REPORT OF INDIVIDUAL DESIGN PROJECT

INTAKE 40

USER PRESENCE - BASED SMART TABLE LAMP

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ABSTRACT

This project presents the design and development of a smart table lamp system tailored for students to promote energy efficiency and productive study habits. The system was engineered to automatically respond to user presence and ambient lighting conditions while tracking study duration in real-time. When the lamp is powered on, it continuously monitors both light intensity using an LDR and human presence using an LD2410B millimeter wave radar sensor. If darkness and user presence are both detected, the system automatically switches on the LED lamp using a relay module, and turns it off once the user leaves the study area. Additionally, a potentiometer was used to allow manual brightness control based on user preference.

The study duration is tracked using real-time data from the DS3231 RTC module. The OLED screen displays the current time, day/night status, and study alerts. The buzzer provides alerts based on the Pomodoro Technique—reminding the user to take a break every 25 minutes of continuous study. The system resets each time the user leaves the desk.

On the software side, an ESP32 microcontroller was used to collect sensor data and control outputs. The ESP32 communicates with Firebase via MQTT to store lamp usage data, including sensor readings and study durations. Node-RED was integrated with Firebase to build a user-friendly web interface that visualizes study patterns and lamp usage through interactive graphs. This solution not only helps reduce electricity wastage but also offers meaningful insights into users' study behaviors.

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND INFORMATION ABOUT THE PROJECT

Nowadays, using a small table lamp for studying and workplace purposes is seen to be a common practice among students and employees. As personalized lighting does not disturb roommates, table lamps are preferred and frequently used by students in boarding places, hostels, and billets. Even students who share rooms with siblings at home use study lamps. Additionally, the aesthetic appeal of lamps was found to be a motivating factor for many students.

To analyze the usage of study table lamps among undergraduates, a survey was conducted across several universities. Out of the 54 undergraduates who participated, 81.5% were found to use table lamps. Among them, 13% use lamps regularly, 33.3% use them frequently, and 33.3% use them occasionally.

Furthermore, 75.9% of respondents preferred personal lighting such as table lamps over overhead room lighting when studying.

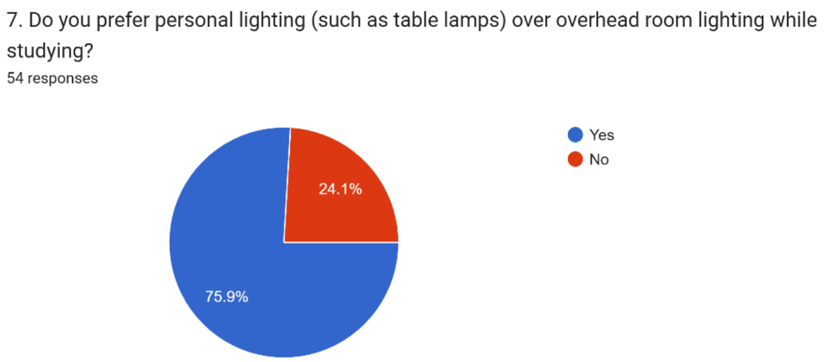


Figure 1.1 : Survey results-I

The following reasons were gathered from respondents for choosing table lamps over over-head lights:

- More accessible than overhead lights.
- More focused illumination helps with focus and reading comfort.
- Reduce eye strain and better visibility due to adjustable brightness.
- Avoid casting shadows on study materials.
- Allow undisturbed study when others in the room are asleep.
- Portability.
- Cost effective due to less power consumption.

These findings showed that the preference for table lamps was influenced by both functional and comfort-related factors, supporting the incorporation of smarter lighting features for undergraduates.

1.2 PROBLEM STATEMENT

Manual operation of their table lamps, leading to unnecessary energy consumption when lamps are accidentally left on and most current systems for tracking study time rely on manual input.

1.2.1 MANUALLY TURNING THE LAMP ON AND OFF IS INCONVENIENT AND ELECTRICITY WASTAGE

One of the main problems identified is the inconvenience of manually turning the lamp on and off. Users might leave the lamp on, thinking they'll be back soon, but they might get distracted and forget about it for a long period of time. This issue was confirmed through the survey results, where 25.9% of respondents admitted that they do not switch off the lamp every time they leave the table for a few minutes, while 46.3% said they only switch it off sometimes.

As a result, unnecessary electricity wastage is caused. This may not be the biggest source of electricity wastage in a household compared to appliances like refrigerators and air conditioners,
But it still contributes to unnecessary energy consumption. Reducing this type of small-scale wastage is valuable in improving energy efficiency.

Figure 1.2.1 : Electricity wastage

1.2.2 LACK OF STUDY TIME TRACKING

A major problem that was identified is the lack of an automated system for tracking study time. Users generally had no proper way to measure or analyze how much time they spent studying or working at their desk. Most of the available methods relied on manual input, which was often found to be inconvenient or inaccurate. According to the survey results, 24.1% of participants were not aware of their daily study duration, while 44.4% had only a rough idea. A few students mentioned using third-party solutions such as Forest (5 users), Clockify (1 user), smartwatches, digital watches, or stopwatch functions to monitor their study goals. These findings confirmed the need and interest toward an automated study tracking solution, highlighting a clear gap that is addressed in this project.

Figure 1.2.2 ; Survey results-II

CHAPTER 2: LITERATURE REVIEW

2.1 KEY STUDIES AND TECHNOLOGIES RELAVANT TO THE PROJECT

Several previous studies and findings have highlighted the importance of personalized lighting and energy efficiency in study environments.

Table lamps were found to,

- Provide focused illumination, reduces distractions and helps students focusing on their work.
- Enhance the visual appeal of a study space, making it a more inviting and motivating environment that positively influences student mood and productivity.

Night-time studying was identified as beneficial for enhancing focus, memory retention, and creativity, especially when supported by personalized lighting patterns. [1][2]

Energy Use and Emissions in Sri Lanka

- In 2022, Sri Lanka recorded 18 million tonnes of energy-related CO_2 emissions, representing 0.05% of global emissions.
- A 74% increase in emissions since 2000 underlines the urgent need for energy-efficient technologies. [3]

Benefits of LED and Smart Lighting:

- LED lamps consume significantly less energy compared to incandescent or halogen bulbs, offering up to 85% energy savings.
- Smart lighting systems that automatically adjust brightness reduces electricity consumption by 30%.
- Additionally, leaving lights on unnecessarily contributes to 5-10% of household electricity bills. [4][5][6]

2.1.1 FIREBASE

Firebase, a product of Google, is a powerful platform that enables developers to build, manage, and expand applications with ease. It simplifies app development by offering a secure and efficient backend, eliminating the need for server-side programming. Firebase supports multiple platforms, including Android, iOS, web, and Unity, making it a flexible solution for developers.

With features like real-time cloud storage, authentication, and NoSQL database support, Firebase ensures flawless data management. Its cloud-based infrastructure allows for faster development, enhanced security, and effortless scalability.

Cloud Firestore

The cloud Firestore is a NoSQL document database that provides services like store, sync, and query through the application on a global scale. It stores data in the form of objects also known as Documents. It has a key-value pair and can store all kinds of data like, strings, binary data, and even JSON trees

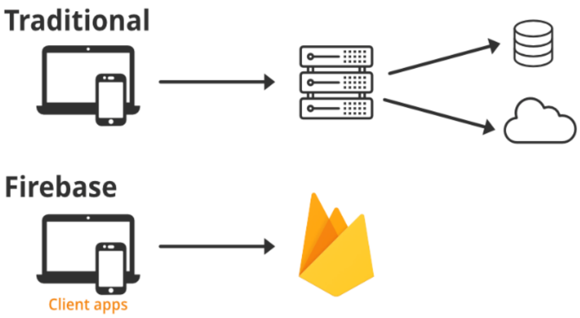


Figure 2.1.1 : Cloud firestore

2.1.2 NODERED

Node-RED is a flow-based programming tool, originally developed by IBM Emerging Technology Services team and now a part of the OpenJS Foundation.

Browser-based flow editing

Node-RED provides a browser-based flow editor that makes it easy to wire together flows using the wide range of nodes in the palette. Flows can be then deployed to the runtime in a single-click. JavaScript functions can be created within the editor using a rich text editor. A built-in library allows you to save useful functions, templates or flows for re-use.

The flows created in Node-RED are stored using JSON which can be easily imported and exported for sharing with others.

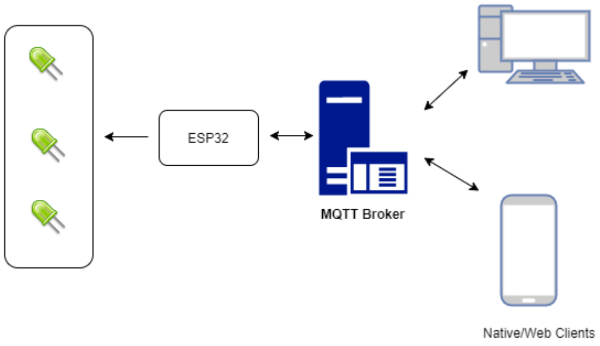


Figure 2.1.2 : Browser-based flow editing

2.1.3 MQTT PROTOCOL

MQTT is an OASIS (Organization for the Advancement of Structured Information Standards) standard messaging protocol or set of rules, used for machine-to-machine communication. The MQTT protocol was invented in 1999 for use in the oil and gas industry. Initially, the protocol was known as Message Queuing Telemetry Transport.
Smart sensors, wearables, and other Internet of Things (IOT) devices typically have to transmit and receive data over a resource-constrained network with limited bandwidth. These IOT devices use MQTT for data transmission, as it is easy to implement and can communicate IOT data efficiently. MQTT supports messaging between devices to the cloud and the cloud to the device.

For this project, Firebase was used as a cloud-based database to store the data received from the ESP32, such as the sensor readings, LDR values, and the lamp's ON/OFF status. The data was sent from the ESP32 to Firebase using the MQTT protocol, which ensures lightweight and reliable data transmission. Node-RED was used to retrieve and manage this data from Firebase. The analysis and visualization of the stored data were carried out using tables and graphs in Node-RED, making it easier to monitor study patterns and system performance.

2.2 SOURCES RELEVANT TO DESIGN CHOICES

2.2.1 THE POMODORO TECHNIQUE

The Pomodoro Technique was invented in the late 1980s by Francesco Cirillo, a university student. The Pomodoro Technique is a time management method in which you do focused work during 25-minute intervals known as pomodoros and take a five-minute break.

1. Get your to-do list and a timer (actual tomato timer optional - any timer will do!)
2. Set your timer for 25 minutes, and focus on a single task until the timer rings.
3. When your session ends, mark off one Pomodoro and record what you completed.
4. Then enjoy a five-minute break.
5. After four pomodoros, take a longer, more restorative 15–30-minute break.

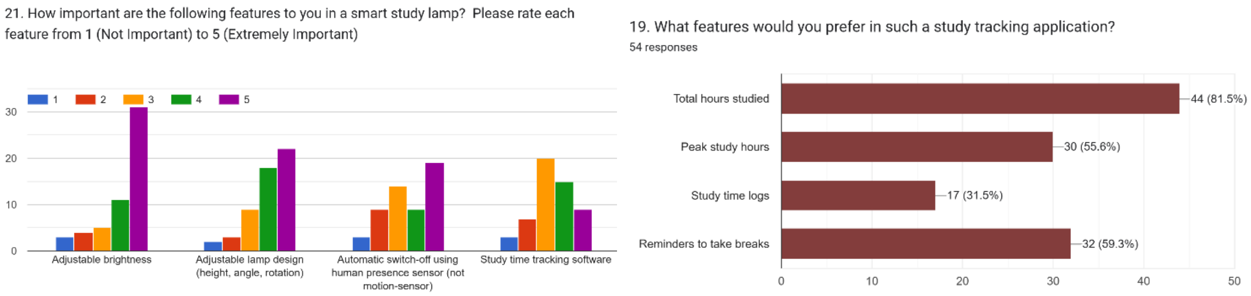


Figure 2.2.1 : Survey results-III

According to the survey results, brightness level was considered important by most participants. Therefore, a potentiometer was included to allow users to adjust the brightness as needed. An adjustable lamp panel was also designed, allowing users to change its height, angle, and rotation depending on the task. Automatic switch-off was made possible using a human presence sensor, as many users highlighted the importance of such a feature. An OLED display was used to show the current time and the duration studied until the user leaves the table. To support better study habits, the Pomodoro Technique was followed, where a reminder was given after 25 minutes of studying through a buzzer sound to suggest a 5-minute break. Based on the literature review, LED strips were used to improve energy efficiency.

