Edge-AI Assisted Occupancy-Adaptive Climate Control System

Project Members:

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  Task: Hardware Integration (Sensors, Relays, OLED), Firmware Development (ESP32, TinyML model)
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  Task: Cloud, Node-RED & MQTT Integration, Dashboard Development, Testing & Documentation

Subject Title: Embedded IoT Systems

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1. Problem Statement and Objectives

Problem Statement

Indoor climate control systems such as air conditioning and heating units are often inefficient and waste energy by operating when no one is present in a room. Current systems rely heavily on cloud services or manual intervention to adjust the climate, leading to unnecessary energy consumption. There is a need for an intelligent system that can automatically adjust climate conditions based on occupancy and environmental data while being energy-efficient.

Objectives

The goal of this project is to develop an IoT-based system that automatically adjusts the indoor climate using real-time environmental and occupancy data. The system aims to:

1. **Automate climate control** by adjusting temperature, humidity, and light conditions based on real-time sensor data.
2. **Implement Edge AI** using TinyML on the ESP32 to predict user comfort levels without the need for cloud-based processing.
3. **Detect human presence** using PIR sensors to control HVAC devices like fans and AC units.
4. **Log environmental data** (temperature, humidity, light, and motion) to Blynk for analysis and model training.
5. Provide a **mobile-friendly dashboard** for monitoring and manual override of the system.
6. **Reduce energy consumption** by preventing HVAC operation when no one is present.

2. System Architecture / Block Diagram

System Architecture Overview

The system is structured in layers for efficient processing and control. Below is an outline of the architecture:

- **Sensors Layer**:
  - **DHT11** (Temperature & Humidity)
  - **PIR Sensor** (Occupancy Detection)
  - **LDR** (Light Level Detection)
- **Processing Layer (ESP32)**:
  - Collects data from the sensors.
  - Runs TinyML models locally for comfort prediction.

- Activates relay to control the HVAC (fan/AC).
  - Displays status on the OLED screen.
  - Sends data to **Blynk** cloud for monitoring and analysis.
  - Publishes sensor data and system status to the **MQTT broker**.
- **Cloud Layer (Blynk)**:
  - Stores environmental data.
  - Provides a web/mobile dashboard for user interaction.
- **User Interface Layer**:
  - Allows users to view real-time data and manually override automatic climate control.
- **Communication Layer (MQTT):**
  - Provides lightweight, real-time communication between ESP32 and Node-RED.
  - ESP32 publishes sensor data and subscribes to control commands via MQTT topics.
- **Flow & Integration Layer (Node-RED):**
  - Receives sensor data from MQTT.
  - Processes and routes data using flow-based logic.
  - Forwards data to Blynk Cloud and can send control commands back via MQTT.

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4. Hardware and Software Description

Hardware Components

1. **ESP32 Dev Module**: Central controller that integrates sensors, processes data, and executes TinyML models.
2. **DHT11**: Temperature and humidity sensor used for monitoring the room's conditions.
3. **PIR Sensor**: Used for detecting human presence in the room.
4. **LDR**: Measures ambient light level to help adjust the system.
5. **Relay Module**: Switches HVAC devices (fan/AC) based on decisions made by the ESP32.
6. **OLED Display**: Shows real-time data and system status.
7. **Power Source**: USB or battery to power the entire system.
8. **Miscellaneous**: Jumper wires, breadboard, and optional casing for assembly.

Software Stack

1. **PlatformIO / Arduino IDE**: Used to write, compile, and upload the firmware to the ESP32.
2. **TinyML / TensorFlow Lite Micro**: Tiny machine learning library for deploying models on microcontrollers.
3. **Blynk Cloud**: Provides cloud storage, real-time data visualization, and a mobile/web dashboard for system control.

4. **MQTT Protocol:** Enables lightweight, real-time communication between the ESP32 and Node-RED using publish/subscribe messaging.
5. **Node-RED:** Used for flow-based data processing, integration, and routing of sensor data received via MQTT.

