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Iot-Based Environmental Monitoring and Prediction System Using Thinkspeak

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ABSTRACT
The surveillance of environmental conditions is crucial for the conservation of nature and for equipping individuals to adapt to variations in weather patterns or pollution levels. This initiative focuses on the development of a cost-effective and straightforward system that leverages Internet of Things (IoT) technology to assess parameters such as temperature, humidity, air quality, light intensity, and precipitation. The system utilizes sensors to gather data, which is subsequently transmitted online, allowing users to easily access and interpret the information. The primary objective of this project is to establish a system capable of continuously monitoring these environmental variables in real time. The sensors interface with a microcontroller that relays the data via Wi-Fi to an online platform, specifically Thinkspeak. On this platform, users can visualize the data in user-friendly formats, such as charts and graphs. This facilitates the monitoring of fluctuations and enables proactive measures in response to anomalies, such as deteriorating air quality or excessive rainfall. The findings indicate that the system effectively captures precise data and delivers real-time updates. Additionally, it can notify users of any irregularities, such as abrupt shifts in weather or pollution metrics. In conclusion, this project offers an economical and dependable solution for environmental monitoring through IoT technology, with potential applications in agriculture, urban planning, and disaster preparedness.

Keywords: *IoT (Internet of Things), Environmental Monitoring, Sensors, Data, Microcontroller*

1. INTRODUCTION

The IoT-based environmental monitoring systems play a crucial role in the acquisition and analysis of real-time environmental data, which supports sustainable decision-making processes. These systems employ a range of sensors to track various parameters, including air quality, temperature, humidity, and noise levels, thereby offering essential insights into environmental conditions. Prominent examples, such as EcoSense360 and EENNOS, facilitate the prompt identification of anomalies and trends (Seth et al., 2024; Alam et al., 2024). The integration of cloud databases, such as Firebase, significantly improves data accessibility and analytical capabilities (Alam et al., 2024). Additionally, the implementation of microservice architectures, as highlighted by Çeken, provides adaptability for diverse industrial applications (Çeken, 2024). Innovations like microbial fuel cells offer self-sustaining solutions, which can lower operational costs compared to conventional systems (Saini, 2024). Systems like EcoSense360 employ algorithms for real-time anomaly detection, thereby improving data accuracy and ensuring compliance with regulatory standards (Seth et al., 2024). The use of cloud databases further enhances data accessibility and analysis, as demonstrated in the research by Alam et al. (Alam et al., 2024). This architectural design promotes scalability and flexibility across various applications, ensuring reliable performance (Çeken, 2024). However, despite these advantages, challenges such as high initial setup costs and the requirement for technical expertise may hinder widespread adoption, particularly in developing regions. This underscores the necessity for targeted strategies to improve the accessibility and usability of these systems.

In the study by (Alam et al., 2024) Rapid urbanization and industrialization have raised concerns about environmental quality and sustainability in recent years. The Internet of Things (IoT) has played an important role in monitoring physical phenomena by generating data that can be sent and preserved in the cloud. This work explores an IoT-based environmental monitoring system's potential, using an Arduino-based device for real-time tracking of environmental parameters including sound levels, humidity, dust concentration, total volatile organic compounds (TVOC), carbon dioxide (CO2), and carbon monoxide (CO). Real-time data are collected from various semi-residential and marketplace locations named in Pach raster More, Tomaltola, DowamoyiMore, Fojdarimore, and station road in Jamalpur district of Mymensingh Division, Bangladesh on non-holiday days, providing a representative snapshot of typical environmental conditions. The collected data is stored in a cloud server named firebase database. The implemented monitoring system offers several key features including accuracy and reliability, real-time monitoring data analytics alerts and notifications historical data as well as it can lead to various benefits and impacts of Improved Air and Water Quality Healthier Urban Environment (IAWUE) to enable local authorities and individuals to make educated decisions for a healthier and more sustainable urban environment. Graphical representations of the data revealed distinct patterns and trends, offering valuable insights into air quality variations across different areas. Interestingly, the results showed sound levels slightly below the standard range, indicating a relative control of noise pollution in the sampled areas. The findings of the work will serve as a vital resource for further research and guide policy-making for environmental improvement and sustainable practices in urban settings.

According to (Çeken, 2024) Digital transformation is crucial for organizations to survive, be competitive, and grow in the modern age. IoT is the key to enabling this transformation by connecting devices and optimizing processes. This paper presents the design and implementation of a generic IoT-based real-time environmental monitoring and alarm system. The platform is validated by applying it to a manufacturing plant scenario, where various sensors simulate industrial conditions. Scalable message distribution systems such as MQTT and Apache Kafka facilitate reliable data transmission. A microservice architecture is constructed for the backend services to ensure uninterrupted and high throughput services in the application domain. Instead of deploying a real WSN, traffic generation services were chosen to minimize costs, provide greater control and flexibility, and facilitate faster, scalable testing in a controlled environment. The platform also features an integrated alarm system with an event definition module, which allows users to define custom action rules. This flexible, scalable, and resilient architecture can be used across a wide range of application domains that require digital transformation. The experimental study demonstrates the platform's capabilities and great potential for broader IoT applications.

In the study by (Seth et al., 2024) Innovative technology adoption is crucial for sustainable industrial practices in today's dynamic business climate. EcoSense360 is a revolutionary Industrial Internet of Things (IIoT) system for continuous environmental monitoring in manufacturing facilities, and it is presented in this article. Real-time anomaly detection, predictive maintenance, and energy optimization are the three cornerstone algorithms that make up EcoSense360. As the foundation of EcoSense360, the Real-Time Anomaly Detection Algorithm enables for instantaneous detection of environmental aberrations. The potential for environmental catastrophes is reduced, and crucial concerns may be addressed promptly, thanks to these real-time capabilities. Our testing shows that as compared to conventional approaches, EcoSense360 provides superior outcomes in terms of both data precision and real-time responsiveness, as well as regulatory compliance. EcoSense360 is a proactive and all-encompassing solution for environmental monitoring and management. Real-time environmental insights, predictive maintenance, and sustainable energy use are just a few of the ways in which its algorithms are changing the face of industry. Analysis shows EcoSense360 is superior to conventional approaches to environmental protection, resource conservation, and meeting sustainability targets. EcoSense360 is the best option for businesses that are serious about being environmentally responsible as they face increasing pressure to do so.

