Final Project Bluetooth-Controlled RGB LED Strip

IOT102-SE1817, Group 2

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Abstract

In the era of smart homes and IoT (Internet of Things), intelligent lighting systems have gained significant attention due to their efficiency, flexibility, and automation capabilities. This project, "Bluetooth-Controlled RGB LED Strip," aims to develop a smart LED system that can be controlled via Bluetooth and react to ambient sound levels. The system utilizes an Arduino Uno as the main microcontroller, interfaced with an HC-05 Bluetooth module for wireless communication, a WS2812B RGB LED strip for dynamic lighting effects, and a sound sensor to detect audio levels in the environment.

The proposed system is designed to operate in three modes: (1) an automatic mode, where pre-programmed LED effects are displayed, (2) a sound-reactive mode, where LED brightness and colors change according to real-time audio input, and (3) a manual mode, where users can control LED effects via a smartphone application using Bluetooth. The software implementation is done using Arduino programming, with FastLED and SoftwareSerial libraries to handle LED animations and Bluetooth communication.

The system was tested in different environments to evaluate its responsiveness, power efficiency, and user experience. Results show that the Bluetooth connectivity is stable within a range of 10 meters, and the sound-reactive mode effectively maps audio intensities to LED animations, providing an immersive lighting experience. Compared to conventional static LED strips, this system enhances user interaction and automation while maintaining a low-cost and scalable design. This project demonstrates a practical application of IoT in home automation and entertainment lighting, with potential future enhancements such as WiFi control and AI-based lighting adaptation.

I. INTRODUCTION

The development of IoT-based smart lighting systems has revolutionized home automation, providing users with more control, energy efficiency, and interactivity. Traditional LED lighting solutions offer only basic functionalities, such as static illumination or simple remote switching, which limits their adaptability to different user preferences and environmental conditions [1]. With the advancements in wireless communication and embedded systems, integrating IoT technology into lighting solutions has become a promising approach. This research focuses on designing a Bluetooth-controlled RGB LED strip system that allows users to wirelessly control LED effects while also enabling sound-reactive lighting.

Several studies have explored the potential of IoT in lighting automation. For instance, Tellez et al. [1] introduced an IoT framework for smart lighting that enhances energy efficiency and user comfort. Similarly, Cai et al. [2] proposed an intelligent LED control system that dynamically adjusts brightness based on external inputs. However, many existing solutions rely on complex and expensive WiFi-based infrastructure, which may not be feasible for small-scale applications. In contrast, Bluetooth technology provides a low-cost, easy-to-implement alternative for short-range communication in smart lighting.

This project proposes a Bluetooth and sound-reactive LED system using an Arduino Uno, an HC-05 Bluetooth module, and a WS2812B LED strip. Unlike conventional LED controllers that require manual switching or basic remote control, this system introduces three operation modes: an automatic mode with pre-defined animations, a sound-reactive mode where LEDs respond to environmental audio, and a manual mode where users can customize lighting effects via a smartphone. The use of FastLED and SoftwareSerial libraries in Arduino facilitates smooth LED transitions and real-time Bluetooth communication.

By implementing this system, we aim to demonstrate the practical applications of IoT in smart lighting. The study evaluates key performance factors, including Bluetooth connectivity range, real-time responsiveness to sound levels, and power consump- tion efficiency. The results provide valuable insights into the feasibility of using Bluetooth-based control for dynamic LED systems in home automation and entertainment applications. Future improvements may include WiFi-based cloud integration, AI-driven lighting adaptation, and voice-controlled operation to further enhance system functionality and user experience.

II. METHODS AND MATERIALS

A. System Model and Block Diagram

The Bluetooth-Controlled RGB LED Strip system is designed to function as an interactive and intelligent lighting solution that incorporates wireless Bluetooth communication and sound-reactive capabilities. This system enhances ambient lighting by providing three different operating modes: Automatic Mode, Sound-Reactive Mode, and Manual Mode. In Automatic

Mode, the LED strip runs through a predefined sequence of lighting effects continuously, making it ideal for decorative or mood lighting. In Sound-Reactive Mode, the LED brightness and colors dynamically adjust based on the real-time intensity of ambient sounds, creating a visually immersive experience synchronized with the surrounding audio environment. Lastly, Manual Mode allows users to take full control of the LED effects using a Bluetooth-connected mobile application, enabling them to customize colors, brightness levels, and effect patterns according to their preferences.

