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An IoT-Enabled Smart Sensor System for Real-Time Monitoring of Soil and Air Conditions with Integrated Web-Based Farming Guidance

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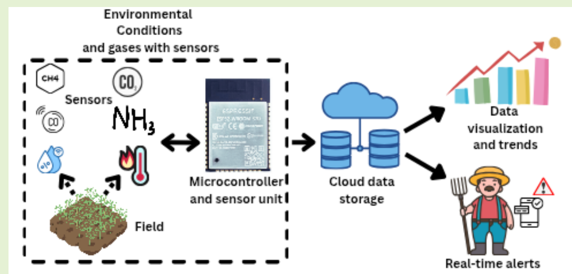
***Abstract*—Modern agriculture faces persistent challenges including inefficient resource utilization, exposure to harmful gases, and limited availability of real-time environmental data. In this work, an Internet of Things (IoT)-based smart farming system was developed using an Embedded System on a Chip, SoC (ESP32)-powered sensor network to continuously monitor soil moisture, temperature, humidity, and airborne gases such as carbon monoxide (CO), methane (CH_4), ammonia (NH_3), and hydrogen sulphide (H_2S). Sensor data are transmitted wirelessly to a web application featuring real-time graphical dashboards, air quality and flammable gas alerts, and recommendations on safe exposure intervals based on sensed concentrations. The system further provides crop-specific guidance, automatic fertilizer estimation, and educational content on pest and disease management. An integrated finance module tracks costs, revenue, and profit to support agricultural decision-making. Field validation demonstrates the system's scalability, modularity, and its potential to enhance safety, sustainability, and profitability across diverse farming environments.**



***Index Terms*—Crop guidance, Fertilizer calculation, Financial tracking, Gas sensors, IoT technology, Pest control tips, Real-time air quality monitoring, Soil moisture, Smart agriculture.**

I. Introduction

Modern agriculture faces critical challenges, including inefficient resource use, limited monitoring infrastructure, and exposure to harmful gases. Despite technological progress, many farmers remain reliant on traditional practices, which often leads to excessive input use, lower yields, and soil degradation [1], [2]. Hazardous gases such as carbon monoxide (CO), methane (CH_4), ammonia (NH_3), and hydrogen sulphide (H_2S) further complicate farm environments by harming plant growth, disrupting soil microbial activity, and endangering human health [3]–[5]. For instance, CO impairs microbial life, CH_4 contributes to global warming, NH_3 destabilizes nitrogen uptake, and H_2S is toxic at elevated concentrations. To address such issues, Internet of Things (IoT) systems have become increasingly prevalent in agriculture, with numerous studies demonstrating improvements in decision-making and sustainability [6]–[11]. Sensor-based platforms for soil and water monitoring, cloud-enabled visualization, and automation tools including those that implement image-based disease detection, system integration with drones, and LoRa communications have advanced smart farming practices [12]–[28]. However, many existing approaches are often fragmented, offering limited integration and lacking comprehensive decision support. While recent efforts demonstrate the impact of IoT and cloud computing on food and water security [9], [10] and the potential of renewable energy and robotics for sustainability [11], there remains a need for holistic, farmer-centric systems.

Motivated by these gaps, the scope of this paper is to introduce an integrated digital agriculture platform that empowers farmers with actionable, real-time data, supporting both productivity and safety. Specifically, the system is built around a unified IoT sensor network utilizing an Embedded System on a Chip (ESP32) microcontroller to monitor soil moisture, temperature, humidity, and toxic gases (CO, CH_4, NH_3, H_2S) simultaneously. Coupled with a web-based dashboard that supports interactive visualization, safety alerts, and comprehensive recommendations across crop health, pest management, irrigation, and financial planning, the system has been validated in the field for accuracy, robust connectivity, and usability. Compared to state-of-the-art solutions, this approach provides improved sensor coverage and greater integration of functions.

The main contributions of this proposed work are as follows:

1) Design and development of a multi-parameter IoT monitoring system, including gases such as CO, CH_4, NH_3, H_2S, as well as temperature, humidity, and soil moisture;

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the entire system is powered using a battery.
2) Development of an interactive dashboard for farmers, featuring real-time alerts for anomalies and a comprehensive guidance platform that includes fertilizer calculation, pest and disease management, cultivation tips, and financial overview.
3) Implementation and field validation targeting small- and medium-scale farm environments, providing comprehensive, real-time environmental and safety data.

The rest of the paper is organized as follows. Section II describes the system overview, including hardware, software, and sensor calibration. Section III covers data flow and communication, with sensor collection, cloud logging, and visualization. Section IV presents sensor data analysis and visualization tools. Agricultural features and user interface are discussed in Section V. Section VI details real-world deployment, challenges, and results. Finally, Section VII concludes the paper and outlines future directions.