According to (Dewangga et al., 2024) This study aimes to develop an environmental information system called the Environmental Monitoring System (EENNOS) to monitor air environmental conditions. ENNOS is an Internet of Things (IoT) based system that monitors air environmental conditions in the form of temperature, humidity and carbon dioxide. The research was conducted using the 4D development method which consisted of the Define, Design, Develop, and Disseminate stages. EENNOS was developed using a DHT 22 sensor for DHT 22 temperature and humidity and a carbon dioxide sensor with MQ-135. The controller used is Arduino uno ESP8266 with output sending using the internet to the database and presented on the dashboard and displayed on a 16x2 liquid crystal screen. The output is in the form of dashboard innovations that are registered with copyrights and scientific publications in the form of articles in the Journal of Environmental Sciences.

In the study by (Li et al., 2024) Based on the market research report by the International Market Analysis Research and Consulting Group (IMARC) Group, the global market for environmental monitoring has surpassed USD20billionin2022.ItisprojectedtogrowtooverUSD31 billion by 2028, primarily driven by the increasing demand for environmental monitoring in developing nations, particularly China. However, implementing an Environmental Monitoring System (EMS) poses significant challenges in terms of scale and cost. In rural areas, the deployment of EMS typically requires a substantial number of sensors, predominantly powered by battery packs, solar panels, and stationary power supplies. Except for stationary power supplies, the other two methods entail a considerable number of resources for monitoring and replacement, leading to higher operational costs. To address these challenges, this research project aims to propose a self-sustaining Internet of Things (IoT) monitoring system. This system integrates a power generator based on moss-based microbial fuel cells (MFCs), which generate a voltage output through photosynthesis. Additionally, the system will incorporate a voltage booster circuit to amplify the power output to a usable level of 3.3 volts. This voltage level enables the system to power various IoT devices, such as MCUs and a wide range of sensors, enhancing its versatility and applicability. By eliminating the need for solar panels and reducing maintenance costs and frequency, the proposed system has the potential to reduce overall expenses significantly. This cost reduction would facilitate wider adoption of the system by companies and countries, contributing to the mitigation of environmental pollution.

2. METHOD

BMS System (Battery Management System) Monitors and controls battery performance, state of charge, and health. Ensures safe and efficient battery operation. ESP32 Microcontroller Processes data, connects to Wi-Fi, and communicates with sensors and cloud platforms. Acts as the brain of the system, enabling IoT connectivity and data processing. Gas Sensor Detects gas concentrations (e.g., CO, CO2, NOx) in the environment. Provides critical data for air quality monitoring. Rain Detection Sensor Detects rainfall and measures precipitation levels. Enables monitoring of weather conditions and potential flood alerts. Light Intensity Sensor Measures ambient light levels. Provides data for monitoring daylight hours, solar radiation, and

energy harvesting. Buzzer Produces audible alerts for notifications, warnings, or system events. Enables real-time alerts and notifications for critical events. LCD (Liquid Crystal Display) Displays system data, sensor readings, and notifications. Provides a local user interface for monitoring and interacting with the system. Web App Connectivity Module (Thingspeak) Cloud-based IoT platform for data visualization, analysis, and storage. Enables remote monitoring, data logging, and analytics for the environmental monitoring system. Buck Converter Converts input voltage to a lower output voltage for powering system components. Ensures efficient power management and reduces energy waste. Battery Provides power to the system components. Enables autonomous operation and reduces reliance on external power sources. Humidity Sensor Measures moisture content in the air. Ensures optimal conditions for agriculture, HVAC, and weather monitoring. Air Quality Sensor Detects pollutants like CO_2, VOCs, and particulate matter. Maintains air quality for health and environmental safety. Temperature Sensor Measures ambient temperature. Regulates climate control and prevents overheating in systems. 12V Charger Supplies power to the monitoring system. Ensures continuous operation, especially for remote deployments. Enclosure/Packaging Protects components from environmental damage. Enhances durability and reliability in harsh conditions.
The system consists of key components working together to monitor environmental conditions:

- Power Supply energizes the system.
- Sensors collect data on environmental parameters.
- ESP32 Microcontroller processes sensor data and controls outputs.
- Cloud/ThingSpeak enables remote data storage and monitoring.
- Buzzer alerts users when thresholds are exceeded.
- LCD Display shows real-time sensor readings and warnings.

