ORIGINAL PAPER

MICROCONTROLLER-BASED TEMPERATURE AND FACE DETECTION SYSTEM FOR SMART LABORATORY CONTROL AND MONITORING

Abstract

Efficient and reliable laboratory management requires precise monitoring and control of environmental conditions such as temperature, occupancy, and equipment use. However, traditional monitoring methods such as manual measurements can be time-consuming, labor-intensive, and prone to error. Additionally, there is often a need for remote monitoring and control, especially in large facilities or during off-hours. To address these challenges, this paper presents the design and implementation of a comprehensive monitoring and control system for a laboratory. The system employs an ESP32 microcontroller board and various sensors to automate temperature, occupancy, and equipment monitoring. Furthermore, the system can be remotely controlled via SMS through a GSM network, providing an effective way to manage laboratory conditions from a distance. The system's accuracy was evaluated by comparing temperature readings with those of a reference thermometer and testing face detection and relay control functions. The results of the tests demonstrate that the system is reliable and accurate in monitoring and controlling the laboratory environment. Overall, this system provides an efficient and effective solution for laboratory management, reducing the need for manual monitoring and improving the accuracy of environmental data collection.

Keywords: Temperature monitoring, Smart Lab Control, Sensors, ESP32

1.0. Introduction

The recent COVID-19 pandemic has drastically changed the way academic institutions operate worldwide (Ali, 2020; Maatuk et al., 2022). Since students often gather in classrooms and laboratories for practical classes, it has become essential to implement crowd control measures to maintain a safe environment for everyone. Crowd control refers to the measures taken to manage and regulate the movement and behavior of large groups of people in public spaces (Manikanda Kumaran et al., 2020).

One of the most crucial measures is to limit the number of students allowed in a laboratory at any given time, which can help reduce the risk of transmission by ensuring that physical distancing measures are followed.

Additionally, another measure that has been widely implemented is the use of temperature screening to ensure that no one with a fever or elevated body temperature enters the laboratory. This is done by measuring the body temperature of each individual and comparing it to a set threshold. Effective implementation of these crowd control measures is vital in ensuring that the virus is not spread among learners, as well as instructors and other staff members who are present in the laboratory. By implementing these measures, academic institutions can help prevent the spread of the virus and ensure that students can continue to learn in a safe and healthy environment (Chaturvedi et al., 2021; Maatuk et al., 2022).

However, there are several problems associated with the existing methods of implementing crowd control measures in university laboratories. Firstly, limiting the number of students allowed in the laboratory at any given time can be challenging to enforce. Some students may not adhere to the rules and may try to sneak into the laboratory, which increases the risk of crowding and makes it difficult to maintain social distancing (Poongothai et al., 2018).

Secondly, monitoring the body temperature of students can be time-consuming and may require additional personnel. It is also possible for individuals with the virus to be asymptomatic and not exhibit a fever, making this measure less effective in identifying potential carriers of the virus. Lastly, some institutions may not have the necessary resources and equipment to implement these measures effectively. This can lead to a lack of consistency in the implementation of these measures across different laboratories and departments, which can increase the risk of virus spread (Ali, 2020).

Apart from the aforementioned, the use of traditional thermometers can also slow down the process of monitoring large crowds, leading to long lines and increased risk of exposure to the virus. These challenges have underscored the need for innovative methods of temperature measurement that are contactless, efficient, accurate, and capable of handling high volumes of people.

Specifically, there is an increased need for innovative methods of temperature measurement and crowd control measures in various settings, including educational institutions where students gather for lectures and laboratory practicals (Guntur et al., 2023). This need for smarter laboratories was highlighted by Espinilla et al. (2018) where authors proposed a system that monitors temperature, humidity, and light intensity and uses a database to view status history. The results show that appliances in the lab can be remotely monitored and controlled, reducing their energy consumption.

