed navigation efficiently. But, in more complex environments, the performance decreased as there was no automated reaction to unexpected objects. The results highlighted that without extra sensory input beyond the brain-computer interface, there are limits to how efficiently the system can handle real-world obstacles.

9.3 Comparative Analysis with Existing Systems

When compared to existing mind-controlled wheelchair systems, the primary difference lies in the use of a single motor in your design, while many commercial systems use multiple motors to enable a more refined and flexible control system. For example, some high-end systems are capable of all-direction movement, such as rotating in place and navigating tighter spaces with greater ease. These systems also tend to incorporate multi-sensory feedback systems that guide the wheelchair based on environmental changes and obstacles detected through sensors.

Systems such as Toyota’s autonomous wheelchair and the BrainGate neural interface utilize more complex algorithms, more precise signal interpretation, and integrated environmental sensors. These systems can steer around obstacles independently, in contrast to your system, where user input or mobile control is necessary when navigating around barriers.

Despite these differences, your system excels in simplicity and accessibility. Using only one motor, the design is cost-effective and straightforward, offering control via both EEG signals and mobile app, which may be more user-friendly for certain applications and cost-conscious users.

CONCLUSION

The mind-controlled wheelchair project has been a breakthrough in assistive technology, giving individuals with severe physical disabilities or paralysis the opportunity to regain a degree of independence. By using brain signals, users can move the wheelchair forward, backward, or stop— all through the power of thought. This is made possible by integrating intuitive technology designed to be responsive and easy to use.

The most exciting achievement is how the system combines both hardware and software in a seamless way. It enables the user to operate the wheelchair on their own, without needing traditional physical controls or help from others.

Safety has been a top priority in the design of the system. The emergency stop button ensures the user can stop the wheelchair immediately in any unexpected situation. There's also a mobile control feature, allowing caretakers or users themselves to control the wheelchair with a phone, further enhancing flexibility.

A key point to note is how the design keeps things simple with just one motor for basic movements. This not only makes the system efficient but also ensures the wheelchair can be used in everyday settings. The success of this project demonstrates that mind-controlled technology can play a pivotal role in helping those with severe mobility limitations— and opens the door for even more advanced solutions in the future.

Final Remarks and Takeaways

This project has shown just how life-changing brain-controlled technology can be for individuals with mobility challenges. By giving users the ability to control their wheelchair with brain signals, it opens up new possibilities for people who may have felt that moving around was no longer possible on their own. The ability to operate a wheelchair with minimal effort helps restore a sense of autonomy and freedom to those who need it most.

The inclusion of safety features like the emergency stop button helps ensure users feel secure while using the system, providing peace of mind. The mobile control option also offers another layer of flexibility, which can be especially helpful for caretakers or situations that require extra support.

While the current version of the wheelchair system is practical and functional, there is always room to make it even better. Future upgrades could improve how the system reads brain signals, detect obstacles to prevent accidents, and even enhance comfort for users who wear the EEG kit for extended periods.

In the grand scheme, this mind-controlled wheelchair is a significant step forward in assistive technology. It’s proof that technology can bridge the gap between disability and freedom. As advancements continue, we can expect even more adaptable, reliable, and accessible solutions for improving mobility— giving more people the freedom they deserve.

REAL WORLD APPLICATIONS

The mind-controlled wheelchair developed in this project can truly make a difference for people facing mobility challenges. It’s designed to help individuals with severe physical disabilities gain more independence and perform everyday tasks without relying heavily on others for assistance. Here are some ways this system could be used in real life:

For Individuals with Severe Mobility Impairments: This wheelchair is a game-changer for people who can’t control their limbs due to conditions like spinal cord injuries, neurodegenerative diseases, or cerebral palsy. By using brain signals, they can control the wheelchair and move around, offering them the freedom to do things they otherwise couldn’t, like going places or attending events, all with just their thoughts.

In Care Homes and Rehabilitation Centers: In care facilities and rehab centers, this mind-controlled wheelchair can help residents take charge of their environment. It could significantly reduce the need for caregiver assistance, allowing users to perform activities independently. In rehabilitation, it could be used to help people with mobility challenges practice movement as part of their therapy, speeding up their recovery while also improving their emotional well-being.

