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Smart Wheelchair Kit for Paralyzed Patients with Effective EMG and EOG Controls

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Abstract: This project presents the development of an intelligent assistive mobility system designed to enhance the independence of individuals with severe paralysis through a retrofittable smart wheelchair kit. The system integrates multiple control mechanisms, including Electromyography (EMG), Electrooculography (EOG), joystick-based manual control, and Bluetooth-enabled wireless operation, enabling flexible and user-adaptive navigation. EMG signals obtained from voluntary muscle activity and EOG signals derived from eye movements are continuously acquired and processed to detect user intent. These bio-signals undergo signal conditioning, filtering, and threshold-based decision-making to generate accurate directional commands for wheelchair movement, ensuring reliable and responsive control even for users with minimal physical capability. A microcontroller-based control unit manages all inputs and interfaces with motor drivers to regulate speed and direction. Performance evaluation is conducted based on response time, control accuracy, and user adaptability, demonstrating that the multi-modal approach significantly improves accessibility and usability while maintaining low implementation cost and practical feasibility.

Keywords - Smart wheelchair, assistive technology, EMG control, EOG control, bio-signal processing, Bluetooth control, Arduino, motor driver, mobility assistance, rehabilitation engineering, human-machine interface, adaptive control systems, low-cost assistive devices, paralyzed patient mobility.

mobility solution. In recent years, advancements in bio-signal processing and embedded systems have opened new possibiliti for developing intelligent control systems. This project aims to design and develop a retrofittable smart wheelchair kit th integrates multiple control mechanisms, enabling users with varying levels of physical ability to operate a convention wheelchair efficiently.

At the core of the proposed system lies microcontroller units such as Arduino UNO and Arduino Mega, which facilitate real-tir data acquisition and processing for decision-making. The system utilizes a Bio Amp EXG Pill module to capture

Electromyography (EMG) signals from muscle activity and Electrooculography (EOG) signals from eye movements. These signals are processed through amplification, filtering, and threshold-based algorithms to accurately interpret user intent and translate it into directional commands. Additionally, a joystick module is incorporated to allow manual control, while a Bluetooth module enables wireless operation through a mobile application. The integration of multiple control modes ensures flexibility, reliability, and ease of use for both users and caregivers.

The processed control signals are transmitted to a motor driver module (L298N), which regulates the movement and speed of the wheelchair motors. The system ensures smooth navigation by coordinating inputs from different control sources and prioritizing commands based on the selected mode of operation. Furthermore, the modular design of the system allows it to be easily mounted onto existing wheelchairs without

I. INTRODUCTION

Mobility is a fundamental requirement for independent living, yet it remains a significant challenge for individuals suffering from severe paralysis and neuromuscular disorders. Conventional wheelchairs, which rely on manual operation, are not suitable for users with limited or no motor control. Although advanced solutions such as EEG-based control systems exist, they are often expensive, complex, and not easily accessible to a wider population. This creates a strong need for a cost-effective, adaptable, and user-friendly assistive requiring structural modifications, making it a practical and scalable solution. The inclusion of multiple control interfaces also provides redundancy, ensuring continued operation even if one control method is not feasible for the user.

The proposed system significantly reduces the dependency on expensive technologies while maintaining high functionality and reliability. It minimizes the need for external assistance, thereby improving the quality of life and independence of individuals with mobility impairments. Moreover, the system is designed to be scalable, allowing the integration of additional features and advanced control techniques in the future. By combining bio-signal processing, wireless communication, and embedded control systems, the developed smart wheelchair represents a promising step towards accessible, affordable, and intelligent assistive mobility solutions.

II. RELATED WORKS

Recent advancements in assistive technologies have significantly improved mobility solutions for individuals with severe physical disabilities. Intelligent wheelchair systems have evolved from simple joystick-controlled devices to advanced multi-modal control systems incorporating biomedical signals, wireless communication, and embedded processing. These developments aim to enhance user independence, safety, and adaptability in real-world environments.

Several research works have focused on the use of Electromyography (EMG) signals for wheelchair control. EMG-based systems detect electrical activity generated by muscle contractions and translate them into control commands. These systems are particularly beneficial for patients who retain partial muscle functionality. Signal acquisition using surface electrodes, followed by amplification, filtering, and threshold-based classification, has been widely adopted. However, challenges such as signal noise, electrode placement sensitivity, and user fatigue remain key concerns in EMG-based control systems.