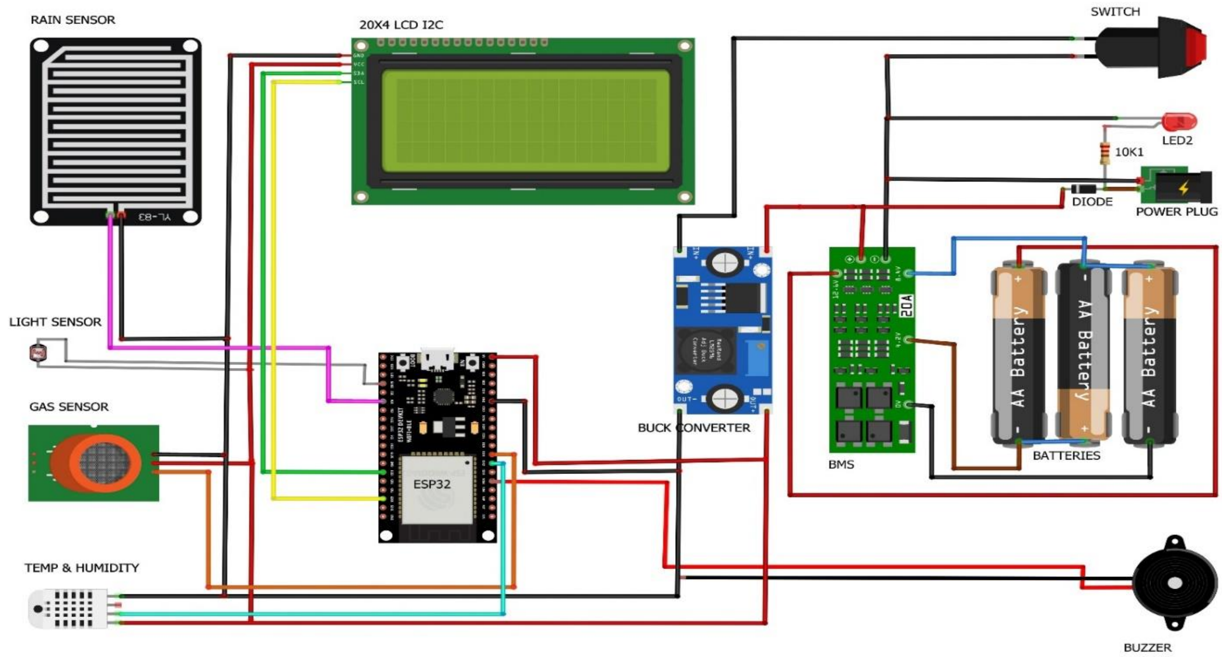


Fig 1 Circuit Diagram of Proposed Prototype

Algorithm
Start the system.
Initialize the ESP32 microcontroller and all sensors:
i) Gas Sensor
ii) DHT Sensor (Temperature & Humidity)

iii) Rain Sensor
iv) Light Intensity Sensor
3. Continuously Read Sensor Data and Send to Thingspeak and LCD:
i) Read gas sensor value.
ii) Read DHT sensor values (temperature and humidity).
iii) Read rain sensor value.
iv) Read light intensity sensor value.
4. Process Sensor Data:
i) If the gas level exceeds the threshold, activate the buzzer alert.
ii) If the temperature level exceeds the threshold, activate the buzzer alert.
iii) If rain is detected, activate the buzzer alert.
iv) If the light intensity level exceeds the threshold, activate the buzzer alert.
v) If the push button is pressed, reset the system.
5. Store or transmit data to the cloud (Thingspeak)
6. Repeat the process continuously in a loop.

SUMMARY OF THE ENVIRONMENTAL MONITORING SYSTEM CIRCUIT DIAGRAM

Core Components:

- ESP32 microcontroller as the brain
- 4 environmental sensors (rain, light, gas, temperature/humidity)
- 16x4 LCD screen for data display
- Battery power system with BMS and buck converter

Key Features:

- Battery powered with external power option
- Multiple sensor inputs for comprehensive monitoring
- Visual display of readings
- Alert system (LED and buzzer)
- Power management through BMS

3. USE CASE (SUMMARY OF THE ENVIRONMENTAL MONITORING SYSTEM USE CASE DIAGRAM)

This use case diagram shows the workflow of the IoT-based environmental monitoring system with three main actors:

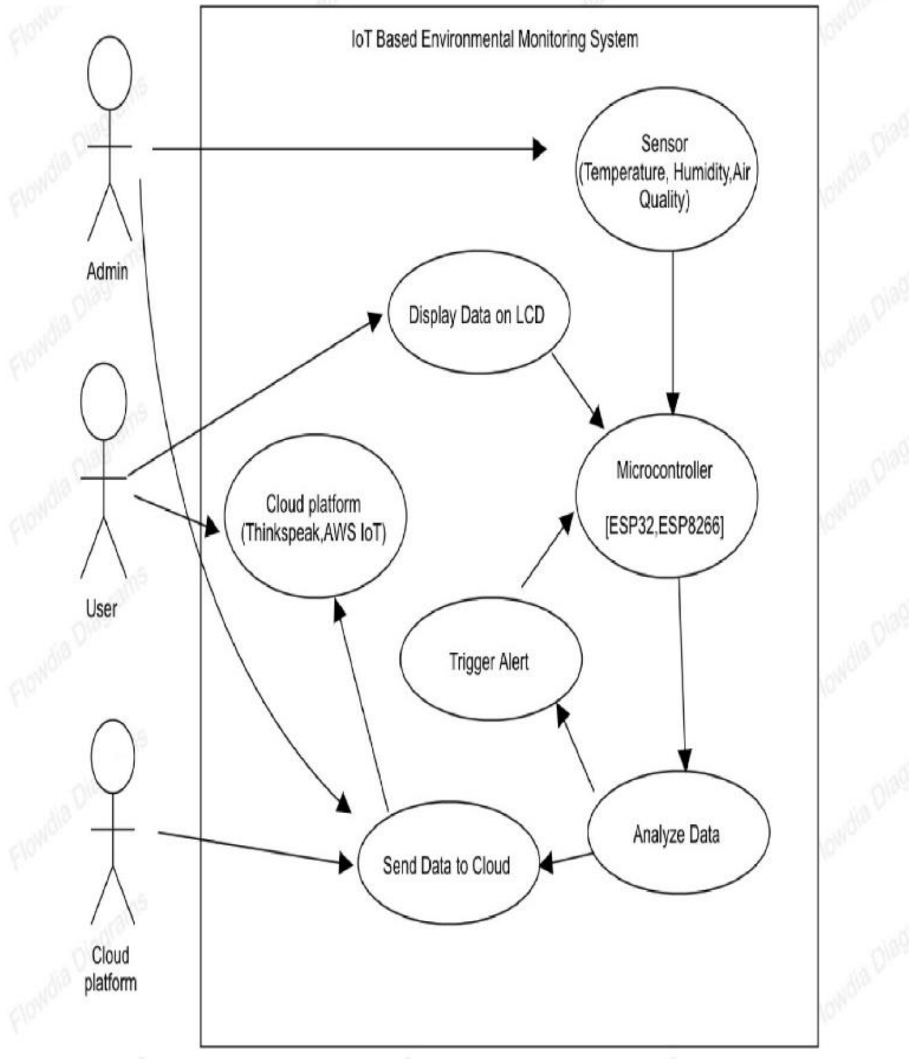
1. Admin
2. User
3. Cloud platform

The system's key functions include:

