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Intelligent AI + IoT Safety System for Worker Protection in Cracker Factories

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Abstract—The cracker manufacturing industry involves highly hazardous working environments where workers are exposed to risks such as gas leakage, fire outbreaks, smoke formation, and abnormal temperature rise. These hazards can lead to serious industrial accidents if they are not detected at an early stage.

Traditional safety systems in many factories rely on manual monitoring or basic alarm systems that cannot continuously observe environmental conditions or provide intelligent analysis of potential risks. Therefore, there is a need for an advanced safety monitoring system that can detect dangerous situations in real time and ensure worker protection. This project proposes an Intelligent Artificial Intelligence and Internet of Things based safety system designed specifically for worker protection in cracker factories. The system uses multiple environmental sensors including gas sensor, fire sensor, smoke sensor, and DHT11 temperature sensor to continuously monitor the surrounding environment. These sensors detect hazardous conditions such as gas leakage, fire presence, smoke generation, and temperature changes. The sensor data is collected and processed using the ESP32 microcontroller integrated with the INDUS Board Coin. The processed information is displayed locally on an LCD screen so that workers can easily observe the environmental conditions inside the factory. In addition, the ESP32 transmits the collected data to an IoT cloud platform using wireless communication. The cloud platform allows supervisors to remotely monitor the factory environment and receive alerts when unsafe conditions occur. Artificial Intelligence techniques can further analyze the sensor data to identify abnormal patterns and predict potential hazards before they become serious accidents. The proposed system provides real-time monitoring, early hazard detection, and intelligent safety alerts. By integrating sensors, IoT technology, and AI-based analysis, the system improves workplace safety and helps prevent accidents in cracker manufacturing industries. This solution offers an efficient, low-cost, and reliable approach to protect workers and enhance industrial safety management.

Index Terms—Artificial Intelligence, Internet of Things (IoT), Industrial Safety Monitoring, ESP32 Microcontroller, Gas Leakage Detection, Fire Detection, Smoke Monitoring, Temperature Monitoring, Worker Safety, Smart Industrial Systems.

I. INTRODUCTION

Industrial safety has become a critical concern in hazardous working environments such as cracker manufacturing factories. These industries involve the use of explosive chemicals and highly flammable materials during the production process. Workers operating in such environments are frequently exposed to risks including gas leakage, smoke generation, fire outbreaks, and abnormal temperature rise. If these hazardous conditions are not detected in the early stages, they may lead to serious accidents, property damage, and loss of human life. Therefore, implementing an efficient and intelligent safety monitoring system is essential to ensure worker protection and maintain safe industrial operations.

Traditional safety monitoring systems used in many small and medium-scale factories mainly rely on manual inspection or basic alarm mechanisms. These conventional methods are often unable to provide continuous monitoring of environmental conditions or detect multiple hazards simultaneously. As a result, dangerous situations may remain unnoticed until they become critical. The absence of real-time monitoring, automated alert systems, and remote accessibility further increases the risk of delayed emergency response. These limitations highlight the need for advanced safety solutions capable of continuously monitoring environmental parameters and providing early warnings during hazardous situations.

Recent advancements in technologies such as Artificial Intelligence (AI), Internet of Things (IoT), and smart sensor networks have enabled the development of intelligent industrial monitoring systems. IoT-based systems allow sensors to collect environmental data and transmit it to cloud platforms for real-time monitoring and analysis. Artificial Intelligence techniques can further analyze the collected data to detect abnormal patterns and predict potential hazards before they escalate into serious incidents. By integrating multiple sensors with IoT communication and intelligent data analysis, it is possible to develop a smart safety monitoring system that significantly improves workplace safety.

In this research work, an intelligent AI and IoT-based safety monitoring system is proposed for worker protection in cracker factories. The system utilizes environmental sensors such as gas sensors, fire sensors, smoke sensors, and temperature sensors to continuously monitor hazardous conditions. The collected data is processed using the ESP32 microcontroller and transmitted to a cloud platform for remote monitoring. The system also provides real-time alerts and warnings when unsafe conditions are detected. This approach enhances industrial safety management by enabling early hazard detection, remote supervision, and intelligent analysis of environmental conditions.

II. Problem Definition and Solution

A. Existing System

At present, safety monitoring in many cracker manufacturing factories is mainly based on manual supervision and basic alarm systems. Workers and supervisors are responsible for visually inspecting the working environment and identifying hazardous conditions such as gas leakage, smoke formation, or abnormal temperature rise. However, manual monitoring is often unreliable because it depends on human attention and reaction time. In busy production environments, dangerous conditions may go unnoticed until they become critical, which increases the possibility of accidents and injuries.

Some industries have implemented basic electronic safety systems such as standalone fire alarms or gas leakage detectors. These systems are usually designed to monitor only a single parameter and operate independently without integration with other safety components. As a result, they cannot provide a comprehensive safety monitoring solution capable of detecting multiple hazardous conditions simultaneously. Furthermore, these conventional systems often lack real-time data communication and remote monitoring capabilities, making it difficult for supervisors to monitor safety conditions continuously.