In addition to EMG, Electrooculography (EOG) has been explored as an alternative control mechanism for individuals with extremely limited muscular movement. EOG-based systems utilize eye movements such as left, right, and blink actions to generate navigation commands. Research has shown that EOG signals can be reliably captured using non-invasive electrodes and processed through signal conditioning and pattern recognition techniques. These systems offer a viable solution for patients with high-level paralysis, although issues related to signal drift and calibration requirements need to be addressed.

Wireless communication technologies, particularly Bluetooth-based control systems, have been integrated into smart wheelchair designs to provide flexibility and remote accessibility. Smartphone-controlled wheelchairs enable caregivers or users with partial mobility to operate the system efficiently. These systems typically use mobile applications to send directional commands to a microcontroller, which then drives the motors accordingly. Bluetooth control also serves as a backup mode in multi-modal systems, ensuring operational redundancy and user safety.

Traditional joystick-controlled wheelchairs remain one of the most reliable and widely used methods for mobility assistance. Many modern smart wheelchair systems retain joystick control as a primary or fallback mechanism due to its simplicity, responsiveness, and ease of use. Research has emphasized integrating joystick control with advanced methods such as EMG and EOG to create hybrid systems that cater to users with varying levels of physical ability.

Some advanced systems have explored the use of Electroencephalography (EEG) for brain-controlled wheelchairs, where neural signals are directly interpreted to control movement. While EEG-based systems offer high potential for completely paralyzed individuals, they require expensive equipment, complex signal processing, and extensive training, making them less accessible for widespread use. This limitation has led to increased interest in cost-effective alternatives such as EMG and EOG-based control systems.

Embedded system platforms such as Arduino have played a crucial role in the development of low-cost smart wheelchair prototypes. Microcontrollers like Arduino Uno and Arduino Mega are widely used for integrating multiple input modules and controlling motor drivers. Motor control is typically achieved using driver circuits such as L298N Motor Driver, which enables bidirectional control of DC motors used in wheelchair movement.

Overall, existing research demonstrates that multi-modal control systems combining EMG, EOG, Bluetooth, and joystick inputs provide a more flexible and user-centric approach compared to single-mode systems. These systems improve reliability, adaptability, and accessibility while addressing the limitations of individual control methods. The proposed project builds upon these advancements by developing a retrofittable, low-cost, and modular smart wheelchair control kit, specifically designed to enhance usability and compatibility with conventional wheelchairs.

Some advanced research has focused on Electroencephalography (EEG)-based brain-controlled wheelchairs, where neural signals are interpreted to generate movement commands. Although EEG-based systems offer promising solutions for completely paralyzed individuals, they require expensive hardware and complex signal processing techniques, limiting their practical adoption.

Embedded platforms such as Arduino have played a crucial role in developing cost-effective assistive systems. Microcontrollers like Arduino Uno and Arduino Mega are widely used to integrate multiple control inputs and manage motor drivers. Motor control is typically implemented using driver modules such as L298N Motor Driver, enabling efficient bidirectional control of wheelchair motors.

Overall, existing research indicates that multi-modal control systems combining EMG, EOG, Bluetooth, and joystick inputs provide improved flexibility, reliability, and accessibility compared to single-mode systems. The proposed system builds upon these approaches by developing a low-cost, modular, and retrofittable smart wheelchair control kit suitable for real-world applications.

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III. METHODOLOGY

The proposed smart wheelchair system utilizes multi-modal control mechanisms, including biomedical signal processing and wireless communication, to assist individuals with severe mobility impairments. The system is designed as a modular and retrofittable kit that integrates signal acquisition, processing, decision-making, and motor actuation. The methodology consists of five major components, namely control input modules, signal acquisition and processing, decision-making logic, user interface and control flexibility, and motor control actions.

A. Control Input Modules and Data Acquisition

1. Joystick Control Module:

The joystick provides direct manual control of the wheelchair. It generates analog signals corresponding to directional movements such as forward, backward, left, and right. These signals are continuously monitored by the microcontroller and used for real-time navigation.

2. Bluetooth Control Module:

The Bluetooth module enables wireless communication between the wheelchair and a smartphone device. Control commands are transmitted from a mobile application and received by the microcontroller, allowing remote operation by the user or caregiver.

3. EMG Signal Acquisition Module:

The Electromyography (EMG) module captures electrical signals generated by muscle contractions using surface electrodes. These signals reflect the user's intentional muscle activity and are used as control inputs for wheelchair movement.

4. EOG Signal Acquisition Module:

The Electrooculography (EOG) module detects eye movements such as left, right, and blink actions. Electrodes placed around the eyes measure voltage variations caused by eye movement, enabling control for users with minimal muscular ability.