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5. Methodology and Flowchart

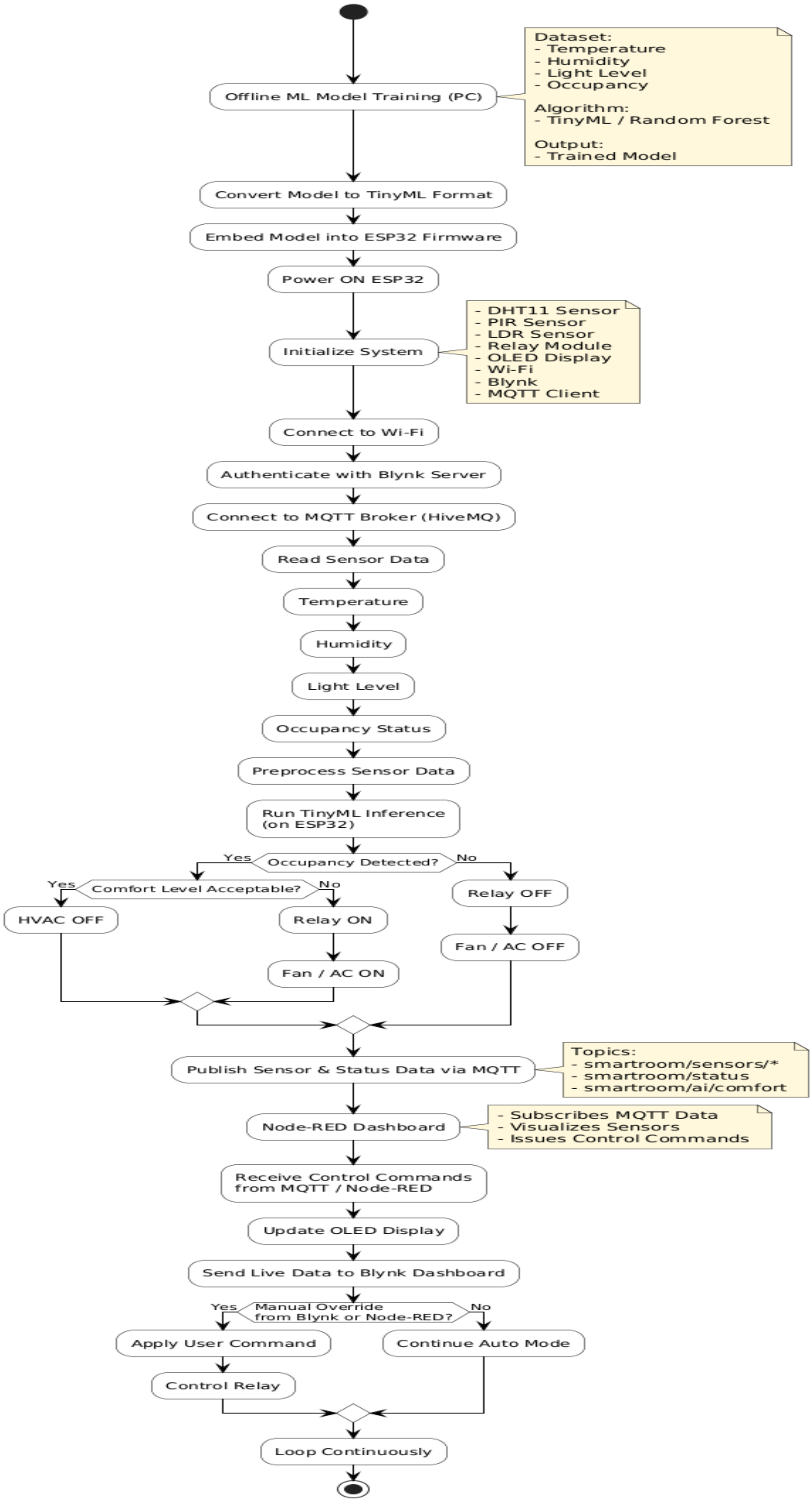
Methodology

The system operates in a real-time, responsive loop. Here is the general flow of the system:

1. **Data Collection**: The ESP32 reads data from the sensors (temperature, humidity, light, motion).
2. **Comfort Prediction**: The TinyML model processes sensor data locally to determine the comfort level.
3. **HVAC Control**: If the comfort level is not optimal, the system activates or deactivates the HVAC using the relay module.
4. **User Monitoring**: Data is logged to **Blynk** cloud, where users can monitor system performance via a mobile-friendly dashboard.
5. **Manual Override**: Users can override automatic settings through the Blynk dashboard if desired.