At Hospitals: For long-term patients or those struggling with mobility in a hospital, this wheelchair can make a big difference. It allows them to navigate the hospital independently, move through different departments, and have greater freedom without needing someone to push the wheelchair. This kind of mobility can boost patients’ morale, make their time in the hospital more comfortable, and help improve their overall experience during recovery.

In Public Spaces: Imagine navigating busy shopping malls, airports, or public transport hubs without needing assistance. With these mind-controlled wheelchairs, individuals with physical disabilities can more easily make their way through such spaces. This opens up many opportunities for social participation, helping them feel more independent and confident in public settings.

FUTURE EXTENSION

Enhancements and Future Research Opportunities

Although the mind-controlled wheelchair works well today, there’s always room for improvement. Here are a few ideas for future upgrades to make it even better:

Improving Signal Accuracy: While the current EEG system lets users control basic movements like moving forward and stopping, increasing the accuracy of the signals could make the control smoother and more intuitive. By improving the way the system interprets brain signals, users could have more precise control, leading to a more seamless experience.

Adding Smarter Navigation: Right now, the wheelchair allows for basic movement control, but we could add sensors, like ultrasonic or LIDAR sensors, to help the wheelchair avoid obstacles on its own. This would make the wheelchair safer to use, as it could navigate complex environments—like busy hallways or crowded rooms—without bumping into obstacles.

Making the EEG Headset More Comfortable: Wearing an EEG headset for extended periods can be uncomfortable, which could deter users from using the system for long hours. Future models should focus on making these headsets more comfortable, lightweight, and ergonomic so that users can wear them without discomfort.

Customized User Settings: It’s important that this system adapts to the unique needs of each individual. Giving users the ability to customize settings—like adjusting signal thresholds or changing how they control the wheelchair—could make it even more accessible and useful for a wider range of people, including those with different levels of disabilities.

REFERENCES

1. S. Jahangir and R. Ahmadi, "EEG-based control systems for assistive technologies: A review," *Journal of Robotics and Automation*, vol. 18, no. 2, pp. 125-140, 2021.
2. Malik, V. Raghunandan, and R. Gupta, "Development of mind-controlled wheelchairs for individuals with mobility impairments," *International Journal of Assistive Robotics*, vol. 5, no. 3, pp. 102-115, 2020.
3. Z. Hassan, S. Nur, and M. Rahim, "Assistive devices in healthcare using mind-computer interfaces," *IEEE Transactions on Biomedical Engineering*, vol. 68, no. 6, pp. 423-431, Jun. 2020.
4. W. Zhao and X. Wei, "Design and integration of assistive wheelchair control using EEG signals," *J. Assistive Robotics*, vol. 32, no. 1, pp. 150-167, 2021.
5. J. Qian, L. Wei, and T. Yang, "Signal processing methods for EEG-based mind control in wheelchairs," *Biomedical Signal Processing and Control*, vol. 57, pp. 345-356, Oct. 2021.
6. R. Patel and M. Desai, "Obstacle detection and path planning using ultrasound sensors in intelligent wheelchairs," *Journal of Intelligent Mobility Systems*, vol. 24, no. 5, pp. 313-327, May 2022.
7. P. Li and Z. Wang, "Real-time wheelchair control using an EEG-based brain-computer interface," *IEEE Transactions on Robotics*, vol. 37, no. 4, pp. 944-951, Aug. 2019.
8. "EEG-based assistive systems: An overview," *Neurotechnology Research Journal*, [Online]. [Accessed: Dec. 15, 2024].
9. *XYZ Robotics*, "Smart wheelchairs and applications for disabled individuals using EEG," [Online].. [Accessed: Dec. 15, 2024].
10. R. Kumar and A. D. Singh, "Implementing feedback control in assistive robotics," in *Proc. Int. Conf. on Assistive Technology*, 2018, pp. 45-49.\ S. Lee, Y. Shin, S. Woo, K. Kim and H. N. Lee,“Review of wireless brain-computer interface systems,” in Brain-Computer Interface Systems: Recent Progress and Future Prospects. London, UK: IntechOpen Limited, pp. 215–238, 2013.
11. M. Shibata, C. Zhang, T. Ishimatsu, M. Tanaka, and J. Palomino, Improvement of a

joystick controller for electric wheelchair user, Modern Mechanical Engineering, vol. 05, pp. 132–138, 01 2015.

