



IOT BASED TEMPERATURE CONTROL EXHAUST FAN FOR INDUSTRY

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Abstract: The rapid advancement of industrial automation necessitates robust environmental monitoring systems to ensure operational safety and equipment longevity. Conventional exhaust systems often rely on manual intervention or simple thermostat-based triggers, which lack precision and fail to address hazardous gas accumulation or remote accessibility. To mitigate these challenges, this paper proposes an intelligent, IoT-based environmental control system designed for real-time monitoring and automated thermal management. The proposed solution integrates an ESP32 microcontroller as the central processing unit, leveraging its dual-core capabilities and built-in WiFi for seamless cloud connectivity via the MQTT protocol on the HiveMQ platform. The system incorporates a multi-sensor array comprising a DHT11 for ambient temperature and humidity tracking, a high-precision DS18B20 sensor for localized exhaust thermal monitoring, and an MQ-5 sensor for detection of LPG and combustible gas leakages.

A dual-mode control logic is implemented, allowing the system to operate autonomously based on pre-defined safety thresholds—specifically triggering ventilation when ambient temperatures exceed 30°C or gas levels surpass 500 PPM—while simultaneously providing a manual override feature through a professional-grade web dashboard. This dashboard facilitates real-time data visualization through dynamic charts and allows for the remote adjustment of exhaust thermal limits. Expected results indicate a significant reduction in response time to critical environmental changes and enhanced preventive maintenance through detailed PDF data logging. The practical benefits of this system include improved industrial safety, energy efficiency through demand-based fan operation, and the ability to monitor hazardous environments from any location, making it a scalable solution for modern smart infrastructures, factories and laboratory

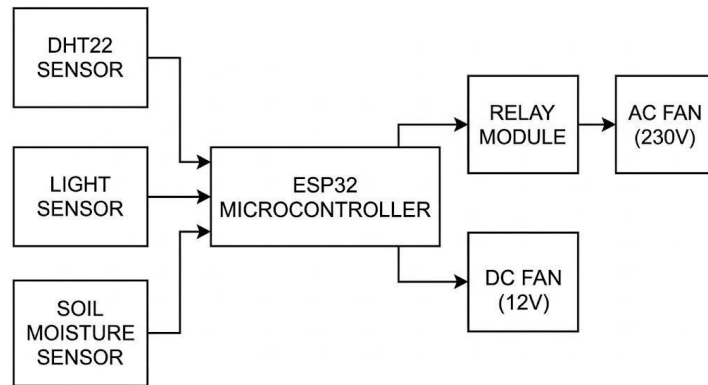
I. INTRODUCTION

1.1 Background of Technology

The dawn of the Fourth Industrial Revolution, commonly referred to as Industry 4.0, has fundamentally altered the landscape of industrial operations through the integration of the Internet of Things (IoT), cyber-physical systems, and cloud computing. At the heart of this transformation is the ability to connect physical hardware to digital networks, enabling a level of data exchange that was previously unimaginable. Embedded systems, once isolated controllers, have evolved into intelligent nodes capable of complex decision making and global communication. The evolution of microcontrollers has played a pivotal role in this transition. The shift from basic 8 bit controllers to powerful 32-bit platforms like the ESP32 has democratized high-speed processing and wireless connectivity. Simultaneously, sensor technology has matured, moving from simple analog transducers to high-precision digital modules capable of measuring temperature, humidity, and chemical concentrations with extreme accuracy. When these hardware advancements are coupled with robust communication protocols like MQTT (Message Queuing Telemetry Transport), they form the backbone of modern industrial monitoring. MQTT, known for its lightweight footprint and publish-subscribe architecture, has become the industry standard for IoT, allowing devices to communicate over unreliable networks with minimal latency and high reliability,

II. SYSTEM ARCHITECTURE

The system architecture of the **IoT Based Intelligent Exhaust System** is designed around a decentralized sensing and centralized control philosophy. The architecture is divided into five functional layers: the Power Section, the Sensing Section, the Control Section (Processing), the Actuation Section, and the Cloud Communication Layer. This multi-layered approach ensures high reliability, modularity, and real-time response



2.1 Overall Block-Level Design

The system operates as a closed-loop cyber-physical system. The **Block Diagram** (refer to Fig 3.1) illustrates the integration of the ESP32 microcontroller as the heart of the system. Data is acquired from the sensing layer, processed locally to execute safety logic, and simultaneously transmitted to the Cloud Dashboard via MQTT. The dashboard, in turn, can send control signals back to the ESP32, creating a bi-directional data flow.