Fig. 1. Overview Of The System

II. Overview of the System

The proposed IoT-based smart agriculture monitoring system enables real-time tracking of environmental and soil parameters to support data-driven farming practices. It integrates a range of gas sensors, including MQ5, MQ7, MQ135, and MQ136 for detecting gases such as CO, CH_4, NH_3, and H_2S. A Digital Humidity and Temperature (DHT22) sensor monitors ambient temperature and humidity, while a capacitive soil moisture sensor assesses soil hydration levels. All sensors interface with an ESP32 microcontroller, which provides both Wi-Fi and Bluetooth connectivity. Sensor data is collected at regular intervals and transmitted to a cloud-based Google Sheet via Google Apps Script, enabling centralized data logging and real-time visualization. The front-end web dashboard, developed using React.js, displays sensor readings through interactive gauge meters, issues alerts when predefined thresholds are exceeded, and provides recommendations on safe exposure durations to the farmer. Additional modules are incorporated for fertilizer requirement calculations, pest and disease identification, cultivation best practices, and financial record-keeping tailored for farmers. The platform also supports periodic data visualization and trend analysis to aid in long-term decision-making.

A. Hardware Architecture

The hardware architecture is centered around an ESP32 microcontroller, which serves as the core processing and communication unit. A range of analog and digital sensors are interfaced with the ESP32 through its General Purpose Input/Output (GPIO) pins, with careful consideration of voltage compatibility, signal conditioning, and power requirements. The gas sensing module comprises MQ5, MQ7, MQ135, and MQ136 sensors, which are capable of detecting various harmful gases including carbon monoxide CO, CH_4, NH_3, and H_2S. These sensors are powered by a regulated 5V supply, and their analog voltage outputs are routed to the Analog-to-Digital Converter (ADC) channels of the ESP32. Given the ESP32's 3.3V ADC input range, appropriate voltage dividers or signal conditioning circuits are employed where necessary to ensure safe and accurate readings. The DHT22 sensor is used to measure ambient temperature and relative humidity. It is connected to a designated digital GPIO pin and is periodically sampled using a timing-based polling method. The sensor communicates through a single-wire digital protocol, making it efficient for low-power applications. A capacitive soil moisture sensor is used to assess the volumetric water content of the soil. This sensor also outputs an analog voltage proportional to soil moisture level and is connected to one of the ESP32's ADC pins for continuous monitoring. The entire system is powered via a regulated 5V DC source. For field deployments, especially in remote agricultural settings, the design accommodates a battery-backed solar power supply to enable off-grid operation. A power management module ensures reliable switching between power sources and provides protection against voltage fluctuations. The complete hardware configuration, including the sensor connections, power routing, and GPIO pin mapping, is illustrated in the schematic diagram provided below. This schematic offers a detailed view of the wiring layout, ensuring reproducibility and ease of deployment.

B. Software Architecture

The software architecture is composed of a three-tiered stack, ensuring modularity, scalability, and ease of integration. The front-end is developed using React.js, offering a dynamic and responsive user interface for real-time monitoring, data visualization, and user interaction. Sensor readings, system status, and historical trends are displayed through interactive components such as gauge meters, charts, and alert notifications. The backend is implemented using Node.js (JavaScript), which acts as an intermediary between the frontend interface and the data sources. It handles Application Programming Interface (API) requests, data validation, business logic, and communication with the database. This layer ensures efficient processing of user inputs, threshold comparisons, and auto-

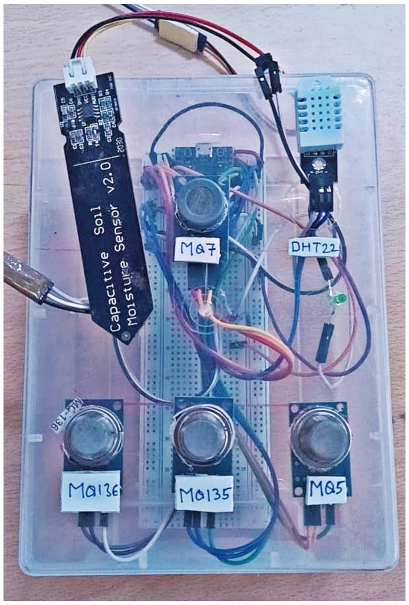

Fig. 2. Prototype of the implemented IoT-based monitoring system.

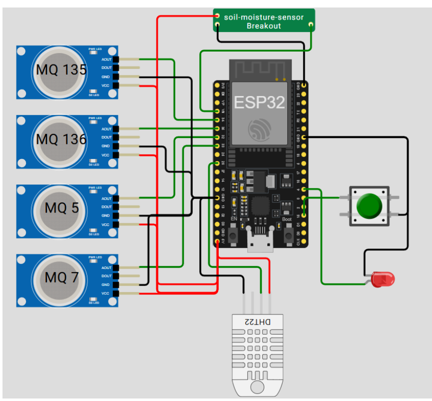

Fig. 3. Schematic diagram of the proposed system.

mated alert triggers based on predefined sensor limits. For data storage, MongoDB is employed as a Not only Structural Language Query (NoSQL) database solution, chosen for its flexibility in handling semi-structured sensor data and ease of scaling. It stores real-time sensor logs, historical records, and user-configured parameters such as threshold values and preferences. The ESP32 microcontroller communicates with the system via Hypertext Transfer Protocol (HTTP) POST requests. It transmits sensor data directly to a Google Sheet through a Google Apps Script-based endpoint. This integration facilitates quick and centralized data logging in a familiar spreadsheet environment, which can be further processed or linked to visualization tools if needed. This hybrid architecture, combining cloud-based data logging with a full-stack web application, ensures robustness, ease of access, and platform independence for both end-users and developers.

