

Brain-Controlled Assistive Device Using EEG and IOT for Physically Disabled

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Abstract - Physical disabilities often restrict an individual's ability to perform routine tasks independently. Traditional assistive devices generally require physical movement or speech, making them unsuitable for users suffering from paralysis or severe motor impairments. Brain-Computer Interface (BCI) technology provides an alternative communication pathway by enabling direct interaction between the human brain and external devices. This paper presents a Brain-Controlled Assistive Device using Electroencephalography (EEG) and Internet of Things (IoT) technology for physically disabled individuals. EEG signals are acquired through gel electrodes and processed using a BioAmp EXG Pill module. The processed signals are analyzed by an Arduino UNO R4 WiFi microcontroller to detect the user's concentration level. When the concentration exceeds a predefined threshold, a command is transmitted wirelessly through HC-05 Bluetooth modules to a receiver unit, which activates a relay-controlled bulb. The developed prototype demonstrates a low-cost, non-invasive, and user-friendly solution for hands-free appliance control. Experimental results validate the feasibility of converting human concentration-based brain activity into practical device control applications.

Key Words: Brain Computer Interface, BCI, EEG, BioAmp EXG Pill, Arduino UNO R4 WiFi, Bluetooth Communication, Assistive Technology, IoT, Disability Assistance.

I. INTRODUCTION

Physical disabilities caused by paralysis, spinal cord injuries, stroke, and neuromuscular disorders can significantly limit an individual's ability to perform daily activities independently. Many disabled individuals rely on caregivers to operate basic household appliances and

assistive devices. Conventional control methods such as switches, keyboards, and voice commands often require physical movement or speech capability, making them unsuitable for users with severe motor impairments.

Brain-Computer Interface (BCI) technology provides a promising alternative by establishing direct communication between the human brain and external devices. Electroencephalography (EEG) is one of the most widely used non-invasive techniques for acquiring brain signals due to its safety, low cost, and real-time operation. EEG signals reflect the electrical activity of the brain and can be analyzed to identify mental states such as concentration, attention, and relaxation.

Recent advancements in embedded systems, wireless communication, and IoT technologies have enabled the development of affordable EEG-based assistive systems. Several researchers have demonstrated the use of EEG signals for controlling wheelchairs, smart home appliances, and rehabilitation devices. However, many existing systems require complex signal-processing algorithms, expensive hardware, and extensive user training, limiting their practical adoption.

This paper presents a Brain-Controlled Assistive Device using EEG and IoT for physically disabled individuals. The proposed system utilizes EEG gel electrodes and a BioAmp EXG Pill module to acquire brain signals. The signals are processed using an Arduino UNO R4 WiFi microcontroller, and control commands are transmitted wirelessly through HC-05 Bluetooth modules. When the user's concentration level exceeds a predefined threshold, a relay-controlled bulb is activated. The proposed system offers a simple, low-cost, and non-invasive solution for hands-free appliance control, thereby improving independence and quality of life for physically disabled users.

II. LITERATURE REVIEW

Brain–Computer Interface (BCI) technology has emerged as a promising solution for assisting physically disabled individuals by enabling direct communication between the brain and external devices. Electroencephalography (EEG) is widely used in BCI systems due to its non-invasive nature, low cost, and real-time signal acquisition capabilities.

Anusha and Vasanthi (2018) developed an EEG-based wheelchair control system that demonstrated the feasibility of controlling mobility devices through brain signals, although it required extensive user training.

Khemapech et al. (2019) proposed an EEG-based mobility assistance system and highlighted challenges related to signal noise and classification accuracy.

Al-Quraishi and Elamvazuthi (2020) introduced a smart assistive system for appliance control using EEG signals; however, the system involved complex signal-processing techniques and expensive hardware.

Sharma et al. (2022) integrated EEG with IoT technologies for smart home automation, demonstrating improved accessibility through wireless device control.

Patel et al. (2023) presented a low-cost EEG-based assistive device using microcontrollers and wireless communication modules for appliance control.

Rowida Meligy et al. (2024) developed an IoT-based smart wheelchair controlled through EEG signals and integrated health-monitoring features. The study demonstrated the effectiveness of combining EEG and IoT technologies for mobility assistance but involved a complex hardware architecture and higher implementation costs.