At the core of the system is the Arduino Uno microcontroller, which serves as the primary control unit responsible for processing inputs and executing LED animations. The HC-05 Bluetooth module establishes wireless communication between the Arduino and the mobile application, allowing users to send commands remotely. Additionally, a WS2812B RGB LED strip is used as the primary visual output, enabling the display of complex and smooth lighting animations due to its individually addressable LED feature. A sound sensor is also integrated into the system, continuously monitoring the ambient noise levels and transmitting real-time data to the microcontroller. This sensor plays a crucial role in Sound-Reactive Mode, allowing the LEDs to pulsate and change colors in response to music or environmental sounds.

The system operates through a well-structured process. First, the mobile application sends user-defined commands to the HC-05 Bluetooth module, which then transmits these signals to the Arduino Uno for processing. Based on the received command, the Arduino decides whether to activate a specific lighting effect, adjust brightness levels, or switch between operating modes. If the Sound-Reactive Mode is enabled, the sound sensor continuously captures surrounding noise levels and converts them into digital signals. These signals are processed by the microcontroller, which subsequently modifies the LED brightness and color in synchronization with the detected sound. Finally, the WS2812B LED strip dynamically executes the lighting patterns based on the selected mode and received input, creating an engaging and interactive visual experience.

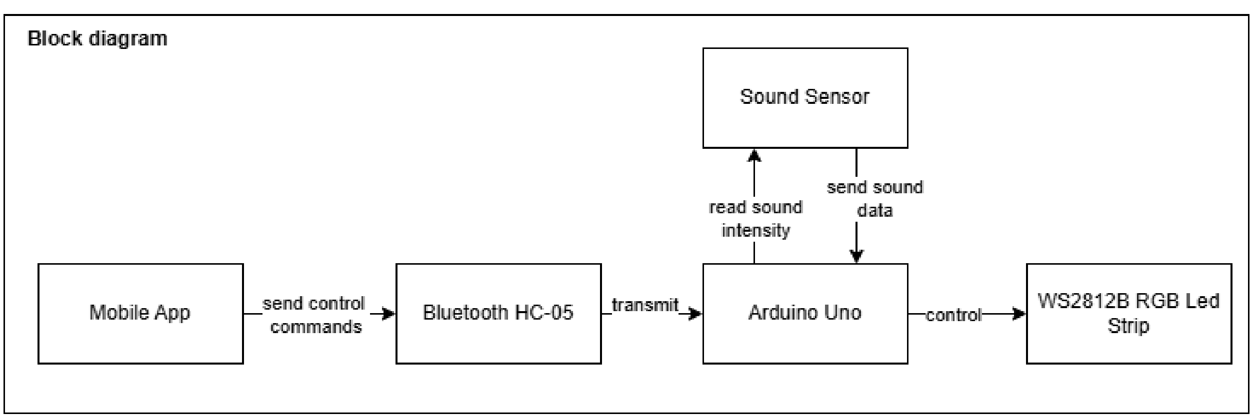

Fig. 1. Block diagram of the developed system.

As depicted in Figure 1, the system architecture clearly outlines the interaction between its core components. The flow of data from the sound sensor and mobile application to the microcontroller and LED strip demonstrates the structured communication that allows the system to function seamlessly. This model enables efficient real-time control of lighting effects while maintaining user-friendly operation. The integration of Bluetooth communication further enhances the usability of the system, enabling remote control without the need for direct physical interaction. Such an implementation makes this lighting system suitable for home automation, event lighting, and interactive art installations, offering users a unique way to enhance their environment through technology-driven lighting solutions.

B. Components and Peripheral Devices

The system consists of multiple carefully selected components that ensure optimal performance, ease of integration, and reliability in IoT-based smart lighting applications. The integration of these components enables the development of a Bluetooth - controlled RGB LED system that is capable of responding dynamically to user input and environmental sound levels. The system incorporates an Arduino Uno as the central microcontroller, a HC-05 Bluetooth module for wireless communication, a sound sensor for real-time sound detection, and a WS2812B RGB LED strip for visually engaging light effects. These components were chosen based on previous studies that highlight the effectiveness of IoT-based lighting systems [1], [2].