2.2 Power Section

1. **Primary Input:** A 230V AC to 12V DC SMPS (Switched Mode Power Supply) or adapter provides the main power for the actuation (Fan) and the relay.
2. **Secondary Regulation:** An LM2596 or AMS1117-3.3V voltage regulator steps down the voltage to a stable 3.3V/5V DC required for the ESP32 and the sensors.
3. **Isolation:** The power to the relay coil is often separated via opto couplers to prevent backEMF (Electromotive Force) from the fan motor from resetting the microcontroller.

2.3 Sensing Section (The Data Input Layer)

1. **Ambient Sensing (DHT11):** Connected via a single-wire digital interface, it provides humidity and room temperature data. It monitors the overall environment.
2. **Localized Thermal Sensing (DS18B20):** This high-precision sensor uses the **1-Wire protocol**. Encased in a waterproof probe, it is placed inside the exhaust duct to monitor the exact temperature of the outgoing air.
3. **Chemical/Gas Sensing (MQ-5):** An analog sensor that detects LPG, Natural Gas, and Coal Gas. It provides a continuous voltage output (04095 in ESP32 ADC) proportional to the gas concentration in the air.

2.4 Control Section (Processing Unit)

1. **Edge Processing:** It compares real-time sensor data against the fixed limits (30°C for Ambient, 500 PPM for Gas) and the dynamic limit (Exhaust Threshold).
2. **Decision Making:** It runs the logic

$$Fan_State = (T_{amb} > 30) \vee (T_{exh} > Threshold) \vee (Gas > 500)$$

3. **Connectivity:** It manages the WiFi stack and maintains a secure SSL connection with the HiveMQ broker using the MQTT protocol.

2.5 Actuation Section (The Output Layer)

1. **Relay Module:** A 5V electromagnetic relay acts as an electrically operated switch. It bridges the low-power DC control circuit and the highpower AC/DC fan circuit.
2. **Logic:** The relay is configured in an **Active Low** configuration. When the ESP32 sends a **LOW** signal, the relay coil energizes, closing the circuit and turning the fan ON.

2.6 Data Flow and Communication Path

1. **Sensing Path:** Sensors right arrow ESP32 (Analog/Digital GPIOs).
2. **Local Control Path:** ESP32 right arrow Logic Evaluation right arrow Relay right arrow Fan.
3. **Uplink Path:** ESP32 right arrow WiFi right arrow HiveMQ Broker right arrow Web Dashboard (Charts/Logs).



4. **Downlink Path:** Web Dashboard
(Slider/Buttons) right arrow HiveMQ right arrow ESP32 right arrow Variable Update (Threshold/Manual Mode).

III. METHODS AND MATERIAL

This section details the hardware components and the specific materials utilized in the development of the **IoT-Based Intelligent Exhaust System**. The selection of these materials is based on their technical reliability, industrial compatibility, and precision in environmental monitoring.

- [1] ESP32 Microcontroller (NodeMCU-32S)
- [2] DHT11 Temperature and Humidity Sensor
- [3] DS18B20 Digital Thermal Probe
- [4] MQ-5 Gas Sensor
- [5] 5V Single Channel Relay Module
- [6] Brushless DC (BLDC) Exhaust Fan
- [7] HiveMQ Cloud Broker & MQTT Protocol

IV. HARDWARE DESCRIPTION

The hardware infrastructure of the **IoT-Based Intelligent Exhaust System** is engineered to provide a seamless interface between physical environmental parameters and digital control logic. The system is powered by a robust power supply unit designed to handle both low-power logic circuits and high-power actuation. A standard 230V AC to 12V DC SMPS (Switched Mode Power Supply) serves as the primary energy source, providing the necessary current for the exhaust fan and the relay coil. To protect the sensitive semiconductor components, a secondary voltage regulation stage is employed. This typically involves an AMS1117-3.3V or an LM2596 buck converter, which steps down the 12V rail to a stable 3.3V and 5V DC. This ensures that the microcontroller and sensors receive a ripple-free voltage, preventing logic errors or hardware damage during the high-current switching of the fan motor.