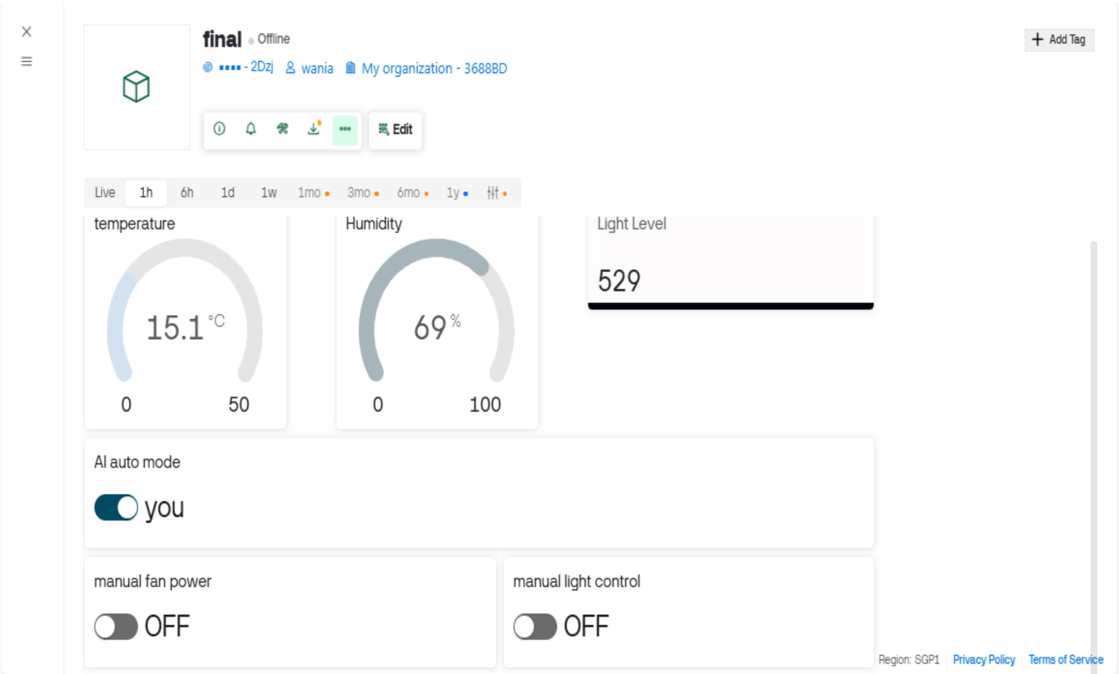
Flowchart

Edge-AI Assisted Occupancy-Adaptive Climate Control System

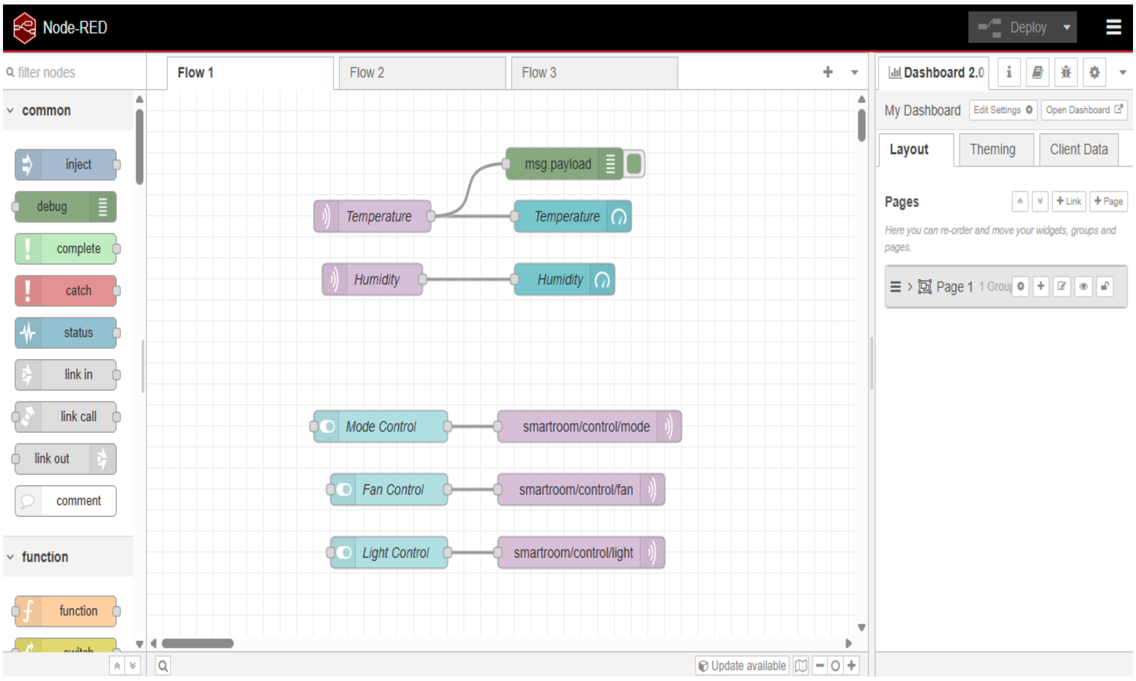


6. Screenshots of Output and Dashboards

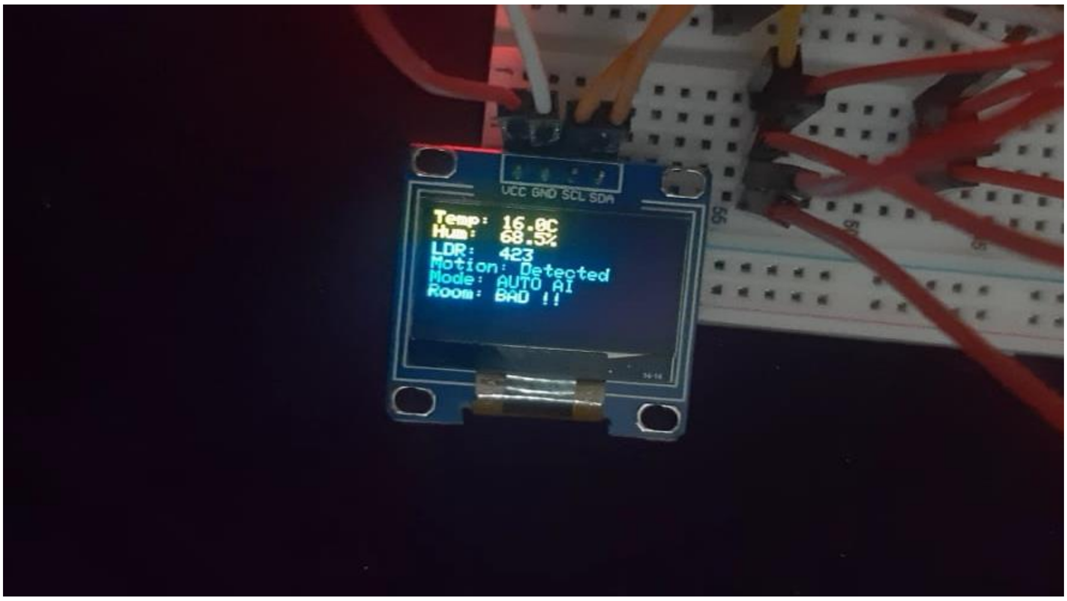
- **Blynk Dashboard**



- **Node-Red Dashboard**



- **OLED Display**:



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7. Results, Conclusion, and Future Scope

Results

- The system effectively adjusts the HVAC operation based on the environmental data and occupancy detection.
- Energy consumption is reduced by turning off HVAC devices when no human presence is detected.
- The real-time data logging and dashboard provide an interactive interface for monitoring and control.

Conclusion

The **Edge-AI Assisted Occupancy-Adaptive Climate Control System** demonstrates the power of IoT and Edge AI in providing intelligent, energy-efficient solutions for climate control. By integrating TinyML on the ESP32, the system is capable of autonomous decision-making without the need for constant cloud processing, ensuring faster responses and reduced latency.

Future Scope

- **Model Enhancement**: Continuously improve the TinyML model with more data for better comfort prediction accuracy.
- **Additional Sensors**: Integrate other environmental factors such as air quality for a more comprehensive climate control system.
- **Smart Home Integration**: Integrate the system with other smart home devices for a seamless and fully automated living experience.