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Industrial Parameters Monitoring 4.0

Yerramsetti Manasa[1], Gantyada Ganesh[2], Matam Divya[3], Madena Sowjanya[4], Maddila Deepika[5], Dokula Mohit Kumar[6]

[1]Assistant Professor, Department of ECE, Dr. Lankapalli Bullayya College of Engineering (Autonomous), Andhra Pradesh, India.

[2,3,4,5,6]Department of ECE, Dr. Lankapalli Bullayya College Of Engineering (Autonomous) / Andhra University, Andhra Pradesh, India.

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Abstract: *Industry 4.0 has accelerated the adoption of Internet of Things (IoT) technologies for intelligent industrial automation, enabling continuous monitoring of critical environmental and operational parameters. This paper presents an IoT-based Industrial Parameters Monitoring System developed using the STM32F446RE microcontroller for real-time monitoring of industrial conditions. The proposed system integrates multiple sensors, including the MQ135 gas sensor, BMP280 pressure and temperature sensor, DHT11 humidity sensor, KY-026 flame sensor, and SW-420 vibration sensor, to collect and process data related to industrial safety and environmental conditions. Sensor data are acquired through ADC, GPIO, and I²C interfaces and displayed locally on a 16×2 LCD. A WE10 Wi-Fi module enables wireless transmission of processed data to the Right Tech Cloud platform through UART communication, facilitating remote monitoring and visualization. The system also incorporates an audible alert mechanism using a buzzer to notify users when abnormal conditions such as gas leakage, fire, or excessive vibration are detected. Experimental evaluation demonstrates reliable real-time data acquisition, cloud connectivity, and continuous monitoring performance. The proposed solution provides a low-cost, scalable, and efficient approach for improving industrial safety, minimizing manual intervention, and supporting predictive monitoring applications in smart manufacturing environments.*

Keywords: *Industry 4.0, Internet of Things (IoT), STM32F446RE, Industrial Monitoring, Embedded Systems, Cloud Monitoring, Gas Detection, Temperature Monitoring, Vibration Detection, Smart Factory.*

I. INTRODUCTION

The rapid evolution of Industry 4.0 has transformed conventional industrial environments into intelligent, interconnected systems capable of real-time monitoring, automation, and data-driven decision-making. The integration of the Internet of Things (IoT), embedded systems, cloud computing, and wireless communication technologies has significantly improved industrial productivity, operational efficiency, and workplace safety. Continuous monitoring of critical environmental and operational parameters has become essential for preventing equipment failures, reducing downtime, and ensuring safe industrial operations.

Industrial environments are often exposed to hazardous conditions such as gas leakage, fire outbreaks, excessive vibration, abnormal temperature, and pressure variations. Traditional monitoring methods rely heavily on manual inspection, which is time-consuming, labor-intensive, and prone to human error. Furthermore, delayed detection of abnormal conditions can result in equipment damage, production losses, environmental hazards, and risks to human life. Therefore, an automated and intelligent monitoring system capable of real-time sensing and remote supervision is highly desirable.

This paper presents an IoT-based Industrial Parameters Monitoring System that continuously monitors multiple industrial parameters using the STM32F446RE microcontroller. The proposed system integrates the MQ135 gas sensor, BMP280 pressure and temperature sensor, DHT11 humidity sensor, KY-026 flame sensor, and SW-420 vibration sensor to acquire real-time environmental data. The collected information is processed by the microcontroller and displayed locally on a 16×2 LCD while simultaneously being transmitted to the Right Tech Cloud platform through a WE10 Wi-Fi module using UART communication. An integrated buzzer provides immediate alerts whenever hazardous conditions are detected.

He proposed system offers a low-cost, reliable, and scalable solution for industrial safety monitoring by combining embedded processing with cloud-based remote monitoring. The system minimizes manual intervention, enables continuous surveillance of industrial environments, and supports the objectives of Industry 4.0 by facilitating real-time data acquisition, visualization, and analysis. The experimental results demonstrate that the developed prototype effectively monitors multiple industrial parameters and provides timely alerts, making it suitable for smart manufacturing and industrial automation applications.