B. Signal Processing and Data Handling

The acquired EMG and EOG signals undergo signal conditioning, including amplification and filtering, to remove noise and improve signal clarity. Biomedical signals are inherently weak and susceptible to interference; therefore, proper filtering techniques are applied to ensure reliable operation.

The processed signals are then analyzed using threshold-based techniques to identify valid user inputs. Each signal is mapped to a specific command based on predefined ranges. Joystick and Bluetooth inputs require minimal processing and are directly interpreted by the microcontroller.

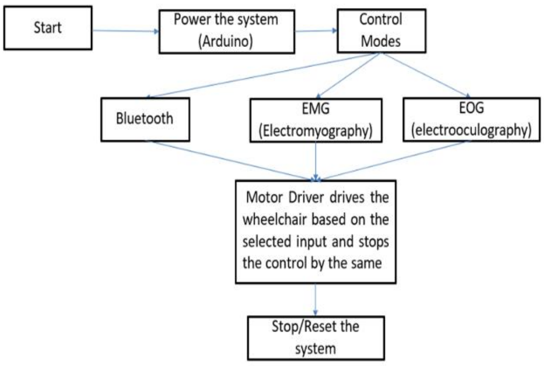
C. Decision Algorithm and Control Logic

The decision-making unit is implemented within the microcontroller, which interprets inputs from multiple control modules and generates appropriate movement commands. The system operates in a mode-based manner, where only one control input (Joystick, Bluetooth, EMG, or EOG) is active at a time to avoid conflicts.

The decision logic evaluates the processed signals and maps them into specific commands such as forward, backward, left, right, or stop. Threshold-based classification is used for EMG and EOG signals, while direct mapping is used for joystick and Bluetooth inputs.

Priority handling ensures safe operation, allowing immediate stopping of the wheelchair in case of invalid or conflicting inputs. This improves system reliability and user safety.

The interpreted signals are converted into movement instructions such as forward, backward, left, right, or stop. Safety conditions are incorporated to halt the wheelchair in case of invalid or unstable input signals. This approach enhances system reliability, responsiveness, and ensures safe operation for the user.



D. Control Mode Selection and User Interaction

The system incorporates a flexible control mode selection mechanism that allows the user or caregiver to choose the most suitable method of operation based on the user's physical capabilities. The available control modes include joystick, Bluetooth, EMG, and EOG, each designed to accommodate different levels of mobility. The selection of the control mode is performed prior to operation, ensuring that only one input module is active at a time. This approach prevents signal conflicts and ensures stable and predictable system behavior during wheelchair navigation.

The user interaction design focuses on simplicity, accessibility, and ease of use, enabling individuals with severe mobility impairments to operate the system with minimal effort. Each control mode provides an intuitive interface, whether through physical movement, muscle activity, eye movement, or remote commands. This adaptability enhances the usability of the system across a wide range of users, while also allowing caregivers to assist when required. The multi-modal approach ensures that the system remains user-centric, reliable, and adaptable to different real-world conditions.

The control mode selection mechanism is designed to ensure seamless switching between different input methods when required. Although the system operates in a single-mode configuration at any given time, the ability to change modes allows the system to adapt to the user's condition or environmental requirements. This feature is particularly useful during training phases or in situations where assistance from a caregiver is needed.

User interaction is further enhanced by maintaining consistent command mapping across all control modes, ensuring that similar actions correspond to the same wheelchair movement. This reduces the learning curve and improves user confidence while operating the system. The simplicity of interaction, combined with reliable mode selection, contributes to a safer and more efficient user experience.

E. Motor Control and Wheelchair Movement

The motor control system is responsible for converting the processed user inputs into physical movement of the wheelchair. This is achieved using the L298N motor driver, which acts as an interface between the microcontroller and the DC motors attached to the wheelchair wheels. The microcontroller generates control signals based on the interpreted commands, which are then transmitted to the motor driver for execution.

The L298N motor driver controls both the direction and speed of the motors. Directional movement such as forward, backward, left, and right is achieved by controlling the polarity of the voltage applied to the motors. Speed control is implemented using pulse-width modulation (PWM) signals generated by the microcontroller, allowing smooth acceleration and deceleration of the wheelchair.

Each movement command received from the active control module is mapped to a specific motor operation. For instance, forward motion is achieved by rotating both motors in the same direction, while turning movements are performed by varying the speed or direction of individual motors. This differential control mechanism enables precise navigation and maneuverability in different environments.