1) Arduino Uno: The Arduino Uno is responsible for handling the system's logic, including receiving Bluetooth commands, processing sensor input, and controlling the LED strip. It is an 8-bit microcontroller featuring 14 digital input/output pins, with six supporting PWM, making it highly suitable for LED intensity modulation. Additionally, it has six analog input pins, allowing it to efficiently read signals from various sensors, such as the sound sensor utilized in this project. With a 16 MHz clock speed, the Arduino Uno processes data in real-time, ensuring smooth LED transitions and prompt responses to external commands.

Fig. 2. Arduino Uno microcontroller board.

2) Board Test: It is a prototype circuit board that helps engineers and electronics students design and test circuit prototypes without the need for soldering components. It is convenient for experimentation and rapid circuit development.

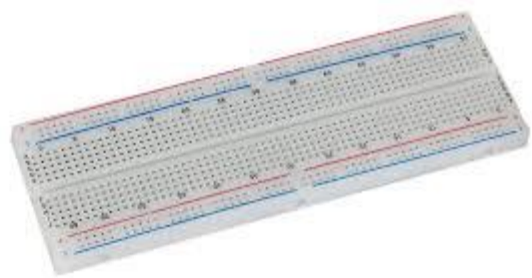

Fig. 3. Board Test

3) Bluetooth HC-05 Module: The HC-05 Bluetooth module provides a stable wireless communication link between the Arduino Uno and a smartphone application, enabling remote control of LED lighting effects. It supports both master and slave modes and operates via serial communication (TX/RX). The module allows for an operational range of up to 10 meters, making it suitable for home automation applications [3]. Users can send commands to modify LED brightness, color, or animation modes via a mobile application, demonstrating the flexibility of Bluetooth-controlled lighting systems.

Fig. 4. HC-05 Bluetooth module used for wireless communication.

4) Sound Sensor: A sound sensor module is integrated into the system to allow for real-time audio detection, a feature that makes the lighting system interactive. This sensor is composed of a microphone, a potentiometer to adjust sensitivity, and an LM393 comparator that processes the incoming sound signals. In Sound-Reactive Mode, the system continuously monitors sound

intensity and dynamically adjusts the LED brightness or color in response to environmental noise, making it suitable for music-synchronized lighting applications [4].

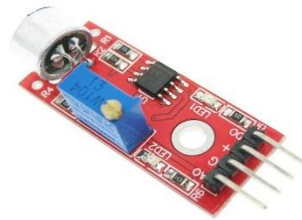

Fig. 5. Sound sensor module for detecting ambient sound levels.

5) WS2812B RGB LED Strip: The WS2812B RGB LED strip is an individually addressable LED strip that enables precise control over each LED using a single data line. It offers 24-bit color depth, allowing for seamless color transitions and dynamic animations. The LED strip supports high-speed PWM control, making it capable of rendering smooth lighting effects. This component is programmed using the FastLED library, which facilitates efficient control and modulation of LED behavior. Recent studies emphasize the benefits of addressable LED strips in IoT-based lighting solutions, particularly in enhancing energy efficiency and visual appeal [5].

Fig. 6. WS2812B RGB LED Strip used in the lighting system.

6) Circuit Schematic: The system's hardware configuration and interconnections are illustrated in Figure 6. The Arduino Uno acts as the central controller, processing Bluetooth commands received from the HC-05 module and audio signals from the sound sensor. These inputs determine the appropriate LED behavior, which is then transmitted to the WS2812B LED strip via a single data pin (D2). The schematic ensures proper power distribution and seamless data transmission between all components.

