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EcoSense: Environmental Parameter Monitoring System using IoT

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Abstract: *Environmental degradation caused by rapid industrialization, urbanization, and increasing vehicular emissions has created a significant need for efficient monitoring systems. Conventional methods are often expensive, limited in coverage, and lack real-time accessibility, making them less effective for dynamic environments. This paper presents EcoSense, an IoT-based environmental monitoring system designed for real-time data acquisition and analysis of key parameters such as temperature, humidity, gas concentration, and particulate matter (PM2.5 and PM10). The system is built around the ESP32 microcontroller, which enables seamless integration of sensors including DHT22, MQ-4, and PMS5003 using digital, analog, and UART communication protocols. The collected data is processed to compute environmental indicators such as the Air Quality Index (AQI), providing meaningful insights into pollution levels. An onboard OLED display offers immediate local visualization, while cloud connectivity through the Blynk platform allows remote monitoring via mobile and web dashboards. Additionally, a buzzer-based alert mechanism is implemented to notify users when environmental conditions exceed predefined safety thresholds. Experimental results demonstrate reliable performance, accurate sensing, and low latency communication. The proposed system is cost-effective, scalable, and suitable for applications in smart cities, industrial environments, and residential monitoring.*

Keywords: IoT, Environmental Monitoring, AQI, ESP32, Blynk, Air Pollution, Smart Systems

I. INTRODUCTION

Environmental monitoring has become essential in addressing the growing challenges posed by air pollution and climate variability. Increasing emissions from industries, transportation, and urban activities have significantly impacted air quality and public health. Conventional monitoring systems, while accurate, are often expensive, stationary, lack real- time accessibility, limiting their effectiveness in dynamic environments.

With the advancement of Internet of Things (IoT) technologies, smart environmental monitoring systems can be developed to provide continuous and remote monitoring. These systems enable real-time data acquisition, processing, and visualization, thereby enhancing decision-making capabilities. The emergence of IoT has enabled the development of smart, distributed monitoring systems capable of continuous data acquisition and remote access. These systems enhance situational awareness and support proactive decision-making

The EcoSense system aims to provide a cost-effective and scalable solution for monitoring environmental parameters in real time. By integrating multiple sensors with cloud connectivity, the system It enables both local and remote data access, making it highly suitable for modern smart environments and sustainable urban applications.

This paper covers the hardware design, software architecture, bench test results, and future directions for the EcoSense-Environmental Parameter Monitoring System using IoT System

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II. COMPONENTS REQUIRED

1. ESP32 Microcontroller
2. DHT22 Temperature and Humidity Sensor
3. MQ-4 Gas Sensor
4. PMS5003 Dust Sensor (PM2.5 & PM10)
5. OLED Display
6. Buzzer Module
7. Connecting Wires
8. Power Supply (5V/3.3V)
9. Enclosure
10. PCB