II.MATERIAL AND METHODS

Materials

The proposed Industrial Parameters Monitoring System consists of embedded hardware components, sensing devices, communication modules, and software tools that work together to monitor industrial parameters in real time. The hardware architecture is centered on the STM32F446RE microcontroller, which acquires data from multiple sensors, processes the collected information, and transmits it to a cloud platform for remote monitoring.

A. STM32F446RE Microcontroller

The STM32F446RE, based on the ARM Cortex-M4 architecture, serves as the central processing unit of the system. It provides high-speed data processing, multiple communication interfaces, Analog-to-Digital Converter (ADC) channels, General Purpose Input/Output (GPIO) pins, and Inter-Integrated Circuit (I^2C) support, making it suitable for real-time embedded applications. The microcontroller collects sensor readings, executes the monitoring algorithm, controls output devices, and manages communication with the Wi-Fi module.

B. Sensors

The monitoring system employs multiple sensors to measure different industrial parameters:

- **MQ135 Gas Sensor:** Detects harmful gases and changes in air quality by providing analog output signals to the microcontroller.
- **BMP280 Sensor:** Measures atmospheric pressure and temperature using the I^2C communication protocol.
- **DHT11 Sensor:** Measures environmental humidity and temperature using a single-wire digital interface.
- **KY-026 Flame Sensor:** Detects the presence of fire or flame by sensing infrared radiation.
- **SW-420 Vibration Sensor:** Detects vibration or mechanical shock to identify abnormal machine conditions.

The combination of these sensors enables continuous monitoring of environmental and safety-related parameters in industrial environments.

C. Output Devices

A 16×2 LCD with an I^2C interface is used to display sensor readings locally, allowing operators to monitor industrial conditions in real time. A buzzer is incorporated as an audible alert mechanism that is activated whenever hazardous conditions such as gas leakage, flame detection, or abnormal vibration are identified.

D. Communication Module

The WE10 Wi-Fi module provides wireless connectivity between the embedded system and the Right Tech Cloud platform. Communication between the STM32F446RE microcontroller and the WE10 module is established through the UART protocol, enabling real-time transmission of sensor data for remote monitoring and visualization.

E. Software Tools

The embedded application is developed using STM32CubeIDE with Embedded C programming language and Hardware Abstraction Layer (HAL) libraries. Sensor data and serial communication are verified using Tera Term, while the Right Tech Cloud platform is used for cloud-based storage, visualization, and monitoring of industrial parameters.

The integration of these hardware and software components provides a cost-effective, reliable, and scalable Industrial IoT platform capable of continuous monitoring, real-time alert generation, and remote supervision of industrial environments.

Procedure Methodology

The proposed Industrial Parameters Monitoring System follows a systematic methodology for real-time acquisition, processing, visualization, and remote monitoring of industrial parameters. The overall system consists of a sensing layer, processing layer, communication layer, and monitoring layer, which work together to provide continuous supervision of industrial environments.

A. System Initialization

The system is initialized using the STM32F446RE microcontroller programmed in Embedded C through STM32CubeIDE. During initialization, all peripherals including GPIO, ADC, I^2C, and UART are configured using the Hardware Abstraction Layer (HAL) libraries. The connected sensors, LCD display, buzzer, and WE10 Wi-Fi module are initialized to ensure proper communication before continuous monitoring begins.

B. Data Acquisition

Multiple sensors are interfaced with the STM32F446RE microcontroller to monitor different industrial parameters. The MQ135 gas sensor provides analog signals that are acquired through the ADC interface. The BMP280 sensor communicates via the I^2C protocol to measure atmospheric pressure and temperature. The DHT11 sensor provides humidity and temperature data through a single-wire digital interface. The KY-026 flame sensor and SW-420 vibration sensor generate digital signals through GPIO pins for fire and vibration detection, respectively. The microcontroller continuously reads these sensor values at regular intervals.