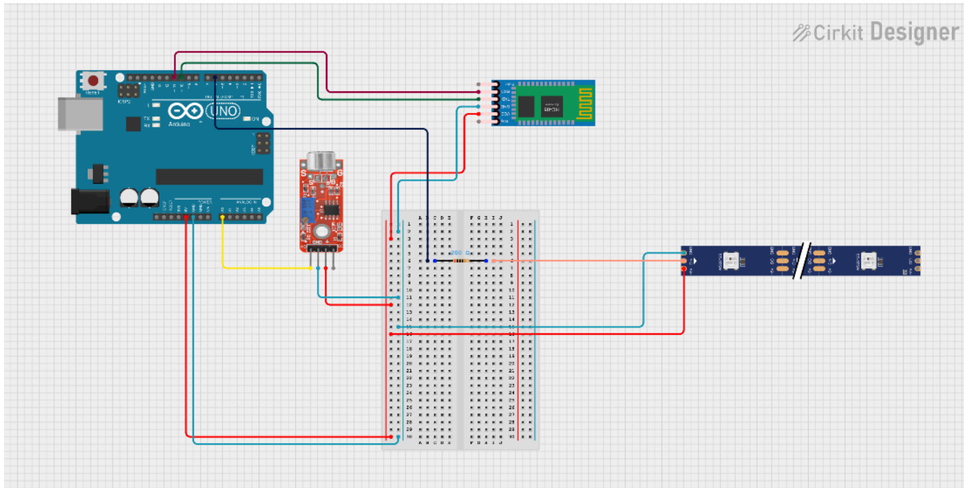

Fig. 7. Circuit schematic illustrating hardware interfacing.

7) Hardware Interfacing Table: Table I provides a detailed overview of the pin mappings between the Arduino Uno and its associated peripherals. This structured representation ensures efficient wiring and logical organization of the system components.

TABLE I

HARDWARE INTERFACING BETWEEN ARDUINO UNO AND ITS COMPONENTS.

Arduino Uno	Sound Sensor	Bluetooth HC-05	WS2812B LED Strip	Power
GND	GND	GND	GND	GND
5V	VCC (5V)	VCC (3.3V)	5V	5V/3.3V
A0	Analog Output	-	-	-
D10	-	TX	-	-
D11	-	RX	-	-
D2	-	-	Control Signal (D2)	-

The careful selection of components and their efficient interconnection ensures the successful implementation of an IoT-based smart lighting system. The Arduino Uno acts as a robust microcontroller, enabling smooth system operation. The HC-05 Bluetooth module allows for wireless user control, while the sound sensor enhances the interactive aspect of the LED strip. The WS2812B LED strip, known for its high color depth and addressability, delivers dynamic lighting effects that respond in real-time to both user commands and environmental sound cues. This integration follows best practices in IoT and smart home automation [6], [7], ensuring an efficient, low-cost, and highly functional lighting system.

C. Software Programming

The software implementation of the Bluetooth-Controlled RGB LED Strip system is developed using the Arduino Integrated Development Environment (IDE) and programmed in Arduino C++. This platform is chosen due to its extensive library support, ease of use, and compatibility with various IoT modules, making it ideal for embedded system development [1]. The firmware is structured to handle Bluetooth communication, sound detection, and LED control, ensuring seamless operation in real time. The main objective of the software component is to allow dynamic switching between different operating modes, provide interactive user control via a mobile application, and enable real-time response to environmental sound levels.

To optimize system functionality, several essential libraries are integrated into the program. The FastLED library is employed to manage the WS2812B RGB LED strip efficiently, enabling smooth transitions and animations with minimal processing overhead. The SoftwareSerial library facilitates communication between the Arduino Uno and the HC-05 Bluetooth module, allowing serial data exchange on alternative digital pins, preventing conflicts with the primary hardware serial interface. The integration of these libraries enhances system performance and ensures precise control over LED animations, while maintaining stable wireless communication [2].

The system workflow follows a structured sequence of operations to maintain optimal performance. Upon startup, the Arduino Uno initializes all hardware components, sets up serial communication, and configures the LED strip. By default, the system operates in Automatic Mode, displaying a predefined sequence of lighting effects. The system continuously listens for incoming Bluetooth commands from the mobile application. If a command is received, the system processes the instruction and updates the LED strip accordingly. If the Sound-Reactive Mode is activated, the sound sensor begins capturing real-time ambient noise levels, dynamically adjusting the LED brightness and effects based on the detected sound intensity. This structured process ensures efficient and responsive system behavior, providing users with an interactive lighting experience.