Poongothai et al. (2018) developed a smart laboratory system on a CIT campus using IoT and mobile application technologies. The system monitors the energy consumption, device utilization, and environmental parameters in the lab for improved energy efficiency and comfort. The system is built with IoT hardware kits, including ESP8266, Arduino UNO, Raspberry Pi3, and sensors, and is controlled through a dashboard developed in Node-RED and a mobile application in Android Studio. The system monitors temperature, humidity, and light intensity and has a database to view status history.

Similarly, Knight et al. (2020) presented the concept of a smart integrated laboratory, where IoT devices and technologies are used to control and monitor laboratory equipment. The authors describe a prototype system, Talk2Lab, that was implemented in a laser facility, and combines sensors, Raspberry Pis, camera feeds, and multiple interaction methods to facilitate laboratory communication. The system was evaluated by laboratory users for usability and potential areas of expansion. The results showed the potential of IoT devices in creating smart laboratories, and the authors further envisioned a fully interconnected laboratory of the future.

Lawal et al. (2021) present a comprehensive review of research on the use of IoT technology in residential and commercial buildings. The objective of the work is to understand the potential of IoT technology in the built environment. The study on residential buildings was divided into three categories (home automation, intelligent energy management systems, and healthcare facilities), while the studies on commercial buildings were divided into four categories (office buildings, healthcare facilities, educational facilities, and restaurants and retail facilities). The paper identifies the trends, benefits, risks, and challenges of IoT implementation in the built environment, with a focus on the integration of various IoT technologies, data storage and processing, and privacy and security risks.

These reviewed works have focused majorly on automation and energy management. Hence, they do not directly address the challenges during a pandemic. The need for this work arises due to the importance of maintaining a safe and hygienic environment in educational environments during a pandemic or any epidemic outbreak. In such a situation, it becomes important to monitor the temperature of individuals entering the laboratory and to limit the number of people at any time to maintain social distancing guidelines. The traditional manual methods of temperature monitoring and crowd control are time-consuming, unreliable, and prone to human error. Therefore, there is a need for a reliable and efficient solution that can accurately monitor temperature and control crowding in educational environments.

Thus, to address this need, this paper proposes a microcontroller-based temperature index and face detection system. The proposed system can measure temperature and limit the number of students in a laboratory to any set value, with a buzzer that sounds an alarm and a screen display that shows when the limit has been exceeded. The system also alerts laboratory attendants of high temperatures above 27C, ensuring a safe and hygienic environment for students and staff. This innovative solution aims to provide a reliable and efficient way of monitoring temperature and overcrowding in educational environments during a pandemic.

2.0. Methodology

2.1. System Specification

The specification of our proposed system includes the use of a GSM network for control and automation through real-time monitoring devices. An Arduino-Nano will transfer user commands to a controller that processes and sends commands to relevant units for appliance control purposes

(Debnath et al., 2023; Yar et al., 2021). A GSM network is to be utilized as a communication medium for remote management in areas with limited internet connectivity. Also, the system interface must be user-friendly and would utilize Short Message Service (SMS) for sending commands and receiving feedback. Temperature readings of people entering and leaving the laboratory are taken to ensure safety during a pandemic. Face detection is used to monitor the number of people entering and exiting the laboratory and to authenticate individuals entering. An ESP32 microcontroller performs commands using a relay switch after password-based authentication through SMS. Furthermore, as extra features, the proposed system saves energy and reduces human effort by automatically switching off loads when not in use. A manual mode is also available for manual management. The use of SMS is emphasized for better and faster communication in areas with network issues.

2.2. System Components

The components used for the proposed system can be classified under the hardware and software components. The description of each classification is presented in the following subsections.