C. Sensor Calibration and Measurement Calculations

Accurate sensor readings require initial calibration to relate raw analog values to meaningful environmental measurements. Two key sensors used in the system, gas sensors and the capacitive soil moisture sensor, are calibrated using standard procedures described below.

1) Gas Sensor Calibration (MQ Series): MQ-series gas sensors output an analog voltage corresponding to gas concentration. The key parameter used to determine gas presence is the resistance ratio R_s/R_0, where R_s is the sensor resistance at the measured gas concentration, and R_0 is the sensor resistance in clean air (baseline).

To calibrate the sensor, R_0 is determined in fresh air using:

$$R_0 = \frac{(V_{\text{supply}} - V_{\text{out}}) \times R_L}{V_{\text{out}}} \tag{1}$$

During operation, R_s is calculated similarly using real-time sensor data:

$$R_s = \frac{(V_{\text{supply}} - V_{\text{sensor}}) \times R_L}{V_{\text{sensor}}} \tag{2}$$

The ratio R_s/R_0 is then compared to the gas characteristic curves provided in the sensor's datasheet to estimate the concentration in ppm.

2) Soil Moisture Sensor Calibration (Capacitive Sensor): The capacitive soil moisture sensor provides an analog output voltage that varies with the volumetric water content in the soil. Higher moisture levels result in lower output voltages. To convert the raw analog value to a percentage, a linear mapping is applied between the sensor's minimum and maximum values.

The moisture percentage is calculated using:

$$\text{Moisture } (\%) = \frac{V_{\text{max}} - V_{\text{read}}}{V_{\text{max}} - V_{\text{min}}} \times 100 \tag{3}$$

where V_{read} is the real-time analog voltage from the sensor, V_{max} is the voltage corresponding to dry soil (calibrated), and V_{min} is the voltage corresponding to fully wet soil (calibrated).

III. Data Flow and Communication

A. Sensor Data Collection and Transmission

The ESP32 microcontroller serves as the central unit responsible for interfacing with all the environmental and gas sensors. Sensor data, including gas concentrations (CO, CH_4, NH_3, and H_2S), temperature, humidity, and soil moisture, is periodically sampled and processed. The ESP32 uses its integrated built-in Wi-Fi to transmit data wirelessly. For data logging, a custom Google Apps Script endpoint is used, acting as a lightweight REST API. The ESP32 sends HTTP POST requests to the endpoint with sensor values as query parameters, which are then automatically logged in a structured format in Google Sheets. This cloud-based approach is not only cost-effective but also scalable for deployment across small to medium-sized agricultural fields, making it particularly suitable for rural farmers with limited infrastructure.

B. Cloud data Logging Integration

The implementation of Google Sheets is considered a lightweight cloud storage solution for the ESP32 sensor data. A custom Apps Script web app processes incoming HTTP POST requests and logs entries chronologically in the spreadsheet. This approach sidesteps the overhead of traditional database systems while remaining cost-effective. Each spreadsheet row captures complete data in timeseries readings and

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status flags in an easily accessible format. The web application can readily fetch and display this information when needed. As an added benefit, team members can share, export, or connect the spreadsheet to analysis tools, making the system both practical and versatile for different user needs. Thus, helps in looking up the trends as per the climate changes, environmental conditions, and peaks can be seen by manual data analytics as well.