The Bluetooth HC-05 module is configured using AT commands, which allow setting the module to function in either master or slave mode. In this project, it operates in slave mode, passively receiving commands from a paired mobile application. The default baud rate of 9600 bps is used to maintain stable serial communication with the Arduino Uno. The setup process includes connecting the TX and RX pins of the HC-05 module to digital pins D10 and D11 on the Arduino Uno, ensuring proper voltage levels for reliable operation. Configuration is performed using a serial terminal application, where commands such as setting the device name, pairing password, and role mode are executed to prepare the module for communication with a smartphone.

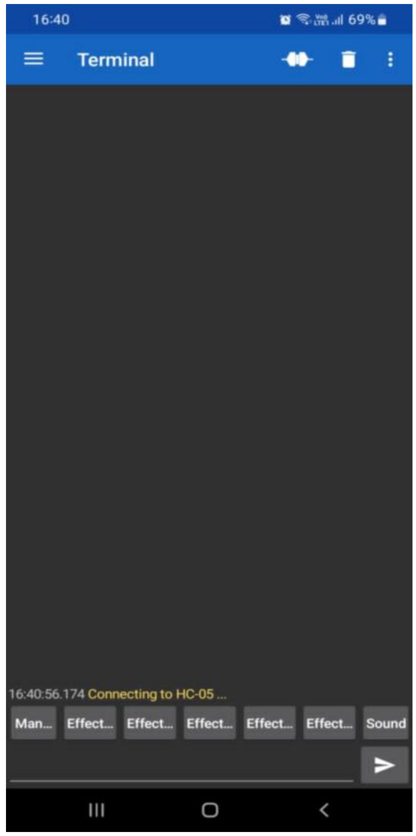

Fig. 8. Bluetooth HC-05 setup and configuration process.

To remotely control the LED strip, a mobile application is used to transmit Bluetooth commands to the HC-05 module. The mobile interface can be developed using platforms such as MIT App Inventor or third-party Bluetooth terminal applications available on Android and iOS devices. The configuration process involves pairing the HC-05 module with a smartphone, opening the Bluetooth application. These commands include options for switching between different modes, adjusting brightness levels. For instance, sending “A” activates Automatic Mode, “S” enables Sound-Reactive Mode, and “M” allows Manual Mode, where users can precisely control LED animation.

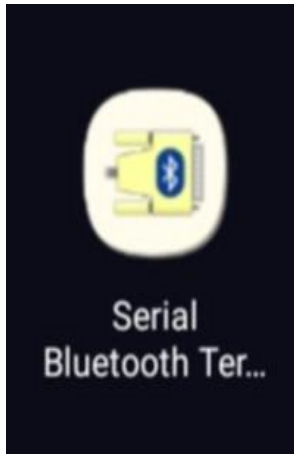

Fig. 9. Mobile application interface for Bluetooth control.

The Arduino Uno continuously monitors Bluetooth inputs and sound intensity levels to determine the appropriate LED behavior. If a Bluetooth command is received, the microcontroller processes the input, switches to the selected mode, and updates the LED strip accordingly. In Sound-Reactive Mode, the sound sensor captures ambient noise levels, and the system maps the detected intensity to LED brightness, providing a real-time reactive lighting experience. The FastLED library is then used to update the WS2812B LED strip, ensuring smooth color transitions and animations. This real-time processing mechanism allows the system to respond dynamically to user inputs and environmental changes, enhancing the overall user experience [4].

To optimize system efficiency, power consumption reduction techniques are implemented. When no Bluetooth command is received for an extended period, the Arduino Uno enters a low-power mode, reducing energy consumption while awaiting new input. Additionally, optimizations in sound processing algorithms minimize latency, ensuring that LED effects react instantaneously to changes in ambient noise levels.

Overall, the software architecture of the Bluetooth-Controlled RGB LED Strip system is designed to deliver a seamless and interactive user experience. By incorporating efficient Bluetooth communication, dynamic sound-based LED responses, and optimized processing algorithms, the system presents a robust IoT lighting solution. The ability to transition smoothly between operational modes, combined with real-time responsiveness, makes this system highly effective for smart home and entertainment applications [6], [7].