The reviewed studies demonstrate the potential of EEG-based assistive systems in healthcare and rehabilitation. However, challenges such as high cost, system complexity, and signal-processing requirements remain. The proposed Brain-Controlled Assistive Device addresses these issues through a simple and affordable architecture using EEG electrodes, BioAmp EXG Pill, Arduino UNO R4 WiFi, HC-05 Bluetooth modules, and relay-based appliance control, providing a practical solution for physically disabled individuals.

III. METHODOLOGY

The proposed Brain-Controlled Assistive Device is developed to assist physically disabled individuals in controlling electrical appliances using brain signals. The system utilizes Electroencephalography (EEG) technology to detect the user's concentration level and

convert it into a control command for operating an external device. The overall system consists of EEG gel electrodes, BioAmp EXG Pill, Arduino UNO R4 WiFi, HC-05 Bluetooth modules, Arduino Nano, relay module, and a bulb as the output appliance.

The working process begins with the acquisition of EEG signals from the user's scalp using non-invasive EEG gel electrodes. These electrodes detect the electrical activity generated by neurons in the brain. Since EEG signals are extremely weak and susceptible to external noise, they are passed to the BioAmp EXG Pill module for amplification and filtering. The BioAmp EXG Pill conditions the signals and provides a clean analog output suitable for processing.

The conditioned EEG signals are then fed to the Arduino UNO R4 WiFi microcontroller. The Arduino continuously monitors the incoming EEG signal values and analyzes variations associated with the user's concentration level. When the user intentionally focuses or concentrates on a specific task, the EEG signal amplitude increases. The microcontroller compares the detected signal with a predefined threshold value. If the threshold is exceeded, a control command is generated.

The generated command is transmitted wirelessly through an HC-05 Bluetooth module configured as a transmitter. At the receiver side, another HC-05 Bluetooth module receives the command and forwards it to an Arduino Nano microcontroller. The Arduino Nano processes the received command and controls a relay module connected to an electrical appliance.

In the proposed prototype, a bulb is used as the assistive output device. When the concentration level exceeds the threshold value, the relay is activated and the bulb switches ON. When the concentration level decreases below the threshold value, the relay is deactivated and the bulb switches OFF. Thus, the system successfully demonstrates brain-controlled appliance operation without requiring any physical movement or manual interaction.

A. System Architecture

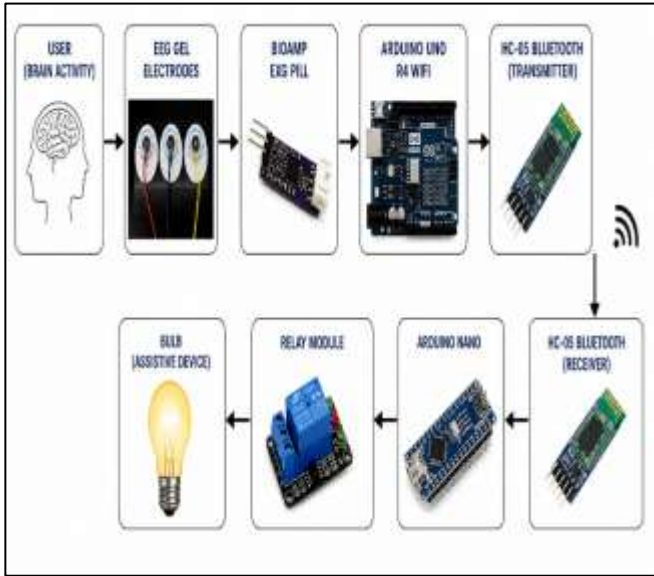


Fig -1: System Architecture Diagram

The system architecture consists of two major sections: a transmitter unit and a receiver unit. The transmitter unit acquires and processes EEG signals, while the receiver unit receives control commands and operates the output device.

B. Hardware Components

1. EEG Gel Electrodes

EEG gel electrodes are non-invasive sensors used to acquire electrical signals generated by the brain. These electrodes are placed on specific positions of the scalp and detect neural activity in the form of voltage fluctuations. The captured EEG signals serve as the primary input to the proposed system.

Specifications:

- Non-invasive signal acquisition
- High sensitivity
- Reusable electrodes
- Suitable for EEG measurements



Fig -2: EEG Gel Electrodes

2. BioAmp EXG Pill

The BioAmp EXG Pill is a compact biomedical signal acquisition module designed to amplify and condition physiological signals such as EEG, ECG, and EMG. It amplifies the weak EEG signals and removes unwanted noise before forwarding them to the microcontroller for analysis.