2.3 EXISTING PRODUCTS AND THEIR LIMITATIONS

Table 2.3 : Existing products in the market and their features

Lamp	Name	Features	Price	Available at
	EZVALO Smart Desk Lamp	APP Control Eye-Caring Auto-Dimming Led Desk Lamp 3 Color Temperature Works with Alexa & Google Assistant	LKR 17,812.89	https://www.amazon.com https://rb.gy/qmpmoe

	ZEEFO Retro LED Night Light PIR Motion Sensor Light	Light will automatically turn on when a user passes within 6 feet of the sensor, **will automatically turn off after about 15-20 seconds**	LKR 4,845.08	https://www.amazon.com/ https://rb.gy/bpd5t2
	Baseus LED Desk Lamp Auto-Dimming Table Lamp	47 " Wide Rectangular Illumination Adjustable Brightness Built-in battery stays up to 13 hrs.	LKR 10,122.34	https://baseusonline.com/ https://rb.gy/d997z4
	3 Way Dimmable Touch Lamp	Touch Control USB & USB-C Charging Ports and Outlet	LKR 5,648.13	https://www.amazon.com/ https://rb.gy/8pntbj
	Xiaomi Mi Smart LED Desk Lamp	Adjustable brightness and color temperature App-controlled Lacks advanced motion detection	LKR 25,724.99	https://www.aliexpress.com/item/32967694580.html https://www.mi.com/ae/product/mi-smart-led-desk-lamp-pro/

2.3.1 HOW THIS PROJECT DIFFERES FROM PRIOR WORK

A market survey was conducted, and several existing products were studied. Most of these lamps were equipped with app or touch control. However, it was found that motion sensor-controlled lamps only responded to motion and were not capable of detecting continuous human presence. Such lamps are not suitable for studying, as the light would not remain on throughout the session. Auto-controlled brightness is also not preferred, since brightness comfort levels varies from person to person. Hence, manual brightness adjustment is considered more effective. Additionally, no lamps were found with the ability to detect night or daytime. Furthermore, no lamps were designed to track usage time or analyze usage patterns. Lamps with flexible features were available, but they were priced high.

Therefore, a clear market gap was observed: no existing product could continuously detect presence, allow manual brightness control, track study time, and respond to ambient light conditions. This gap was addressed through the product developed in this project, making it stand out from existing solutions.

2.4 OVERVIEW OF MARKET TRENDS RELATED THE PROJECT

2.4.1 LED TABLE LAMPS MARKET INSIGHTS

The global LED table lamp market is experiencing significant growth, expected to increase from USD 10.72 billion in 2024 to USD 23.82 billion by 2032, with a CAGR (Compound annual growth rate) of 10.5%. This growth is due to the increasing demand for energy-efficient and sustainable lighting solutions. LED lamps play a key role in reducing electricity bills and carbon emission. Decorative LED lamps rule the market, holding over 60% market share, due to innovations in design, technology, and aesthetic appeal.

2.4.2 GLOBAL SMART LAMP MARKET OVERVIEW

In parallel, the smart lamp market is also growing steadily, estimated to grow from USD 11.30 billion in 2025 to USD 24.37 billion by 2034, at a CAGR of 9.52%. The growth is because of the rise of smart homes and IoT integration. Consumers are increasingly adopting smart lighting systems that can be controlled via mobile apps, sensors, or voice commands. Key service providers in this sector include Philips Lighting, Xiaomi and Samsung Electronics offering products with advanced features such as automation, brightness control, and remote access.

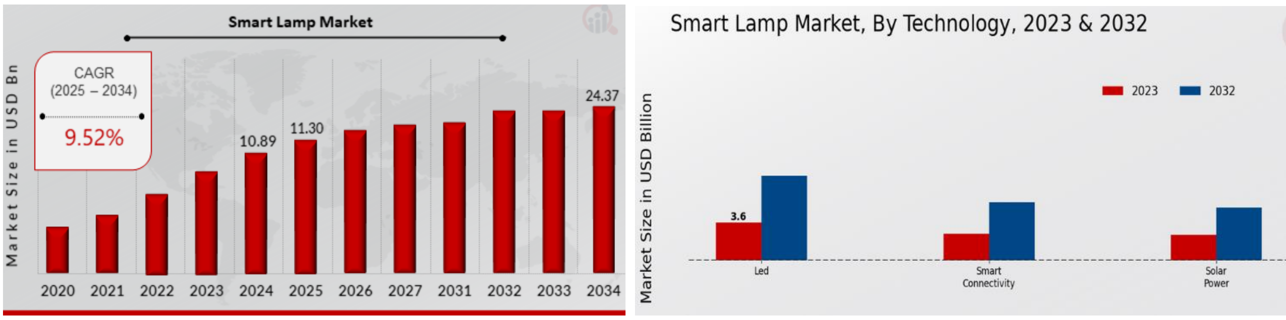


Figure 2.4.2 : Global smart lamp market overview

2.5 Potential user base and application areas

Students and Academic Environments

The system is ideal for students living in hostels or shared accommodations, allowing them to use personalized lighting without disturbing roommates. Additionally, automatic study time tracking and feedback on usage patterns can encourage better time management and promote consistent study habits.

Healthcare and Elderly Care

In environments where mobility is limited, such as the elderly or patients, the lamp offers hands-free operation, enhancing safety and convenience without requiring manual handling.

Office and Workspace Settings

In dynamic office environments, where people often step away from their desks, the automatic lamp control based on presence detection helps conserve energy and maintains efficient lighting without manual switches.

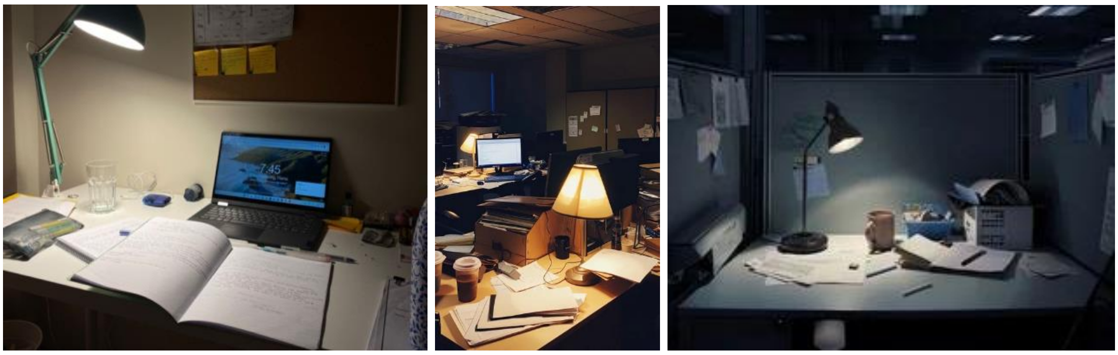


Figure 2.5 : Potential application areas

CHAPTER 3: OBJECTIVES AND AIMS

1. To design and implement a smart table lamp that operates automatically based on user preferences.
2. To develop a user-friendly web interface for monitoring lamp usage.
3. To track study durations and analyze study patterns to enhance productivity.

The objective of this project is to design and implement a smart table lamp system that can automatically respond to human presence and surrounding light conditions. The system is expected to switch on the lamp when both low ambient light and human presence are detected and switch it off when the user leaves. Another key objective is to continuously monitor and record the user's study duration based on presence detection. This data will be sent to a database and later visualized through a web-based interface using graphical representations. The aim is to provide insights into user study habits and enable analysis of usage patterns over a selected period.

CHAPTER 4: DESIGN AND METHODOLOGY

4.1 WORKING PROCEDURE

The intensity of the surrounding environment was continuously measured using an LDR (Light Dependent Resistor). If the analog reading fell below the identified darkness threshold of 600, the system recognized it as dark (night time) and bright threshold of 2500 the system recognized it as bright (day time). If the LDR value is greater than the bright threshold the lamp(LED) switches off. Human presence was detected using the Human presence detection sensor, which was tuned to detect the user only when within the specific range of 0.75 meters.

The system was activated when the rocker switch was turned on. From that point until it was switched off, the system continuously tracked the user's study time while monitoring ambient light levels to automatically switch on the lamp during dark conditions. Upon activation, the OLED screen displayed a “Hello” message and started counting study time if a user was detected within range.

Following the Pomodoro technique, if the user studied for 25 continuous minutes, the buzzer was triggered once to alert the user to take a 5-minute break. If the user left the table at that point, the OLED displayed the message: “You studied for 25 minutes, take a break now.” If the user remained at the table, the system continued tracking the time and issued alerts every 25 minutes. Upon leaving, the total study time was displayed on the screen.

Additionally, a potentiometer was included to allow manual adjustment of brightness based on user preference. Throughout the session, the OLED screen continuously displayed the real-time clock using an RTC module.

The LED strips were switched on only when both darkness and human presence conditions were fulfilled. This operation was handled by the ESP32-WROOM microcontroller, which sent control signals to a relay module. The relay was driven through an NPN transistor that acted as a switch between the ESP32 and the relay’s IN pin.

- **Darkness detection threshold: 600 (calibrated based on the testing environment)**
- **User presence detection threshold: 0.75m**
- **Brightness detection threshold: 2500**

The circuit, along with all the necessary components, was first integrated on a breadboard for testing purposes. Using the Arduino IDE, the code was implemented and to achieve the highest possible efficiency. Once the system was verified to work as expected, the final circuit was soldered onto a dot board. The lamp's link and panel were constructed using wood, while the base enclosure was custom designed in SolidWorks and 3D printed. After assembling all parts, the physical structure of the lamp was finalized, balancing both functionality and aesthetic appeal.

4.2 SOFTWARE IMPLEMENTATION

The ESP32 was connected to Firebase (Cloud Firestore) using the MQTT protocol. Sensor readings including LDR values, human presence detection, and lamp ON/OFF status were sent as MQTT payloads. Each payload included timestamped data and was published to specific topics.

To open the Node-RED interface, **node-RED** was typed into the Command Prompt, and the URL was opened in a web browser. The SSID and password of the Wi-Fi network were included in the ESP32 code in Arduino IDE to ensure both the ESP32 and the PC hosting Node-RED were on the same network.

Firebase acted as the real-time database and was integrated with Node-RED to process and visualize data. The data received by Firebase was automatically forwarded to Node-RED, which displayed it in a user-friendly dashboard using graphical elements such as tables and graphs.