D. Programming Flowchart

The operational logic of the Bluetooth-Controlled RGB LED Strip system follows a structured decision-making process that determines how the system transitions between different modes. The system begins with an initialization phase, during which all hardware components, including the Arduino Uno, Bluetooth HC-05 module, sound sensor, and WS2812B RGB LED strip, are set up and configured. By default, the system operates in Automatic Mode, displaying a sequence of pre-programmed LED animations. However, users can switch to either Sound-Reactive Mode or Manual Mode by sending Bluetooth commands from a mobile application [3]. This transition allows for a more dynamic and interactive lighting experience.

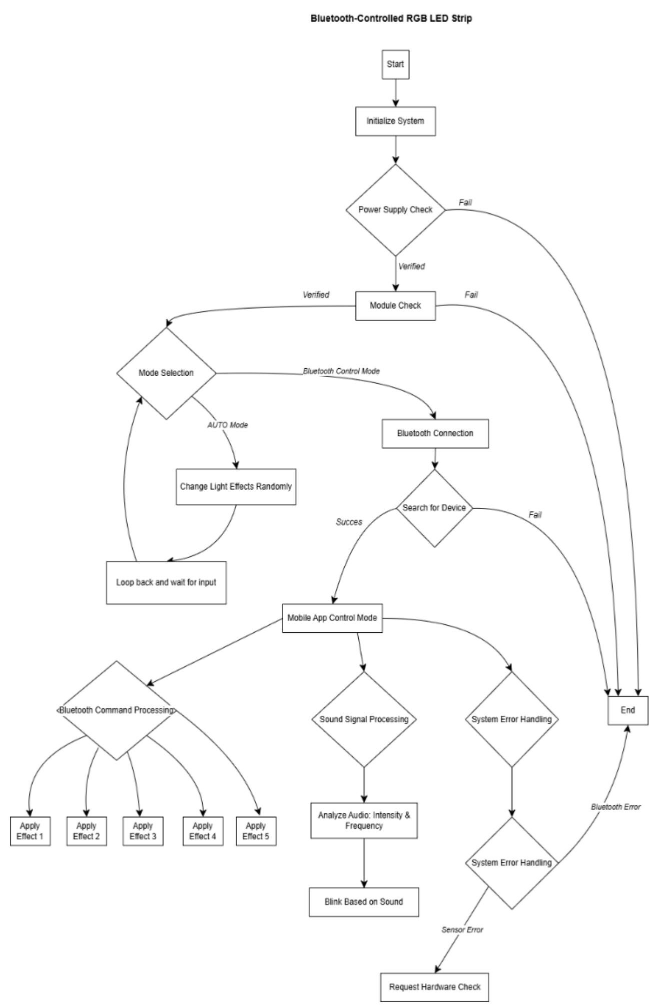

Fig. 10. Flowchart describing system operation.

Figure 8 visually represents the system's workflow, illustrating the sequence of decisions and data processing steps. The flowchart ensures smooth transitions between various operational states, maintaining real-time responsiveness while efficiently processing user inputs and environmental sound variations.

The system follows a structured sequence of operations to ensure smooth functionality. It starts with the initialization phase, where all components are powered on, communication between modules is verified, and the default operating mode is set to Automatic Mode. At this stage, the LED strip begins displaying a pre-programmed sequence of animations. The system then checks for the presence of a Bluetooth connection. If no connection is detected, the system remains in Automatic Mode.

However, if a Bluetooth connection is established, the system transitions into Manual Mode, allowing users to directly control LED effects through the mobile application. If the user selects Sound-Reactive Mode, the sound sensor starts capturing real-time audio intensity and mapping it to the LED brightness levels. The system then continuously processes this input, dynamically updating the LED effects in response to environmental sounds. In cases where the system is in Manual Mode, it listens for new Bluetooth commands, which are immediately processed to adjust the LED color, brightness, or effects according to user preferences. The system then loops back, checking for new inputs while maintaining continuous real-time operation.