Specifications:

- Low-noise signal amplification
- Integrated filtering circuitry
- Supports EEG, ECG, and EMG acquisition
- Analog output interface



Fig -3: BioAmp EXG Pill

3. Arduino UNO R4 WiFi

The Arduino UNO R4 WiFi acts as the primary processing unit of the system. It receives conditioned EEG signals from the BioAmp EXG Pill and performs concentration-level analysis. Based on predefined threshold values, it generates control commands for appliance operation.

Specifications:

- Renesas RA4M1 Microcontroller
- Built-in WiFi capability
- 14 Digital I/O Pins
- 6 Analog Input Pins
- Operating Voltage: 5V



Fig -4: Arduino UNO R4 WiFi

4. HC-05 Bluetooth Module

The HC-05 module provides wireless communication between the transmitter and receiver units. One module is configured as a transmitter and the other as a receiver to establish a Bluetooth communication link.

Specifications:

- Bluetooth v2.0+EDR
- Communication Range: 10 meters
- Operating Voltage: 3.3V–5V
- UART Serial Communication



Fig -5: HC-05 Bluetooth Module

5. Arduino Nano

The Arduino Nano is used at the receiver side to process the received Bluetooth commands and control the relay module. Its compact size makes it suitable for embedded control applications.

Specifications:

- ATmega328P Microcontroller
- 14 Digital I/O Pins
- 8 Analog Inputs
- Operating Voltage: 5V



Fig -6: Arduino Nano

6. Relay Module

The relay module acts as an electrically operated switch that isolates the low-voltage control circuitry from the high-voltage appliance circuit. It enables safe switching of electrical appliances using microcontroller outputs.

Specifications:

- 5V Relay Operation
- Opto-isolated Design
- High Current Switching Capability
- Suitable for AC and DC Loads

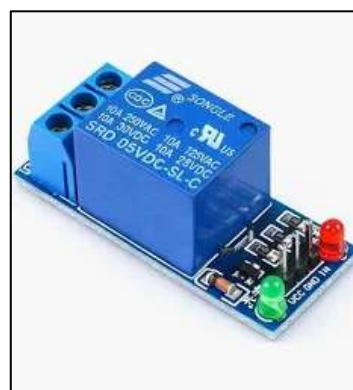


Fig -7: Relay Module

7. Bulb (Output Device)

A bulb is used as the output appliance in the proposed prototype to demonstrate successful brain-controlled operation. The bulb turns ON when the user achieves the required concentration level and turns OFF when concentration decreases.



Fig -8: Bulb

C. Experimental Setup

The complete experimental setup consists of EEG electrodes connected to the BioAmp EXG Pill, Arduino UNO R4 WiFi, HC-05 Bluetooth modules, Arduino Nano, relay module, and bulb. The setup was tested under different concentration conditions to evaluate the performance of the proposed system. The experimental results confirmed successful wireless transmission of EEG-based control commands and reliable operation of the output appliance.



Fig -9: Complete Experimental Setup

IV. RESULTS

The proposed Brain-Controlled Assistive Device was successfully implemented and experimentally validated to assess its capability of controlling an electrical appliance using Electroencephalography (EEG) signals. EEG signals generated by the user's brain activity were acquired through gel-based electrodes and amplified using the BioAmp EXG Pill module. The amplified signals were then processed by the Arduino UNO R4

WiFi, which continuously monitored the user's concentration level in real time.

During experimentation, it was observed that when the user intentionally focused and maintained a higher level of concentration, the EEG signal amplitude exceeded the predefined threshold value. Consequently, a control command was generated and transmitted wirelessly through the HC-05 Bluetooth module to the receiver unit. Upon receiving the command, the Arduino Nano activated the relay module, resulting in the switching ON of the connected electrical bulb. Conversely, when the user's concentration level decreased below the threshold value, the relay was deactivated, causing the bulb to switch OFF.

Figure 10 presents the experimental validation of the proposed system. Figure 10(a) illustrates the **condition** when the user's concentration level remains below the threshold value, and therefore the bulb remains OFF. Figure 10(b) shows the condition when the user achieves sufficient concentration, causing the EEG signal to exceed the threshold value and resulting in the successful activation of the bulb. These observations confirm the system's ability to translate brain activity into appliance control commands without requiring any physical interaction.



