Project field: [x] Biomedical [ ] Computing Engineering [ ] Telecommunications
[ ] Electronics [ ] Automation and Control [ ] Computer Networks
[ ] Telecommunications Management [ ] Others

PROJECT TITLE: Design of a Brain-Controlled Electric Wheelchair System Using Steady-State Visually Evoked Potentials (SSVEPs)

Abstract - This document presents the design and development of a brain-controlled wheelchair for people with motor disabilities. These individuals face daily mobility challenges, which significantly affect their quality of life. Therefore, a solution is proposed, using a brain-computer interface (BCI),that will allow these individuals to achieve autonomous mobility and improve their quality of life. The project consisted of restoring a wheelchair and integrating a Raspberry Pi 4 as a control unit. An interface was designed that generates visual stimuli at different frequencies, each associated with a movement command, which facilitated control of the chair through EEG signals. The result demonstrated that it is possible to develop a wheelchair controlled through brain signals at an affordable cost, with noninvasive, real-time brain control. Future work will focus on improving signal detection accuracy, enhancing the interface design, and increasing user comfort.

***Keywords*:** Brain-computer interface, SSVEP, electric wheelchair, OpenBCI, assistive technology

1 Introduction

Movement assistance for individuals with motor disabilities has seen significant progress in recent years, largely driven by technological advances in neuroscience, embedded systems, and assistive robotics. Despite these developments, many commercial solutions remain prohibitively expensive and inaccessible—particularly in developing countries such as Bolivia—where resources are limited and access to cutting-edge medical technology is scarce.

In this work, we present the design and implementation of a low-cost, brain-controlled electric wheelchair system using Steady-State Visually Evoked Potentials (SSVEP). The system combines a refurbished electric wheelchair, a Raspberry Pi 4 microcomputer, and an OpenBCI Cyton + Daisy EEG acquisition board. A web-based interface was developed to serve as both a visual stimulus generator and a control menu, allowing the user to interact with the system by focusing on flickering targets, each associated with a movement command (forward, backward, left, right). The Raspberry Pi performs onboard signal processing and translates the recognized brain commands into motor actions.

Additionally, the integration of the web interface introduces an Internet of Things (IoT) dimension, enabling caregivers or family members to assist the patient remotely by taking over control of the system when needed. This hybrid solution prioritizes accessibility, autonomy, and affordability, offering a feasible alternative to high-cost commercial neuroprosthetic devices.

2 Project Objective

The objective of this project is to design and develop an electric wheelchair system controlled by brain signals, generated by visual stimuli, for people with motor disabilities.The project seeks to offer a noninvasive, low-cost solution that improves users' quality of life. In addition to helping family members and caregivers to have greater control, comfort and security.

3 Target Audience

This project is designed for individuals with motor disabilities who face challenges in their daily mobility and independence. And for family members and caregivers who support them. Additionally, it may be of interest to hospitals, doctors, nurses, caregivers, and assistive technology developers seeking accessible and functional solutions.

4 Development and Methodology

4.1 Hardware Setup

The project began by restoring a previously non-functional electric wheelchair available in the laboratory. This included troubleshooting power delivery circuits, testing motor response, and ensuring structural and electrical stability. Once operational, a Raspberry Pi 4 was installed as the central processing and control unit (see Figure **??**). The Raspberry Pi interfaces directly with the wheelchair's motor control system to execute four fundamental motion commands: move forward, move backward, turn left, and turn right.

To enable real-time communication with the EEG acquisition module, an OpenBCI Cyton + Daisy board was integrated. This board collects EEG signals—specifically SSVEP and alpha waves—via electrodes placed on the user's scalp, and transmits them to the Raspberry Pi using UART (Universal Asynchronous Receiver/Transmitter) protocol via a USB-Bluetooth dongle.

A lightweight Flask-based web server was implemented on the Raspberry Pi to host the user interface and to manage communication within the local network. This allowed remote access to the control menu and enabled caregivers or family members to monitor the system or take over control if needed.

For motor control, the Raspberry Pi generates PWM (Pulse Width Modulation) signals which are fed to a motor driver circuit connected to the wheelchair's DC motors. This setup enables smooth and proportional speed control for each movement direction. Safety features were implemented to stop motion automatically in case of signal loss or system error.