The decision-making hierarchy within the system ensures efficient task execution and optimal user experience. If the systemdoes not receive any Bluetooth commands, it maintains the current LED effect, ensuring stability in operation. If a new Bluetooth command is detected, the system immediately updates the LED strip to reflect the new settings. Similarly, in Sound-Reactive Mode, the system constantly monitors sound intensity levels and adjusts the LED brightness accordingly. This process ensures an adaptive lighting experience that can dynamically respond to changes in the surrounding environment.

To optimize real-time performance, the system employs asynchronous data reception using interrupt-driven communication. This prevents Bluetooth command processing from interfering with LED animations or real-time sound analysis. The Arduino Uno is programmed to handle multiple tasks simultaneously, ensuring seamless command execution and responsive LED transitions [4]. Additionally, the system integrates the FastLED library to enhance LED control, minimizing computational overhead while ensuring smooth color transitions and animation effects. This approach improves the overall efficiency of the system, particularly when switching rapidly between different operational states.

In conclusion, the flowchart and algorithm design create an intelligent lighting system that delivers a highly interactive experience. Whether through manual control, preset animations, or real-time sound reactivity, the system ensures seamless mode transitions, real time data processing, and a responsive user interface [6], [7]. By leveraging optimized decision-making structures and efficient LED animation handling, the system provides an immersive and dynamic lighting solution tailored for smart environments.

III. RESULTS

A. Prototype Implementation

The Bluetooth-Controlled RGB LED Strip system was successfully implemented using the Arduino Uno, WS2812B LED strip, HC-05 Bluetooth module, and a sound sensor. The prototype was assembled on a breadboard, ensuring proper connections between all components. The Arduino Uno was programmed and interfaced with the hardware to control the LED effects dynamically based on Bluetooth commands and sound intensity levels. The power supply was provided via the Arduino's USB interface, while the LED strip received sufficient voltage from an external power source to ensure stable operation.

During the implementation phase, the HC-05 Bluetooth module was paired with a smartphone application, allowing remote user control. The sound sensor was placed in an optimal position to capture ambient noise effectively. The FastLED library was utilized for controlling the WS2812B LED strip, ensuring smooth animations and real-time response to external inputs. The Bluetooth terminal application was configured to send predefined commands, enabling users to switch between Automatic Mode, Sound-Reactive Mode, and Manual Mode.

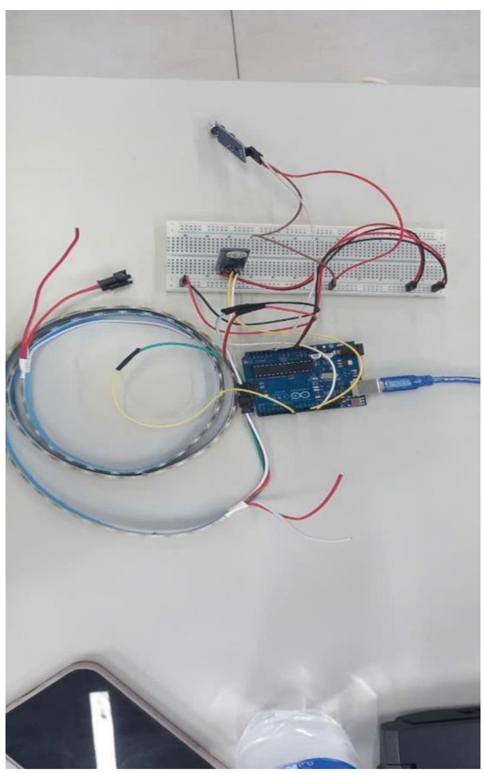

Fig. 11. Prototype implementation of the developed system.

Figure 11 illustrates the final prototype setup, showing the integration of the Arduino Uno, Bluetooth module, LED strip, and sound sensor. The hardware was arranged efficiently to minimize wiring complexity while ensuring signal stability and power efficiency.

B. Experimental Results

The system was tested under different conditions to evaluate its real-time response, accuracy, and performance stability. The Bluetooth communication was tested at varying distances to ensure seamless connectivity between the mobile application and the HC-05 module. The response time of the LED strip to Bluetooth commands was measured, confirming an average delay of less than 200ms, indicating an effective and real-time control mechanism.