III. SYSTEM ARCHITECTURE

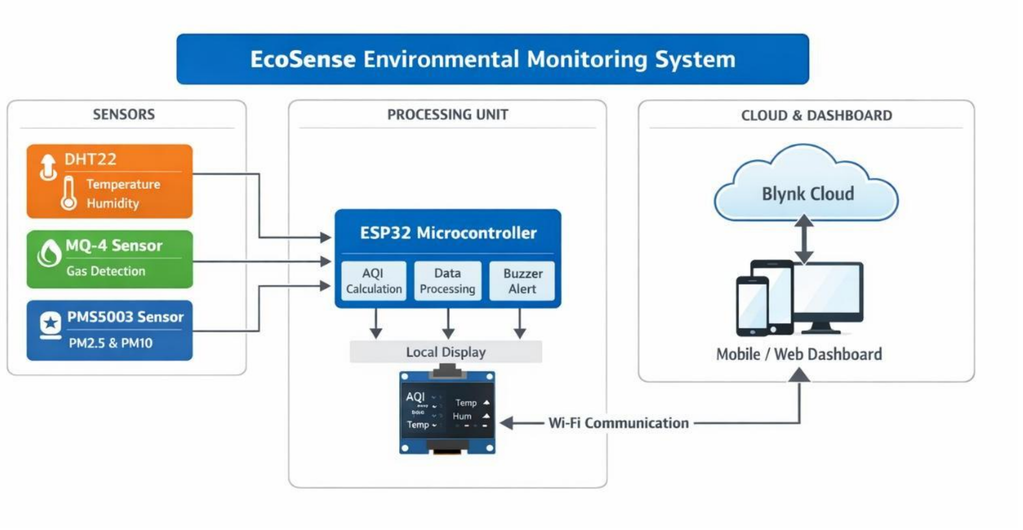

Fig. 1 BLOCK DIAGRAM

The EcoSense system operates in three main stages to ensure efficient environmental monitoring, data processing, and real-time visualization. In the first stage, the ESP32 microcontroller collects data from multiple sensors and processes it locally. In the second stage, the processed data is transmitted over Wi-Fi to the Blynk cloud platform. In the third stage, the cloud server stores the data and presents it on a user-friendly dashboard accessible via mobile and web applications. Figure 1 illustrates the overall system block diagram.

A. Embedded Layer (ESP32 Processing Unit)

The ESP32 microcontroller acts as the central processing unit of the EcoSense system and executes a continuous loop at regular intervals (approximately every 2 seconds). During each cycle, it reads environmental data from all connected sensors. The DHT22 sensor provides temperature and humidity readings through a digital interface, while the MQ-4 sensor outputs analog signals corresponding to gas concentration levels, which are converted using the built-in ADC of the ESP32. The PMS5003 sensor communicates via UART and provides real-time particulate matter values (PM2.5 and PM10).

The ESP32 processes these sensor readings and computes the Air Quality Index (AQI) using predefined mapping algorithms. The processed data is formatted and displayed on an OLED screen using the I2C communication protocol. Additionally, the system evaluates the sensor values against predefined threshold limits to determine whether environmental conditions are safe or hazardous. If unsafe conditions are detected, a buzzer alert is triggered to provide immediate local notification.

B. Wireless Communication Layer (Wi-Fi & Cloud Integration)

The ESP32 utilizes its built-in Wi-Fi module to transmit sensor data to the Blynk IoT cloud platform. Each environmental parameter is mapped to a virtual pin, allowing structured and organized data transmission. The communication occurs periodically, ensuring near real-time updates on the cloud dashboard.

To improve reliability, the system continuously maintains a connection with the Blynk server. In case of temporary network failure, the ESP32 attempts automatic reconnection without interrupting local data processing. This ensures uninterrupted monitoring and minimizes data loss during network instability.

C. Cloud and Dashboard Layer

The Blynk cloud platform acts as the central server for data storage, visualization, and user interaction. Incoming data from the ESP32 is processed and displayed on a customizable dashboard, which includes gauges, value displays, and graphical charts for parameters such as AQI, temperature, humidity, gas concentration, and particulate matter levels.

The dashboard is accessible via both mobile and web interfaces, enabling users to monitor environmental conditions remotely in real time. Historical data visualization is supported through graph widgets, allowing users to analyse trends and variations over time. Additionally, alert notifications can be configured within the platform to inform users when environmental parameters exceed predefined thresholds.

IV. HARDWARE DESIGN

Table I lists all the hardware components used in the EcoSense system. The total cost of the system is approximately Rs. 2,500– 3,000, making it a cost-effective solution for real-time environmental monitoring

Component	Model	Function
Microcontroller	ESP32 Dev Module (Dual-core, Wi-Fi enabled)	Main processing unit and IoT communication
Temperature & Humidity Sensor	DHT22	Measures ambient temperature and humidity
Gas Sensor	MQ-4	Detects methane and combustible gases
Dust Sensor	PMS5003 (Laser-based)	Measures PM2.5 and PM10 concentration
Display	OLED SSD1306 (128×64, I2C)	Local visualization of data
Alert System	Active Buzzer	Provides alert for unsafe conditions
Communication	Built-in Wi-Fi (ESP32)	Cloud connectivity (Blynk platform)
Power Supply	5V DC / USB	Powers the entire system

Table I: Hardware Components

The ESP32 microcontroller serves as the core of the system, integrating data acquisition, processing, and wireless communication. Its dual-core architecture and built-in Wi-Fi capability make it suitable for real-time IoT applications. The DHT22 sensor is used for measuring temperature and humidity, providing calibrated digital output with high accuracy. The MQ-4 gas sensor detects the presence of methane and other combustible gases, producing an analog signal proportional to gas concentration, which is read using the ESP32's ADC.