C. Data Processing

After collecting the sensor readings, the STM32F446RE processes the acquired data according to the programmed monitoring logic. The analog values received from the MQ135 sensor are converted into digital values using the internal ADC. The digital outputs from the remaining sensors are interpreted to determine the current environmental conditions. The processed data are formatted for local display and cloud transmission, while abnormal sensor conditions are identified by comparing the measured values with predefined monitoring conditions.

D. Local Monitoring and Alert Generation

The processed sensor data are displayed in real time on a 16×2 LCD through the I²C interface, allowing operators to observe the current industrial conditions locally. Whenever hazardous conditions such as flame detection, abnormal gas concentration, or excessive vibration are identified, the buzzer is activated to provide an immediate audible warning, enabling rapid response to potential industrial hazards.

E. Cloud Communication

The WE10 Wi-Fi module is connected to the STM32F446RE using the UART communication protocol. After processing the sensor data, the microcontroller transmits the collected information to the WE10 module, which forwards the data to the Right Tech Cloud platform through a wireless network. The cloud platform stores and visualizes the received parameters, enabling remote monitoring through an online dashboard.

F. Continuous Monitoring

The entire monitoring process operates continuously inside the main execution loop of the embedded program. Sensor values are repeatedly acquired, processed, displayed on the LCD, transmitted to the cloud platform, and checked for abnormal conditions. This continuous execution ensures uninterrupted real-time monitoring of industrial parameters and supports timely detection of unsafe operating conditions.

The proposed methodology combines embedded processing, multi-sensor data acquisition, local visualization, cloud connectivity, and real-time alert generation to provide an efficient, reliable, and cost-effective Industrial IoT monitoring solution suitable for Industry 4.0 applications.

III.RESULT

The proposed Industrial Parameters Monitoring System was successfully designed, implemented, and tested using the STM32F446RE microcontroller integrated with multiple environmental sensors and an IoT-based cloud monitoring platform. The experimental results demonstrate the system's capability to continuously monitor critical industrial parameters and provide real-time visualization and alert generation.

The MQ135 gas sensor successfully detected variations in gas concentration, and the analog signals were accurately converted into digital values using the built-in ADC of the STM32F446RE microcontroller. The BMP280 sensor reliably measured atmospheric pressure and temperature through the I²C communication interface, while the DHT11 sensor continuously monitored ambient humidity and temperature. The KY-026 flame sensor effectively detected the presence of fire, and the SW-420 vibration sensor responded to vibration and mechanical disturbances during testing.

The acquired sensor data were processed by the STM32F446RE and displayed on a 16×2 LCD, enabling local real-time monitoring of industrial conditions. The LCD provided clear visualization of the measured parameters, allowing users to observe the operating status of the system without requiring external monitoring equipment.

To support remote monitoring, the processed sensor data were transmitted to the WE10 Wi-Fi module through UART communication. The WE10 module successfully forwarded the collected information to the Right Tech Cloud platform, where the data were visualized in real time using a cloud-based dashboard. This demonstrated reliable wireless communication between the embedded system and the cloud environment, enabling users to monitor industrial parameters remotely.

The alert mechanism also operated as intended during testing. Whenever abnormal conditions such as flame detection, gas leakage, or excessive vibration were encountered, the buzzer was activated immediately, providing an audible warning for rapid operator response. This feature enhances industrial safety by enabling timely detection of hazardous situations.

Throughout the experimental evaluation, the system operated continuously without major functional errors. The successful integration of sensing, embedded processing, local display, wireless communication, cloud monitoring, and alert generation confirms the effectiveness of the proposed Industrial Parameters Monitoring System. The obtained results indicate that the developed prototype provides a reliable, low-cost, and scalable solution for real-time industrial monitoring and supports the implementation of Industry 4.0 concepts in smart industrial environments.