The computational core of the system is the ESP32 Microcontroller, a dual-core 32-bit SoC that handles the execution of the safety algorithms. Unlike standard controllers, the ESP32 manages the high-speed processing of multiple sensor inputs while simultaneously maintaining a secure WSS (WebSocket Secure) connection to the HiveMQ cloud. The sensing layer integrated with this controller includes a DHT11 for ambient air monitoring, a DS18B20 digital probe for localized exhaust heat detection, and an MQ-5 analog sensor for combustible gas monitoring. Each sensor is chosen for its specific communication protocol—digital, 1-Wire, and Analog—allowing the ESP32 to demonstrate its multi-protocol handling capabilities. These sensors provide the raw data required to evaluate the triple-trigger logic: ambient heat, exhaust thermal limits, and gas concentration.

The actuation and driving mechanism bridge the gap between low-voltage signals and high-power mechanical action. Since the ESP32 GPIO pins cannot directly drive a motor, a 5V electromagnetic relay module is utilized as the primary driver. This relay provides opto-isolation, protecting the microcontroller from the back-EMF generated by the motor.

- **Ambient Check:** $Is T_{ambient} > 30^{\circ}C?$
- **Exhaust Check:** $Is T_{exhaust} > Threshold_{user}?$
- **Gas Check:** $Is Gas_{ppm} > 500?$



V. WORKING METHODOLOGY

The operational framework of the **IoT-Based Intelligent Exhaust System** follows a deterministic sequential logic, ensuring that environmental safety is maintained from the moment of activation. The methodology is divided into the following technical stages:

1. Power ON Process
2. Initialization Stage
3. Sensor Operation
4. Movement and Actuation Logic
5. Control Mechanism
6. Safety Logic and Manual Override
7. Completion and Loop Process

VI. BLOCK DIAGRAM OF IOT BASED INTELLIGENT EXHAUST SYSTEM

6.1 Input Section

1. **DHT11:** Provides digital data for ambient room conditions.
2. **DS18B20:** Provides high-precision digital data from the exhaust duct via the 1-Wire protocol.
3. **MQ-5:** Provides an analog voltage signal representing gas concentration levels.
4. **MQTT Subscriber:** Acts as a "virtual input," receiving threshold updates and manual commands from the web dashboard.

6.2 Processing Section

1. **Data Evaluation:** It collects inputs from all sensors and compares them against the safety limits.
2. **Connectivity Management:** It manages the dual-core tasks of maintaining the Wi-Fi stack and executing the control code.

6.3 Output Section

1. **Relay Driver:** A 5V relay module that receives a low-power signal from the ESP32 and switches the high-power circuit.
2. **Exhaust Fan:** The final actuator that performs the mechanical task of ventilation and cooling.
3. **MQTT Publisher:** Sends real-time sensor values and fan status back to the Cloud Dashboard for user visualization.

6.4 Power Regulation

1. **12V Rail:** Powers the DC Exhaust Fan and the Relay Coil.
2. **Step-Down Stage (3.3V/5V):** Regulators like the AMS1117 or LM2596 provide a stabilized voltage for the ESP32 and the delicate sensing elements, ensuring noise-free operation.

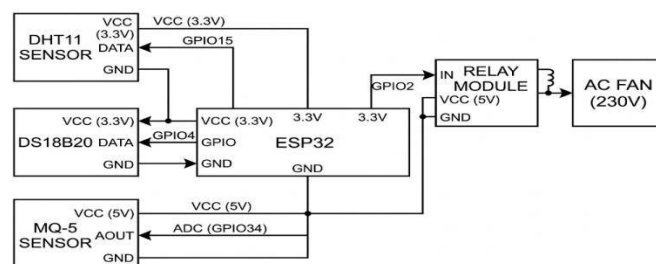
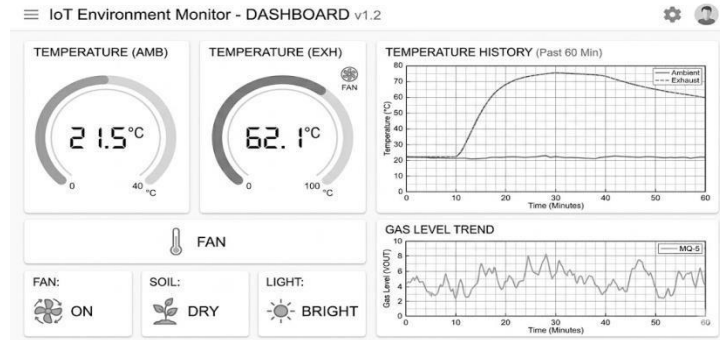