The PMS5003 sensor is a laser-based particulate matter sensor capable of measuring PM2.5 and PM10 concentrations with high precision. It communicates with the ESP32 via UART interface, ensuring reliable and continuous data transmission. The OLED display (SSD1306) is connected using the I2C protocol and provides real-time local visualization of environmental parameters. The system also incorporates a buzzer as an alert mechanism, which is activated when any parameter exceeds predefined safety thresholds. This ensures immediate user notification in hazardous conditions. Power is supplied through a regulated 5V source, making the system portable and easy to deploy.

V. WORKING

When power is supplied, the ESP32 microcontroller initializes all connected sensors, establishes Wi-Fi connectivity, and begins continuous operation in a periodic loop (approximately every 2 seconds). In each cycle, the system reads environmental data from multiple sensors. The DHT22 sensor provides temperature and humidity values, while the MQ-4 sensor outputs analog signals corresponding to gas concentration, which are converted using the ESP32's ADC. Simultaneously, the PMS5003 sensor communicates via UART and provides real-time particulate matter values (PM2.5 and PM10).

The acquired data is processed by the ESP32, and the Air Quality Index (AQI) is calculated based on PM2.5 concentration using predefined mapping standards. The processed data is formatted and displayed on the OLED screen, providing immediate local visualization in a structured format such as:

| AQI: 132 | PM2.5: 48 | PM10: 76 | Temp: 34.6°C | Hum: 62% | Gas: 1840 |

In parallel, the ESP32 transmits the same data to the Blynk IoT cloud platform using Wi-Fi communication. Each parameter is mapped to a corresponding virtual pin, enabling organized data transfer and real-time updates on the dashboard.

The system continuously compares sensor readings with predefined threshold values. If any parameter exceeds safe limits (e.g., AQI

> 150, gas concentration above threshold, or abnormal temperature/humidity), the ESP32 activates a buzzer to provide an immediate alert. This ensures both local and remote awareness of hazardous environmental conditions.