12. B. C.Saharia T, Bauri J, “Joystick controlled wheelchair,” International Research Journal of Engineering and Technology (IRJET), vol. 07, 04 2017
13. S. P. Ahlfors and M. Mody, “Overview of meg,” organizational Research Methods, vol. 22, no. 1, pp. 95–115, 2019.
14. R. Li, D. Yang, F. Fang, K.-S. Hong, A. L. Reiss, and Y. Zhang,“Concurrent fnirs and eeg for brain function investigation: A systematic, methodology-focused review,” Sensors, vol. 22, no. 15, 2022
15. Neurosky, “Greek alphabet soup–making sense of eeg bands,” 2023.Accessed: August 16, 2023
16. Kashif H, Khan MN, Altalbe A., "Hybrid optical-radio transmission system link quality: link budget analysis," IEEE Access, vol. 8, pp.65983-92, 2020 Mar 18
17.] F. Gu, A. Gong, Y. Qu, H. Xiao, J. Wu, W. Nan, C. Jiang, and Y. Fu, “Research on top archer’s eeg microstates and source analysis in different states,” Brain Sciences, vol. 12, p. 1017, Jul 2022.
18. D. Allan, “The history of electric wheelchairs,” 2023.
19. Antora Dev, Md. Asifur Rahman, and Nursadul Mamun, “Design of an EEG-based Brain Controlled Wheelchair for Quadriplegic Patients, in 2018 3rd International Conference for Convergence in Technology (I2CT), November, 2018.
20. Dorian Rotier, Xiadong Zhang, Qian Guo “Research on brain control Technology for Wheelchair”, in 2018, MATEC Web of Conferences, EITCE 2018
21. Utkarsh Sinha, Priyanka Saxena, Kanthi M ”Mind Controlled Wheelchair” in May-June, 2017, IOSR Journal of Electrical and Electronics Engineering, Volume:12, Issue:3
22. Ahmed Maksud, Rakibul Islam Chowdhury, Shaikh
23. Anowarul Fattah, Celia Shahanaz, Sayeed Shafayet, “Low-cost EEG Based Electric Wheelchair with Advanced Control Features”, in TENCON 2017, November, 2017
24. Madhura B N, N Chandana, Navyashree M, “Brainwave controlled automated wheelchair “in 2020, NCDS 2020Conference Proceedings
25. Anjali Singh, Punija Choudhary, Shilpi Basuri, “Review on Brain Controlled

wheelchair "in 2020, March, Volume 7, Issue 1, IJRAR

26. G. Pires, N. Honorio, C. Lopes, U. Nunes and A. T. Almeida, "Autonomous wheelchair for disabled people," in ISIE '97 Proc. of the IEEE Int. Sym. on Industrial Electronics, Guimaraes, Portugal, pp. 797–801, 1997
27. T. Carlson and Y. Demiris, "Human-wheelchair collaboration through prediction of intention and adaptive assistance," in IEEE Int. Conf. on Robotics and Automation, Pasadena, CA, USA, pp. 3926–3931, 2008.
28. J. Long, Y. Li, H. Wang, T. Yu, J. Pan et al., "A hybrid brain computer interface to control the direction and speed of a simulated or real wheelchair," IEEE Transactions on Neural Systems and Rehabilitation Engineering, vol. 20, no. 5, pp. 720–729, 2012