2.3. Hardware Components

Table 1: Hardware components and description

Hardware Component	Hardware Description
Microcontroller (ESP32)	A low-cost microcontroller with integrated Wi-Fi and dual-mode Bluetooth. It acts as the center of the GSM module and enables wireless connectivity.
GSM Module (SIM800L)	A wireless modem that operates on a GSM network, with no limitations on distance. It works anywhere in the world and is controlled by sending commands to the microcontroller (Akhter et al., 2019).
Relays	Used to switch loads by receiving commands from the phone and being controlled by the microcontroller. Transistors are used in place of relays when multiple relays are required to switch at low currents.
IN4007 Diode	A rectifier diode that converts Alternating Current to Direct Current.
Infrared Proximity Sensor	Detects nearby objects without physical contact by emitting an electromagnetic field or infrared beam. The sensor allows the thermometer to take readings at a distance.
ESP32 Camera Module	A low-power, small-sized camera module based on ESP32, used for IoT applications such as wireless video monitoring and Wi-Fi image upload.
AC-DC Converter	Converts incoming and outgoing voltage for the Smart Lab board, protecting the board and producing proper voltage for lab equipment and lighting.

The hardware components include sensor modules, servo motor modules, network modules, liquid crystal, relays, display, buzzer, and power adapter which are all connected to the main Arduino Uno controller. The hardware components are described in Table 1.

2.4. Software Components

2..4.1. ARDUINO Integrated Development Environment (IDE)

Arduino IDE is an open-source software, designed by Arduino.cc and mainly used for writing, compiling, description & uploading code to almost all Arduino Modules (Arduino, 2015). The software makes code compilation easy. It is available for all operating systems which include, MAC, and Windows, and runs on the Java Platform that comes with inbuilt functions and commands that play a vital role in debugging, editing, and compiling the code.

It can perform serial communication with the computer using USB and also work with Digital and Analog signals, sensors, and Actuators. The recommended input voltage is 7-12V while the operating voltage is 5V for most of the Arduino boards. ESP32 Microcontroller is the controller used on the Arduino IDE.

2.4.2.PROTEUS

Proteus is a software tool for microcontroller simulation and embedded systems development (Chalh et al., 2020). It allows users to design and test embedded system designs, including both hardware and software components, without the need for physical prototyping. With Proteus, users can simulate and debug microcontroller-based projects, create and test circuit designs, and even design custom PCB layouts. The software includes a wide range of simulation models and libraries for popular microcontrollers, sensors, and other electronic components. It also features a comprehensive debugging environment that allows users to step through code and examine memory and register values in real time. The proposed system is simulated using this software before implementation to test its operational efficiency.

3.0. SYSTEM ANALYSIS AND DESIGN

We analyse the system into four key sections: power, input, processing, and output. The design procedure for these sections is described next;

3.1. Power Section

Two components make up the power source: a primary source and a secondary source. The primary source is a Lithium-Ion battery, with a voltage range of 3.7V to 4.2V, which is optimal for the SIM800L module. The secondary source is a step-down transformer that converts 220V AC to 5V DC, which charges the battery. Additionally, a boost converter is utilized to maintain a stable 5V voltage by converting the low voltage from the battery. This boost converter is responsible for supplying power to all sub-hardware systems, and it is directly connected to the battery. The secondary source is attached to a full-wave rectifying diode, which requires four diodes. Each diode has a voltage drop of 0.6V, leading to a total voltage drop of 2.4V. To filter the rectified voltage, a capacitor is utilized, which peaks at 5.09V. The resistance, LED current, and voltage value is calculated via Ohm's law. The system's circuit diagram is shown in Figures 1 and 2.

3.2. Input Section:

The input section of the system comprises a GSM module (SIM800L GSM/GPRS) and a thermometer (MLX90614 Non-Contact IR Temperature Sensor).