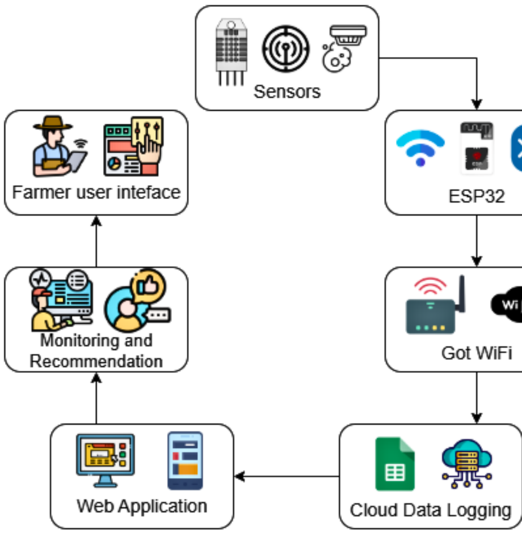

Fig. 4. Data Flow of the System

Timestamp	Temperature (°C)	Humidity (%)	Soil Moisture (%)	CO (ppm)	H_2S (ppm)	CH_4 (ppm)	NH_3 (ppm)	Flammable Index	Air Quality Index
4-24-2025 0:35:17	33.1	75.8	49	0.71	0.591	4.01	1.08	253	44.4
4-24-2025 0:35:48	33.1	75.8	41	0.8	0.56	3.51	1.08	254	43.1
4-24-2025 0:36:18	33.1	75.7	44	0.8	0.549	3.3	1.07	245	42.6
4-24-2025 0:36:47	33.1	75.7	40	0.75	0.53	3.1	1.07	260	41.7
4-24-2025 0:37:18	33.2	75.9	48	0.73	0.531	3	1.07	257	42.3
4-24-2025 0:37:47	33.1	75.9	44	0.74	0.524	3.05	1.07	250	41.5
4-24-2025 0:38:19	33.2	75.8	40	0.73	0.52	3.05	1.07	244	41.7
4-24-2025 0:38:51	33.2	75.7	49	0.76	0.525	3.1	1.08	246	42.9
4-24-2025 0:39:24	33.1	75.7	43	0.7	0.535	3.15	1.07	293	44.1
4-24-2025 0:39:54	33.1	75.8	48	0.71	0.532	3.2	1.07	296	43.9
4-24-2025 0:40:25	33.1	75.7	47	0.73	0.531	3.2	1.07	237	43.6
4-24-2025 0:40:54	33.1	75.8	47	0.74	0.524	3.1	1.07	242	42.9
4-24-2025 0:41:25	33.1	75.6	47	0.72	0.52	3.2	1.07	251	42.3
4-24-2025 0:41:55	33	75.5	48	0.71	0.514	3.1	1.08	261	42.3
4-24-2025 0:42:25	33	75.5	48	0.76	0.505	3	1.08	254	40.9
4-24-2025 0:42:55	33	75.5	47	0.77	0.49	3	1.07	259	39.5
4-24-2025 0:43:26	32.9	75.5	47	0.76	0.48	2.71	1.07	252	38.8
4-24-2025 0:43:56	32.9	75.4	48	0.77	0.532	2.62	1.08	292	41.8
4-24-2025 0:44:27	32.9	75.4	48	0.77	0.534	2.67	1.07	243	42.5
4-24-2025 0:44:57	32.9	75.5	46	0.78	0.529	2.62	1.07	284	41.8
4-24-2025 0:45:27	32.8	75.5	46	0.79	0.529	2.62	1.07	264	42
4-24-2025 0:45:58	32.8	75.5	46	0.77	0.52	2.62	1.08	232	41
4-24-2025 0:46:27	32.8	75.6	48	0.74	0.515	2.53	1.08	232	40.9
4-24-2025 0:46:57	32.8	75.6	48	0.72	0.508	2.39	1.07	232	40.4
4-24-2025 0:47:27	32.8	75.5	48	0.77	0.503	2.35	1.07	219	40.2
4-24-2025 0:47:57	32.8	75.6	48	0.74	0.499	2.39	1.07	222	40.1
4-24-2025 0:48:27	32.7	75.7	46	0.72	0.496	2.31	1.07	231	39.6
4-24-2025 0:48:57	32.7	75.7	48	0.72	0.492	2.26	1.08	214	39.6
4-24-2025 0:49:28	32.7	75.9	46	0.73	0.493	2.31	1.08	230	39.6

Fig. 5. Google sheet data

C. Web Application Visualization

The web application is based on React.js frontend and Node.js backend that work together to pull data from Google Sheets through its API. The web app transforms these raw readings into intuitive visualizations that reveal both immediate conditions and longer-term patterns. This work presents interactive gauge displays for each environmental parameter, giving users a quick way to spot problems at a glance. The system compares incoming values against safety thresholds established during the testing process. When readings exceed these limits, the dashboard highlights concerns using colour-coded warnings alongside practical advice, like how long exposure remains safe, what health effects might occur, and what immediate steps users should take to address the situation.