- Sensor readings (temperature, humidity, air quality)
- Data processing by ESP32/ESP8266 microcontroller
- Local display of data on LCD
- Data analysis
- Cloud data transmission (using ThinkSpeak or AWS IoT)
- Alert triggering based on analysis

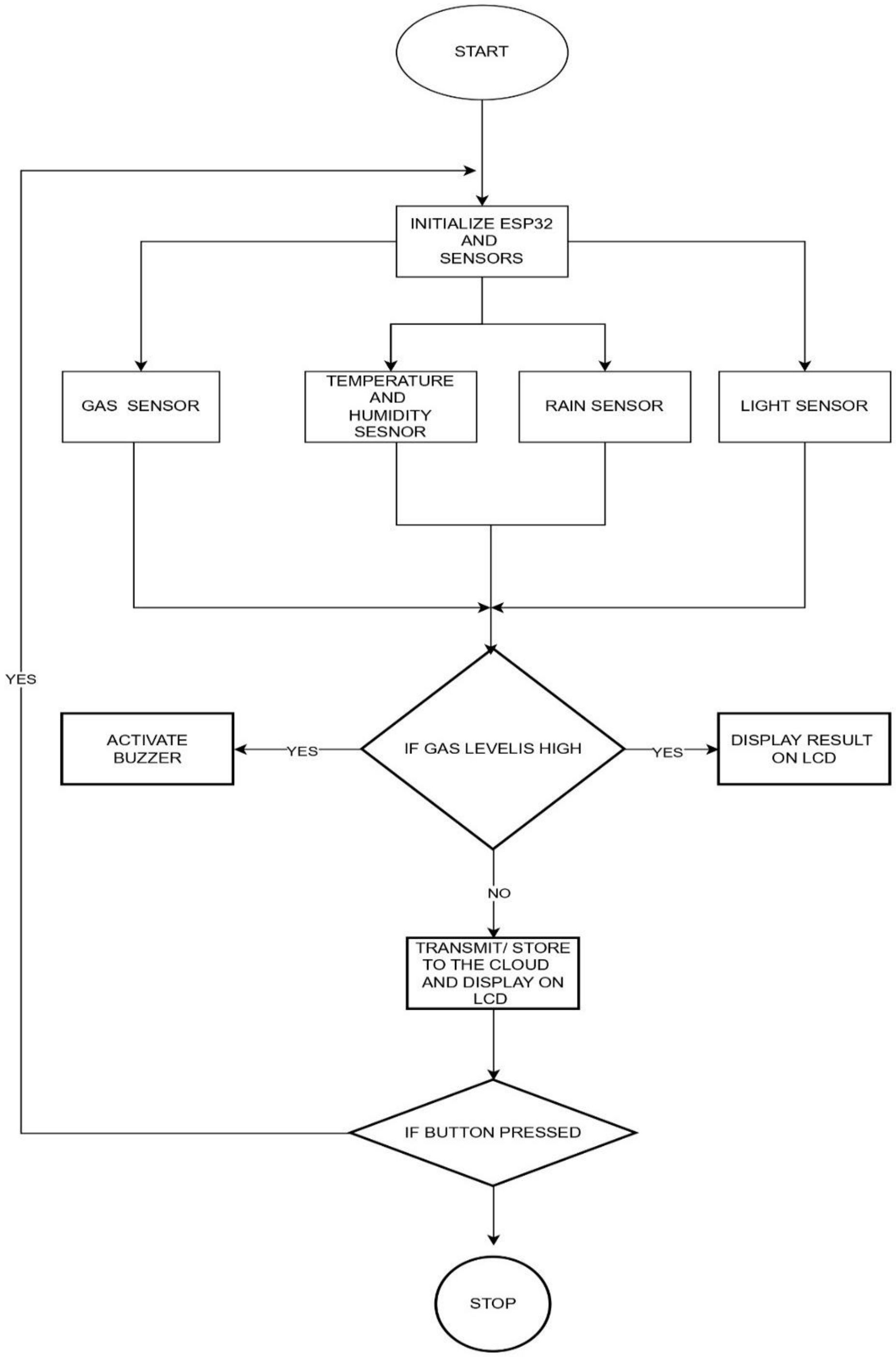
The workflow shows how data flows from sensors through the microcontroller for analysis, then gets displayed locally and sent to cloud platforms where administrators and users can access it. The system is designed to both show readings locally and enable remote monitoring through cloud services

Fig 2 Use Case of Proposed Prototype



Flow Chart

Fig 3 Flow Chart of Proposed Prototype



SUMMARY OF THE ENVIRONMENTAL MONITORING SYSTEM FLOW CHART

This flowchart showing the operation logic of the environmental monitoring system.

System Flow:

1. Start with ESP32 and sensor initialization
2. Four parallel sensor readings:
   - Gas sensor
   - Temperature/humidity sensor

