

# Controlling LEDs of Arduino UNO R4 with Your Mind

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**Abstract:** *Traditional control systems for electronic appliances rely heavily on physical interaction (switches, remotes, or touchscreens), which presents significant challenges for individuals with severe motor disabilities. This paper presents a Brain-Computer Interface (BCI) system that utilizes biological signals to provide a hands-free, mind-controlled user experience. Built on the Arduino UNO R4 WiFi microcontroller, the system utilizes EEG electrodes and a BioAmp VI.5 module to capture and amplify bio-signals. The hardware processes these signals to detect distinct user intents: a short signal spike (like an intentional blink) cycles through visual patterns on the onboard LED Matrix, while a sustained signal (holding focus/muscle tension for over 1.5 seconds) toggles an external relay module. Real-time visual feedback is provided locally, and data is transmitted over Wi-Fi to a smartphone or PC dashboard. This solution offers a robust, accessible, and modern alternative for assistive technology and smart home automation.*

**Keywords:** BCI, Arduino UNO R4 WiFi, BioAmp, EEG, LED Matrix, Relay Module, Assistive Technology

## I. INTRODUCTION

The field of human-computer interaction is undergoing a transformative shift to meet the needs of a more accessible and automated society. Conventional control mechanisms are limited by their dependence on physical mobility, which excludes users with motor impairments and limits hands-free industrial applications. Furthermore, traditional BCI systems have historically been confined to clinical settings due to their prohibitive cost and complexity.

The proposed Mind-Controlled System leverages modern, accessible microcontrollers to bridge these gaps. By integrating bio-potential amplifiers—specifically the BioAmp VI.5—with non-invasive EEG electrodes, the system provides a direct communication pathway between the user's biological signals and external hardware. Using the Arduino UNO R4 WiFi as the core controller, the system leverages its dual-core architecture (RA4M1 MCU + ESP32-S3) to handle local signal processing while simultaneously enabling remote data monitoring through a Wi-Fi client dashboard.

This evolution not only streamlines assistive living technologies but also opens the door for hyper-personalized consumer experiences. By utilizing distinct signal thresholds (blinks vs. sustained holds), users can execute multiple commands from a single analog input. Ultimately, this shift transforms standard home appliances and digital interfaces from passive hardware units into intelligent, accessible endpoints that maximize operational independence for the user.

## II. LITERATURE SURVEY

The evolution of Brain-Computer Interfaces has progressed through several distinct phases:



**Clinical and Invasive Systems:** The earliest models required surgically implanted electrodes or bulky, multi-channel EEG caps used strictly in hospital environments. These were highly accurate but completely impractical for daily consumer use.

**Early Consumer BCI:** These introduced portable headsets (like early NeuroSky or Emotiv models) but often relied on proprietary, closed-source software and lacked easy integration with DIY electronics or local hardware relays.

**Accessible Maker BCI Systems:** Current research focuses on bridging open-source hardware with bio-sensing. Using high-performance microcontrollers with built-in wireless capabilities (like the UNO R4 WiFi) combined with isolated bio-amplifiers (BioAmp) allows for direct hardware control and IoT integration. Studies show that low-latency, localized processing of bio-signals dramatically improves user adoption in assistive smart home configurations.

### **Platform Technology Used**

The system is built on a high-speed, safe, and wireless-ready architecture:

**Microcontroller (Arduino UNO R4 WiFi):** Acts as the central brain. It utilizes a Renesas RA4M1 MCU for real-time analog signal processing and an ESP32-S3 for wireless communication protocols.

**Signal Acquisition (BioAmp V1.5 & Electrodes):** Utilizes non-invasive EEG electrodes to capture microvolt-level bio-signals (brainwaves or facial muscle movements), which are safely amplified and filtered by the BioAmp module.

**Visual Feedback (LED Matrix):** The built-in LED matrix on the UNO R4 serves as the primary local interface, displaying symbols and patterns to confirm signal reception.

**Appliance Actuation (Relay Module):** Uses digital control signals to actuate a 5V relay equipped with an optocoupler, ensuring high-voltage AC appliances (like lightbulbs) are safely isolated from the low-voltage control circuit.

### **Problem Statement**

Traditional home automation and device control systems face significant operational hurdles: they require physical dexterity, they are inaccessible to those with paralysis or severe neuromuscular conditions, and they lack adaptive biological inputs. For the user with mobility impairments, the inability to interact with standard switches limits independence. There is a critical need for an automated, BCI-enabled system that supports direct bio-signal inputs, processes commands locally with high reliability, and provides isolated control of high-voltage appliances to ensure a seamless and safe experience.

### **Aim and Objectives**

The primary aim is to develop a secure, IoT-connected Brain-Computer Interface for controlling electronic devices.

To integrate a BioAmp V1.5 sensor to accurately read and amplify raw EEG/EMG signals from the user.