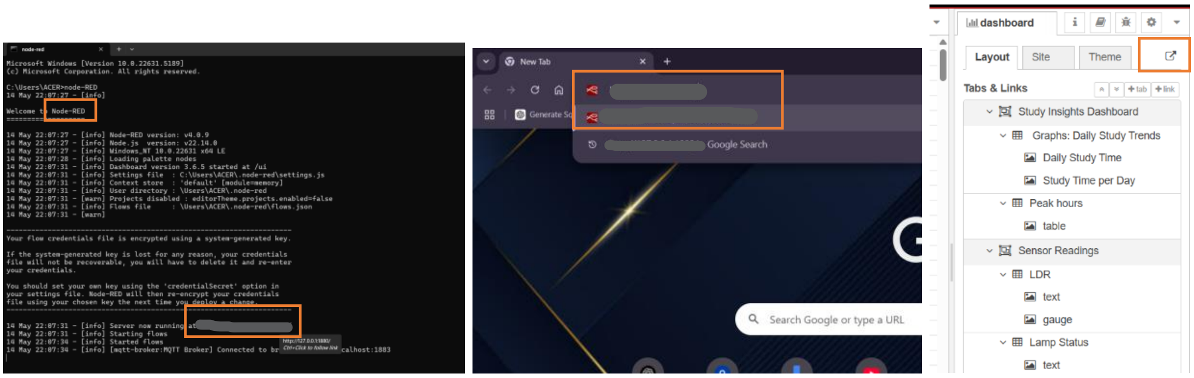


Figure 4.2.1 : Steps to open the node-RED dashboard

Figure 4.2.2 : Arduino IDE for Wi-Fi connectivity

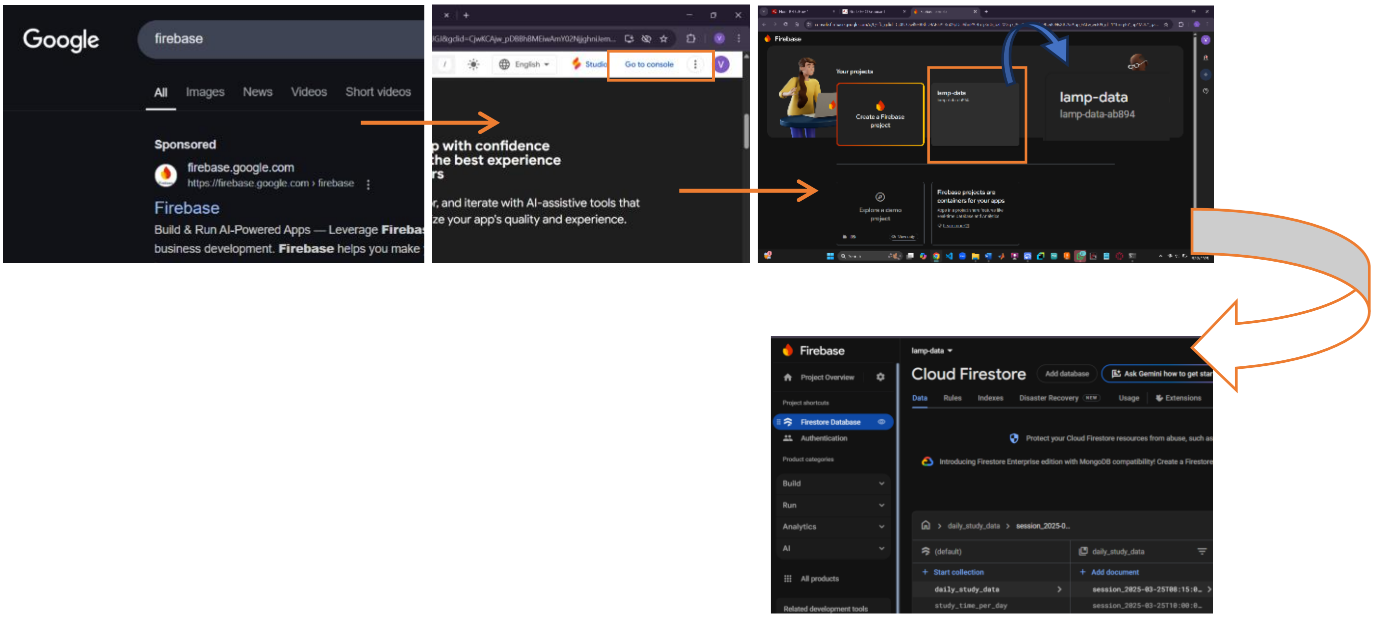


Figure 4.2.3 : Steps to Access and Set Up Cloud Firestore in Firebase

To visualize the graphs, flowchart-like representations "flows" were drawn in Node-RED for each task. Function nodes were customized to define the specific logic required for processing. Two key graphs were generated: Daily Study Time and Study Time Per Day.

In the **Daily Study Time** graph, each session was represented using a start and end timestamp, and the duration between them was calculated. The X-axis showed session start times, while the Y-axis showed session durations.

In the **Study Time Per Day** graph, the total study duration for all sessions within a day was summed and plotted, with each day represented on the X-axis and total study time on the Y-axis.

Additionally, a separate flow was created to identify **peak study hours throughout the week**, which was displayed in a table format to highlight the most active periods of study.

