Project Report

Course Name: IoT and Embedded Systems

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Project Title: BLE Thermostat

1. Introduction

Automation plays a vital role in simplifying tasks, reducing human error, and improving efficiency. This project focuses on automating environmental monitoring by integrating sensors, a display, and BLE communication using an ESP32 microcontroller. Automating such processes provides accurate, real-time data while eliminating the need for manual monitoring, making it invaluable for industries like agriculture, healthcare, and smart homes. It positively impacts decision-making, enhances safety, and saves time by seamlessly integrating into IoT ecosystems. The motivation behind this project is to create a scalable, energy-efficient solution that benefits both individuals and industries through reliable, automated systems.

2. Problem Statement (Empathize & Define)

Environmental monitoring often requires manual effort and lacks seamless integration with IoT systems, leading to inefficiencies and inaccuracies. Users, such as farmers, healthcare providers, and industrial operators, are affected as they rely heavily on precise, real-time data for critical decision-making. Delays or errors in data collection can result in financial losses, compromised safety, or reduced productivity.While existing solutions like standalone sensors or basic monitoring systems provide some functionality, they often lack automation, portability, and efficient data sharing. Their limitations include high costs, complex setups, and limited scalability, making them inaccessible or impractical for widespread use. This project aims to address these gaps by creating an affordable, automated system for real-time monitoring and BLE-based communication, benefiting users through increased efficiency and reliability.

3. Ideation & Proposed Solution

The proposed solution was developed after evaluating various approaches for efficient environmental monitoring and automation. Among several ideas, including standalone devices and Wi-Fi-based systems, the integration of an ESP32-S3 microcontroller with Bluetooth Low Energy (BLE) and MQTT emerged as the optimal choice due to its versatility, low power consumption, and IoT compatibility.

In this solution, the ESP32-S3 acts as the central node, collecting data from connected sensors such as the BMP280 for environmental parameters (temperature, pressure, altitude) and displaying it locally on an SSD1306 OLED. The ESP32-S3 communicates with other devices over BLE and publishes the sensor data to an MQTT broker. The MQTT broker, hosted on a laptop, Raspberry Pi, or any other compatible device, facilitates communication between the ESP32-S3 (publisher) and multiple subscribers.

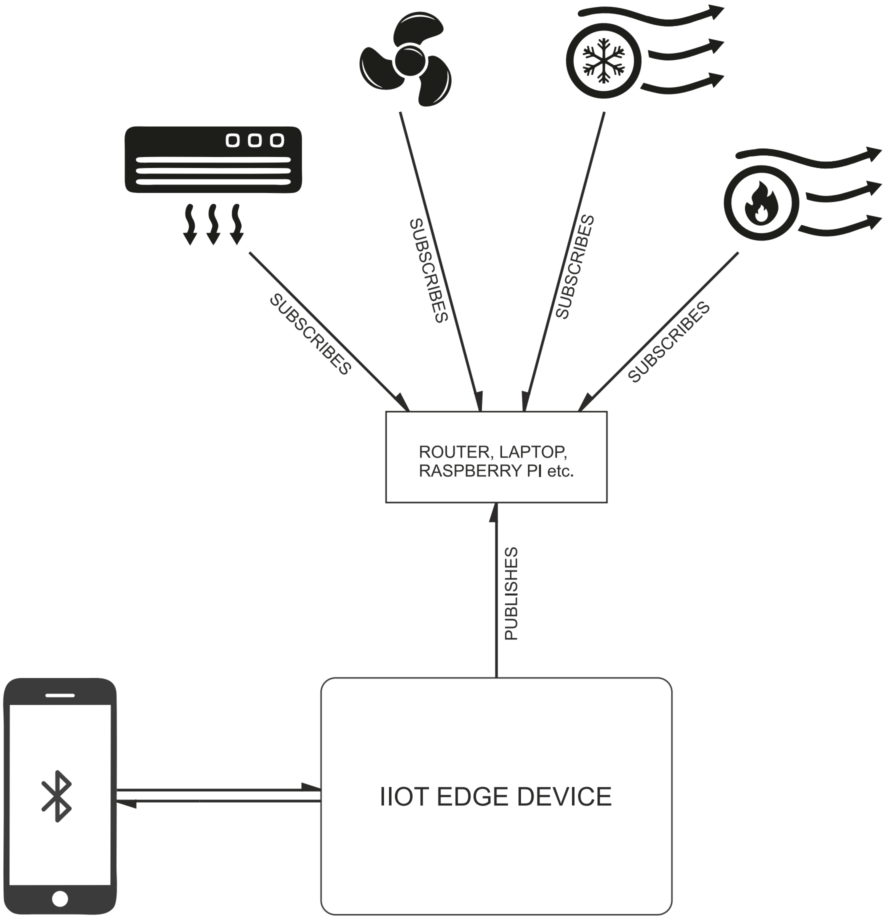
The subscribers, which could include devices like Raspberry Pis, laptops, or routers connected to actuators (e.g., relays, motors, or ESP8266 relay modules), interpret the published data to perform automated actions. For instance:

- A temperature threshold triggers the control of heaters, air conditioners, or fans.

- A humidity or pressure change adjusts automated vents or humidifiers.
- Published events can control automated doors or window blinds, creating a smart home or industrial setup.

This solution leverages the ESP32-S3's BLE for low-power wireless communication and MQTT for scalable and reliable message handling, ensuring seamless integration of sensors, actuators, and control systems. The use of MQTT as a lightweight protocol allows for efficient real-time communication, while BLE ensures compatibility with portable devices, enhancing system flexibility and automation potential.