APPENDIXTURE

APPENDIX 1: CODE

Code of EEG Sensor

```
#include <WiFi.h>
#include <WiFiClient.h>

// Wi-Fi credentials
#define WIFI_SSID "ESP_Wheelchair"
#define WIFI_PASSWORD "12345678"

// TX IP and port
#define RX_IP "192.168.4.1"  // Set this to the IP of the receiver (RX)
#define RX_PORT 12345

// Sensor and filter settings
#define SAMPLE_RATE 256 # sensor collect the data per second
#define BAUD_RATE 115200 #speed of Micro controller for communicating with sensor
#define INPUT_PIN 36

WiFiClient client;

void setup() {
  // Initialize Serial connection
  Serial.begin(BAUD_RATE);

  // Wi-Fi setup
  WiFi.begin(WIFI_SSID, WIFI_PASSWORD);
  while (WiFi.status() != WL_CONNECTED) {
    delay(1000);
    Serial.println("Connecting to WiFi...");
  }

  Serial.println("Connected to WiFi");

  // Connect to RX
  if (client.connect(RX_IP, RX_PORT)) {
    Serial.println("Connected to RX");
```

```
  } else {
    Serial.println("Connection failed");
  }
}

// EEG Filter function (Band-Pass Butterworth IIR digital filter)
float EEGFilter(float input) {
  float output = input;
  static float z1, z2;
  float x = output - -0.95391350*z1 - 0.25311356*z2;
  output = 0.00735282*x + 0.01470564*z1 + 0.00735282*z2;
  z2 = z1;
  z1 = x;
  static float z1_2, z2_2;
  x = output - -1.20596630*z1_2 - 0.60558332*z2_2;
  output = 1.00000000*x + 2.00000000*z1_2 + 1.00000000*z2_2;
  z2_2 = z1_2;
  z1_2 = x;
  static float z1_3, z2_3;
  x = output - -1.97690645*z1_3 - 0.97706395*z2_3;
  output = 1.00000000*x + -2.00000000*z1_3 + 1.00000000*z2_3;
  z2_3 = z1_3;
  z1_3 = x;

  static float z1_4, z2_4;
  x = output - -1.99071687*z1_4 - 0.99086813*z2_4;
  output = 1.00000000*x + -2.00000000*z1_4 + 1.00000000*z2_4;
  2_4 = z1_4;
  z1_4 = x;

  return output;
}

void loop() {
  // Sample EEG signal from the input pin
  static unsigned long past = 0;
  unsigned long present = micros();
  unsigned long interval = present - past;
  past = present;
```

```
  // Timer logic for sample rate
  static long timer = 0;
  timer -= interval;
  if (timer < 0) {
    timer += 1000000 / SAMPLE_RATE;
    float sensor_value = analogRead(INPUT_PIN);
    float signal = EEGFilter(sensor_value);

    // Process signal to determine command data
    int data = 0;
    if (signal > 200) {
      data = 1;
    } else if (signal >= 200 && signal <= 300) {
      data = 2;
    } else {
      data = 5;
    }

    // Send the corresponding command based on the signal value
    String command = String(data);
    sendCommandAndWaitForReply(command);
  }
}

// Send command and wait for a reply (ACK)
void sendCommandAndWaitForReply(String cmd) {
  if (client.connected()) {
    client.println(cmd);  // Send the command to RX
    Serial.print("Sent Command: ");
    Serial.println(cmd);

    // Wait for reply from RX
    String response = client.readStringUntil('\n');
    if (response == "ACK") {
      Serial.println("Command executed successfully, waiting for next...");
    } else {
      Serial.println("Error or no response received");
    }
```

```
  } else {
    Serial.println("Not connected to RX, reconnecting...");
    client.stop();
    client.connect(RX_IP, RX_PORT);  // Reconnect to RX
  }
}
```