- Rain sensor
- Light sensor

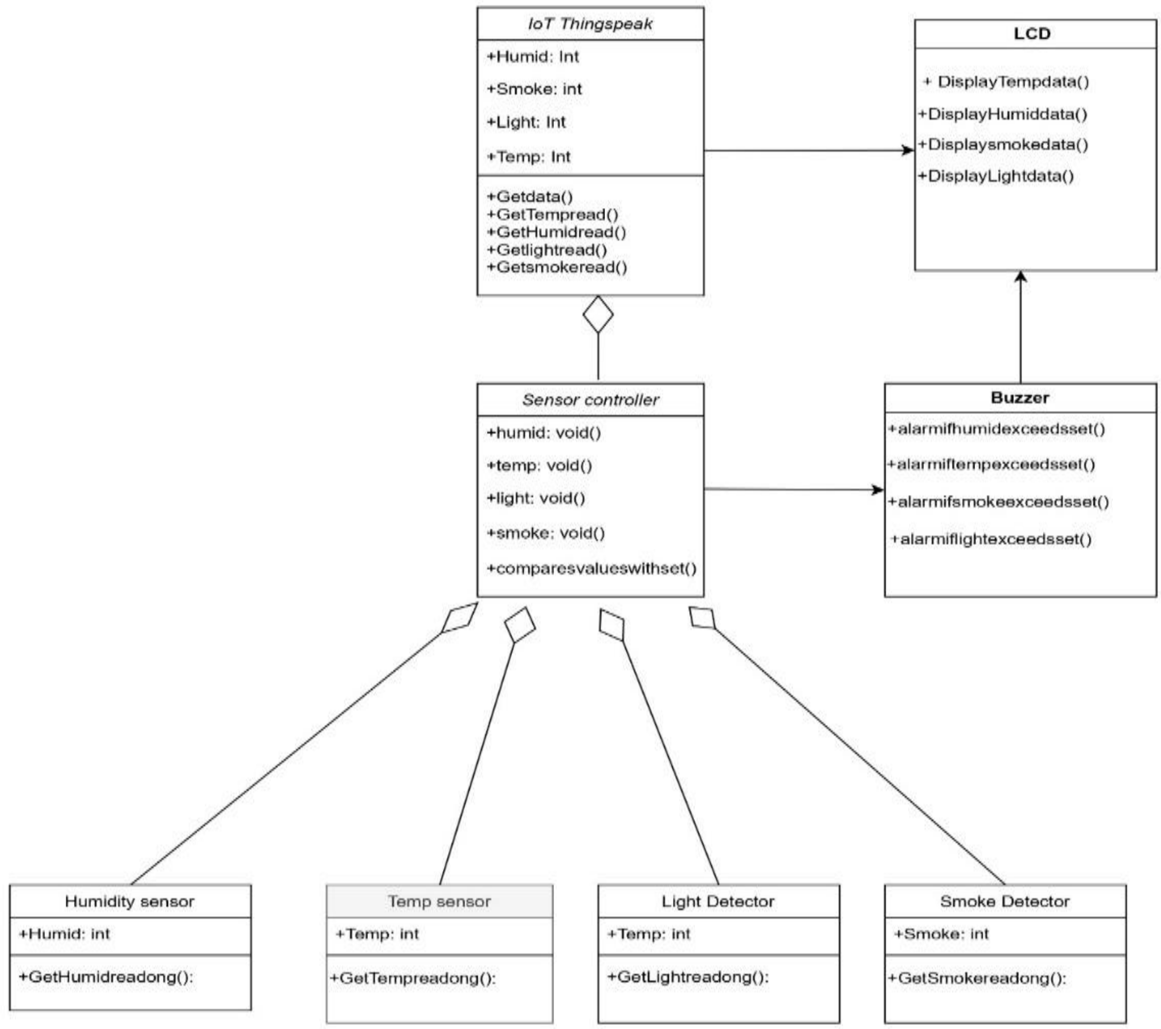
Decision Logic:

• If gas levels are high:
  - Activate buzzer alarm
  - Display results on LCD

• If gas levels are normal:
  - Store data to cloud
  - Display on LCD

Loop Control:

• System continues monitoring until button is pressed
• When button is pressed, system stops
• If no button press, returns to sensor readings



Class Diagram
Fig 4   Diagram of Proposed Prototype

Summary of the Environmental Monitoring System Class Diagram

This class diagram shows the object-oriented structure of the IoT environmental monitoring system:

Main Classes:

IoT Thingspeak (Main Class) Stores sensor values (humidity, smoke, light, temp) Contains methods to get readings from all sensors

Sensor Controller Manages all sensor operations Handles sensor readings and comparisons Connects to four sensor subclasses

Individual Sensors (4 Classes) Humidity Sensor Temperature Sensor Light Detector Smoke Detector

NB: Each with their own read methods

Output Classes:

LCD: Displays data for each sensor type

Buzzer: Handles alarms for different threshold violations

Relationships:

Sensor Controller inherits from IoT Thingspeak

Four sensors are associated with Sensor Controller

LCD and Buzzer receive data from Sensor Controller

This structure shows a clear hierarchy of components with the sensor controller acting as the central management unit between data collection (sensors) and output (LCD/Buzzer) components.

Pseudocode

```
STEP 1   BEGIN
STEP 2 // Initialize Components
INITIALIZE TEMPERATURE_SENSOR
INITIALIZE HUMIDITY_SENSOR
INITIALIZE RAIN_SENSOR
INITIALIZE SMOKE_SENSOR
INITIALIZE LIGHT_SENSOR
INITIALIZE OLED SCREEN
INITIALIZE RESET_BUTTON
INITIALIZE ALARM_BUZZER
INITIALIZE CONNECT_WIFI
STEP 3. WHILE System is active
      WAIT (10 seconds) //delay before taking reading
 i)   // check for connectivity
    IF WIFI is CONNECTED Succefully THEN
       DISPLAY_OLED ("WiFi Connected!")
 ELSE
        DISPLAY_OLED ("WiFi Not Connected!")
    ENDIF
ii)    // Read Sensor values and assign to variables
    Temperature=READ(TEMPERATURE_SENSOR)
    Humidity=READ(HUMIDITY_SENSOR)
    Rain= READ(RAIN_SENSOR)
   Light_intensity= READ(LIGHT_SENSOR)
    Gas= READ(SMOKE_SENSOR)
IF   Light_Intensity > LIGHT_THRESHOLD THEN
DISPLAY_OLED (“DayStatus: Day”)
ELSE
DISPLAY_OLED (“DayStatus: Night”)
ENDIF
iii)// Display Data on OLED
```

```
   DISPLAY_OLED ("Temp: Temperature °C")
   DISPLAY_OLED ("Humidity: %")
   DISPLAY_OLED ("Gas: ")
   DISPLAY_OLED ("Rain: ")
   DISPLAY_OLED ("Daystatus: ")
  iv)  // Check Thresholds and Activate Buzzer
   IF Temperature > TEMP_THRESHOLD OR Humidity > HUMIDITY_THRESHOLD OR
Rain > Rain_threshold THEN
       ACTIVATE_BUZZER
   ELSE
       DEACTIVATE_BUZZER
 ENDIF
  v)  // Send Data to ThingSpeak
   IF WIFI is CONNECTED THEN
       SEND DATA TO_THINGSPEAK
   ELSE
       DISPLAY_OLED ("WiFi Not Connected!")
   ENDIF
   // Check if Reset Button is Pressed
   IF RESET_BUTTON is PRESSED THEN
Reinitialize from step 2
ELSE
No action will be performed
   ENDIF

     WAIT (10 seconds) // delay before next reading
    START from step 3.
   ENDWHILE
END.
```

Summary of the Environmental Monitoring System Activity Diagram

The above diagram is the activity diagram of the IoT based environmental monitoring project.