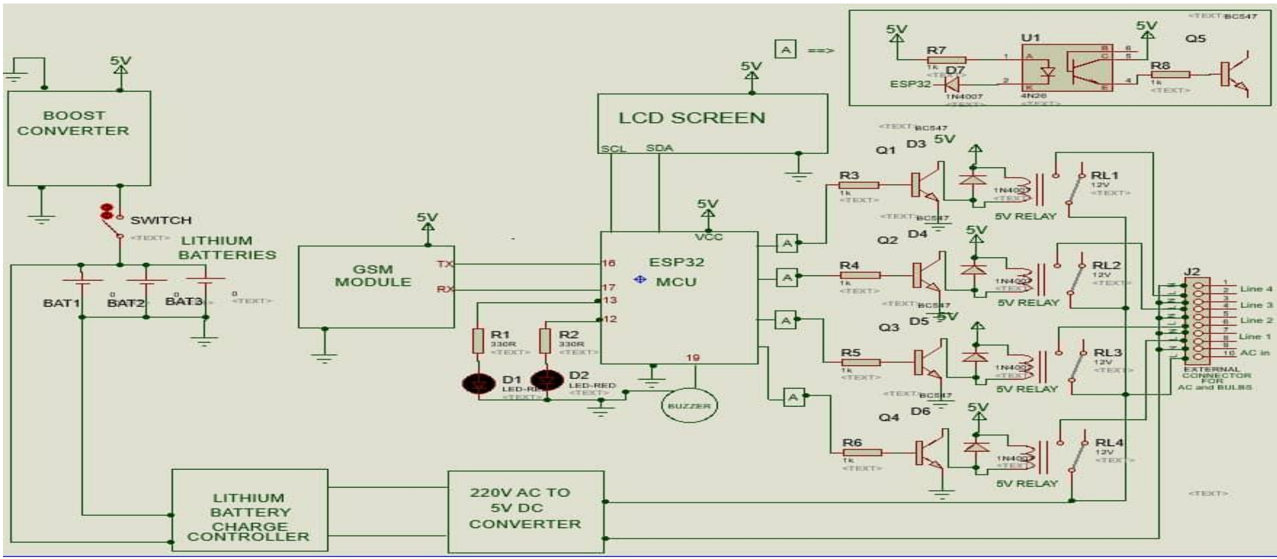


Figure 1: Circuit diagram of the proposed System

The GSM module receives commands from the user, while the thermometer measures the temperature of an object and triggers an alarm if the temperature surpasses the set value. The selection of the GSM module was influenced by the challenges of attaining a reliable 3G network in the project's location. Bluetooth was unsuitable due to its limited range.