To ensure safety and reliability, the system incorporates immediate stop functionality and stable motor response under varying input conditions. In the absence of valid input signals or in the presence of unstable commands, the motors are automatically brought to a halt. This prevents unintended movement and enhances user safety, making the system dependable for real-time operation.

The motor control system is designed to provide consistent performance and efficient power utilization during operation. Proper interfacing between the microcontroller and motor driver ensures minimal signal delay and accurate execution of commands. The system is capable of handling continuous operation while maintaining smooth and stable wheelchair movement. This reliability in motor performance enhances the overall effectiveness of the wheelchair and ensures a comfortable and safe experience for the user.

IV.RESULT

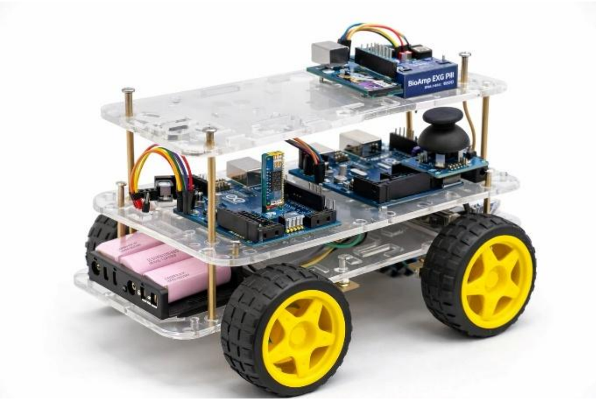
The developed smart wheelchair system was successfully implemented and tested under various operating conditions using joystick, Bluetooth, EMG, and EOG control modes. The system demonstrated reliable performance in interpreting user inputs and converting them into accurate movement commands. Each control module was tested independently to evaluate its functionality, response time, and ease of use.

The joystick control mode provided smooth and precise navigation with minimal delay, making it suitable for users with partial motor control. The Bluetooth control mode enabled effective wireless operation through a smartphone, allowing caregivers to control the wheelchair remotely with consistent response and stability. Both modes showed high reliability due to their direct input nature and minimal signal processing requirements.

The EMG-based control system successfully detected muscle activity and translated it into movement commands. The signal processing techniques, including filtering and thresholding, ensured accurate detection of intentional muscle contractions. Similarly, the EOG-based control system effectively recognized eye movements such as left, right, and blink actions, enabling hands-free operation for users with severe paralysis. Although slight variations in signal strength were observed, the system maintained consistent performance after calibration.

Overall, the multi-modal control approach proved to be effective in enhancing accessibility and flexibility. The system exhibited satisfactory response time, stable motor control, and reliable command execution across all modes. The results confirm that the proposed retrofit kit is a feasible, low-cost, and adaptable solution for assisting individuals with mobility impairments, while maintaining compatibility with conventional wheelchairs. The performance of the system was further evaluated based on response time and command accuracy. It was observed that the joystick and Bluetooth modes exhibited faster response due to direct signal input, while EMG and EOG modes required slight processing time for signal conditioning and threshold detection. However, the delay remained within acceptable limits and did not significantly affect real-time operation. The accuracy of command recognition in EMG and EOG modes improved with proper electrode placement and calibration, ensuring reliable user control.

The system also demonstrated good adaptability across different users and operating conditions. During testing, users were able to gradually adapt to EMG and EOG control mechanisms with minimal training. The modular design of the system allowed easy integration with a conventional wheelchair, confirming its retrofit capability. These observations highlight the practicality and effectiveness of the proposed system in providing an accessible and user-friendly mobility solution for individuals with severe physical impairments.



V. CONCLUSION

The proposed smart wheelchair system successfully demonstrates the implementation of a multi-modal control approach designed to assist individuals with severe mobility impairments. By integrating joystick, Bluetooth, EMG, and EOG control mechanisms into a single modular and retrofittable unit, the system provides a flexible and user-centric solution for wheelchair navigation. The use of biomedical signals such as EMG and EOG enables individuals with limited or no limb movement to control the wheelchair effectively, thereby improving their independence and quality of life.

Furthermore, the system achieves its objective of providing an affordable alternative to existing high-cost assistive technologies, particularly those based on complex brain-computer interfaces. The modular design allows easy installation on conventional wheelchairs without requiring structural modifications, making it practical for real-world applications. Experimental results confirm that the system offers satisfactory performance in terms of response time, signal accuracy, and operational reliability across all control modes. Overall, the project establishes a strong foundation for the development of cost-effective, adaptable, and clinically relevant assistive mobility solutions, with potential for further enhancements and wider adoption in the field of rehabilitation engineering.

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