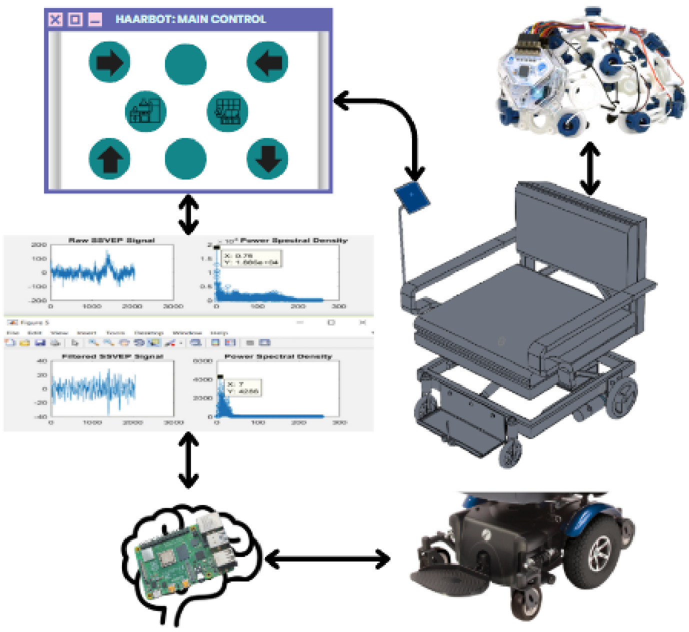

Figure 1: General Project Diagram

Figure 2: Adapted electric wheelchair controlled via Raspberry Pi

4.2 SSVEP Menu and Web-Based Interface (IoT Integration)

A web-based interface was designed to serve both as the visual stimulus generator and as a user control menu. Hosted on the Raspberry Pi, this interface rendered four flickering rectangles, each at a distinct frequency, to evoke Steady-State Visually Evoked Potentials (SSVEP) in the user's visual cortex.

The assigned frequencies were:

- **10.75 Hz** – Move Forward
- **11.75 Hz** – Move Backward
- **13.75 Hz** – Turn Left
- **14.25 Hz** – Turn Right

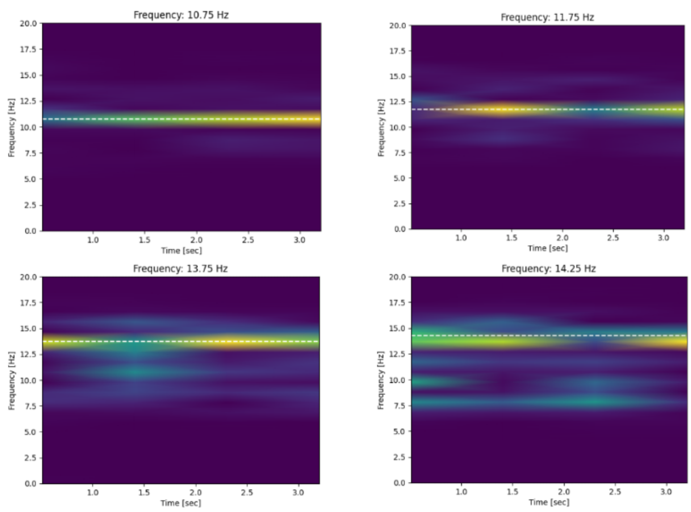

Figure 3: Signal Analyzed from the dataset

By focusing on one of the flickering elements, the user could issue a command without any physical interaction. This design also introduced an IoT layer, allowing remote access to the system interface, enabling caregivers or relatives to monitor and assist the user.

Figure 4: Web interface with SSVEP control menu

4.3 EEG Acquisition with OpenBCI

For EEG signal acquisition, the system used the **OpenBCI Cyton + Daisy** module with 16 channels. Electrodes were positioned over occipital regions (e.g., O1, O2, Oz) following the international 10–20 system, to capture the brain's visual response to flickering stimuli.

The EEG data was transmitted in real-time to the Raspberry Pi via Bluetooth, enabling continuous monitoring and classification.