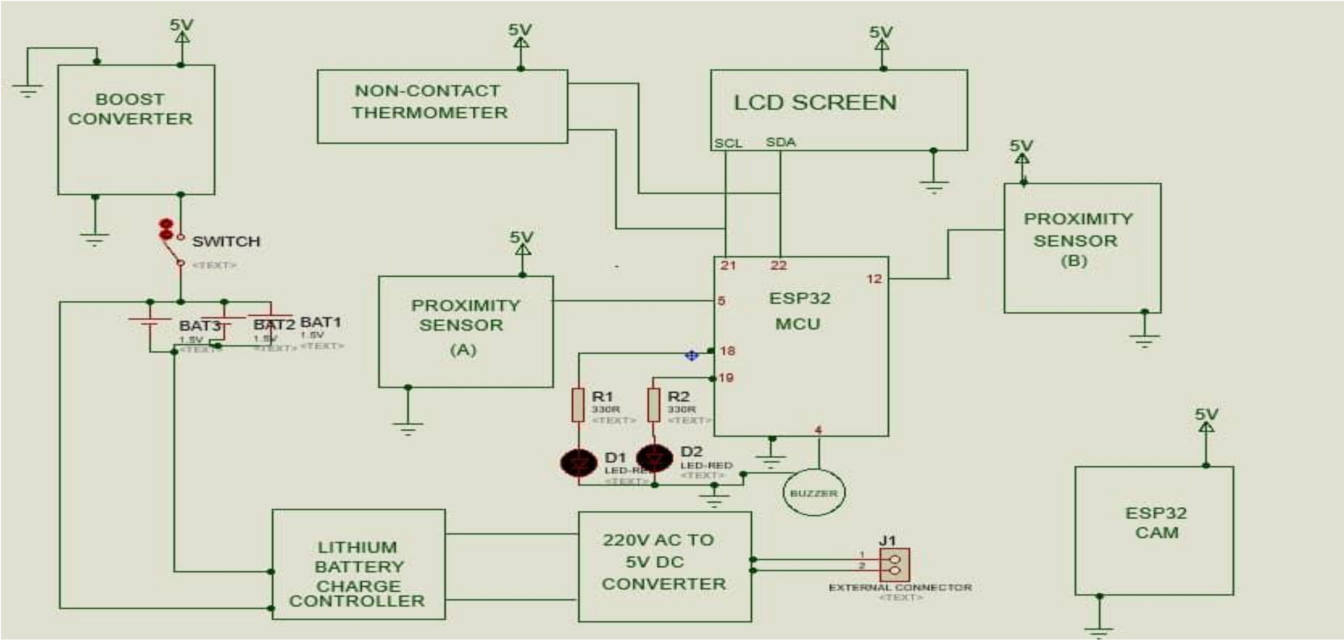


Figure 2: Circuit Diagram of the various modules of the Micro-Controller unit.

3.3. Processing Section

The ESP32 microcontroller is responsible for processing commands received from the GSM module, camera module, or thermometer. With its 3.3V pin and 36 I/O pins, the ESP32 is well-suited for the system design and is powered directly by the boost converter (Abd Jalil et al., 2021; Iriho, 2022). The Arduino functions as the core of the project and handles the interpretation of the received command, triggering the buzzer or relay as needed. However, the output pins of the Arduino are insufficient to power the relay coils. To address this, a resistor-transistor arrangement is used to amplify the current and enable the relays to be powered from the primary 5V DC supply without overloading the Arduino pins.

3.4. Output Section

The output section of the system comprises several components, including a relay control unit, buzzer, LCD, and RGB LEDs. The relay control unit is responsible for switching various appliances connected to the system's output, with a maximum contact rating of 10A and a maximum voltage of 270VAC/28VDC. The buzzer produces an alarm sound when the thermometer senses a value above the set threshold. The LCD provides information on the state of the device and the output from the thermometer, while the normal and RGB LEDs indicate the device's power status and output. Tables 1-3 present the specifications of some hardware components used in the system.

Table 1: Specifications of the thermometer device

Feature	**Value**
Supply Current	1.5mA
Operating voltage	3.6V – 5V
Object Temperature Range	-70 – 382.2 degree
Ambient Temperature Range	-40 – 125 degree
Accuracy	0.02 degree
Field of view	80 degree
Distance between object and sensor	2cm – 5cm (approx.)

Table 2: ESP32 Technical Specifications

Feature	**Value**
Operating Voltage	3.3V
Recommended Input Voltage for Vin pin	7V – 12V
Analog Input Pins	Up to 18
Digital I/O Pins	36 (Out of which 16 provide PWM output)
DC Current on I/O Pins	20 mA
DC Current on 3.3V Pin	40 mA
Flash Memory	4 MB
SRAM	520 KB
WIFI	802.11 b/g/n
Frequency (Clock Speed)	160 MHz to 240 MHz
Communication	SPI, I2C, CAN, UART, I2S
Bluetooth	V4.2 BR/EDR and BLE
Touch sensors	10

Table 3: Specifications of the relay unit

Feature	Value
Contact Rating	10A
Maximum Voltage	270VAC/28VDC
Coil Voltage	5VDC
Coil Current	71.4mA
STurn on Voltage	3.5VDC
Coil Resistance	70 Ohms
Single Pole	Double Throw
Turn off voltage	Min 0.5VDC

3.5. Load Analysis

The load analysis involves calculating the current requirements of various appliances, including bulbs, air conditioners, fans, and televisions, and determining if a 5V, 10A single pole double throw relay on a single-phase supply can handle the load. For example, a 25W bulb requires 0.11A of current, allowing the relay to handle up to 90 of these bulbs. However, an air conditioner (AC) with a 2.5KW power rating requires 11.3A of current, exceeding the relay's 10A rating, and thus cannot be controlled using the relay. For a 300W appliance such as a fan or television, which requires 1.36A of current, the relay can handle up to 7 of these appliances.

