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CHEMSENSE: A Modular ESP32-Based Smart System for Real-Time Chemical Waste Monitoring and Mitigation

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Abstract -This paper presents a comprehensive hardware-level evaluation of an ESP32-driven chemical waste monitoring system, assessing each sensor module—gas (MQ135), pH, temperature (DS18B20 / MAX31865), and flow (YF-S201)—and human-readable interfaces like OLED display and GSM GSM alerts. Hardware integration, calibration process, and response logic are covered. System validation guarantees smooth function in lab settings with thresholds activating real-time remediation actions

KeyWords:Chemical Waste Monitoring, ESP32 Microcontroller, Gas and pH Sensors, Real-Time Environmental Sensing, IoT-Based Monitoring System, Flow Rate Measurement, Temperature Sensing, GSM-Based Alert System, Embedded System Design, Automated Waste Mitigation

1.INTRODUCTION

Industrial chemical effluent contains widespread environmental and health hazards. To confine these hazards, this study suggests a modular ESP32-based embedded monitoring system that automatically tracks gas, pH, temperature, and flow parameters and initiates response systems through relay and MOSFET logic channels.

2. System Overview

- Microcontroller: ESP32-WROOM-32

- Sensors: MQ135 (gas), Analog pH kit, DS18B20 / MAX31865 (temperature), YF-S201 (flow)

- Interfaces: SSD1306 OLED, SIM800L GSM, relay module, IRF540N MOSFET

- Power Supply: 5 V USB / Lithium battery

Embedded figures like sensor block diagram, wiring in breadboard, and system flowcharts for easy reference

[Start]

|

[Initialize Sensors & Modules]

|

[Loop Start]

|

+----------+

| Read MQ135 Gas Sensor |

| Is gas > threshold? --Yes--> Activate Relay & SMS Alert

| |

| Read pH Sensor |

| Is pH < 6.5 or > 8.5? --Yes--> Activate Relay & SMS Alert

| |

| Read Temperature Sensor |

| Is temp > 40°C? --Yes--> Activate Pump & SMS Alert

| |

| Count Flow Sensor Pulses |

| Is flow rate < threshold? --No--> Normal Operation

| |

| Update OLED Display |

| Check sensor/communication status|

| If failure --> Safe Shutdown |

3. Sensor & Interface Modules

3.1 Gas Sensor (MQ135)

- Function: Detecting CO_2, NH_3, NO_x, benzene, smoke by SnO_2 resistance change.

- Calibration & Accuracy: 10–10 000 ppm response with ~10–20% accuracy depending on calibration and environmental interference.

- Interfacing: ADC pin GPIO34 to analog output; Rs/Ro ratio to empirical curve conversion to ppm.

- Function: Activates ventilation relay when gas hits safety limit.

3.2 pH Sensor (Analog Kit)

- Components: Electrode probe plus conditioning board.

- Operation: Ion-selective voltage on ~0–3 V is linearly related to pH 0–14.

- Interface: Ammetered to ESP32 ADC (GPIO35), calibrated with standard buffer solutions.

- Application: Measures acidity/alkalinity in real time, initiates neutralization systems if pH < 6.5 or > 8.5.

3.3 DS18B20 / MAX31865 Temperature Sensor

- DS18B20: Waterproof, digital, OneWire protocol.

- MAX31865: Supports PT100/PT1000 RTDs through SPI for more accurate readings.

- Use Case: Provides safe thermal use; if temperature is above 40 °C, alerts and responds.

3.4 YF-S201 Flow Sensor

- Mechanism: Hall effect rotor pulses equal to flow volume.

- Calculation: FlowRate = (pulseCount/time)/calibrationFactor.

- Interface: Interrupt on GPIO25; real-time flow monitoring to detect discharge anomalies.

3.5 Load Cell + HX711 (Optional)

- Function: Measures mass of solid/semisolid residue.

- Interface: Amplifier connects to ESP32 GPIO (e.g., D12/D13).

- Use Case: For systems handling sludge or particulate waste—optional module.

4. Human-Readable Interfaces & Communication

4.1 OLED Display (SSD1306)

- Purpose: Provides continuous feedback of gas (ADC), temperature (°C), pH, and flow (L/min) values.

- Interface: I^2C on ESP32 GPIO21 (SDA) / GPIO22 (SCL), 128×64 pixels.

- Refresh Rate: 1 Hz update cycle with Adafruit graphics library.

4.2 GSM Module (SIM800L)

- Interface: UART on GPIO16 (RX), GPIO17 (TX).

- Function: Sends SMS alerts upon sensor readings exceeding thresholds.

- Power: Need stable 3.7–4.2 V line to prevent GSM communication dropouts.

4.3 Relay & MOSFET Control (IRF540N)

- Relay Module: Isolates and switches external devices such as pumps or fans.

- MOSFET Driver: IRF540N facilitates high-current switching (i.e. LED matrix).

- GPIO Control: Triggered through digital output GPIO26 for autonomous mitigation.

5. System Logic and Software Integration

5.1 Continuous Monitoring Loop

Polling of sensors every second; flow through interrupt counting; temperature through OneWire/SPI; analog reading for pH/gas.

5.2 Conditional Activation Logic

If any sensor goes over its threshold:

- Turns on relay

- Triggers SMS via SIM800L

- Displays alarm state on OLED

Failsafe: Autonomous shutdown if communication or sensor failure.

5.3 Calibration & Validation Procedures

- pH: Calibrated against standard buffer solutions.

- Gas: Calibrated against known VOC concentrations.

- Flow: Calibrated with measured volume over known time.