Code for motor actions

```
#include <WiFi.h>
#include <LiquidCrystal_I2C.h>
#include <ESPAsyncWebServer.h>

// Pins
#define BUZZER_PIN 19
#define MOTOR_IN1 5
#define MOTOR_IN2 18
#define EMERGENCY_PIN 23  // Emergency shutdown button (Active Low)

// Wi-Fi Hotspot credentials
#define WIFI_SSID "ESP_Wheelchair"
#define WIFI_PASSWORD "12345678"

// LCD Initialization
LiquidCrystal_I2C lcd(0x27, 16, 2);

// State variables
bool isTransmissionEnabled = false;
bool isEmergency = false;

// Web server
AsyncWebServer server(80);

// TCP server
WiFiServer tcpServer(12345);  // Listening on port 12345

// Function prototypes
void handleCommand(const String &cmd);
void stopMotors();
void emergencyShutdown();  // Function declaration
```

```
void startTCPServer();
void stopTCPServer();

void setup() {
  Serial.begin(115200);

  // Initialize LCD
  lcd.begin();
  lcd.backlight();
  lcd.setCursor(0, 0);
  lcd.print("Initializing...");

  // Initialize GPIO
  pinMode(BUZZER_PIN, OUTPUT);
  pinMode(MOTOR_IN1, OUTPUT);
  pinMode(MOTOR_IN2, OUTPUT);
  pinMode(EMERGENCY_PIN, INPUT_PULLUP);  // Set emergency pin as input with
pull-up
  stopMotors();

  // Initialize Wi-Fi as AP
  WiFi.mode(WIFI_AP);
  WiFi.softAP(WIFI_SSID, WIFI_PASSWORD);
  Serial.println("Hotspot started");
  lcd.clear();
  Serial.print("IP Address: ");
  Serial.println(WiFi.softAPIP());
   lcd.setCursor(0, 0);
  lcd.print(WiFi.softAPIP());

  // Start web server
  setupWebServer();

  // Start TCP server
  tcpServer.begin();
  Serial.println("TCP Server Started on port 12345"); =
  delay(2000);
  lcd.clear();
}
```

```
void loop() {

  // Handle incoming TCP client connections if transmission is enabled
  if (isTransmissionEnabled) {
    WiFiClient client = tcpServer.available();
    if (client) {
      String command = client.readStringUntil('\n');  // Read the incoming data (command)
      command.trim();  // Remove any extra whitespace, newline characters, etc.
      Serial.print("Received Command: ");
      Serial.println(command);

      // Beep the buzzer each time data is received
      digitalWrite(BUZZER_PIN, HIGH);
      delay(100);  // Beep duration
      digitalWrite(BUZZER_PIN, LOW);

      // Handle the command if transmission is enabled and no emergency is active
      if (!isEmergency && command.length() > 0) {
        handleCommand(command);
      }

      // Wait for 2 seconds after executing the command before sending ACK
      delay(2000);  // Wait for 2 seconds

      // Send acknowledgment back to TX
      client.println("ACK");

      client.stop();  // Close the connection
    }
  }

  // Emergency shutdown check
  if (digitalRead(EMERGENCY_PIN) == LOW) {
    if (!isEmergency) {
      isEmergency = true;
      emergencyShutdown();  // Trigger emergency shutdown
    }
  } else if (isEmergency) {
    isEmergency = false;
```

```
    lcd.clear();
    lcd.setCursor(0, 0);
    lcd.print("System Ready");
    stopMotors();
  }
}

// Handle motor control and buzzer based on command
void handleCommand(const String &cmd) {
  int commandValue = cmd.toInt();  // Convert the command string to an integer
  lcd.clear();

  if (commandValue == 1) {  // Sensor UP
    lcd.print("Sensor: Front");
    digitalWrite(MOTOR_IN1, LOW);  // Active Low
    digitalWrite(MOTOR_IN2, HIGH);  // Active Low
    beepBuzzer();
  } else if (commandValue == 2) {  // Sensor DOWN
    lcd.print("Sensor: Back");
    digitalWrite(MOTOR_IN1, HIGH);  // Active Low
    digitalWrite(MOTOR_IN2, LOW);  // Active Low
    beepBuzzer();
  } else if (commandValue == 3) {  // Web UP
    lcd.print("Web: Front");
    digitalWrite(MOTOR_IN1, LOW);  // Active Low
    digitalWrite(MOTOR_IN2, HIGH);  // Active Low
    beepBuzzer();
  } else if (commandValue == 4) {  // Web DOWN
    lcd.print("Web: Back");
    digitalWrite(MOTOR_IN1, HIGH);  // Active Low
    digitalWrite(MOTOR_IN2, LOW);  // Active Low
    beepBuzzer();
  } else if (commandValue == 5) {  // Stop
    lcd.print("Action: STOP");
    stopMotors();
    beepBuzzer();
  } else {
    lcd.print("Unknown Cmd");
  }
```

```
  // Print the command to Serial Monitor
  Serial.print("Command Executed: ");
  Serial.println(commandValue);
}
// Function to stop motors
void stopMotors() {
  digitalWrite(MOTOR_IN1, HIGH);  // Active Low
  digitalWrite(MOTOR_IN2, HIGH);  // Active Low
}
// Function to beep the buzzer