3.6. PSEUDOCODE

The pseudocode explains the software design of the system.

Step 1: Import necessary libraries

Step 2: Create objects for the MLX thermometer, ESP32 Microcontroller, and LCD

Step 3: Declare variables for RGB LEDs, relays, relay LEDs, sensor pin, and buzzer

Step 4: Set the states of the flashers

Step 5: Initialize the libraries and set pins as input/outputs

Step 6: Display a welcome message

Step 7: Set temperature range between 36.3℃ and 37.3℃ and counter to 30

Step 8: Test the design

Step 9: If the temperature is above range, activate the buzzer and turn on the red LED

Step 10: If the temperature is within range, turn on a green LED

Step 11: If a face is detected, turn on the blue LED and activate the relay

Step 12: Display temperature and face detection status on LCD

Step 13: Repeat steps 9-12 until the counter reaches 0

Step 14: Display the end message on LCD and turn off the LEDs and buzzer

Step 15: End the program

4.0. IMPLEMENTATION, FUNCTIONALITY, TESTING

4.1. IMPLEMENTATION

After ensuring that all the connections are properly made, the system is powered on by connecting it to the main power source. The boost converter and step-down transformer work together to provide a stable 5V DC supply to the system. The system is then initialized by loading the required software and setting up the necessary parameters, such as the temperature threshold for the thermometer and the number of people threshold for the camera module. Once the system is initialized, it starts monitoring the temperature and the number of people in the laboratory. If the temperature exceeds the set threshold or the number of people exceeds the set limit, the system sends an alert to the user via SMS and triggers the alarm buzzer. The LCD shows the status of the appliances and the temperature and the number of people in the laboratory.

The user can also control the appliances by sending SMS commands to the system through the GSM module. For example, sending the command "AC ON" will turn on the air conditioner, while sending "AC OFF" will turn it off. The Relay Control Unit switches the states of the appliances on and off based on the SMS commands received from the user. Finally, the system is tested thoroughly to ensure that all the components are functioning properly and the appliances are being controlled as expected. Any issues that arise during testing are addressed and resolved before the system is put into use.

4.2. SYSTEM FUNCTIONALITY

The functionality of the system relies on multiple components working in tandem to monitor and regulate the temperature, people count, and appliances in a laboratory. An AC-DC converter charges the battery, which powers the system components. The ESP32 Microcontroller serves as the central controller, relaying electrical signals to the relay to toggle connected appliances from OFF to ON when it receives an SMS command over the GSM network. The MLX 90614 thermometer measures the temperature through the proximity sensor, while the ESP32 Camera Module and Proximity sensor collaborate to detect people's faces entering or leaving the lab.

The face detection system's working principle combines two signals: Face detected = 1, No Face detected = 0, Body sensed by the Infrared sensor =1, and Nobody sensed by the Infrared sensor = 0. Users can send commands to the ESP32 Microcontroller through text messages over the GSM network. Additionally, two RPG LEDs indicate the thermometer and GSM module's operation statuses. The LCD exhibits temperature, people count, and appliance status and the Relay Control Unit toggles the appliances from ON to OFF. A plastic box that splits into three mini-housings organizes and simplifies installation, and thorough testing ensures correct functioning before installation. Finally, the appliances link to the Relay Control Unit.

4.3. TESTING

Figures 3 and 4 display the internal and external views of the proposed system, including the thermometer. The system underwent testing to evaluate its accuracy in temperature measurement and face detection. A relay control test was also conducted to ensure that the relay operated correctly and switched the appliances on and off as intended. Subsequent subsections present the outcomes of each test.

Figure 3: Internal View of the System

Figure 4: External View of the System

4.3.1.Temperature accuracy test

To ensure the accuracy of temperature readings obtained from the system, a comparison test is conducted with a known temperature source, such as a reference thermometer. The system is placed in a location where temperature values are measured every 60 minutes, and these readings are compared with those obtained from the reference thermometer. The results of this comparison test over 24 hours are presented in Figure 5, demonstrating the system's ability to measure temperature accurately.