1. The device starts with a stable power supply or it can use battery.
2. The microcontroller is then initialized. The ESP 32 microcontroller used.
3. The sensors collect environmental data. Temperature, humidity or air quality sensors.
4. After the data is collected from the sensors, the data is then transferred wirelessly from the sensors to the gateway.
5. Data aggregation and processing occurs at step 5. Here, the data at the gateway is processed and filtered before transferred to the cloud.
6. The cloud platform collects filtered data. Stores the data, performs advanced analytics, identifies trends and generates insights.
7. The data from the cloud is then stored in a user accessible platform, that is, a platform where the data would be accessible by users.

Sequence Diagram

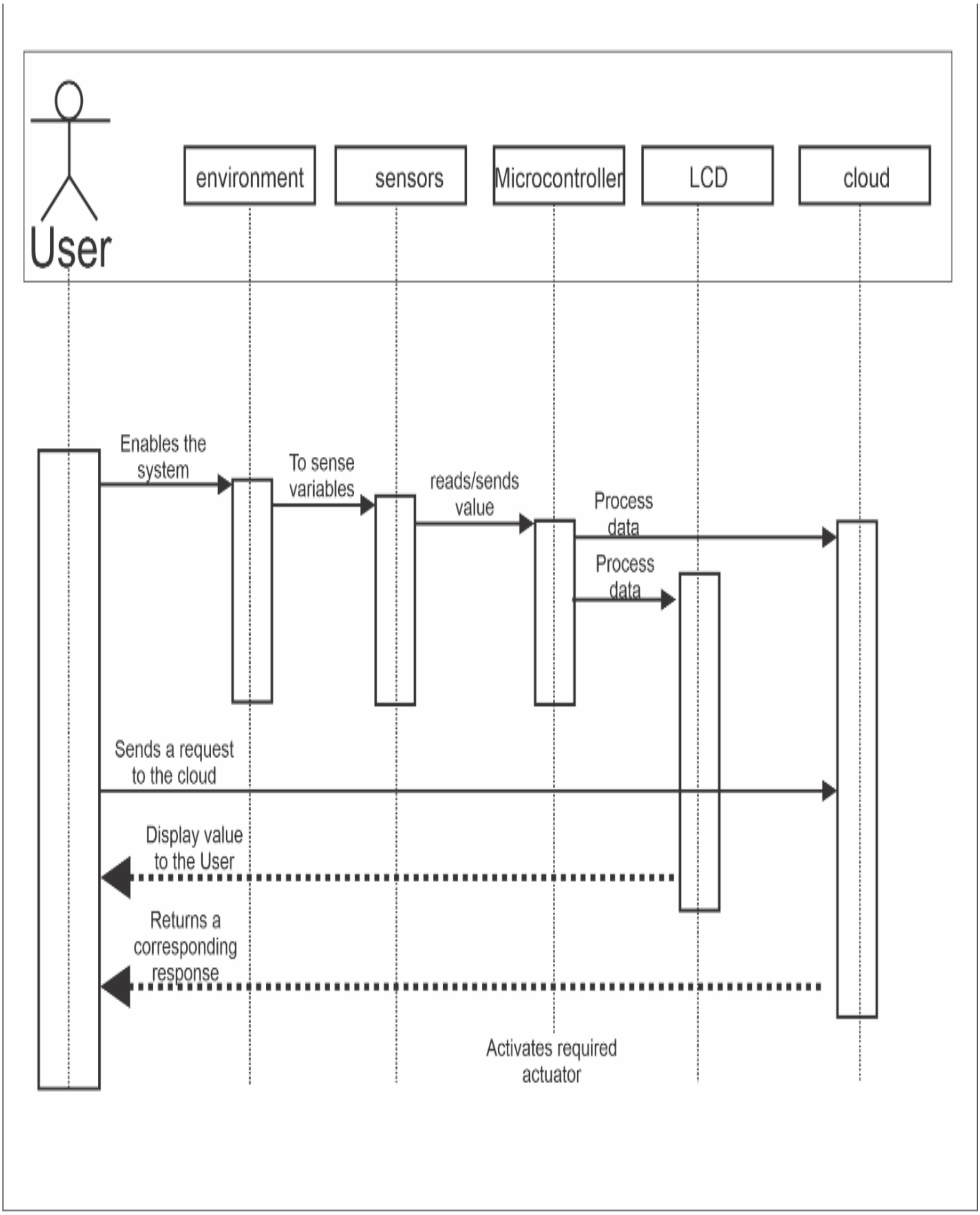
Fig 5 Sequence Diagram of Proposed Prototype

This sequence diagram shows the flow of interactions in the IoT environmental monitoring system:

- Main Sequence:

1. User enables the system
2. Environment variables are sensed by sensors

3. Sensor data is read/sent to microcontroller
4. Microcontroller processes data and sends to:
   - LCD for display
   - Cloud for storage
 - ➢ Return Flow:



1. System displays values to user
2. Cloud returns corresponding response
3. System activates required actuators if needed

The diagram illustrates how data flows from environmental sensing through processing to both local display and cloud storage, with feedback loops to the user. It shows the complete cycle from data collection to user feedback in a time-ordered sequence. The key components (User, Environment, Sensors, Microcontroller, LCD, and Cloud) all interact in a specific order to create a complete monitoring and feedback system.3.12 Design Analysis

3.12.1 Summary

The IoT environmental monitoring system is designed to collect, analyze, and visualize environmental data in real-time. The system combines distributed sensor networks with cloud computing to provide actionable insights for environmental management and decision-making.