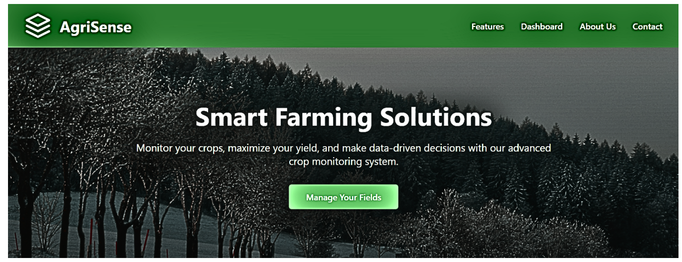

Fig. 6. Home Page of Website

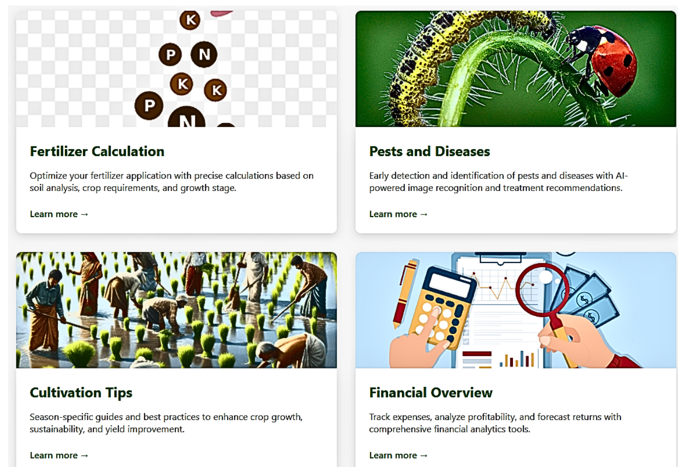

Fig. 7. Home Page of Website

IV. Sensor Data Analysis

A. Exposure Risk and Recommendations

The system monitors sensor data in real time and compares it against predefined thresholds to assess environmental safety. Each gas sensor (e.g., MQ5, MQ7, MQ135, MQ136) is calibrated with safety standards for gases like CO, CH4, NH3, and H2S. Based on these readings, the system classifies exposure levels into three categories: Safe, Caution, and Hazardous.

These levels are shown on a colour-coded gauge in the dashboard:

i. **Green (Safe):** Readings are within safe limits.
ii. **Yellow (Caution):** Values nearing unsafe levels; brief exposure may be tolerated but needs attention.
iii. **Red (Hazardous):** Limits are exceeded; prolonged exposure poses health risks.

When hazardous levels are detected, the system alerts users and displays key details such as the gas type, current level, safe exposure time, and health warnings.

B. Data Visualization Tools

The web application provides real-time visualization of all sensor data using interactive charts and gauges. Parameters are categorized for easier analysis:

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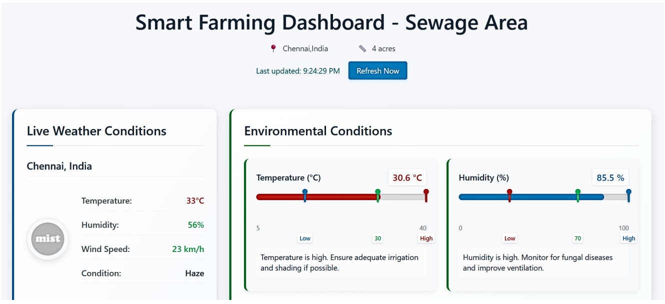

Fig. 8. Dashboard with Gauge and Threshold-based Alerts for Temperature, Humidity and Soil Moisture

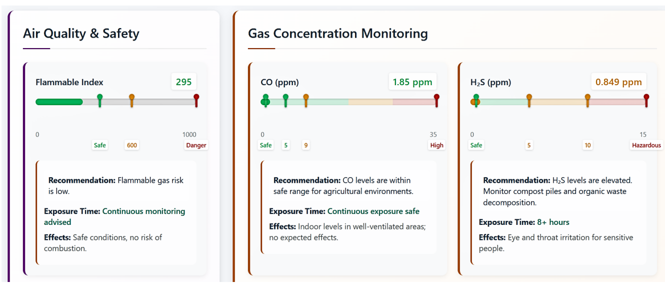

Fig. 9. Dashboard with Gauge and Threshold-based Alerts for Gas

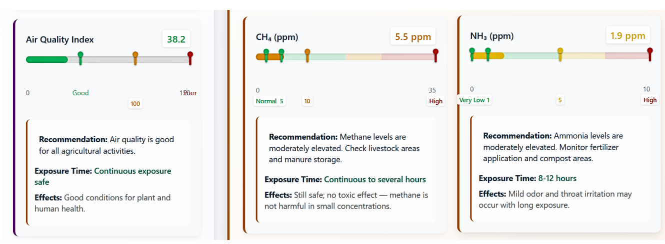

Fig. 10. Dashboard with Gauge and Threshold-based Alerts for Air Quality

i. **Environmental Parameters:** Includes temperature, humidity, and soil moisture. Line charts with range markers (e.g., "Low", "Optimal", "Dry") allow users to monitor field conditions.
ii. **Gas Concentration Levels:** For gases like CO, CH_4, NH_3, and H_2S, charts show live values with colored range lines indicating safety levels such as "Safe", "Caution", and "Hazardous".
iii. **Air Quality and Flammability:** Air quality and overall flammability index are visualized with circular gauges and trend lines to highlight variations over time.
iv. **Individual Sensor Analysis:** Users can isolate a specific parameter to view its dedicated plot, enabling better focus and comparison across different timeframes.

Each graph is updated in real-time from Google Sheets, ensuring accurate and up-to-date monitoring. The interface supports selection of date ranges and sensor types to enhance user control over data visualization.

V. Agricultural Features and User Interface

The smart farming system offers essential features such as fertilizer calculation, where farmers input land area to receive precise Nitrogen, Phosphorus, and Potassium (NPK) requirements and suggested fertilizers like Urea, Diammonium Phosphate (DAP), and Muriate of Potash (MOP). It also provides pest and disease detection support, giving crop-specific insights into common issues, symptoms, and treatments. For better planning, the platform shares weekly cultivation tips tailored to each crop's growth cycle. Additionally, the financial dashboard helps users monitor income, expenses, and profitability per crop, promoting informed farm management.