IV.DISCUSSION

The experimental results demonstrate that the proposed Industrial Parameters Monitoring System successfully integrates embedded systems and IoT technologies to provide continuous monitoring of critical industrial parameters. The STM32F446RE microcontroller efficiently acquired, processed, and managed data from multiple sensors, enabling reliable real-time monitoring of gas concentration, temperature, humidity, pressure, flame detection, and vibration.

The use of multiple communication interfaces, including ADC, GPIO, I²C, and UART, enabled seamless integration of heterogeneous sensors and peripheral devices. The MQ135, BMP280, DHT11, KY-026, and SW-420 sensors operated effectively within the system, providing continuous environmental data that were displayed locally on the LCD and transmitted to the cloud platform. This demonstrates the capability of the embedded platform to support simultaneous acquisition and processing of

multiple sensor inputs.

Cloud integration through the WE10 Wi-Fi module significantly improved the usability of the system by enabling remote monitoring of industrial parameters. The successful transmission of sensor data to the Right Tech Cloud dashboard verified the effectiveness of the wireless communication architecture. Real-time visualization allows operators to monitor industrial conditions without being physically present at the monitoring location, reducing manual inspection and improving operational efficiency.

The implemented alert mechanism also contributed to the overall effectiveness of the system. The buzzer responded immediately when abnormal conditions such as flame detection, excessive gas concentration, or vibration were detected, providing an additional safety feature for industrial environments. This immediate response can assist operators in taking corrective actions before hazardous situations become more severe.

Although the developed prototype demonstrated reliable operation, certain limitations were observed. The system employs low-cost sensors intended primarily for educational and prototype development; therefore, measurement accuracy and long-term stability may not satisfy the requirements of harsh industrial environments. In addition, cloud-based monitoring depends on continuous Wi-Fi connectivity, and the current implementation focuses on monitoring and alert generation without advanced functions such as predictive maintenance, automated control actions, or data security mechanisms.

Overall, the proposed Industrial Parameters Monitoring System demonstrates the feasibility of combining embedded processing, multi-sensor data acquisition, wireless communication, and cloud technology into a compact and cost-effective Industrial IoT solution. The successful implementation validates its suitability as a prototype for Industry 4.0 applications and provides a strong foundation for future enhancements, including intelligent data analytics, predictive maintenance, integration with PLC/SCADA systems, and improved cybersecurity for large-scale industrial deployment.

V.CONCLUSION

This paper presented the design and implementation of an IoT-based Industrial Parameters Monitoring System for real-time monitoring of critical industrial environmental conditions. The proposed system successfully integrates the STM32F446RE microcontroller with multiple sensors, including the MQ135 gas sensor, BMP280 pressure and temperature sensor, DHT11 humidity sensor, KY-026 flame sensor, and SW-420 vibration sensor, to continuously monitor essential industrial parameters.

The acquired sensor data were processed efficiently by the embedded system, displayed locally on a 16×2 LCD, and transmitted to the Right Tech Cloud platform through the WE10 Wi-Fi module using UART communication. The implemented cloud connectivity enabled remote monitoring and real-time visualization of industrial parameters, while the integrated buzzer provided immediate alerts whenever hazardous conditions such as gas leakage, flame detection, or excessive vibration were detected.

Experimental evaluation demonstrated that the developed system operated reliably under different monitoring conditions and successfully performed real-time data acquisition, local display, wireless communication, cloud-based monitoring, and alert generation. The proposed solution reduces manual monitoring efforts, enhances industrial safety, and supports continuous supervision of industrial environments through a cost-effective and scalable embedded IoT architecture.

Although the developed prototype effectively demonstrates the concept of Industry 4.0-based industrial monitoring, future improvements may include the use of industrial-grade sensors, advanced data analytics, predictive maintenance algorithms, secure cloud communication, automatic control actions, and integration with PLC and SCADA systems. These enhancements would further improve system reliability, scalability, and applicability in large-scale industrial automation.

Overall, the proposed Industrial Parameters Monitoring System provides an efficient, reliable, and economical solution for smart industrial monitoring and establishes a strong foundation for future Industrial IoT applications.

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