Fig -10: Experimental validation of the proposed Brain-Controlled Assistive Device: (a) Low concentration state with bulb OFF



Fig -10:Experimental validation of the proposed Brain-Controlled Assistive Device: (b) High concentration state with bulb ON.

The developed prototype demonstrated reliable real-time operation and stable wireless communication between the transmitter and receiver units. The response of the system was consistent across multiple trials, indicating effective EEG signal acquisition, processing, and command transmission. The successful operation of the relay-controlled appliance validates the feasibility of utilizing concentration-based EEG signals for assistive control applications.

The obtained results confirm that Brain-Computer Interface (BCI) technology can provide an alternative communication and control mechanism for individuals with severe physical disabilities. By enabling hands-free appliance control through brain signals, the proposed system has the potential to enhance independence, accessibility, and quality of life for users with limited motor capabilities. Furthermore, the low-cost hardware implementation demonstrates the practicality of developing affordable BCI-based assistive solutions for real-world applications.

V. DISCUSSION

The experimental results demonstrate the feasibility of controlling an electrical appliance using EEG-based brain signals. The proposed system successfully converts the user's concentration-related brain activity into control commands, enabling hands-free operation of a bulb. This validates the effectiveness of Brain-Computer Interface (BCI) technology as a potential assistive solution for physically disabled individuals who may have limited or no motor capabilities.

The use of EEG gel electrodes and the BioAmp EXG Pill provided effective acquisition and conditioning of brain signals, while the Arduino UNO R4 WiFi successfully processed the incoming data and detected concentration levels. Furthermore, the HC-05 Bluetooth modules ensured reliable wireless communication between the transmitter and receiver units, allowing real-time appliance control without the need for physical connections.

One of the major advantages of the proposed system is its low-cost and non-invasive design. Unlike many advanced BCI systems that require expensive hardware and complex signal-processing techniques, the proposed architecture utilizes readily available components and a simple threshold-based approach for concentration detection. This makes the system affordable, easy to implement, and suitable for educational, research, and assistive applications.

However, the performance of the system depends on factors such as proper electrode placement, signal quality, and the user's ability to maintain concentration. EEG signals are highly sensitive to noise and external interference, which may affect system performance under certain conditions. Despite these challenges, the developed prototype demonstrated stable operation during testing and successfully achieved concentration-based control of the output device.

Overall, the proposed Brain-Controlled Assistive Device provides a practical demonstration of EEG-based appliance control and highlights the potential of BCI technology in enhancing the independence and quality of life of physically disabled individuals. Future improvements can focus on increasing system accuracy, reducing noise effects, and extending the system to control multiple appliances and smart-home devices.

VI. CONCLUSIONS

The developed Brain-Controlled Assistive Device using EEG and IoT technology demonstrates the feasibility of controlling electrical appliances through concentration-based brain activity. The proposed system successfully acquires EEG signals using gel electrodes, processes them through the BioAmp EXG Pill and Arduino UNO R4 WiFi, and transmits control commands wirelessly using HC-05 Bluetooth modules. The experimental implementation confirmed that the user's concentration level could be utilized to control a relay-operated bulb without requiring any physical interaction.

Although the developed prototype successfully demonstrated real-time appliance control, the

performance of the system is influenced by factors such as signal noise, electrode placement, and variations in user concentration. In some cases, maintaining a stable concentration level for prolonged periods may affect the consistency of system operation. Therefore, further improvements in signal acquisition and processing techniques are necessary to enhance system reliability and responsiveness.

The proposed system can be further improved by collecting a larger set of EEG data and implementing advanced signal-processing or machine-learning algorithms for more accurate concentration detection. The use of additional EEG channels and improved electrode configurations may also increase signal quality and system accuracy. Furthermore, integrating multiple control commands could enable the operation of several appliances simultaneously, thereby expanding the functionality of the system.

The results obtained from this work indicate that EEG-based Brain-Computer Interface technology has significant potential for assistive applications. With further optimization and testing, the proposed system could be effectively deployed in real-world environments to improve the independence and quality of life of physically disabled individuals. Future work will focus on enhancing accuracy, supporting multiple device control, and evaluating system performance under different users and operating conditions.

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