Pseudo-code IoT-Enabled Smart Agriculture Monitoring and Alert System

```
Initialize: ESP32, serial communication, EEPROM, sensors (Temperature/Humidity (DHT22), Soil Moisture, Gas sensors (MQ5, MQ7, MQ135, MQ136)), Calibration Button, Status LED
Start DHT sensor
Load calibration constants from EEPROM
Connect to WiFi, retry if needed
Indicate status using LED
while system is running do
    if Calibration button is pressed then
        if Short press then
            Calibrate selected individual gas sensor; update EEPROM
        else if Long press then
            Calibrate all gas sensors in sequence; update EEPROM
        end if
    end if
    if Serial command received then
        Process command:
        if "calibrate" then
            Calibrate all sensors, update EEPROM
        else if "calibrate mqX" then
            Calibrate selected MQ sensor
        else if "read" then
            Read and display all sensor data
        else if "start"/"stop" then
            Enable/disable continuous readings
        else if "wifi" then
            Reconnect WiFi
        else if "send" then
            Read sensors and send data to cloud
        end if
    end if
    if Continuous reading is active and sampling interval elapsed then
        Read and average all sensor values (temperature, humidity, soil moisture, gas sensors)
        Convert and process raw readings (resistance, PPM, indices)
        Apply calibration corrections and filters
        Display readings
        if Any gas exceeds threshold then
            Trigger gas alert (dashboard/email/SMS)
        end if
        if Soil moisture below threshold then
            Issue irrigation recommendation
        end if
        if Temperature above threshold then
            Issue cooling/shade suggestion
        end if
        if Send interval elapsed then
            Format sensor values for cloud upload
            Send readings (HTTP) to Google Sheet endpoint
            Indicate send status with LED and serial output
        end if
    end if
end while
```

VI. Real-World Implementation

A. Deployment Location and Setup

The system has been successfully deployed at a water treatment plant, where toxic gas accumulation poses a significant health and safety risk. This pilot deployment is located within the premises of IIITDM Kancheepuram. The sensing unit, housed in a weather-resistant and dust-proof enclosure, includes an ESP32 microcontroller interfaced with MQ5, MQ7, MQ135, and MQ136 gas sensors, a DHT22 sensor for temperature and humidity monitoring, and a capacitive soil moisture sensor for environmental reference. All components are arranged compactly to optimize space while ensuring adequate ventilation for accurate gas detection. The ESP32 collects and transmits data at regular intervals to a cloud-based Google Sheet via HTTP POST using Google Apps Script. A companion web interface visualizes the data in real time using dynamic charts, allowing users to track pollutant levels against predefined safety thresholds. Each data point is precisely time-stamped, enabling chronological analysis, anomaly detection, and alert generation in the event of hazardous gas concentration spikes. Over a continuous 672-hour monitoring period, the system demonstrated consistent performance, capturing minute-by-minute fluctuations in gas concentrations and environmental parameters. This deployment validates the system's reliability under real-world conditions, particularly in harsh industrial environments. Additionally, the data and visual trends serve as a valuable reference for maintenance personnel, environmental engineers, and decision-makers responsible for operational safety and compliance monitoring.

Fig. 11. System Installed at water treatment plant

B. Challenges in Real-World Scenarios

Several challenges were faced during deployment:

i. **Sensor Calibration:** Higher temperature and humidity drift affect gas sensor readings, requiring frequent calibration of sensors.

ii. **Wi-Fi Connectivity:** Signal instability in remote areas affected data transmission, managed using reconnection logic.

iii. **Power Supply:** Ensuring continuous power in remote locations was a challenge, requiring proper power planning.

iv. **Environmental Effects:** High Humidity causes condensation on sensor caps, impacting the overall accuracy.

C. Observed Results and Data Trends

This section presents the observed sensor data trends collected from the deployed IoT system. The plotted graphs illustrate fluctuations in gas concentrations (CO, CH_4, NH_3, H_2S) over time, providing insights into environmental conditions.