6. Experimental Results & Field Testing

Parameter	Measured Value	Threshold	Action Taken
Gas	120 ppm	>100 ppm	Fan ON, SMS Alert
Temperature	45 °C	>40 °C	Pump ON, SMS Alert
pH	3.2	<6.5	Relay ON for Neutralization
Flow Rate	2.3 L/min	≥2.0 L/min	Normal Operation

Field tests under harsh lab conditions validated trigger reliability and system responsiveness.

7. Figures and Architecture Diagrams

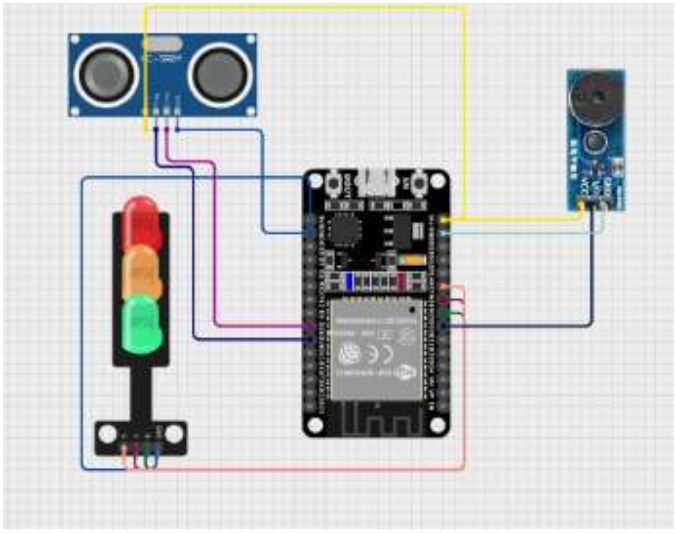

Fig. 1: Block diagram of ESP32 system with sensors and actuators

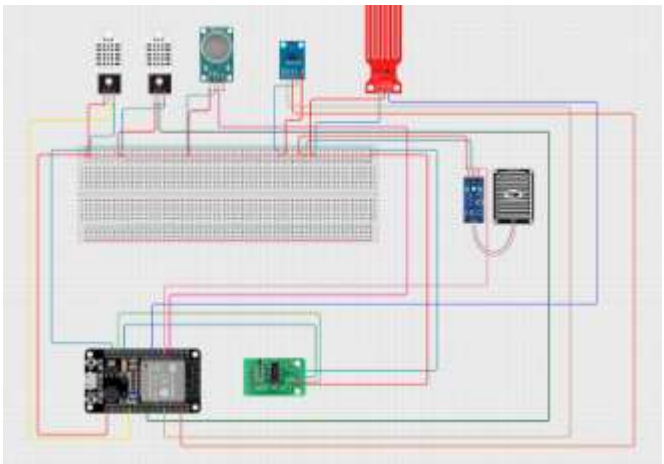

Fig. 2: Breadboard wiring layout for flow, gas, pH, temperature, OLED, GSM

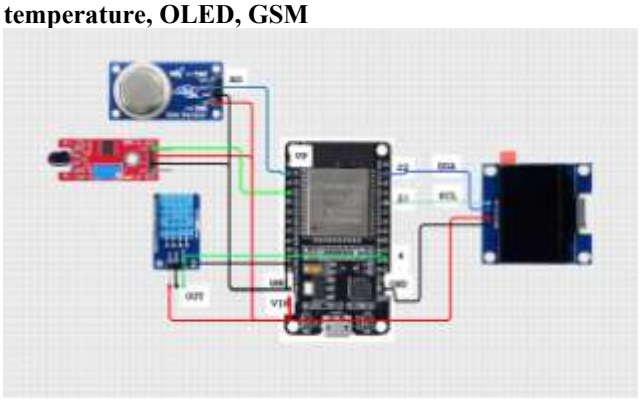

Fig. 3: Full system connectivity overview with relay and MOSFET control points

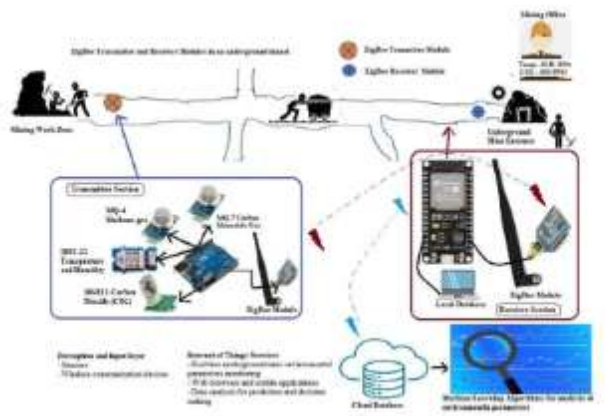

Fig. 4: High-level operational flowchart from sensing through alerting

8. Discussion

- Modularity: Independent calibration and upgradeability of each sensor without system rewire.
- Scalability: Facilitates optional load cell, extra sensor channels, cloud integration.
- Reliability: Dual alerts (OLED + SMS), low-power consumption, fault-detection self-reset.
- Compliance & Safety: Compliant with standard industrial safety levels; flexible compliance with local environment laws.

9. Future Work

- Cloud Integration: Integrate with Firebase, Thingspeak, or AWS IoT for remote monitoring.
- Machine Learning: AI-powered anomaly detection for predictive maintenance.
- Solar Power Architecture: Install in off-grid locations utilizing solar-battery modules.
- Standardization: Adhere to IEC 61010 or ISO 14001 industrial safety standards.

10. References

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