3.12.2 System Architecture

- **Hardware Components**

1. **Sensor Nodes**
    - Temperature
    - Humidity (DHT22/SHT30)
    - Air quality (PM2.5, PM10, CO_2)
    - Light intensity
    - Rain Detection

2. Gateway Device
    - ESP32
    - OLED Display Module
    - Battery Management System
    - Buck Converter
    - Battery backup with 12V charger
    - ThinkSpeak

3.12.3 Communication Architecture

1. Gateway to Cloud
- HTTP protocol for data transmission
- TLS/SSL encryption
- HTTP/REST for configuration
- ThinkSpeak for cloud communication

Cloud Platform Design

Storage Layer
- mySQL for database management

4. SYSTEM DESIGN

Figure 4.1 shows Wiring of the Hardware System that includes the sensors and the battery pack unit.

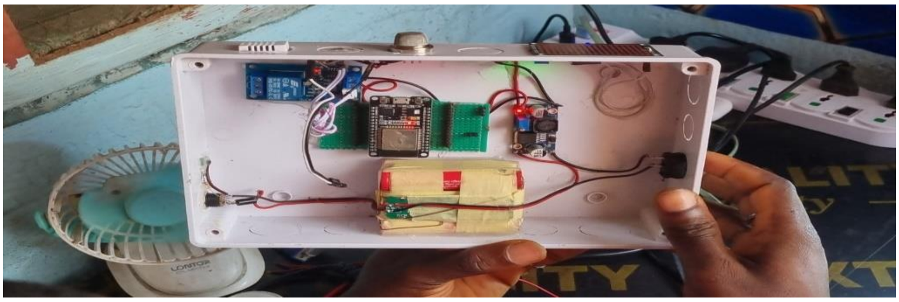


Figure 4.2 Protype Enclosure Top View

Figure 4.3 Power and Reset Side View 1

Figure 4.4 Led Indicator and Charging Port Side View 2.

Figure 4.5 Rain, Smoke, Light Intensity and Temp. Sensor Side View 3.

WORKING PRINCIPLES

The system employs an ESP32 microcontroller as the central processing unit, interfaced with various environmental sensors to measure parameters like temperature, humidity, air quality,

light intensity, and rainfall. The process begins with the initialization of the microcontroller and sensors. The system continuously reads data from the sensors. If any readings exceed predefined thresholds, the system activates a buzzer to alert users. Additionally, data is transmitted to the cloud (ThingSpeak) for storage and further analysis. This setup allows for real-time monitoring and remote access to environmental data.ESP 32 Program Code

The Program Code is used for the microcontroller is written in C Language. And it's as follows:

```
#include <Wire.h>
#include <LiquidCrystal_I2C.h> #include <DHT.h>
#include <WiFi.h> #include <HTTPClient.h>
#define DHTPIN 4 // DHT22 signal pin #define DHTTYPE DHT22
#define GAS_SENSOR_PIN 34
 // Analog pin for Gas sensor #define RAIN_SENSOR_PIN 26
// Digital pin for Rain sensor #define LIGHT_SENSOR_PIN 27
// Digital pin for Light sensor #define BUZZER_PIN 14
// Buzzer pin
#define RESET_BUTTON_PIN 13
// Push button pin
DHT dht(DHTPIN, DHTTYPE);
LiquidCrystal_I2C lcd(0x27, 20, 4);
// WiFi Credentials
const char* ssid = "Goldmindz_Electronic"; const char* password = "Godisgreat";
// ThingSpeak Credentials
```

System Implementation

The core components include the ESP32 microcontroller, rain sensor, light intensity sensor, gas sensor, and DHT sensor (for temperature and humidity). The system is powered by a battery with a Battery Management System (BMS) and a buck converter for efficient power management. The system's circuit design integrates all sensors with the ESP32 microcontroller. The microcontroller processes the sensor data, displaying it on a 16x4 LCD screen, and triggers alerts through a buzzer when necessary. The system's algorithm involves reading sensor data, processing it, and sending it to both the LCD for local display and the cloud for remote monitoring. The data flow follows a structured pattern, as outlined in the flow chart and block diagram, ensuring seamless operation from data collection to user notification.

WIFI WORKING PRINCIPLE

The Microcontroller is WiFi Module Configured by the program code. When the device is turned on, the LCD displays "Connecting to WiFi" as shown in Figure 4.6. Hence, for the LCD

to display the sensor's readings, an admin hotspot has to be connected to the device and configured using the following credentials:
Hotspot Name: Goldmindz_Electronic
Hotspot Password: Godisgreat
Once the hotspot is changed to these, the LCD displays the real-time readings from the sensors as shown Figure 4.2. Figure 4.6 LCD start-up display

CLOUD (THINKSPEAK) WORKING PRINCIPLE
Another alternative to monitoring or tracking environmental atmospheric conditions set on the system is via cloud- ThinkSpeak.
ThingSpeak is a cloud-based platform designed for the Internet of Things (IoT), allowing users to collect, visualize, and analyze live data streams from connected devices in real-time, essentially acting as a central hub to store and analyze sensor data from various IoT devices, with the ability to integrate with MATLAB for advanced data processing and analysis; it's often used for prototyping and proof-of-concept IoT projects due to its ease of use and data visualization capabilities.
Using ThingSpeak Software
First visit https://thingspeak.mathworks.com, click "Get Started For Free". Sign in using the following credentials:
Email: sa.uchechukwu@stu.unizik.edu.ng
Password: Sammy@1999
Once done, some displays are shown as in Figure 4.7, Figure 4.8 and Figure 4.9, showing the real time information of the system.