4.4 Signal Processing and Command Execution

The Raspberry Pi processed incoming EEG signals using Python. The signal processing pipeline included:

1. **Bandpass filtering** between 6–30 Hz to isolate SSVEP signals.
2. **Fast Fourier Transform (FFT)** applied to EEG windows for frequency analysis.
3. **Frequency classification** to detect which stimulus the user was attending to.
4. **GPIO-based motor control** to issue the corresponding movement command.

This enabled real-time brain-driven control of the wheelchair based purely on the frequency of the evoked potential.

Figure 5: SSVEP signal acquisition and frequency classification results

5 Challenges and Discussion

One of the main challenges faced during this project was the accurate acquisition and classification of EEG signals. Brain signals are inherently weak and highly susceptible to noise, especially in real-world environments. The system relied on the precise detection of SSVEP, which required careful electrode placement and consistent visual stimulus design.

Another challenge was the integration of hardware and software in a compact, affordable, and reliable system. The use of a Raspberry Pi 4 as the processing unit required optimizations in signal processing algorithms to ensure real-time performance without latency. Additionally, ensuring safe and smooth wheelchair movement based on brain commands demanded a robust control pipeline, particularly when dealing with potential misclassifications or false positives.

During development, datasets of EEG signals were collected under controlled conditions to train and test classification accuracy. Multiple channels from the occipital region were analyzed and interpolated to enhance the quality of the data. Principal Component Analysis (PCA) was applied to reduce dimensionality and improve frequency classification performance. However, it was noted that inter-subject variability remained a major factor, requiring individual calibration sessions for each user.

Despite these challenges, the hybrid control system combining SSVEP and IoT-enabled remote access provided an effective and inclusive user experience. However, future iterations must address issues related to electrode comfort, dry-skin impedance, and overall setup complexity for deployment in real-world scenarios.

6 Results

The implemented system successfully demonstrated the feasibility of brain-controlled electric wheelchair navigation using non-invasive EEG signals. Real-time signal acquisition and processing were achieved using the OpenBCI Cyton + Daisy board, with command recognition based on four distinct SSVEP frequencies.

The collected EEG datasets showed clear spectral peaks corresponding to the visual stimuli frequencies. Interpolation across multiple occipital channels improved signal clarity, and PCA further refined feature selection for accurate classification. Tests conducted with volunteer participants revealed an average command recognition accuracy above 70%, with minimal delay in motor response.

The wheelchair was able to move forward, backward, and turn left or right based solely on the user's focused visual attention. Additionally, the integrated web interface enabled remote assistance, enhancing safety and accessibility.

Overall, the system met its objectives of affordability, functionality, and user autonomy. It laid a strong foundation for future enhancements in adaptive EEG interfaces, improved comfort, and broader clinical applications.

7 Conclusion

This work presented the development of a low-cost, brain-controlled electric wheelchair system based on SSVEP signals. By restoring a non-functional wheelchair and integrating it with a Raspberry Pi and an OpenBCI EEG interface, we successfully enabled users to control movement using only their visual attention to flickering stimuli. The implementation of a web-based interface allowed for intuitive interaction and introduced an IoT aspect that permits remote assistance by caregivers.

The system demonstrated that it is feasible to achieve real-time, non-invasive brain control of a wheelchair using affordable and open-source tools. This makes the proposed approach particularly suitable for deployment in low-resource environments, such as in many communities across Bolivia and other developing countries.

Future work will focus on increasing the robustness of the frequency classification algorithm, reducing latency, and improving user comfort through better interface design and electrode placement. Additionally, expanding the control set and incorporating feedback mechanisms could further enhance the system's usability and safety.

List of Abbreviations and Acronyms

- **BCI** – Brain-Computer Interface
- **EEG** – Electroencephalography
- **SSVEP** – Steady-State Visually Evoked Potentials
- **GUI** – Graphical User Interface
- **FFT** – Fast Fourier Transform
- **IoT** – Internet of Things

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colback=white,colframe=black,width=1cm,height=1cm,boxrule=0.5pt,arc=0pt,center title **Student's personal data – 01**

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English ✓

Reading (3) Writing (2) Conversation (3)

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