4. **Design & Architecture (Prototype & Testing)**



Hardware Used (AID IOT IIOT Edge Device)
ESP32-S3
BMP280
SSD1306
Pushbuttons(optional)
Buzzer(optional)

Software Stack
Visual Studio Code
PlatformIO
BLE Terminal(android)

5. Implementation Details

The ESP32-S3 is programmed to detect devices connected to the I2C bus, including the BMP280 sensor and the SSD1306 OLED display. During initialization, the microcontroller scans the I2C bus for the BMP280 and SSD1306 addresses. If the BMP280 sensor is not detected, a message is displayed on the SSD1306 OLED and also printed on the serial monitor. In scenarios where neither the BMP280 nor the SSD1306 is detected, an error message is shown exclusively on the serial monitor. This approach ensures that the system provides clear diagnostic feedback to the user, enabling easier troubleshooting in case of sensor or display failures.

Protocols Used

- MQTT

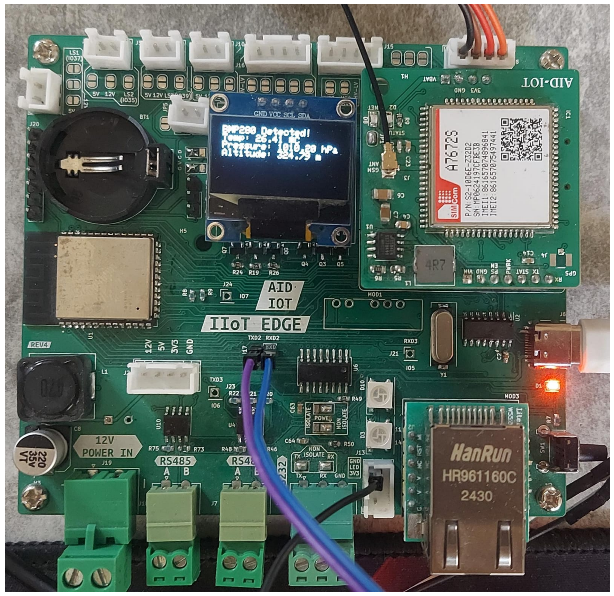
  The MQTT protocol facilitates lightweight, real-time communication between the ESP32-S3 and other devices. The ESP32-S3 acts as a publisher, sending data to the broker. Subscribers, such as Raspberry Pi or laptops, retrieve this data and control connected actuators like fans, heaters, and automated doors.

- Bluetooth Low Energy (BLE)
  - BLE enables wireless communication between the ESP32-S3 and nearby devices for direct monitoring of sensor data.

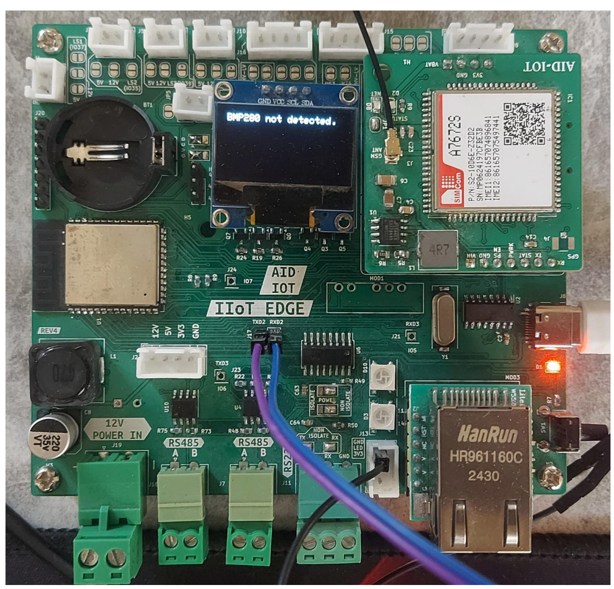
- I2C (Inter Integrated Circuit)
  - The I2C protocol is used for interfacing the BMP280 sensor and SSD1306 OLED with the ESP32-S3.

This implementation combines BLE for local, low-power communication and MQTT for global, scalable device integration, ensuring seamless automation and monitoring in smart systems.

6. **Testing & Validation**



sensor status



sensor status if malfunctioned

BLE terminal output

7. Results & Impact

This prototype is working successfully with bluetooth of ESP32S3, but requires more enhanced by attempting to connect more wireless deevices to it.

8. Future Scope & Enhancements

We can develop a dedicated smartphone app to control the BLE thermostat remotely, allowing users to adjust temperature settings, schedule heating and cooling cycles, and monitor energy consumption in real time. Additionally, the app can provide push notifications for temperature alerts, system malfunctions, or maintenance reminders. Another enhancement is integrating an IR transceiver, enabling the thermostat to control a wide range of electronic devices such as air conditioners, TVs, and wireless ceiling fans. This would allow seamless automation, where users can set schedules to turn on/off devices based on environmental conditions.

For industrial applications, we can implement wireless relay systems using ESP8266 modules, allowing multiple controllers to communicate over a BLE network. This setup can be used to automate large-scale HVAC systems, manage temperature zones across different areas, or control industrial machinery remotely. Lastly, enhancing the security of the BLE network is crucial. By making the BLE communication non-discoverable to unauthorized devices, implementing encryption, and adding authentication layers, we can ensure that only trusted users can access and control the thermostat, reducing the risk of cyber threats.

9. Conclusion

In conclusion, enhancing the BLE thermostat with a mobile app, IR transceiver, and wireless relay integration can significantly improve its functionality for both home and industrial applications. Additionally, implementing stronger security measures will ensure safe and reliable operation. These advancements make the thermostat more versatile, efficient, and secure for modern automation needs.