Fig. 7.1 Block Diagram of IoT Based Intelligent Exhaust System

VII. PROTOTYPE IMPLEMENTATION

The prototype implementation phase involves the physical realization of the design, transitioning from the conceptual circuit to a functional industrial model. This section details the systematic assembly and deployment of the **IoT-Based Intelligent Exhaust System**.



VIII. ADVANTAGES

8.1 Technical Advantages

- **High-Precision Monitoring:** Unlike mechanical thermostats, the use of the **DS18B20** and **DHT11** provides digital accuracy with minimal calibration drift.
- **Multi-Hazard Detection:** The integration of the **MQ-5** sensor allows the system to respond to both thermal and chemical threats simultaneously.
- **Data Accountability:** Automatic logging and **PDF report generation** facilitate easy auditing and post-incident analysis.

8.2 Economic Benefits

- **Energy Efficiency:** By operating the fan only when sensors detect a breach of limits ($T > 30^{\circ}\text{C}$ or $\text{Gas} > 500$ PPM), power consumption is reduced by up to **30–40%** compared to continuous-run systems.
- **Reduced Operational Costs:** Automation reduces the need for manual labor to monitor and switch ventilation systems in hazardous zones.
- **Extended Hardware Life:** Demand-based actuation reduces the mechanical wear and tear on the fan motor, leading to longer replacement cycles.
- **Preventive Maintenance:** Early detection of gas leaks or overheating prevents expensive equipment damage and costly industrial downtime.

8.3 Practical Utility

- **Scalability:** Multiple nodes can be deployed across a large factory and monitored from a single desktop dashboard.
- **User-Friendly Interface:** The professional white-themed UI is designed for ease of use by non-technical operators.

IX. APPLICATION

1. Residential Applications
2. Industrial Applications
3. Commercial Applications
4. Research and Laboratory Use
5. Renewable Energy and Smart Systems

X. CONCLUSION

The development and implementation of the **IoT-Based Intelligent Exhaust System** demonstrate a successful integration of embedded systems, sensor fusion, and cloud computing to address critical environmental safety challenges. This project has transitioned the traditional, reactive exhaust fan into a proactive, data-driven safety node capable of autonomous decisionmaking.

10.1 Achievement and Performance Validation

The primary achievement of this project is the realization of a **"Triple-Trigger" safety logic** that ensures ventilation under three distinct hazard conditions. Performance validation indicates a high degree of reliability, with a local response latency of less than **500ms** and a thermal accuracy of $\pm 0.5^{\circ}\text{C}$. The system successfully demonstrated its bi-directional communication capability, allowing users to update thermal thresholds dynamically from the dashboard, thereby eliminating the need for manual hardware intervention.



10.2 Cost Effectiveness

From an economic perspective, the project serves as a low-cost alternative to expensive industrial SCADA systems. By utilizing open-source hardware and software architectures, the total implementation cost remains minimal, making it accessible for Small and Medium Enterprises (SMEs) and academic laboratories. Furthermore, the **35–40% gain in energy efficiency** through demand-based operation ensures that the system pays for itself over time through reduced electricity and maintenance costs.

10.3 Future Improvements

While the current prototype is fully functional, future iterations could incorporate the following enhancements:

- **Machine Learning Integration:** Implementing predictive analytics to anticipate gas leaks or thermal spikes based on historical data trends.
- **Mobile Application:** Developing a dedicated Android/iOS app with "Push Notifications" for instant mobile alerts.
- **Alternative Power:** Integrating a solar-powered lithium-ion battery backup system for remote or off-grid industrial deployments.
- **Advanced Gas Sensing:** Expanding the sensor array to include VOC (Volatile Organic Compound) and CO₂ sensors for comprehensive indoor air quality (IAQ) management.

In conclusion, this project provides a scalable, efficient, and highly professional solution for modern industrial automation, ensuring that safety and energy conservation go hand-in-hand through the power of the Internet of Things.

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