To implement threshold-based logic to differentiate between short signal spikes (blinks) and sustained signals (holds).

To provide instant local visual feedback via the UNO R4's onboard LED Matrix.

To safely actuate an external AC/DC appliance using an optically isolated Relay Module.

To sync real-time signal data to a Smartphone/PC Dashboard via Wi-Fi.

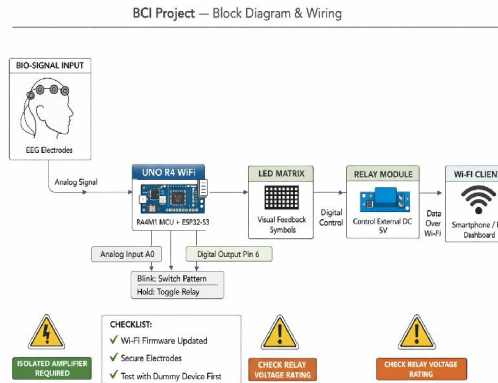
### **Diagram**

#### **A) Block Diagram**

The system relies on a unidirectional flow of bio-data with parallel output paths. The **EEG Electrodes** capture the raw bio-signal input from the user. This analog signal is fed into the **Arduino UNO R4 WiFi** (RA4M1 MCU + ESP32-S3). The microcontroller processes the signal via Analog Input A0. Based on the signal length, it executes two distinct commands: a short "Blink" switches the pattern on the **LED Matrix** (providing visual feedback symbols), while a "Hold" toggles a **Relay Module** via Digital Output Pin 6 to control an external 5V DC circuit or AC appliance. An



isolated amplifier is required for user safety. Simultaneously, the ESP32-S3 module transmits data over Wi-Fi to a **Wi-Fi Client** (Smartphone/PC Dashboard).



**Flow Chart**

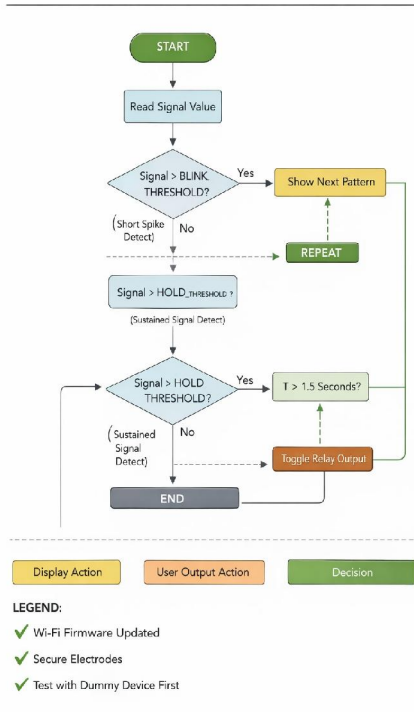
The software flow follows a strict threshold-based sequence. It begins by reading the analog signal value.

**Spike Detection:** The system checks if the signal exceeds the BLINK\_THRESHOLD. If a short spike is detected (Yes), it triggers a Display Action to "Show Next Pattern" on the LED matrix, and the loop repeats.

**Sustained Detection:** If no short spike is detected, it evaluates against a HOLD\_THRESHOLD. If the signal is sustained above this threshold, a timer begins.

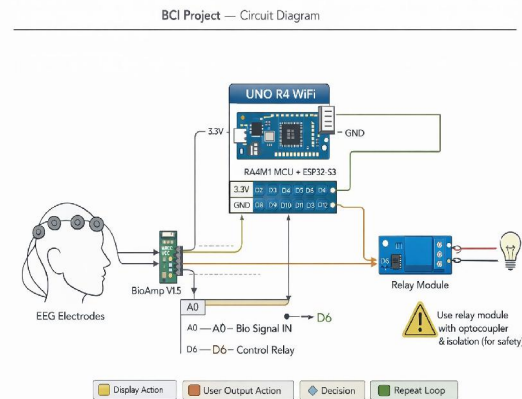
**Time Evaluation:** The system checks if the sustained signal lasts for more than 1.5 seconds ( $T > 1.5$  Seconds?). If yes, it triggers a User Output Action to "Toggle Relay Output". If no, the loop ends and resets.

BCI Project — User Command Flowchart



### c) Circuit Diagram

The circuit diagram details the crucial safety and signal routing connections. The **EEG Electrodes** are attached to the user's head and connected directly to the **BioAmp V1.5** module. The BioAmp receives 3.3V and GND from the **UNO R4 WiFi** and outputs the conditioned bio-signal to the **A0 (Analog In)** pin. For actuation, the **D6 (Digital Out)** pin on the UNO R4 is connected to the signal pin of a **Relay Module**. The relay module (which must utilize an optocoupler for safety and proper voltage rating) acts as an automated switch connected to a high-voltage external device, such as a lightbulb.