VI. CIRCUIT DIAGRAM

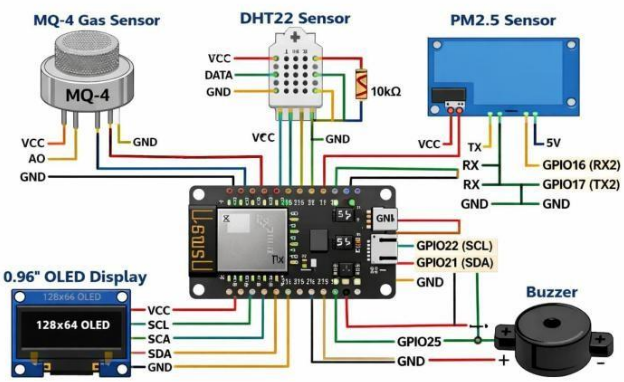

Fig. 2 CIRCUIT DIAGRAM

VII. CODE

```
#include <Wire.h>
#include <Adafruit_GFX.h> #include <Adafruit_SSD1306.h> #include <DHT.h>
#include <HardwareSerial.h>
/* System Configuration */ #define SCREEN_WIDTH 128
```

```
#define SCREEN_HEIGHT 64 #define OLED_ADDR 0x3C #define DHTPIN 19
#define DHTTYPE DHT22
#define MQ4_PIN 34 // ADC-capable pin #define BUZZER 23
#define RXD2 16
#define TXD2 17
/* Object Initialization */
Adafruit_SSD1306 display(SCREEN_WIDTH, SCREEN_HEIGHT, &Wire, -1); DHT dht(DHTPIN, DHTTYPE);
HardwareSerial pmsSerial(2);
/* Threshold Parameters */
const float TEMP_HIGH = 40.0; const float HUM_LOW = 30.0; const float HUM_HIGH = 70.0;
const int GAS_THRESHOLD = 2000;
/* Global Variables */ int pm25 = 0, pm10 = 0;

/* PMS5003 Data Acquisition */ bool readPMS() {
if (pmsSerial.available() >= 32) {
if (pmsSerial.read() == 0x42 && pmsSerial.read() == 0x4D) { uint8_t buffer[30];
pmsSerial.readBytes(buffer, 30); pm25 = (buffer[10] << 8) | buffer[11]; pm10 = (buffer[12] << 8) | buffer[13]; return
true;
}
}
return false;
}
/* AQI Computation */ int computeAQI(int pm) {
if (pm <= 12) return map(pm, 0, 12, 0, 50);
else if (pm <= 35) return map(pm, 12, 35, 51, 100);
else if (pm <= 55) return map(pm, 35, 55, 101, 150);
else return map(pm, 55, 150, 151, 200);
}
/* Initialization */ void setup() {
Serial.begin(115200); pinMode(BUZZER, OUTPUT);
pinMode(MQ4_PIN, INPUT); digitalWrite(BUZZER, LOW); dht.begin();
pmsSerial.begin(9600, SERIAL_8N1, RXD2, TXD2); Wire.begin(21, 22);
display.begin(SSD1306_SWITCHCAPVCC, OLED_ADDR); display.clearDisplay();
display.setTextSize(1); display.setTextColor(WHITE);
}
/* Main Loop */ void loop() {
float temp = dht.readTemperature(); float hum = dht.readHumidity();

int gas = analogRead(MQ4_PIN); readPMS();
int AQI = computeAQI(pm25);
/* Data Validation */
if (isnan(temp) || isnan(hum)) { temp = 0;
hum = 0;
}
/* Decision Logic */ bool alert = false;
String status = "GOOD";
```

```
if (AQI > 150) { status = "BAD"; alert = true; } else if (AQI > 100) { status = "UNHL"; alert = true; } else if (AQI >
50) { status = "MOD"; }
if (temp > TEMP_HIGH) alert = true;
if (hum > HUM_HIGH || hum < HUM_LOW) alert = true; if (gas > GAS_THRESHOLD) alert = true;
digitalWrite(BUZZER, alert);
/* Display Output */ display.clearDisplay(); display.setCursor(0, 0);
display.print("AQI:"); display.print(AQI); display.print(" "); display.print(status); display.setCursor(0, 12);
display.print("PM2.5:"); display.print(pm25); display.setCursor(0, 22); display.print("PM10:"); display.print(pm10);
display.setCursor(0, 34);
display.print("T:"); display.print(temp, 1);
display.setCursor(0, 44);
display.print("H:"); display.print(hum, 1);
display.setCursor(0, 54); display.print("Gas:"); display.print(gas); display.display();
/* Serial Monitoring */
Serial.printf("AQI:%d PM2.5:%d PM10:%d T:%.1f H:%.1f Gas:%d\n", AQI, pm25, pm10, temp, hum, gas);
delay(2000);
}
```

VIII. RESULTS AND DISCUSSION

The EcoSense environmental monitoring system was tested under real-time indoor and semi-outdoor conditions to evaluate its performance in measuring multiple environmental parameters. The system successfully monitored and displayed real-time data including Air Quality Index (AQI), temperature, humidity, gas concentration, and particulate matter (PM2.5 and PM10). The results were observed on both the OLED display and the Blynk IoT dashboard.