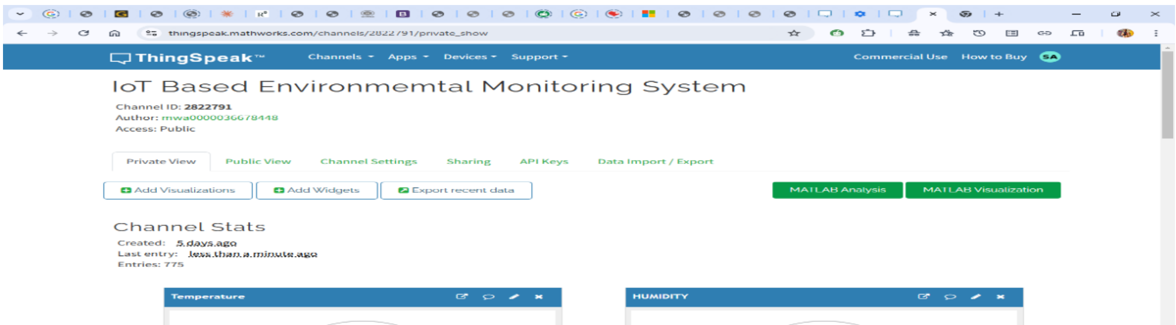


Figure 4.7 ThinkSpeak web view interface display 1

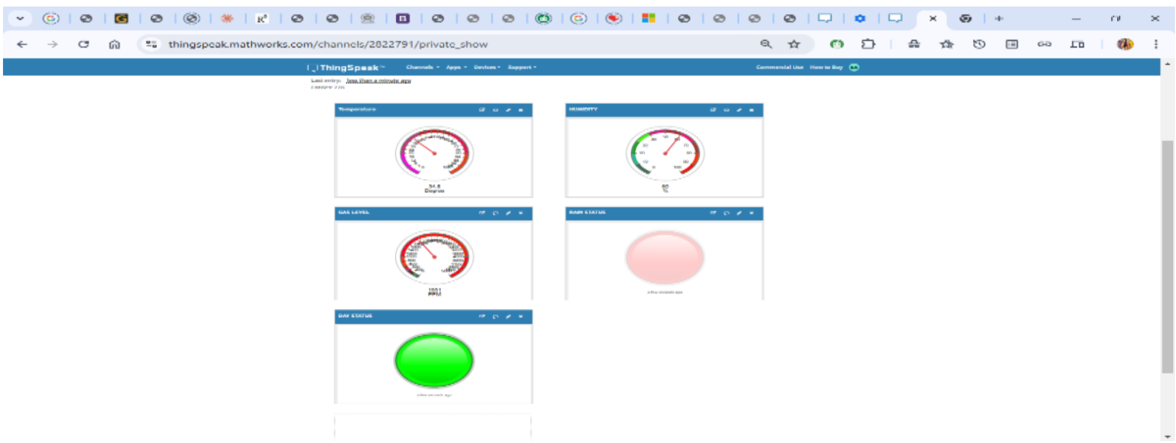


Figure 4.8 ThinkSpeak sensors display 2 (Private View)

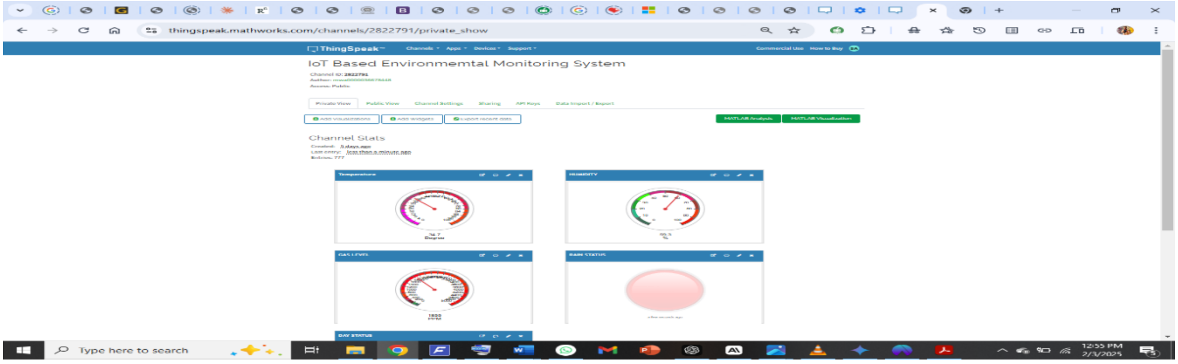


Figure 4.8 ThinkSpeak sensors display 3 (Public View)

CONCLUSION

The system effectively tracks and reports environmental conditions, providing real-time updates and alerts. Operational challenges such as sensor calibration, maintenance, and cost considerations (hardware, cloud services, and training) are acknowledged. The system's data quality is maintained through regular calibration and validation checks. Future enhancements aim to improve system capabilities with advanced analytics, AI-powered predictions, and integration with other environmental systems. These improvements could facilitate more precise environmental monitoring and automated responses to detected changes, thereby broadening the system's application scope. The IoT-based environmental monitoring system is designed to continuously track and detect various atmospheric conditions, including rain, smoke, light, and temperature, using specialized sensors. These sensors collect real-time data, which is then processed by the system to assess environmental changes. The main objective of this device is to provide timely information about fluctuations in environmental conditions. When a sensor detects that a certain parameter has exceeded its predefined threshold, the system triggers an alert. This is done in two ways: the LCD display visually presents the detected values, while the buzzer emits an audible warning to notify users of significant changes. By integrating these features, the system ensures proactive environmental monitoring, allowing users to stay informed about their surroundings and take necessary precautions when needed.

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BIOGRAPHIES OF AUTHORS

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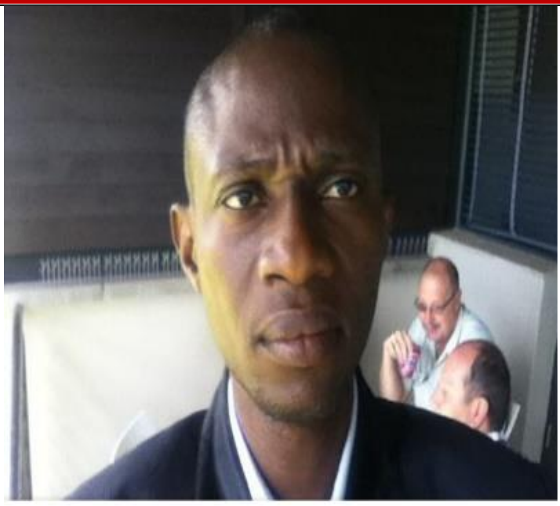

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