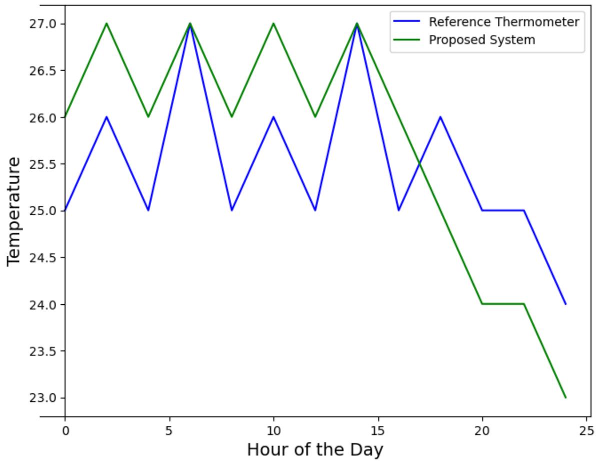
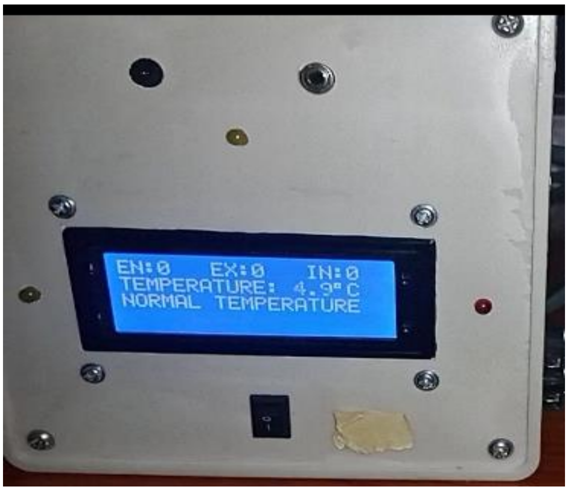


Figure 5: Observed temperature readings across the proposed system and a thermometer device.

4.3.2. Relay and Display test

This test involves checking if the messages and data are displayed correctly on the LCD and a test that checks if the relay is functioning correctly and turning on and off the appliances as expected. Figures 6 and 7 present the LCD and relay control test results.



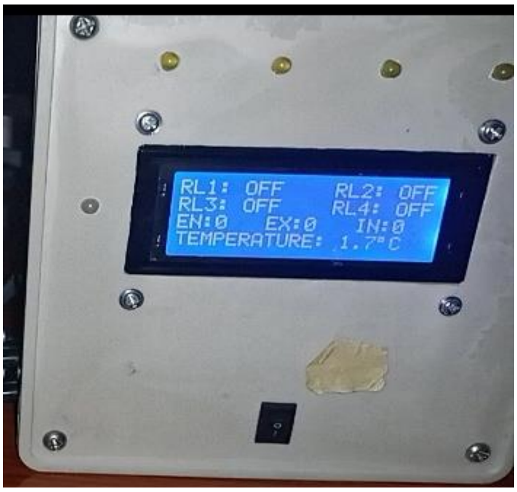


Figure 6: LCD Display of the System

Figure 7: Relay control test

5.0. CONCLUSION

The Microcontroller-based temperature and face detection system offer a highly efficient and effective solution for monitoring temperature and detecting the presence of people in a given space. By converting Alternating Current (AC) to Direct Current (DC) and utilizing components such as the ESP32 Microcontroller board, MLX 90614 thermometer, and ESP32 Camera Module with Infrared Sensor, the system can accurately measure temperature, detect individuals, and activate appliances through the Relay Control Unit. The components are securely housed in separate mini-housings within a durable plastic box, ensuring their safety and longevity.

Before final installation, the entire system undergoes thorough testing to verify its proper functioning, with the temperature and face detection status conveniently displayed on an LCD screen. This Microcontroller-based system provides a reliable and convenient solution for enhancing safety and comfort in various environments.

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