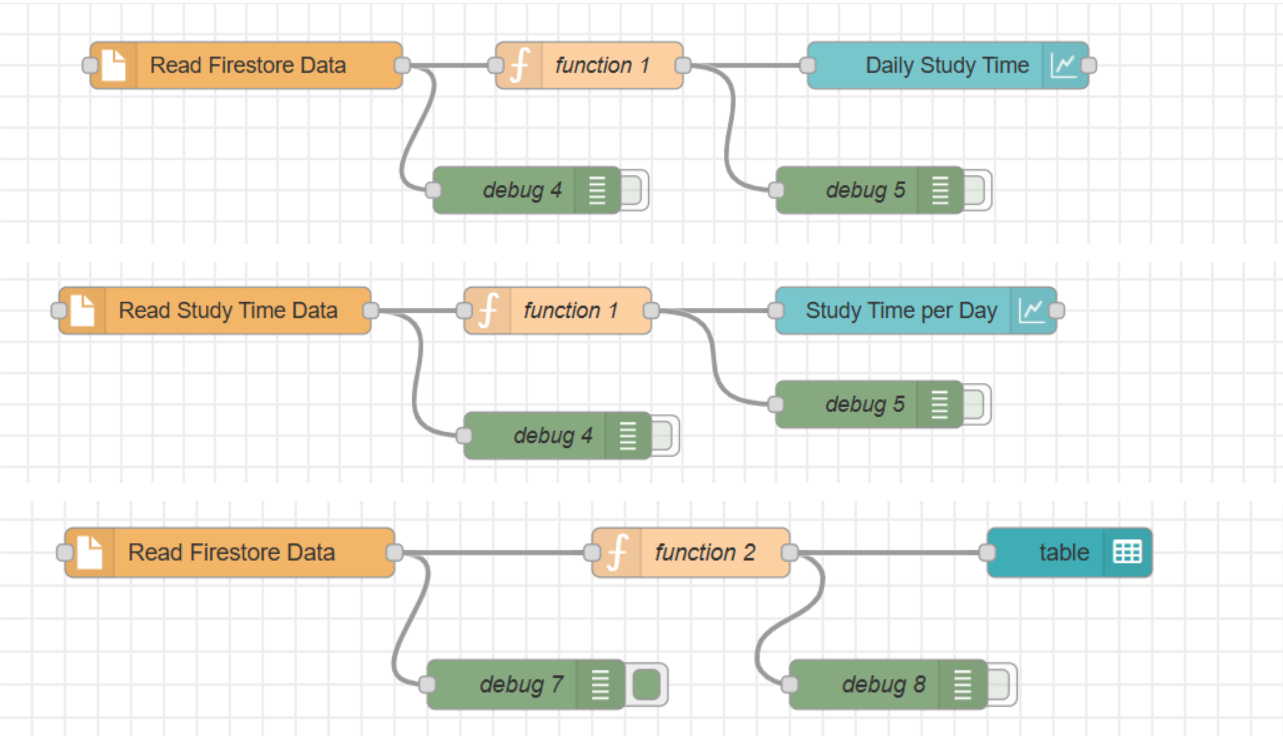


Figure 4.2.4 : Flows of the Node-RED Dashboard for Study Time Analysis

4.3 BLOCK DIAGRAM

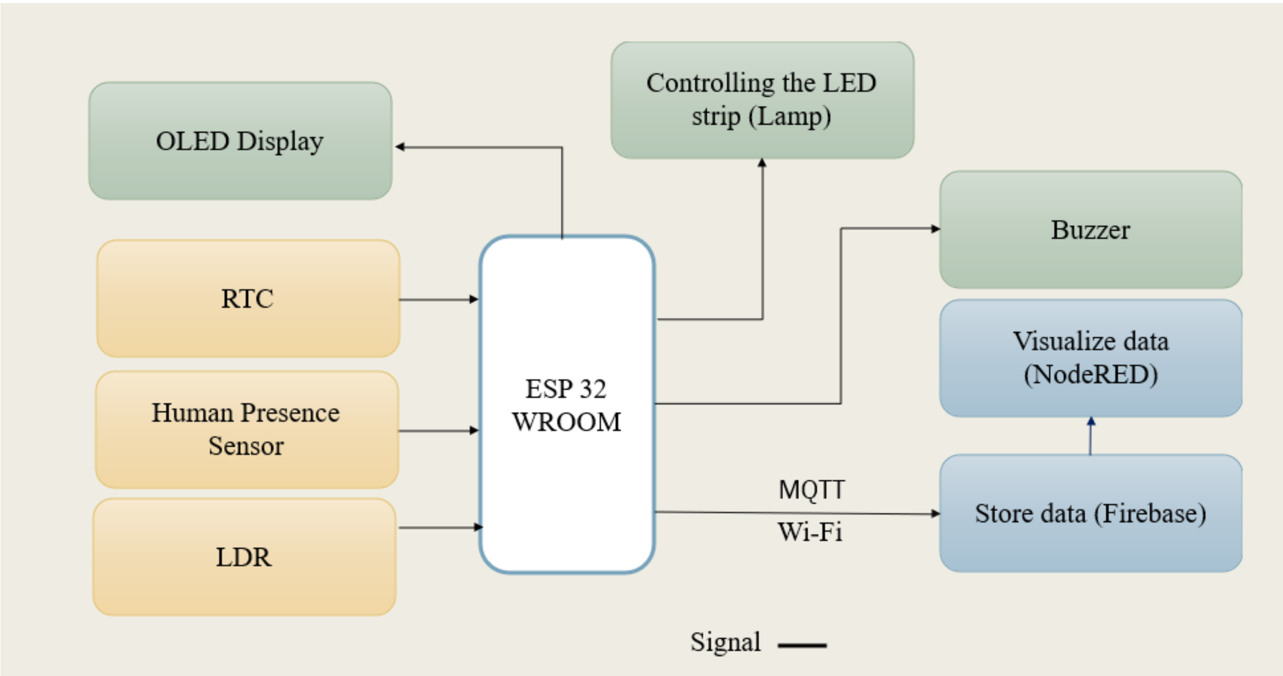


Figure 4.3 : Block diagram

4.4 FLOW CHART

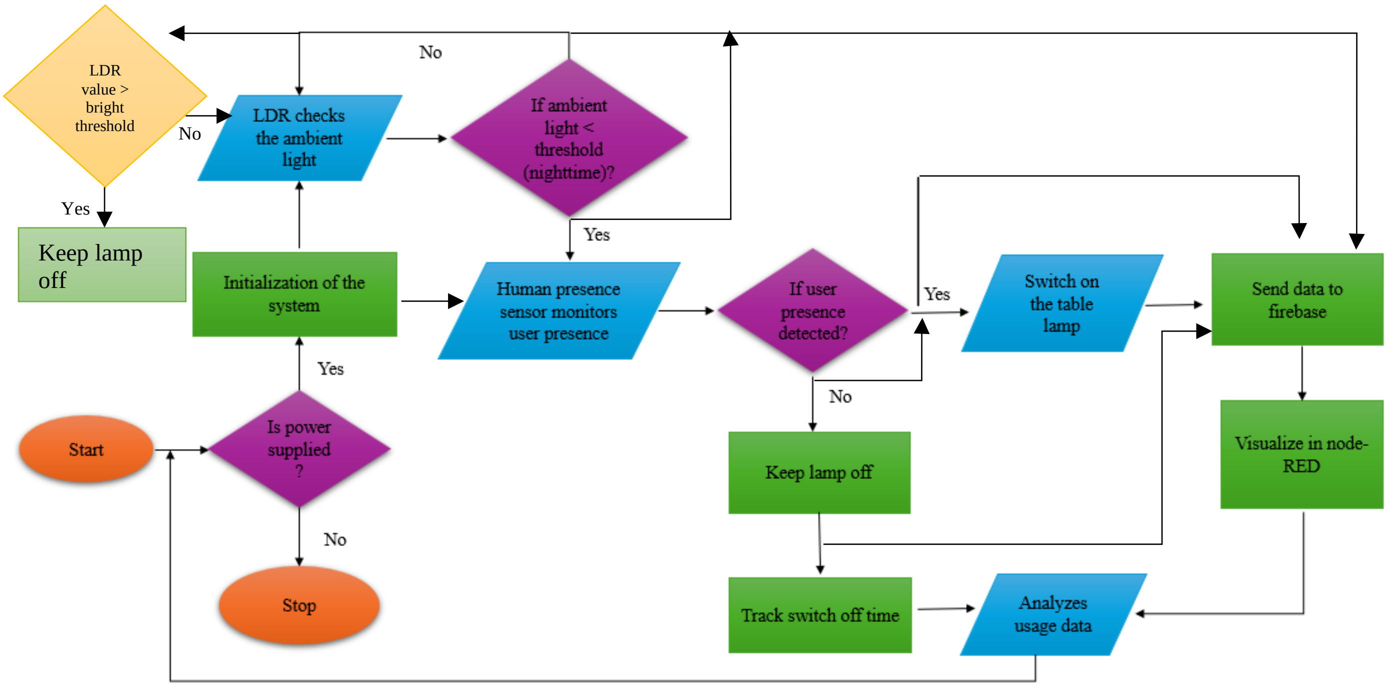


Figure 4.4 : Flow chart

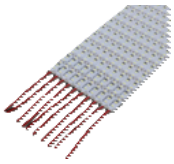
4.5 COMPONENTS

Table 4.5.1 Components and their features

Component		Model Name	Features
	The development board (ESP32 DevKit with a WROOM module)	ESP32-WROOM-32	Operating current Average: 80 mA Operating voltage/Power supply 3.0 V ~ 3.6 V 40-MHz crystal oscillator. 3.3V (Logic) / 5V (Power) Digital output Built-in Wi-Fi and Bluetooth connection Architecture 32 bits

	Human presence detection sensor	HLK LD2410B	Operating voltage 5V Operating frequency 24-24.25 GHz logic level is 3.3 V Default baud rate of the serial port 256000 Max range-675cm Resolution-75cm Input power supply capacity 200mA wide detection angle of ±60°
	Real time Clock memory module (RTC)	DS3231	Accuracy ±2ppm from 0°C to +40°C Size: 38mm(L)* 22mm(W)* 14mm(H) Operating voltage :3.3 - 5 .5 V Battery - LIR2032 or CR2032
	OLED display module	0.96 inch 128X64 OLED Display Module Blue Yellow I2C IIC	Size: 0.96 Resolution: 128X64 Color: Blue and Yellow Support wide voltage: 3.3V-5V DC Operating Current 9-12mA
	DC to DC adjustable step-down buck module	MP1584	Switching Frequency: 100kHz to 1.5MHz 4.5V to 28V Operating Input Range Output Voltage: 0.8V-18VDC Continuous Output Current: Max. 3A Dimensions: 22mm*17mm*4mm(l*w*h)
	5VDC 1 Way 1 Channel Relay Module		Supply voltage – 3.75V to 6V Quiescent current: 2mA Current when the relay is active: ~70mA Relay maximum contact voltage – 250VAC or 30VDC Relay maximum current – 10A

	AC/DC Power Adaptor	MSA-C2000IC12.0-24B-ZZ	Input 200-240V Output 12V 2A Input ~50/60Hz 0.7A max
	DC Jack Barrel Connector Male Power Terminal		Maximum Current 5A Voltage range 3V to 24V The internal diameter: 2.1mm External diameter: 5.5mm.
	5V mini buzzer		Rated Voltage: 5 V Operating Voltage: 3~5V Max Rated Current: ≤32 mA Min. Sound Output at 10cm: 85 dB Body Size: 4mm
	Potentiometer	B10k potentiometer	Power Rating: 0.3W Maximum Input Voltage: 200Vdc Standard Resistance Tolerance ± 10% Rotational Life: 2000K cycles
	Light Dependent Resistors	LDR	Max voltage (VDC): 150 Max power dissipation (mW): 100 Light resistance (10 Lux)(KΩ): 30-50 Dark resistance(MΩ): 3.0 Rise Response Time(ms): 20 Fall Response Time(ms): 30 Body Size: 4mm
	Rectangular Rocker Switch	SPST	Electrical Rating: 125V AC 6A / 250V AC 3A Material : Plastic, Metal Overall Dimensions 14.8x10.3x16.5mm (LxWxH)

	LED Strip Rigid White 3x48 Bulb 4014		Operating voltage 12V DC 1-100KΩ resistance change
	npn	2n2222	Collector current 800 mA Power Dissipation 500mW operate temperature -65 C to 200 C Collector base voltage 60V Collector Emitter Voltage 30V Emitter Base voltage 5V

ESP32 DevKit with a WROOM module

The ESP32 is a f low-cost and low-power System on a Chip (SoC) microcontroller developed by Espressif. ESP32 DevKit development board with a WROOM module offers a highly flexible and powerful platform with 30 pins, out of which 25 are GPIOs (General Purpose Input Output Pins). This Development board comes with an onboard antenna for Wi-Fi signal. The GPIOs can be programmed to serve various purposes such as digital input/output, analog input, PWM output, touch sensing, and communication protocols like I2C, SPI, and UART.

The ESP32 includes two 8-bit DAC channels for converting digital signals to true analog voltages. Input-only pins (GPIO 34) cannot be used for output tasks. The board also provides 21 PWM-capable GPIOs (excluding input-only pins), which can be used to control devices such as motors, LEDs, and buzzers. The ESP32 has two I2C bus interfaces, but no dedicated I2C pins. Instead, it allows for flexible pin assignment, meaning any GPIO pin can be configured as I2C SDA (data line) and SCL (clock line). It also includes SPI each capable of functioning in master or slave mode, making it suitable for high-speed peripheral communication. The board supports three UART interfaces UART0, UART1, AND UART2. UART2 available for connecting to external serial devices like GPS modules or sensors. BOOT and RESET/EN buttons to put the board in flashing mode or reset (restart) the boardThese diverse hardware features make the ESP32 DevKit a highly adaptable choice for smart systems, IoT devices, and real-time embedded applications.

TX0 and RX2 pins on the ESP32 are primarily used for flashing and serial debugging. Therefore, these pins were not used for connecting the sensor to avoid conflicts during programming and monitoring.

For power supply, the ESP32 was powered through the “VIN” pin using a 5V source, while the “GND” pin was connected to the common ground of the circuit to ensure proper reference and stability.

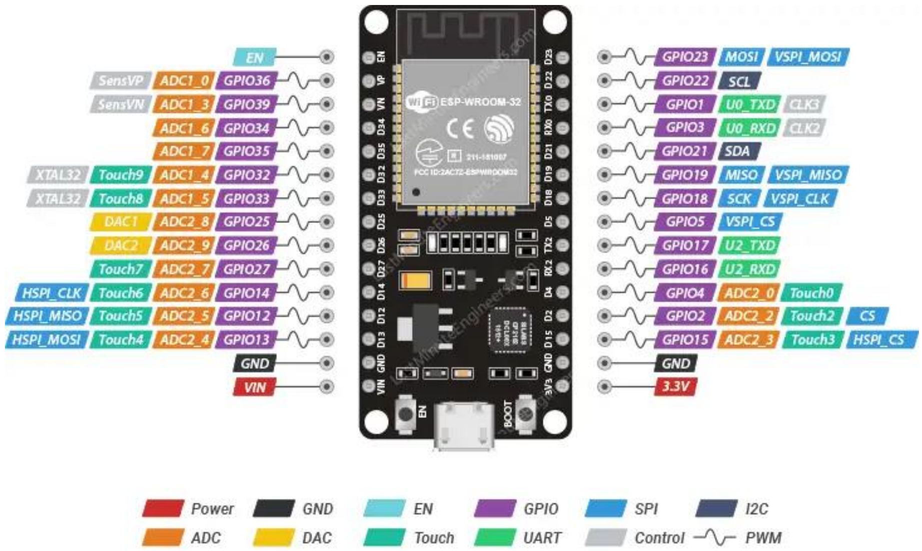


Figure 4.5.1 : ESP32 DevKit with a WROOM module

Table 4.5.2 :ESP 32 connected pins with other components

Component	Component pin	ESP32- pin
Human presence sensor	TX RX	RX2 TX2
RTC	SDA SCL	GPIO 21 GPIO 22
LDR		GPIO 34
OLED	SDA SCL	GPIO 21 GPIO 22
npn	Base	GPIO 25
Buzzer		GPIO 26

Human presence detection sensor

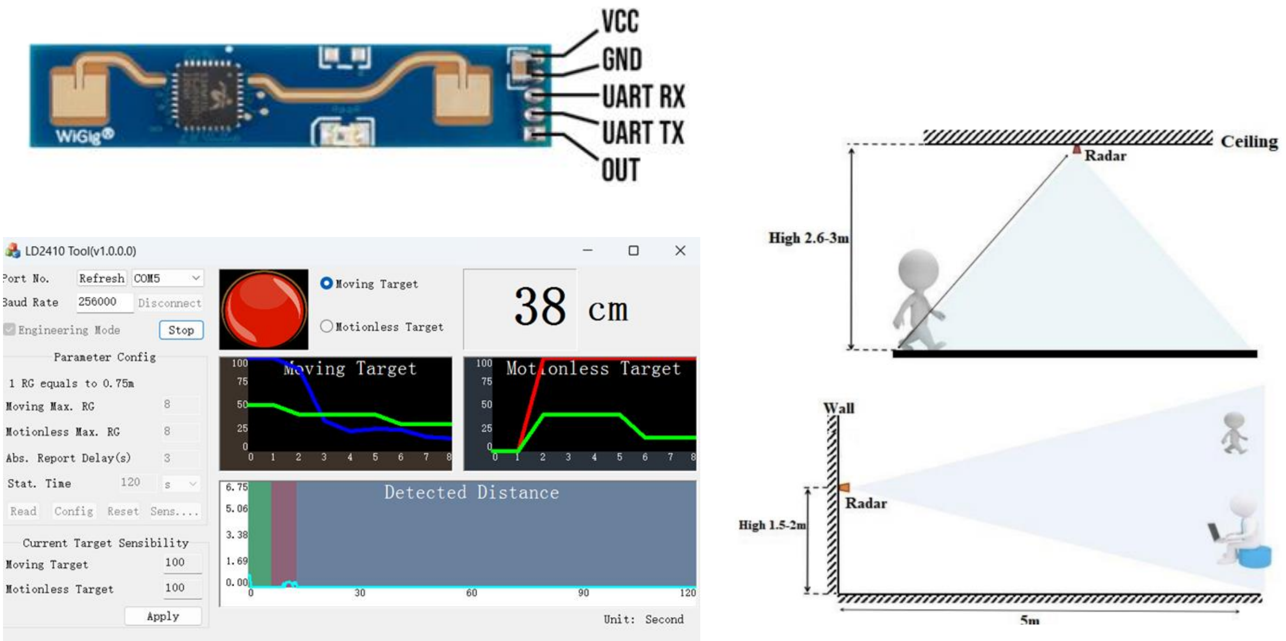


Figure 4.5.2 : Human presence detection sensor

The LD2410B is a high-sensitivity human presence detection module developed by Hilink Electronics. It uses advanced 24 GHz FMCW (Frequency-Modulated Continuous Wave) radar technology. this module can detect moving, stationary, micro-moving, sitting, and lying human bodies. It defines sensing distance, sensitivity levels per distance gate, and unmanned delay time. The sensor provides output via UART and GPIO and includes a bluetooth connection. Provides a visual configuration tool which can tune the sensor .