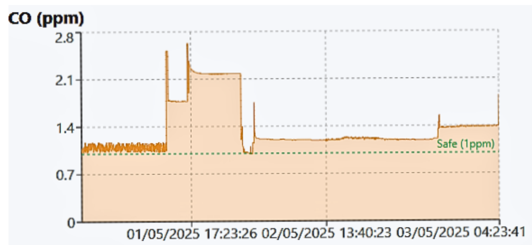

Fig. 12. CO Gas concentration measurements

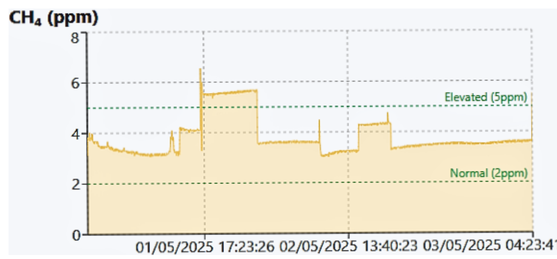

Fig. 13. CH_4 Gas concentration measurements

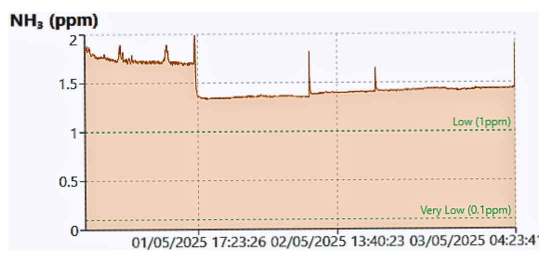

Fig. 14. NH_3 Gas concentration measurements

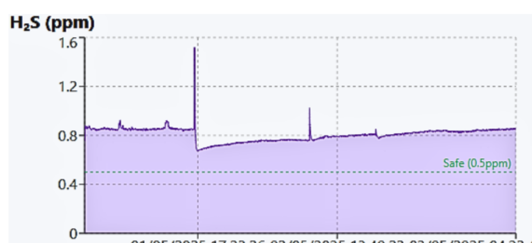

Fig. 15. H_2S Gas concentration measurements

i. **Ammonia (NH_3) and Hydrogen Sulfide (H_2S):** These gases showed higher concentrations in the area prone to wastewater. This is primarily due to the presence of

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TABLE I
COMPARISON OF MAINSTREAM IOT-BASED AGRICULTURE SYSTEMS FROM RECENT LITERATURE

Paper/System	Sensors Monitored	Architecture /Tech	Gas Monitoring	Decision Support Features	Limitations
Manasa Reddy et al. [26]	Soil moisture, Temp, Humidity	IoT, Cloud Dashboard	No	Crop growth alerts, threshold notifications	No gas/air quality data, basic analytics
Boralkar et al. [13]	Soil moisture and Environmental sensors	IoT	No	System overview and Operation	No implementation is done only study
Obaideen et al. [2]	Soil moisture, Weather	IoT (Survey)	No	Hardware overviews, system taxonomy	Review only, no implementation/data
Udatalapally et al. [1]	Soil moisture	IoT, Cloud dashboard	No	Hardware implementation, Sensor based irrigation	No gas/air quality data, single soil moisture system
Bruno et al. [4]	MOX Gas Sensors (CH_4, CO, etc.), Temp, Humidity	Embedded AI, Smart Gas Sensing	Yes	Gas recognition, AI-based alerts	No crop/pest analytics, limited environmental coverage
Morchid et al. [9]	Soil moisture, Irrigation water, Weather	IoT, Cloud Computing	No	Precise irrigation scheduling, food security focus	No toxic gas, pest, or crop analytics
Morchid et al. [10]	Soil moisture, Water security sensors	IoT, Embedded, Cloud	No	Enhanced water security, smart irrigation management	Limited focus (irrigation/water); not full farm integration
Rehman et al. [11]	Energy resources, Soil, Equipment	IoT, Energy Mgt., Robotics	No	Precision energy management, renewables, robotics	Energy-centric; few farm environmental parameters
Proposed System	Soil moisture, Temp, Humidity, CO, CH_4, NH_3, H_2S	IoT, ESP32, Web Dashboard	Yes	Crop, fertilizer, pest, air/gas alerts, finance module, full dashboard	Initial calibration required, recently validated

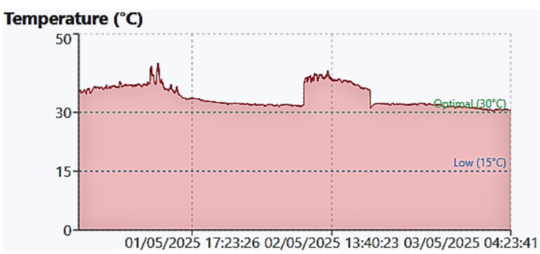

Fig. 16. Temperature measurements

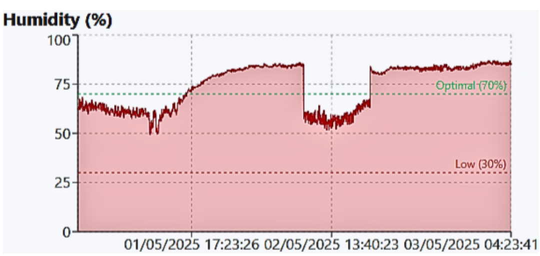

Fig. 17. Humidity readings

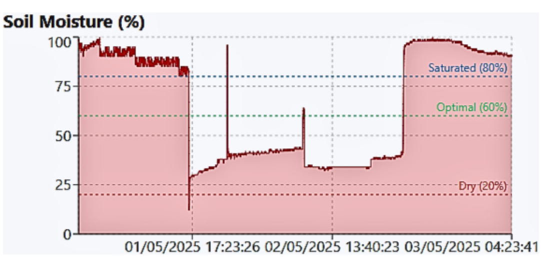

Fig. 18. Soil moisture levels

decomposing organic waste, stagnant water, and the use of nitrogen-based fertilizers in nearby zones.