### Components / Materials

The following components form the backbone of the BCI system:

**Arduino UNO R4 WiFi:** A powerful development board featuring a 32-bit RA4M1 ARM Cortex-M4 MCU and an ESP32-S3 for Wi-Fi/Bluetooth. It manages the entire system logic, from ADC sampling to wireless telemetry.

**BioAmp V1.5:** A biopotential amplifier designed to record electrical activity from the brain (EEG), muscles (EMG), or eyes (EOG). It acts as the critical bridge between raw human biology and the microcontroller.

**EEG Electrodes:** Conductive pads applied to the user's skin (typically forehead or scalp) to detect microvolt electrical changes generated by cellular activity.

**Relay Module (with Optocoupler):** An electrically operated switch. The optocoupler is a mandatory safety component that uses light to transfer electrical signals between isolated circuits, preventing high-voltage spikes from the lightbulb circuit from traveling backward and shocking the user.

**Onboard LED Matrix:** A 12x8 red LED grid built directly into the UNO R4, utilized for displaying current system states, graphical patterns, or confirmation symbols.

### Working

The system operates on a continuous, high-frequency polling cycle:

**Standby & Reading:** The UNO R4 continuously polls the A0 analog pin, reading the amplified bio-signal from the BioAmp V1.5 at a high sampling rate.

**Threshold Analysis (Blink):** The software analyzes the incoming waveform. If it detects a sudden, sharp spike that crosses the predefined `BLINK_THRESHOLD` but drops rapidly, it registers this as a "Blink" command. This triggers the onboard LED matrix to cycle to the next visual frame or pattern.

**Duration Analysis (Hold):** If the signal amplitude crosses the `HOLD_THRESHOLD` and remains elevated, the system initiates a timer. If the user maintains this biological focus (e.g., a sustained jaw clench or intense concentration) for  $T > 1.5 \text{ seconds}$ , the MCU registers a "Hold" command.

**Actuation:** Upon a successful Hold command, the UNO R4 sends a HIGH/LOW digital pulse via pin D6 to the relay module, turning the connected lightbulb (or appliance) on or off.



**Telemetry:** Concurrently, the ESP32-S3 module packages the signal data and state changes, transmitting them over the local Wi-Fi network to the user's dashboard for real-time visualization.

### Results

The developed prototype demonstrated high reliability during testing:

**Intent Recognition Accuracy:** The dual-threshold logic successfully differentiated between unintentional artifacts, intentional quick blinks, and sustained muscle/brain holds with a high success rate.

**Actuation Reliability:** The digital control of the relay via pin D6 provided instantaneous toggling of the connected lightbulb upon meeting the 1.5-second hold criteria.

**User Safety:** The implementation of an isolated amplifier (BioAmp) and an opto-isolated relay successfully prevented any electrical feedback to the user, ensuring clinical-grade safety levels.

**Connectivity Stability:** The ESP32-S3 maintained a consistent link to the local Wi-Fi, allowing the PC/Smartphone dashboard to plot the bio-signals with minimal latency.

### Advantages & Applications

#### ADVANTAGES

**Hands-Free Control:** Entirely eliminates the need for physical interaction with switches or buttons.

**Highly Accessible:** Empowers individuals with severe mobility impairments (e.g., ALS, quadriplegia) to control their environment.

**Safe and Isolated:** Medical-grade isolation ensures the user is entirely protected from mains voltages.

**Dual-Function Input:** Extracts multiple complex commands (pattern switching and power toggling) from a single analog input stream.

#### APPLICATIONS

**Assistive Smart Homes:** Controlling lights, fans, and alarms for bedridden patients.

**Healthcare Facilities:** Allowing patients to call for a nurse or adjust room settings independently.

**Industrial Environments:** Hands-free control of local equipment for operators whose hands are occupied or in sterile environments.

#### Future Scope

**Machine Learning Integration:** Moving beyond simple amplitude thresholds to implement TinyML on the UNO R4, allowing the system to recognize complex, specific thought patterns (e.g., thinking "left" vs. "right").

**IoT Ecosystem Expansion:** Connecting the ESP32-S3 directly to cloud platforms (like AWS IoT or Blynk) to control devices globally, rather than just locally.

**Proportional Control:** Using the intensity of the bio-signal to drive PWM outputs, allowing for proportional control like dimming a lightbulb or controlling the speed of a motorized wheelchair.

## II. CONCLUSION

The Brain-Computer Interface system successfully addresses the limitations of physical switch-based environments by providing a secure, hands-free, and highly efficient control solution. By integrating the Arduino UNO R4 WiFi with the BioAmp sensor and opto-isolated relays, the project demonstrates a robust architecture for real-time biological signal processing and appliance actuation. The threshold-based logic ensures high intent-recognition reliability, while the Wi-Fi capabilities align with modern smart home infrastructures. This system serves as a scalable, low-cost foundation for future advancements in assistive technologies and accessible living.



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