Additionally, the module can detect humans even behind non-metallic barriers, due to its shell penetration ability. This compact 7 mm × 35 mm module has a pin spacing of 1.27 mm and 5 pin holes. An important feature of the LD2410B is the “no-one duration”, where the sensor continues to output a "human present" status briefly after a person leaves. Only after this delay, if no presence is re-detected, the system changes the output to "no one". This behavior enhances stability and avoids false triggers due to brief absences or signal noise.

For this project, the two libraries “ld2410” and “MyLD2410” were used to tune the sensor. The example codes “basicSensor”, “setupSensor”, “factory_reset”, “modify_parameters”, “print_parameters”, “sensor_data”, “set_baud_rate”, and “set_bt_password” were also used to configure and control the sensor.

Real time Clock Memory Module (RTC)

The DS3231 is a highly accurate, low-cost I2C-based real-time clock (RTC) module. It operates using a 32 kHz temperature-compensated crystal oscillator (TCXO) and a built-in crystal for precise timekeeping. One of its key features is its ability to maintain accurate time even during power interruptions because of the battery input. The module keeps track of seconds, minutes, hours, day, date, month, and year, with automatic adjustments for months having fewer than 31 days, including leap year corrections. It ensures consistent and reliable timekeeping across a wide range of environmental conditions. Its compact design make it an ideal choice for time-sensitive embedded applications such as data logging, alarms, and smart automation systems.

You should use a LIR2032 battery, which is rechargeable. But if you use a CR2032 battery, which is non-rechargeable, you must disconnect the battery charging circuit by unsoldering and removing the resistor (labelled in the below diagram)

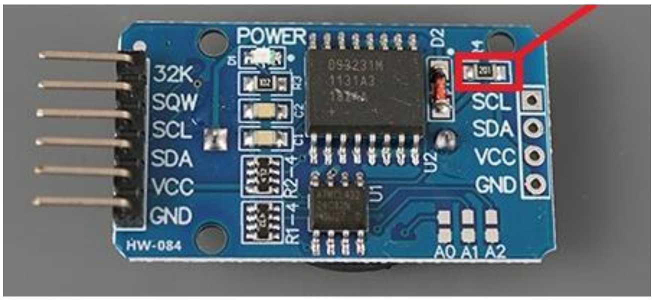


Figure 4.5.3 : RTC pin diagram

DC to DC Adjustable Step-Down Buck Module

The MP1584 is a step-down voltage regulator that includes a built-in high-side MOSFET, which is placed on the top part of the power path. This allows it to handle and switch high input voltages, such as 12V, making it suitable for converting higher voltages down to lower levels like 5V or 3.3V. Inside the regulator, there are two main switches: the high-side switch connects the input voltage to the inductor, and the low-side switch connects the inductor to ground. When the high-side switch is turned on, current flows through to the load. When it's turned off, the low-side switch or a diode keeps the current flowing smoothly. This design helps maintain a stable output while safely handling higher input voltages. Its frequency foldback feature helps prevent inductor current runaway during startup, and it includes thermal shutdown protection to ensure reliable and fault-tolerant operation.

In this project, two MP1584-based buck converters were used to step down a 12V input into 5V and 3.3V outputs, which were then used to power various components of the smart lamp system efficiently and safely.

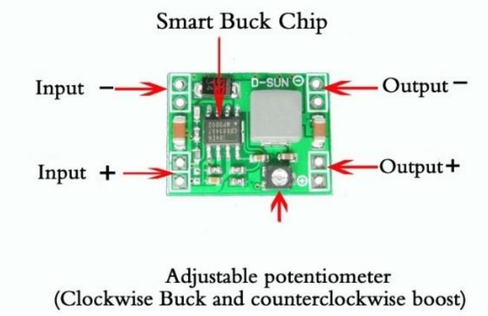


Figure 4.5.4 : Step down buck module

5VDC 1 Way 1 Channel Relay Module

A is an electromagnet, B armature, C spring, D moving contact, and E fixed contacts. There are two fixed contacts, a normally closed one and a normally open one. When the coil is not energized, the normally open contact is the one that is off, while the normally closed one is the other that is on. Supply voltage to the coil and some currents will pass through the coil thus generating the electromagnetic effect. So the armature overcomes the tension of the spring and is attracted to the core, thus closing the moving contact of the armature and the normally open (NO) contact or you may say releasing the former and the normally closed (NC) contact. After the coil is de-energized, the electromagnetic force disappears and the armature moves back to the original position, releasing the moving contact and normally closed contact. The closing and releasing of the contacts results in power on and off of the circuit.

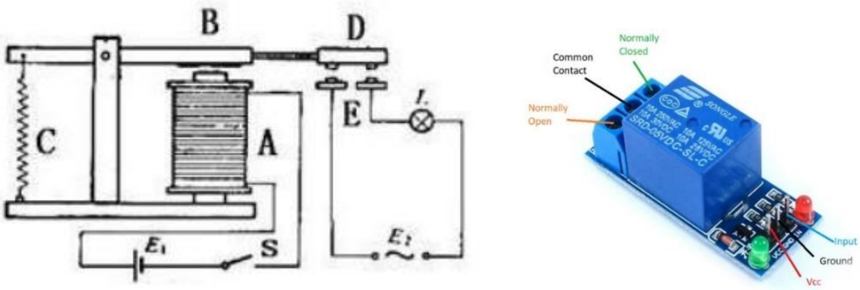


Figure 4.5.5 : Relay module

Potentiometer

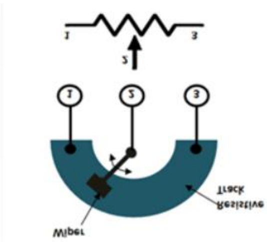


Figure 4.5.6 : Potentiometer pin diagram

In a 10k potentiometer, here if we measure the resistance between terminal 1 and terminal 3 we will get a value of 10k because both the terminals are fixed ends of the potentiometer. For an example if we place the wiper exactly at 25% from terminal 1 as shown above and if we measure the resistance between 1 and 2 we will get 25% of 10k which is 2.5K and measuring across terminal 2 and 3 will give a resistance of 7.5K. So the terminals 1 and 2 or terminals 2 and 3 can be used to obtain the variable resistance and the knob can be used to vary the resistance and set the required value.

The potentiometer is connected in series with the 12V LED strip to control the current flow. In this project, it is used to adjust the brightness of the LED strip manually. It acts like a variable resistor to limit or increase power to the strip.

LDR

Photo resistors, also known as light dependent resistors (LDR), are light-sensitive devices most often used to indicate the presence or absence of light or to measure the light intensity. In the dark, their resistance is very high, sometimes up to 100 ohms, but when the LDR sensor is exposed to light, the resistance drops dramatically, sometimes even to a few ohms, depending on the light intensity. LDR has a sensitivity that varies with the wavelength of the light applied and is a nonlinear device.

SPST Rectangular Rocker Switch Black/Red 2-Pin (Mini)

Electric switches mounted in thermoplastic casing, are used to activate or cut an electrical circuit manually or automatically. For this, the switch once actuated, allows the passage of electric current. In this project the rocker switch controls the main power flow from the DC jack to the rest of the circuit. When turned ON, it allows current to flow and powers up all connected components. When turned OFF, it cuts off power to the entire system.

DC Jack Barrel Connector (Male Power Terminal)

This connector brings 12V DC power from an external adapter into the circuit. It serves as the main power input source for all other components. The connector ensures a secure and stable power connection to the project.

5V Mini Buzzer

The buzzer is used to alert the user after studying for 25 minutes. It produces a short beep to notify the user to take a break. It only activates when the required continuous study duration is met.

12V LED Strip

The LED strip is used as the lamp that turns ON only when it is dark and a human is detected near the table. It gets 12V power through the relay and brightness is controlled via the potentiometer. It acts as the main illumination source in the system.

npn

Figure 4.5.7 : npn pin diagram

It's a current controlled transistor. So, a small current at the base terminal is used to drive high current between the other two terminals. It is used for switching purposes because of its fast response time.

In this project the 2N2222 acts as a switch for controlling the relay. When GPIO25 from the ESP32 sends a HIGH signal, it provides base current through the 10k resistor, turning the transistor ON. This allows current to flow from the 5V source through the relay coil to GND, activating the relay.

AC/DC Power Adaptor

The 12V power adapter is the primary power source for this entire project. It provides the necessary voltage to power high-power components like the LED strip via the relay. This 12V input is also used as the source voltage for buck converters, which step it down to 5V and 3.3V to safely power other components like the relay module, ESP32, sensors, OLED, and RTC.

A 12V battery pack with a female DC barrel connector was also considered for powering the system in case of a power failure, as it was compatible with the male DC plug used in the circuit.

4.6 CRITICAL DESIGN DECISIONS

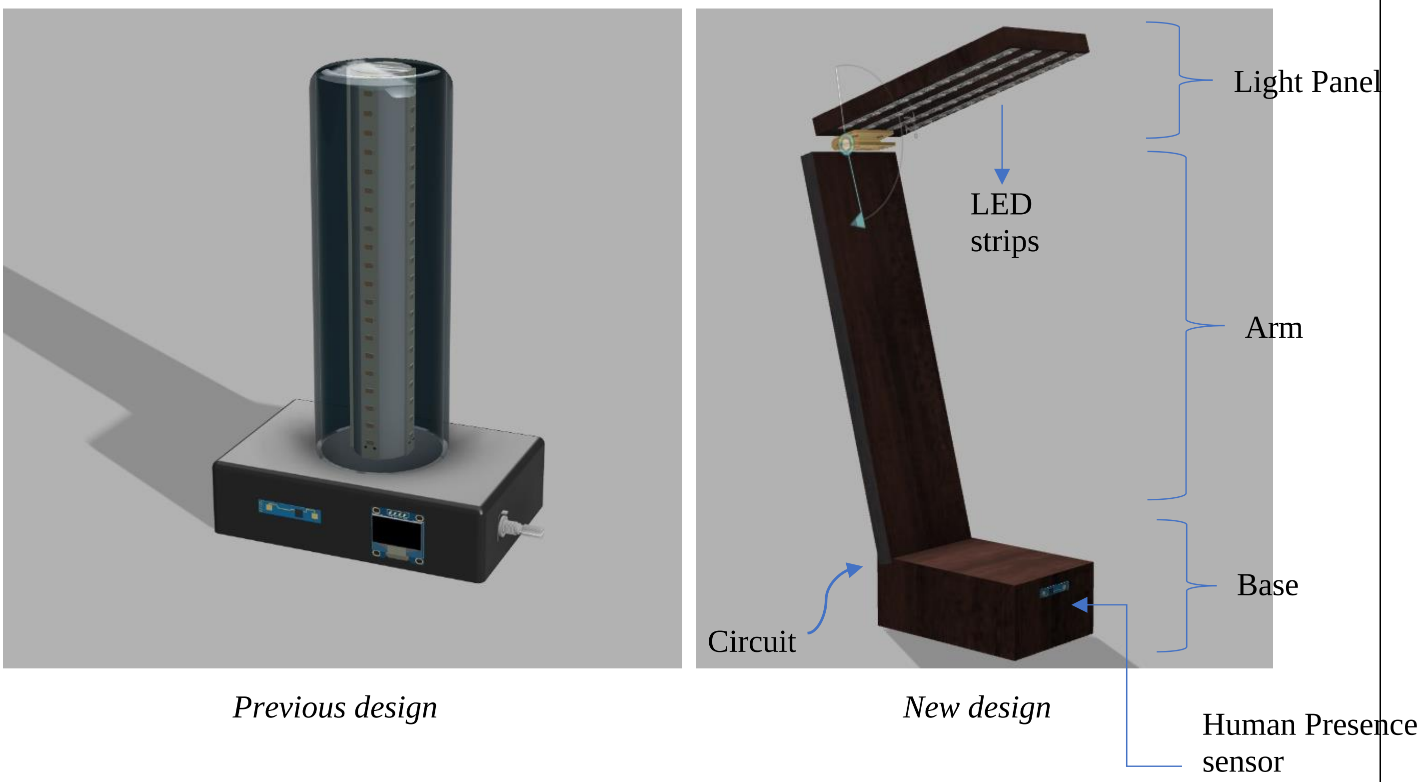


Figure 4.6.1: Comparison of new design with previous designs

Several design enhancements were implemented in the new design of the lamp compared to the previous design. Focused light projection was ensured by the direct light of the panel to a specific area instead of spreading it everywhere. A wooden casing was used to minimize heat transfer from the LED strips during extended usage while also maintaining an aesthetic appearance. An adjustable panel was included allowing the user to change the lighting angle for different tasks. Dual power options were added to improve portability and ensure uninterrupted operation during power failures. A 12V adapter was used for continuous operation, and a 12V battery pack was included as a backup (can be connected to the same DC male socket). The lamp was designed to project light effectively over approximately 0.75 meter with a 180-degree spread.