ii. **Carbon Monoxide (CO) and Methane (CH_4):** Moderate levels were observed, likely due to anaerobic decomposition and microbial activity in the moist, oxygen-deficient water treatment environment.

iii. **Air Quality Trends:** The overall air quality index frequently touched the "Caution" level due to the continuous release of gaseous pollutants from stagnant wastewater and decaying matter.

iv. **Data-Driven Insights:** Real-time monitoring revealed consistent patterns in gas build-up during peak decomposition hours, reinforcing the effectiveness of the system in identifying pollution sources.

v. **Need for Intervention:** These findings highlight the importance of deploying such monitoring systems in polluted zones to guide safety measures and early warnings for health risks.

VII. CONCLUSION AND FUTURE WORK

This study presents a functional IoT-based monitoring system deployed across agricultural and water treatment sites. Powered by an ESP32 microcontroller and a suite of gas and environmental sensors (CO, CH_4, NH_3, H_2S, temperature, humidity, and soil moisture), the system effectively captures and transmits real-time data to a google sheet cloud and the data is called from sheets using REST API which can be visualized in the developed farmer website dashboard. Key features include live sensor visualization, gas analytics, fertilizer calculators, and crop-specific recommendations. Over a 672-hour period, the system recorded 40,320 data points with high timestamp accuracy (±2 seconds). Elevated NH_3 and H_2S levels were observed in the treatment zone, linked to organic decomposition and fertilizer runoff. The platform also integrates modules for expense tracking, cultivation planning, and pest/disease reference data, offering a scalable, cost-effective solution to aid sustainable farming practices and

TABLE II
FEATURE-BASED COMPARISON BETWEEN THE DEVELOPED SYSTEM AND OTHER AGRICULTURAL MONITORING PLATFORMS

Features	Internet-of-agro-things [1]	Smart irrigation systems [2]	Agriculture system ESP32 [13]	Smaiot [14]	**Developed Device (Proposed work)**
Soil Quality Sensors	✓	✓	✓	✗	✓
Air Quality Sensors	✗	✗	✗	✗	✓
Environment Quality Sensors	✗	✗	✓	✓	✓
Wi-Fi and Bluetooth	✓	✓	✓	✓	✓
Cloud Data Integration	✓	✗	✗	✓	✓
Interactive Dashboard	✗	✗	✓	✓	✓
Farmers Website and Recommendations	✗	✗	✗	✗	✓
Real-time Alerts	✗	✗	✗	✓	✓
Multiple Fields Monitoring	✗	✗	✗	✗	✓
Fertilizers Calculations	✗	✗	✗	✗	✓
Financial Recordings Profit and Loss	✗	✗	✗	✗	✓

Note: (✓), addressed; (✗), not addressed.

support smallholder farmers.

The proposed IoT-enabled smart agriculture system offers superior integration by monitoring diverse environmental parameters, including toxic gases, beyond mainstream solutions. Its real-time visualization, decision support, and financial management deliver actionable insights. Experimental validation confirmed enhanced responsiveness and usability, positioning the system as a holistic, scalable platform for sustainable, efficient smart farming.

Future enhancements include a lightweight Android app with real-time alerts, automated irrigation via soil moisture–driven actuators, and AI-based pest detection through image analysis. Long-range communication (LoRa) and drone-assisted monitoring are also proposed to expand the system's reach and precision capabilities in low-connectivity rural areas. Integrating a Zigbee network enhances the precision of agricultural monitoring by enabling dense, low-power sensors across the entire field. This ensures no affected area is overlooked, allowing for timely interventions. As a result, crop health and yield are optimized, leading to increased profitability. Such advancements contribute to the vision of a prosperous and sustainable agricultural economy.

VIII. RESULTS

The IoT-based monitoring system was deployed and evaluated in agricultural environments at a site influenced by water treatment activities to assess real-time environmental and soil conditions and support data-driven agronomic decision-making. Using an ESP32 microcontroller integrated with sensors for CO, CH_4, NH_3, H_2S, temperature, humidity, and soil moisture, the system reliably captured and transmitted data to a Google Sheets cloud. In the water treatment–impacted site, elevated concentrations of NH_3 and H_2S were consistently observed, indicating pollution from decomposing organic matter and nitrogen-rich fertilizer runoff. The platform's real-time dashboard enabled visualization of environmental trends, issued alerts when gas thresholds were breached, and offered tools for fertilizer estimation and field comparison. Designed for accessibility, the interface supported smallholder farmers with crop-specific recommendations, irrigation guidance, and pest or disease alerts. Additional modules allowed tracking of farm expenses and optimization of input usage. Overall, the system demonstrated its potential as a cost-effective, modular tool for promoting sustainable agriculture by improving input efficiency, reducing environmental stress, and empowering farmers with actionable insights for better decision-making. Sources have been added in this GitHub link here to search.

IX. ACKNOWLEDGMENT

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