void beepBuzzer() {
  digitalWrite(BUZZER_PIN, HIGH);
  delay(100);  // Beep duration
  digitalWrite(BUZZER_PIN, LOW);
}

// Emergency shutdown procedure
void emergencyShutdown() {
  // Stop the motors immediately
  stopMotors();

  // Display emergency message on LCD
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("   Emergency");
  lcd.setCursor(0, 1);
  lcd.print("    Shutdown");

  // Sound the buzzer for emergency alert
  digitalWrite(BUZZER_PIN, HIGH);
  delay(500);  // Buzzer duration
  digitalWrite(BUZZER_PIN, LOW);
}
void setupWebServer() {
  server.on("/", HTTP_GET, [](AsyncWebServerRequest *request) {
    String html = R"rawliteral(
      <!DOCTYPE html>
      <html lang="en">
      <head>
```

```
<meta charset="UTF-8">
<meta name="viewport" content="width=device-width, initial-scale=1.0">
<title>ESP32 RX Control</title>
<style>
 body {
  font-family: 'Arial', sans-serif;
  background: #000;
  color: white;
  text-align: center;
  margin: 0;
  padding: 0;
 }
 h1 {
  font-size: 3em;
  margin-top: 20px;
  text-shadow: 0px 0px 20px rgba(255, 255, 255, 0.8);
 }
 button {
  background: linear-gradient(45deg, #00bcd4, #4caf50);
  border: none;
  color: white;
  padding: 15px 30px;
  font-size: 1.2em;
  margin: 15px;
  border-radius: 10px;
  box-shadow: 0 4px 6px rgba(0, 0, 0, 0.3);
  cursor: pointer;
  transition: all 0.3s ease;
  width: 180px;  /* Ensures all buttons are uniform */
 }
 button:hover {
  transform: translateY(-5px);
  box-shadow: 0 10px 15px rgba(0, 0, 0, 0.3);
  background: linear-gradient(45deg, #4caf50, #00bcd4);
 }
 input[type="checkbox"] {
  width: 40px;
  height: 40px;
  cursor: pointer;
```

```
      border-radius: 50%;
      appearance: none;
      background: #444;
      box-shadow: 0px 0px 5px rgba(255, 255, 255, 0.5);
      transition: background 0.3s, transform 0.3s;
    }
    input[type="checkbox"]:checked {
      background: #4caf50;
      transform: scale(1.2);
    }
    input[type="checkbox"]:checked:before {
      content: '';
      position: absolute;
      top: 10px;
      left: 10px;
      width: 20px;
      height: 20px;
      background: white;
      border-radius: 50%;
      box-shadow: 0px 0px 10px rgba(255, 255, 255, 0.6);
    }
    .glowing {
      text-shadow: 0px 0px 10px rgba(255, 255, 255, 0.8), 0px 0px 20px rgba(255, 255,
255, 0.6), 0px 0px 30px rgba(255, 255, 255, 0.4);
    }
    label {
      font-size: 1.2em;
      margin-top: 20px;
      display: block;
    }
  </style>
  <script>
    async function sendCommand(cmd) {
      await fetch(`/command?cmd=${cmd}`);
    }
    function toggleTransmission(enabled) {
      fetch(`/toggle?enabled=${enabled}`);
    }
  </script>
```

```
    </head>
    <body>
      <h1 class="glowing">ESP32 RX Control</h1>
      <div>
        <button onclick="sendCommand('3')">UP</button>
        <button onclick="sendCommand('4')">DOWN</button>
        <button onclick="sendCommand('5')">STOP</button>
      </div>
      <br><br>
      <label for="toggle">Connect Helmet:</label>
      <input type="checkbox" id="toggle" onchange="toggleTransmission(this.checked)">
    </body>
    </html>
  )rawliteral";
  request->send(200, "text/html", html);
});

server.on("/command", HTTP_GET, [](AsyncWebServerRequest *request) {
  if (request->hasParam("cmd")) {
    String cmd = request->getParam("cmd")->value();
    handleCommand(cmd);
  }
  request->send(200, "text/plain", "OK");
});

server.on("/toggle", HTTP_GET, [](AsyncWebServerRequest *request) {
  if (request->hasParam("enabled")) {
    String enabled = request->getParam("enabled")->value();
    isTransmissionEnabled = (enabled == "true");
    Serial.print("Transmission Enabled: ");
    Serial.println(isTransmissionEnabled ? "True" : "False");

    // If transmission is enabled, start listening on TCP server
    if (isTransmissionEnabled) {
      startTCPServer();
    } else {
      stopTCPServer();
    }
  }
```

```
    request->send(200, "text/plain", "OK");
  });

  server.begin();
}


// Start TCP server to listen for incoming commands
void startTCPServer() {
  tcpServer.begin();
  Serial.println("TCP Server started and listening...");
}

// Stop TCP server and stop listening for connections
void stopTCPServer() {
  tcpServer.stop();
  Serial.println("TCP Server stopped.");
}
```

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