3-Dimensional view

Side view Front view

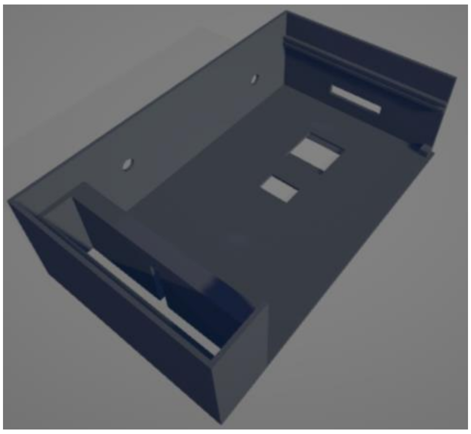
Figure 4.6.2: 3Dimnesional views of the lamp

critical design decisions.

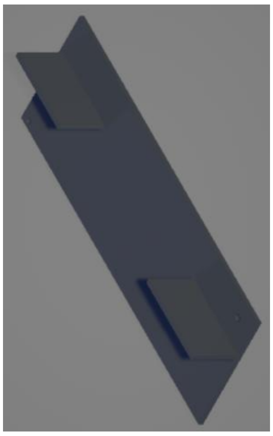
A casing was designed for the panel to cover it along with the LED strips. This helped focus the light directly onto the table, instead of spreading it around the room. The purpose was to create a more personalized lighting experience for the user.

A glass sheet was used as a protective cover for the soldered LED strips to shield them from the external environment. Additionally, the glass was used as it helped diffuse the light, resulting in a softer and more evenly spreaded illumination.

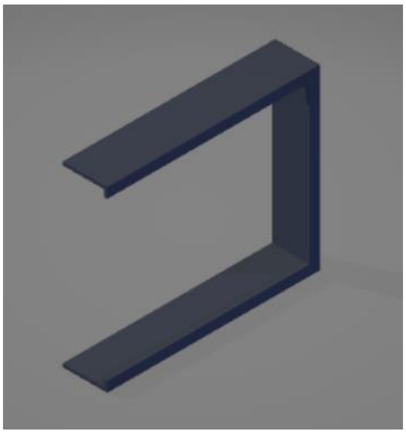
A railing was designed inside the enclosure casing to allow the circuit board to slide in easily. This made it convenient for future modifications, battery replacements, or checking the circuit. A separate slider was also designed to move along the same railing for a short distance and cover the open side of the enclosure. To secure the slider to the casing, two M3 self-tapping screws were used.



Casing

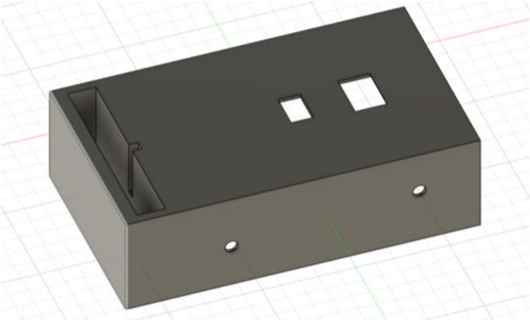


Slider

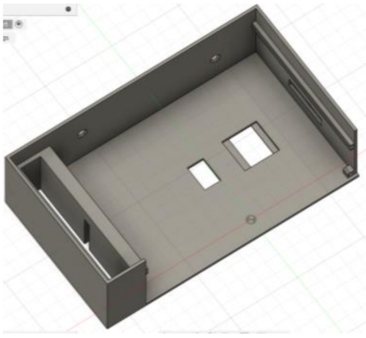


Panel casing

Base enclosure 3D view

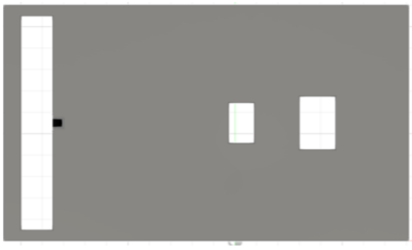


Top view

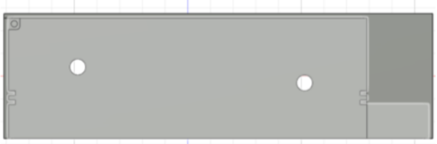


Bottom view

Base enclosure 2D view



Top view



Side view

Figure 4.6.3 :3D Printed designs

4.7 COST-SAVING MEASURES IMPLEMENTED

The lamp was not entirely designed using PLA or 3D printing due to cost constraints, as the estimated expense was around 10,000 LKR. Instead, wood was used for the panel and linkage parts, while only the base enclosure was 3D printed using PLA+. The base of the enclosure itself was first constructed from wood to reduce costs.

Although wood-finish filaments were available, they were priced nearly twice as high. Therefore, a grey-colored PLA+ filament with 100% infill was used to ensure sufficient strength to support the wooden structure. To give a uniform appearance to the 3D-printed enclosure with the wooden parts, a wooden-design sticker was pasted, enhancing the overall aesthetics.
wooden lamps are often associated with higher aesthetic value compared to fully 3D-printed ones. Therefore this design approach not only ensured cost-effectiveness but also gave the lamp a natural and appealing appearance.

4.8 LIST OF COMPONENTS WITH COSTS AND THE TOTAL PROJECT COST

Table 4.8 : List of components with cost

Component	Cost (lkr)
Human presence sensor	1,400
ESP-WROOM-32 microcontroller	1,300
LED Strip	200
12V 2A SMPS adaptor	650
OLED screen	500
1 Channel Relay module	350
Real Time clock memory module	380
Step down Buck module *2	300
Vero board (dot board)	220

LDR, Buzzer, Switch, DC Jack Barrel Connector, Potentiometer (10k)	30 + 40 + 10 + 60 + 30 = 170
Miscellaneous Components	500
3D print	2500
Total	8470/=