The Sound-Reactive Mode was evaluated by playing music and varying the sound intensity in the environment. The LED brightness and effects responded dynamically, proving that the system can effectively synchronize with external audio sources. Different levels of ambient noise were tested, and the sensor successfully captured real-time variations, mapping intensity levels to LED brightness.

For the Manual Mode, the user was able to send custom LED color and brightness commands via the Bluetooth application. The system executed the received commands accurately, updating the LED strip without delays. The Automatic Mode displayed a seamless transition between pre-programmed animations, ensuring a visually appealing effect.

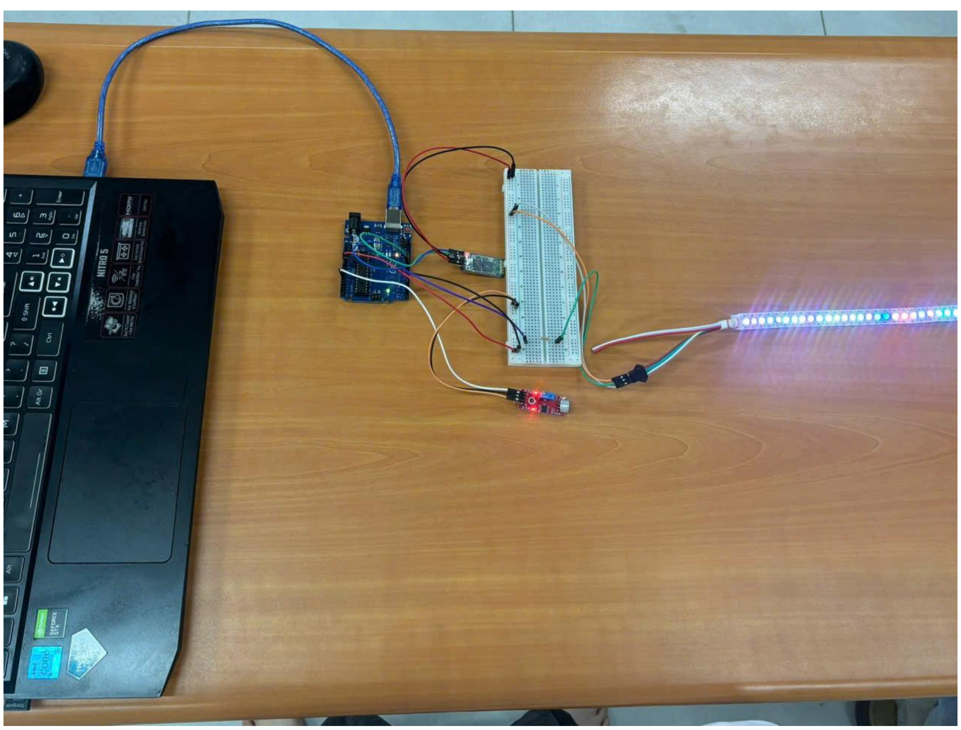

Fig. 12. System in different operational modes.

Figure 12 presents the system operating in different modes, highlighting the flexibility of the developed solution. The brightness, color transition, and sound responsiveness.

IV. CONCLUSION

The Bluetooth-Controlled RGB LED Strip system was successfully developed and tested, achieving real-time lighting control, sound reactivity, and Bluetooth-enabled operation. The system demonstrated smooth transitions between different lighting effects, ensuring an interactive and visually appealing experience. The experimental results validate the effectiveness and responsiveness of the system in multiple operational modes.

Overall, the developed system presents an innovative and cost-effective solution for smart lighting applications, with potential use cases in home automation, entertainment setups, and interactive displays. The combination of Bluetooth connectivity, real-time sound interaction, and programmable LED effects makes this system an attractive option for modern smart lighting solutions.

TABLE II

AUTHOR'S CONTRIBUTION

#	Student ID	Student Name	Tasks
1	SE181943	Trương Hào Hiệp	Draw block diagram, flowchart
2	SE181958	Trịnh Bích Trầm	Study conception and design
3	SE181954	Nguyễn Mai Tường Vy	Program Arduino and ESP8266
4	SE181957	Trương Thị Kim Lý	Write report, prepare presentation

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