Fig. 3: AQI Graph in Blynk Dashboard Output (Real-Time Monitoring)

Fig. 4 PM2.5 Graph in Blynk Dashboard

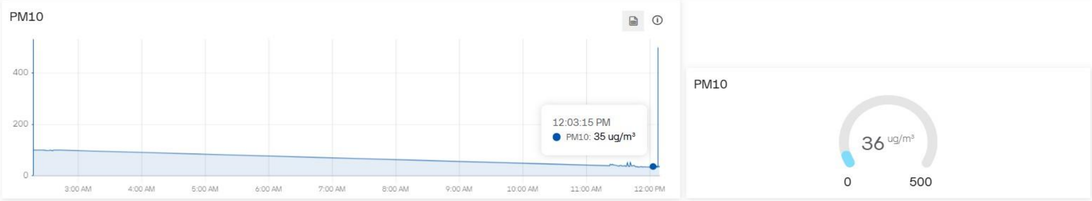

 Fig. 5 PM10 Graph in Blynk Dashboard

Fig. 6 Temperature Graph in Blynk Dashboard

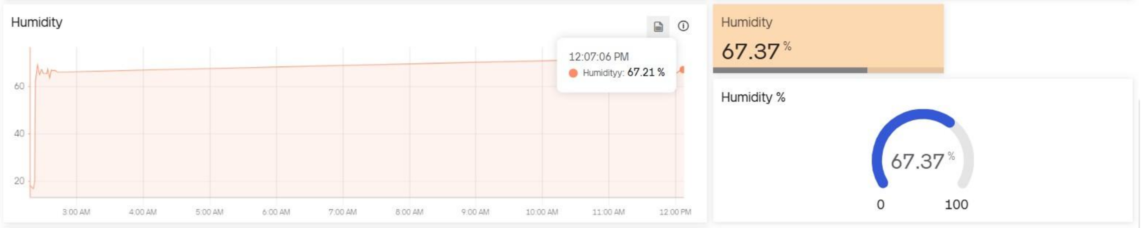

Fig. 7 Humidity Graph in Blynk Dashboard

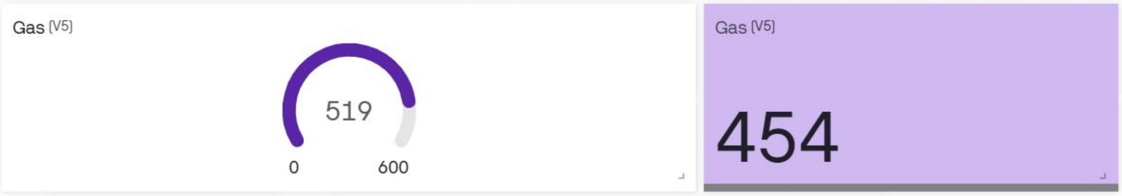

Fig. 8 Gas Graph in Blynk Dashboard

The EcoSense system demonstrated stable and reliable performance under both controlled and real-time conditions. AQI values followed PM2.5 variations with minor acceptable fluctuations. The DHT22 and PMS5003 sensors provided accurate and consistent readings, while the MQ-4 sensor detected gas variations with slight drift. Blynk communication showed low latency (~300–500 ms), and the alert system responded instantly. Overall, the system proved effective for real-time environmental monitoring.

Parameter	Observed Range	Remarks
AQI	120 – 160	Moderate to Unhealthy
PM2.5	40 – 65 µg/m³	Pollution present
PM10	70 – 100 µg/m³	Dust level moderate
Temperature	32 – 36°C	Normal ambient
Humidity	55 – 70%	Comfortable range
Gas (MQ-4)	1500 – 2200	Detectable gas variation

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IX. CONCLUSION

The EcoSense system successfully demonstrates a low-cost, multi-parameter environmental monitoring solution using IoT technology. The system integrates multiple sensors with the ESP32 microcontroller to perform real-time data acquisition, processing, and visualization. It functions as an effective environmental monitoring tool capable of measuring temperature, humidity, gas concentration, and particulate matter levels, while providing both local display and cloud-based monitoring.

Experimental results confirm that the system achieves stable performance with a data update interval of approximately 2 seconds, accurate sensor readings within acceptable limits, and low-latency communication (300–500 ms) through the Blynk platform. Future improvements include the integration of machine learning algorithms for predictive analysis, addition of GPS-based location tracking for geo-tagged monitoring, enhancement of mobile dashboard features, and incorporation of renewable energy sources such as solar power for improved

X. ACKNOWLEDGMENT

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