4.9 CIRCUIT DESIGN

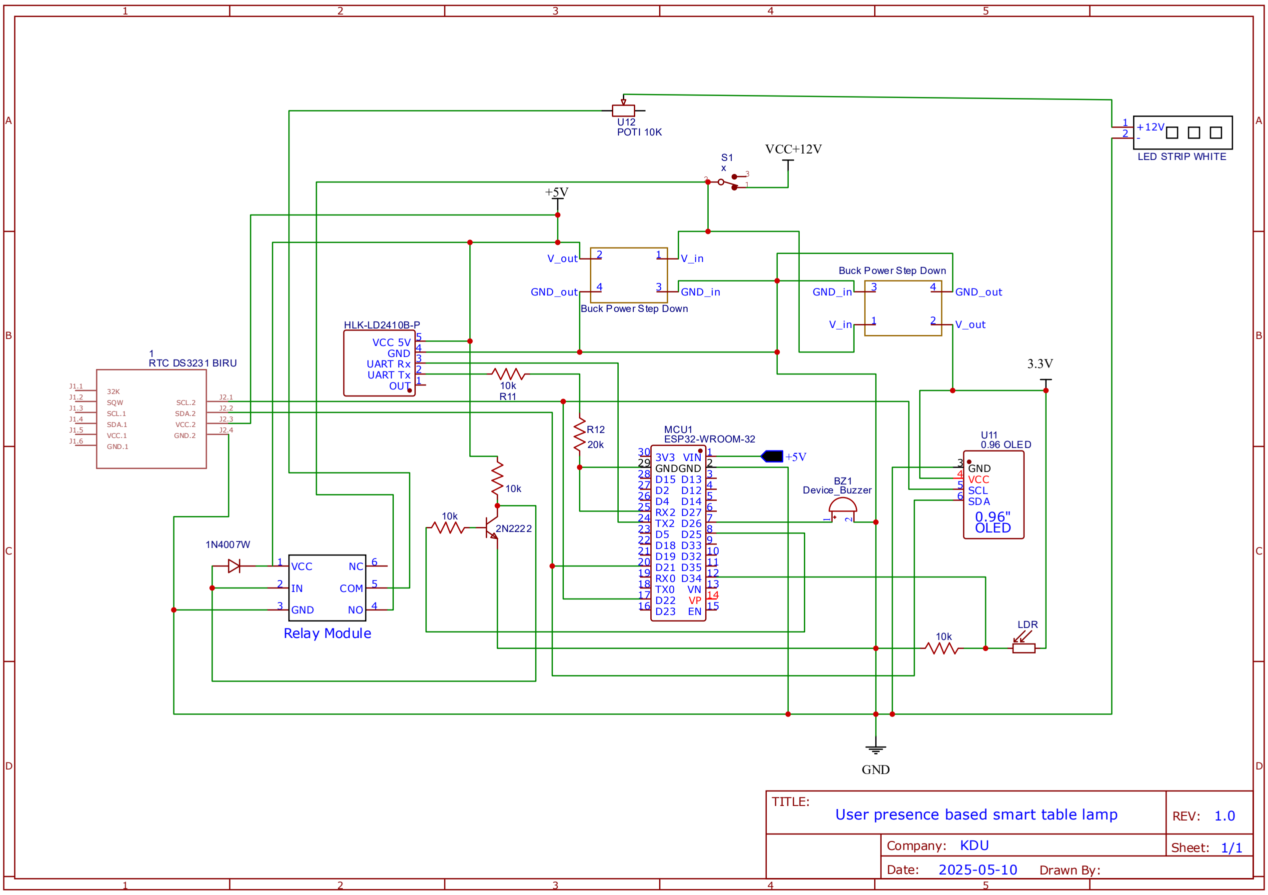


Figure 4.9.1 : Circuit design

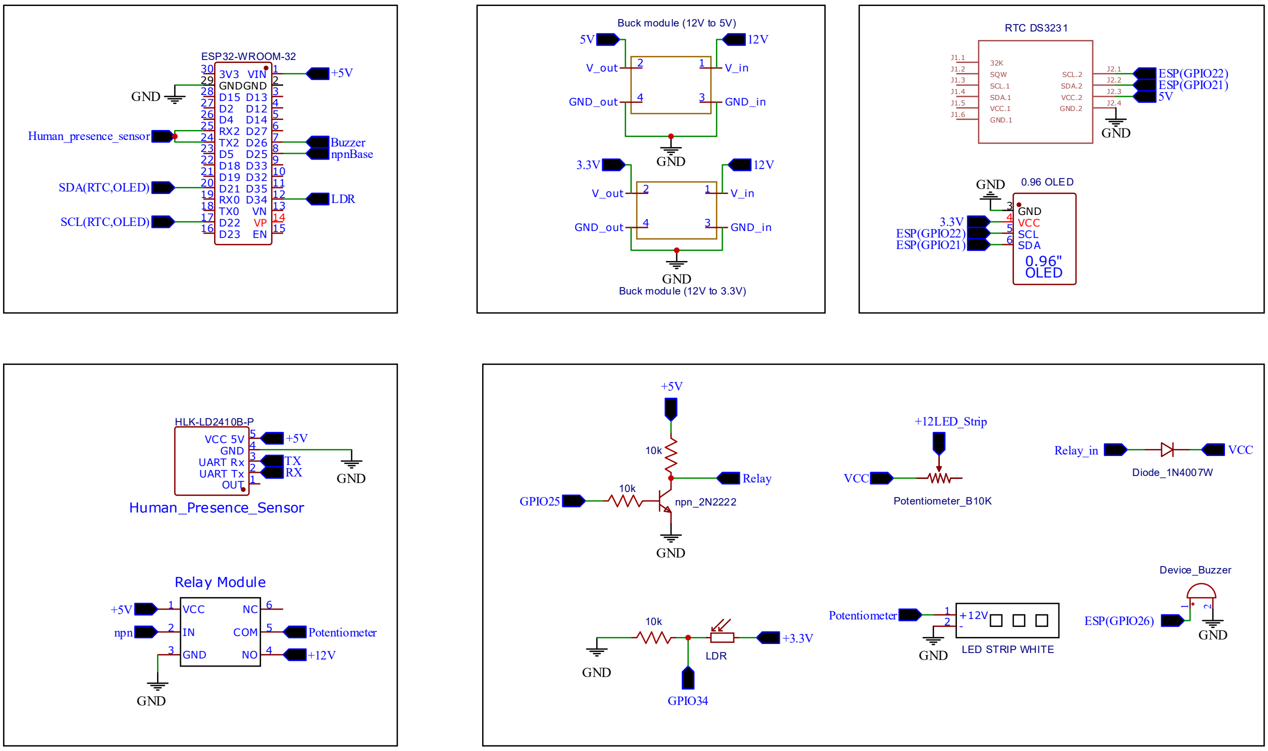


Figure 4.9.1 : Circuit design

In this project, the relay module was connected in a way that allows it to control the LED strip based on the signal coming from an NPN transistor. VCC of the relay was connected to 5V, providing the necessary power for the relay coil.

- GND of the relay goes to the common ground of the circuit.
- The IN pin (control signal input) of the relay is connected to the emitter of the NPN transistor. The transistor acts as a switch for the relay, when the base of the NPN transistor receives a signal from the ESP32, it completes the path to ground, allowing the relay to activate.
- The COM (Common) pin of the relay was connected to the LED strip, which is the load you want to control.
- The NO (Normally Open) pin was connected to one terminal of the physical switch that controls the main power supply. This setup ensured that the circuit is only powered when both the relay was activated and the manual switch is ON.

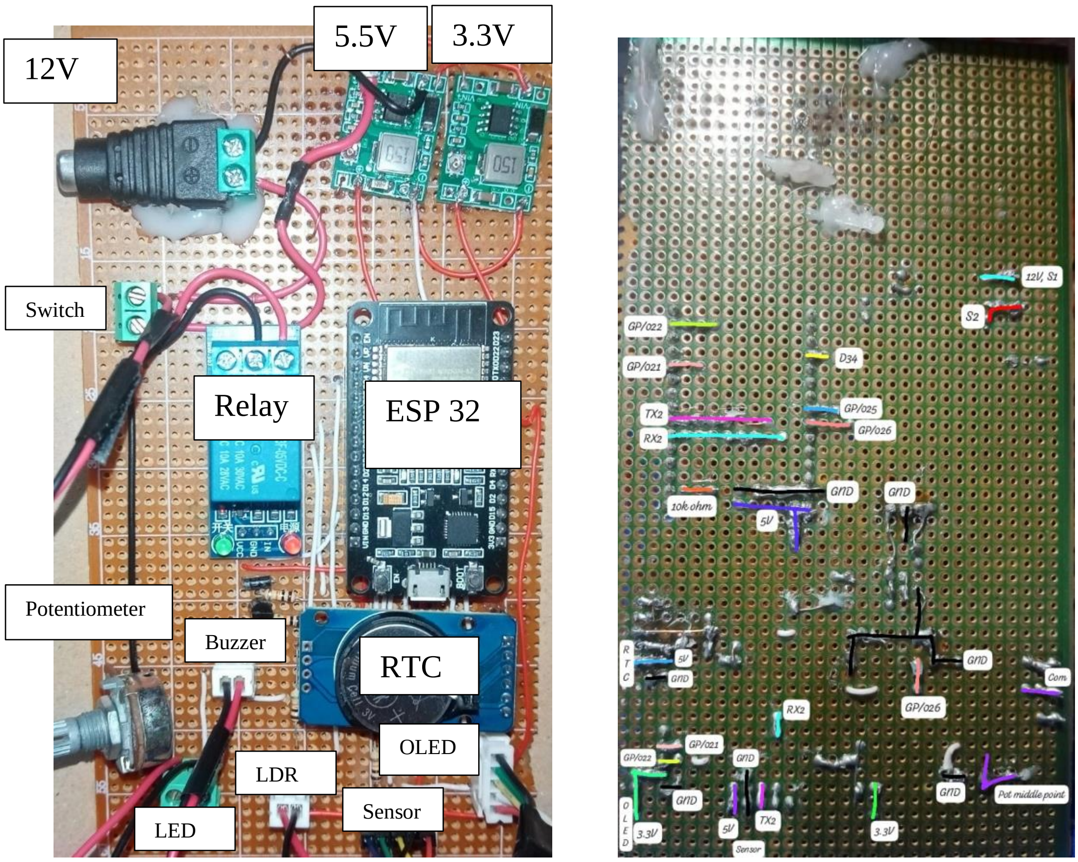


Figure 4.9.2 : Soldered circuit

CHAPTER 5: FINAL OUTCOME AND DISCUSSION

5.1 HARDWARE

5.1.1 CALIBRATION AND RESULTS

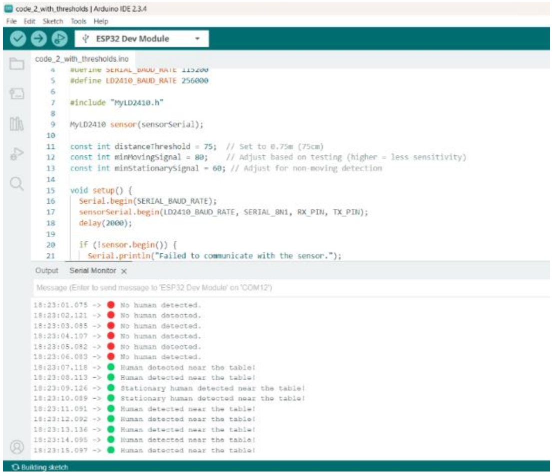


Figure 5.1.1.1 : Calibration of Human Presence Sensor

Figure 5.1.1.2 : Calibration of LDR

The primary objective of this project was to design and implement a smart table lamp that could automatically respond to ambient light and human presence, track study duration, and visualize user activity through a user interface. The final system successfully met these goals.

The lamp was able to detect low ambient light using an LDR and detect human presence using a radar-based sensor (LD2410B). Based on these inputs, the ESP32 microcontroller controlled the relay to switch the lamp ON or OFF accordingly. The OLED display showed real-time data, study duration, and alert messages based on the Pomodoro technique, and a buzzer was used to notify users after 25 minutes of study time. The study data were sent to Firebase via MQTT and visualized using Node-RED in the form of graphs and tables.

The project was conducted based the assumption that the student is studying the whole time he/she is at the table

Figure 5.1.3: Final Demonstration of the Smart Table Lamp Functionality

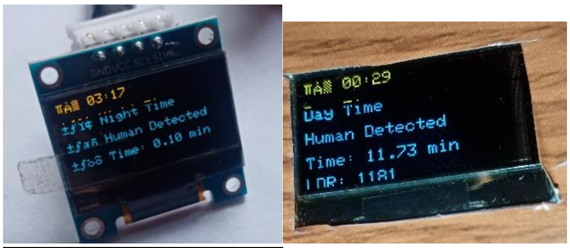
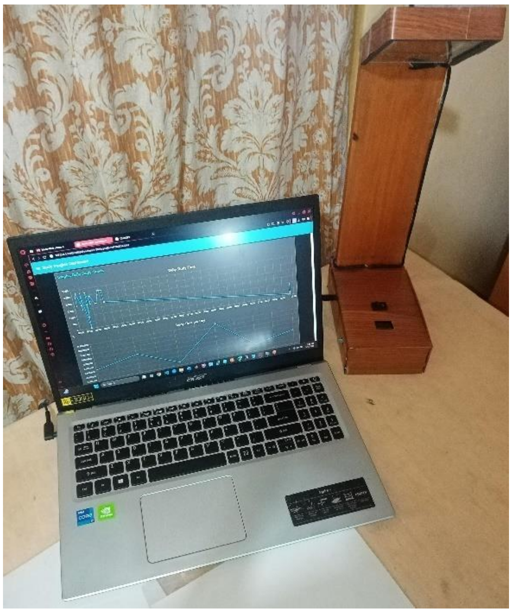


Figure 5.1.4: OLED Display



5.2 SOFTWARE

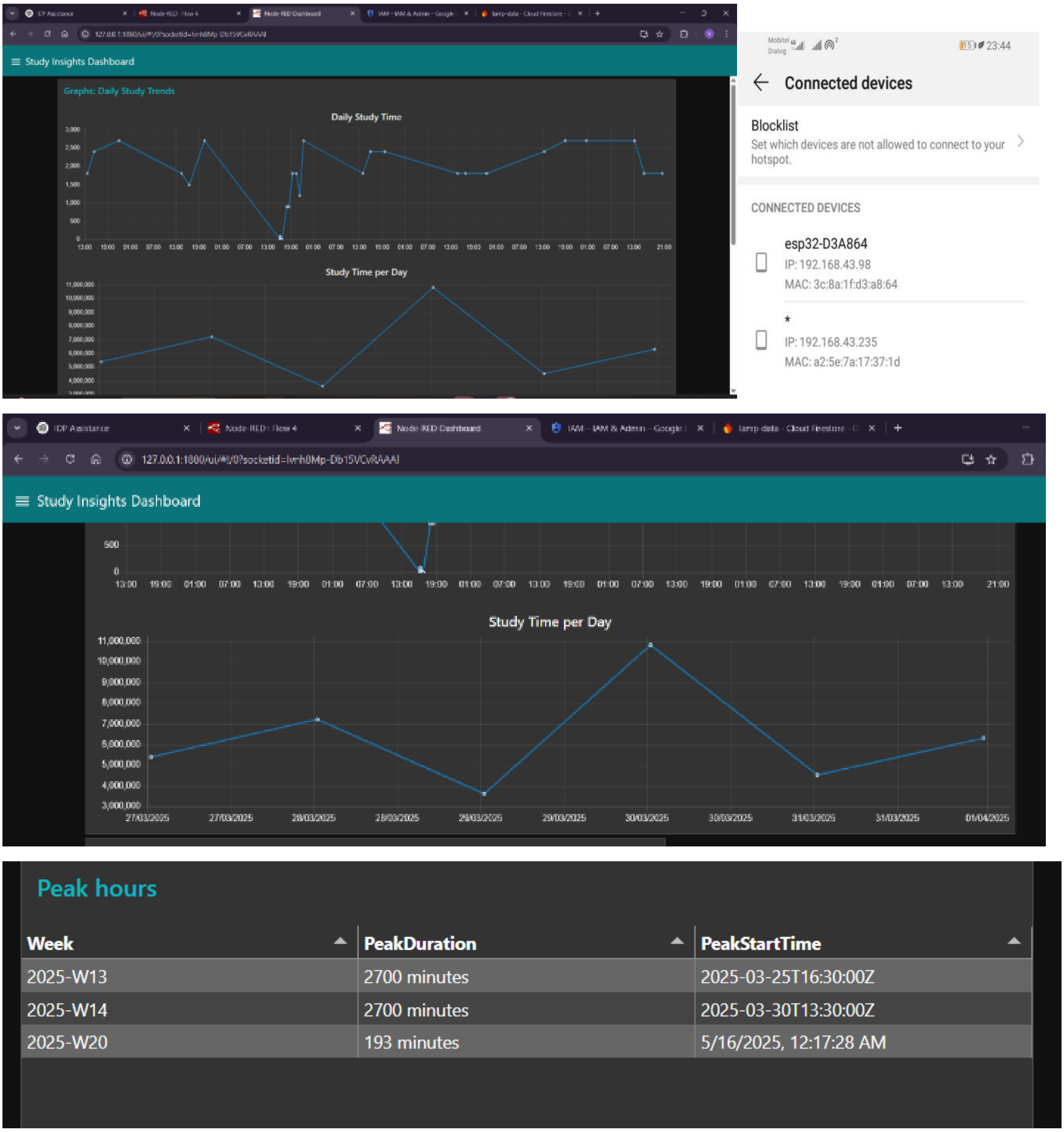


Figure 5.2: Representation of analyzed data

Table 5.2 : Software used

Purpose	Software
3D design	Fusion
	Solidworks
Database	Cloud firestore
Web interface	Nodered
Circuit design	Easyeda
Code	Arduino IDE
Run node-red	Command window

5.3 SIGNIFICANT TECHNICAL ISSUES FACED DURING THE PROJECT DEVELOPMENT

Table 5.3: Technical issues faced and corrective measures taken

Issue	Solution
The PIR sensor could only detect motion, so it wasn't reliable for knowing if someone was there throughout a time period.	Switched to the microwave radar sensor, which can continuously detect human presence.
The sensor's pins are very close together (1.27mm), making it hard to solder.	Use pin connectors with the precise gap between pins without soldering
When the LED strip emits light, the LDR was detecting it and LEDs kept turning ON and OFF continuously.	The LDR position and shielding adjusted in the base design and the code was given a bright threshold to switch off. (2500)
The human presence sensor has its own software for tuning, but the TTL converters didn't work for it.	Tested example codes from some library and calibrated the sensor manually.
The radar sensor gave false readings, varying the detected distance continuously, and sometimes detected non-human objects also.	Reduced the sensor's sensitivity, ignored non-human targets, and set the code to detect only human within a specific distance.

Misalignment in 3D Printed Enclosure – The openings for external components like the potentiometer and DC jack were not aligned correctly in the initial 3D-printed enclosure design.	The enclosure openings were adjusted manually by heating and widening the holes using a soldering iron.
Switch Pin Obstruction – The relay placement blocked the switch pins when sliding the circuit board into the designed rail.	The pins of the switch were carefully bent to opposite directions to avoid physical interference with the relay.
Circuit Damage Due to Loose ESP Fit – Frequent removal and reinsertion of the ESP32 after uploading trial codes caused loosening and eventually shorted components.	A new ESP32 and other damaged components were purchased and securely fixed; extra care was taken during insertion.

Despite these difficulties, the system functioned reliably, proving the feasibility of integrating hardware and software components to create a context-aware, user-friendly study lamp. The project not only achieved its intended objectives but also opened up ideas for future improvements such as app control and circuit miniaturization.

CHAPTER 6: CONCLUSIONS AND FUTURE WORKS

The development of the smart table lamp system successfully fulfilled all intended objectives. A fully functional hardware setup was implemented using the ESP32 microcontroller, LDR, LD2410B human presence sensor, DS3231 RTC, buzzer, relay, and OLED display. The system was designed to automatically control the LED lamp based on ambient light and human presence, reducing unnecessary power usage. Real-time monitoring and brightness control were effectively enabled through sensor integration and a user-controlled potentiometer.

The software integration was accomplished using Firebase and Node-RED. Sensor readings and lamp usage data were successfully transmitted via MQTT and stored in the cloud using Firebase. A real-time dashboard was created in Node-RED to visualize user study patterns through graphs, meeting the objective of building a user-friendly interface for tracking study time.

The study duration tracking mechanism, based on the Pomodoro Technique, functioned reliably. Alerts were triggered after every 25 minutes of continuous study using the buzzer and visual OLED prompts, helping promote productive habits.

This project provided hands-on experience in IoT-based smart system design, embedded systems programming, cloud integration, and real-time data visualization. Through a combination of hardware design and software architecture, the system demonstrated how modern electronics and cloud technologies can enhance day-to-day tasks such as studying, while promoting energy-efficient solutions.

6.1 FUTURE WORKS

For future improvements, a more compact design like a printed circuit board (PCB) is planned. This would allow for the development of a smaller lamp structure, potentially enabling a cost-effective 3D-printed design. The current relay module is intended to be replaced with an IRLZ44N MOSFET, which would reduce space and improve efficiency. Similarly, buck converters could be replaced with voltage regulators such as the L7805 to manage space. Instead of using a full ESP32 development board, a smaller microcontroller chip or processor may be used to further minimize the circuit size.

Power options could also be expanded to include both USB and battery power, along with a system to notify the user when charging is required. In addition, integrating mobile app control would enhance user convenience compared to using a web interface.

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CODE

```
#include <Wire.h>
#include <RTClib.h>
#include <Adafruit_GFX.h>
#include <Adafruit_SSD1306.h>
#include "MyLD2410.h"
#include <WiFi.h>
#include <PubSubClient.h>

// ===== WiFi & MQTT Config =====
const char* ssid = "HUAWEI Y6s";
const char* password = "veenz@123";
const char* mqtt_server = "192.168.43.235";

WiFiClient espClient;
PubSubClient client(espClient);

// Pin Definitions
#define RELAY_PIN 25
#define LDR_PIN 34
#define BUZZER_PIN 26
#define DARK_THRESHOLD 600
#define BRIGHT_THRESHOLD 2500

// OLED Settings
#define SCREEN_WIDTH 128
#define SCREEN_HEIGHT 64
#define OLED_RESET -1
Adafruit_SSD1306 display(SCREEN_WIDTH, SCREEN_HEIGHT, &Wire, OLED_RESET);

// LD2410B Settings
#define sensorSerial Serial1
#define RX_PIN 16
#define TX_PIN 17
#define LD2410_BAUD_RATE 256000

// Global Objects
RTC_DS3231 rtc;
MyLD2410 sensor(sensorSerial);

// Study Logic
bool humanDetected = false;
bool studying = false;
bool lampOn = false;
bool buzzerAlerted = false;

bool lastHumanState = false;

unsigned long lastCheck = 0;
```

```
unsigned long sessionStart = 0;
unsigned long lastBuzzTime = 0;
const int checkInterval = 1000;

void setup_wifi() {
  delay(10);
  Serial.println("Connecting to WiFi...");
  WiFi.begin(ssid, password);
  while (WiFi.status() != WL_CONNECTED) {
    delay(500);
    Serial.print(".");
  }
  Serial.println("\nWiFi connected");
}

void reconnect() {
  while (!client.connected()) {
    Serial.print("Connecting to MQTT...");
    if (client.connect("ESP32Client")) {
      Serial.println("connected");
    } else {
      Serial.print(" failed, rc=");
      Serial.print(client.state());
      delay(2000);
    }
  }
}

void setup() {
  pinMode(RELAY_PIN, OUTPUT);
  pinMode(BUZZER_PIN, OUTPUT);
  pinMode(LDR_PIN, INPUT);
  digitalWrite(RELAY_PIN, LOW);
  digitalWrite(BUZZER_PIN, LOW);

  Serial.begin(115200);
  sensorSerial.begin(LD2410_BAUD_RATE, SERIAL_8N1, RX_PIN, TX_PIN);
  delay(1000);

  if (!sensor.begin()) {
    Serial.println("LD2410B sensor failed");
    while (true);
  }

  sensor.enhancedMode();
  sensor.setNoOneWindow(1);
  sensor.setMaxMovingGate(2);
  sensor.setMaxStationaryGate(2);
  sensor.setGateParameters(2, 35, 45);
```

```
  if (!rtc.begin()) {
    rtc.adjust(DateTime(2025, 5, 16, 00, 43, 0));
    Serial.println("RTC failed");
    while (1);
  }

  if (!display.begin(SSD1306_SWITCHCAPVCC, 0x3C)) {
    Serial.println("OLED failed");
    while (true);
  }

  display.clearDisplay();
  display.setTextSize(1);
  display.setTextColor(SSD1306_WHITE);
  display.setCursor(15, 25);
  display.print("Hello!");
  display.display();
  delay(5000);

  setup_wifi();
  client.setServer(mqtt_server, 1883);
}

void loop() {
  if (!client.connected()) reconnect();
  client.loop();

  if (millis() - lastCheck < checkInterval) return;
  lastCheck = millis();

  DateTime now = rtc.now();
  int ldr = analogRead(LDR_PIN);
  bool isDark = ldr < DARK_THRESHOLD;

  // Human Detection
  humanDetected = false;
  if (sensor.check() == MyLD2410::Response::DATA) {
    int distance = sensor.detectedDistance();
    int moving = sensor.movingTargetSignal();
    int stationary = sensor.stationaryTargetSignal();
    if (sensor.presenceDetected() && distance < 100 &&
       (sensor.movingTargetDetected() && moving > 35 ||
        sensor.stationaryTargetDetected() && stationary > 45)) {
      humanDetected = true;
    }
  }

  // MQTT State Change Publish
  if (humanDetected != lastHumanState) {
    if (humanDetected) {
```

```
    client.publish("study/enter", "Human entered the study table.");
    Serial.println("MQTT: study/enter published");
  } else {
    client.publish("study/left", "Human left the study table.");
    Serial.println("MQTT: study/left published");
  }
  lastHumanState = humanDetected;
}

// Study Timer Logic
if (humanDetected) {
  if (!studying) {
    sessionStart = millis();
    lastBuzzTime = sessionStart;
    studying = true;
  }

  float minutesStudied = (millis() - sessionStart) / 60000.0;
  if (millis() - lastBuzzTime >= 120000) {
    buzz();
    displayMessage("⏱" + String(minutesStudied, 2) + " min\nTake a break!");
    lastBuzzTime = millis();
  }
} else if (studying) {
  float minutesStudied = (millis() - sessionStart) / 60000.0;
  displayMessage("You studied\n" + String(minutesStudied, 2) + " mins");
  studying = false;
  delay(5000);
}

// ✅ Updated Lamp Control
if (!lampOn && (ldr < DARK_THRESHOLD) && humanDetected) {
  lampOn = true;
  digitalWrite(RELAY_PIN, HIGH);
} else if (lampOn && ((ldr > BRIGHT_THRESHOLD) || !humanDetected)) {
  lampOn = false;
  digitalWrite(RELAY_PIN, LOW);
}

// OLED Display
display.clearDisplay();
display.setCursor(0, 0);
display.print(" ⏰ ");
printTime(now);
if (humanDetected) {
  display.setCursor(0, 20);
  display.print("Human Detected");

  float mins = (millis() - sessionStart) / 60000.0;
  display.setCursor(0, 35);
```

```
    display.print("Time: ");
    display.print(mins, 2);
    display.print(" min");

    display.setCursor(0, 50);
    display.print("LDR: ");
    display.print(ldr);
  }
  display.display();
}

void buzz() {
  digitalWrite(BUZZER_PIN, HIGH);
  delay(500);
  digitalWrite(BUZZER_PIN, LOW);
}

void printTime(DateTime now) {
  if (now.hour() < 10) display.print('0');
  display.print(now.hour());
  display.print(':');
  if (now.minute() < 10) display.print('0');
  display.print(now.minute());
}

void displayMessage(String msg) {
  display.clearDisplay();
  display.setCursor(0, 20);
  display.println(msg);
  display.display();
}
```