In addition, many existing safety systems are not connected to intelligent data analysis platforms. Without the use of Internet of Things (IoT) technology and Artificial Intelligence (AI), the collected sensor data cannot be analyzed effectively to detect patterns or predict potential hazards. This limitation reduces the efficiency of industrial safety management and increases the risk of accidents in high-risk environments such as cracker factories where flammable materials and explosive chemicals are present.

B. Problem Definition

- Many cracker factories still rely on manual safety monitoring which is inefficient and prone to human error.
- Existing safety devices typically monitor only a single environmental parameter instead of providing integrated multi-sensor monitoring.
- Lack of real-time monitoring and remote alert systems delays emergency response during hazardous situations.
- Conventional systems do not utilize IoT connectivity or intelligent analysis for early hazard detection.
- There is a need for a smart, automated, and cost-effective industrial safety monitoring system.

C. Proposed Method

The proposed system introduces an intelligent safety monitoring solution that integrates Artificial Intelligence (AI) and Internet of Things (IoT) technologies to protect workers in cracker manufacturing factories. The system is designed using an ESP32 microcontroller which acts as the central processing unit responsible for collecting, processing, and transmitting sensor data.

Multiple environmental sensors are integrated into the system to monitor hazardous conditions in real time. These include gas sensors for detecting harmful gas leakage, smoke sensors for identifying smoke presence, fire sensors for detecting flames, and temperature sensors for monitoring abnormal heat levels. The sensors continuously measure environmental parameters and send the collected data to the ESP32 microcontroller.

The ESP32 processes the sensor readings and determines whether the detected values exceed predefined safety thresholds. When a hazardous condition is identified, the system immediately activates warning mechanisms such as a buzzer and alert notifications. At the same time, the sensor data is transmitted through Wi-Fi connectivity to an IoT cloud platform, allowing supervisors to monitor factory safety conditions remotely.

By integrating IoT connectivity and intelligent monitoring, the proposed system provides continuous environmental surveillance, early hazard detection, and real-time alerts. Compared to traditional safety monitoring methods, the proposed solution significantly improves worker protection, reduces accident risks, and enhances industrial safety management. The system is also designed to be cost-effective, scalable, and easy to implement in small and medium-scale industries.

III. Block Diagram and Its Description

The block diagram represents the overall architecture of the proposed AI and IoT based safety monitoring system designed to protect workers in hazardous environments such as cracker manufacturing factories. The system integrates multiple environmental sensors, a microcontroller processing unit, communication modules, and output devices to detect dangerous conditions and provide real-time alerts.

At the core of the system is the Arduino Uno microcontroller, which functions as the central processing unit responsible for collecting data from different sensors, processing the information, and controlling the system outputs. The microcontroller continuously monitors environmental parameters and determines whether the detected values exceed predefined safety thresholds.

The power supply unit provides the necessary electrical energy required for the operation of all components in the system. It ensures stable voltage regulation for the microcontroller, sensors, and output modules so that the system can operate reliably without interruption.

Several sensors are connected to the Arduino microcontroller to monitor different hazardous conditions in the working environment. A gas sensor is used to detect the presence of harmful or combustible gases that may leak during chemical handling processes in cracker factories. When the gas concentration exceeds a safe limit, the sensor sends a signal to the microcontroller indicating a potential gas leakage situation.

A fire sensor is included in the system to detect flames or sudden fire outbreaks. This sensor helps identify fire hazards at an early stage, allowing the system to trigger warning alerts before the fire spreads and causes major damage. The smoke sensor continuously monitors the air quality to detect the presence of smoke particles. Smoke is often an early indicator of combustion or overheating processes, and early detection helps prevent serious accidents.

A temperature sensor is used to measure the surrounding environmental temperature. Abnormal temperature increases may indicate overheating equipment, chemical reactions, or possible fire hazards. The temperature readings are constantly analyzed by the microcontroller. All sensor readings are processed by the Arduino, and the results are displayed on an LCD display module.

The system is also connected to an IoT communication module, which enables wireless transmission of sensor data to cloud platforms or remote monitoring systems. This feature allows supervisors or safety authorities to observe real-time factory conditions from remote locations and respond quickly to emergencies.

An AI-based analysis module can be integrated with the IoT platform to analyze collected sensor data, detect abnormal patterns, and predict potential hazardous situations. Artificial intelligence techniques improve the accuracy and efficiency of the monitoring system by enabling intelligent decision-making and early warning mechanisms.

IV. Hardware Description

1. Arduino Uno

The Arduino Uno is the main controller used in the proposed safety monitoring system. It acts as the central processing unit responsible for collecting sensor data, processing the information, and controlling the output devices. The Arduino Uno is based on the ATmega328P microcontroller and is widely used in embedded system applications due to its simplicity, reliability, and ease of programming. It provides multiple digital and analog input/output pins that allow various sensors and modules to be connected easily.

In this system, the Arduino Uno receives signals from different sensors such as the gas sensor, fire sensor, smoke sensor, and temperature sensor. These sensors continuously monitor environmental conditions and send their readings to the Arduino. The microcontroller processes the received data and compares it with predefined threshold values to determine whether a hazardous condition exists.

2. Gas Sensor

The gas sensor is an important component used to detect the presence of harmful or combustible gases in the surrounding environment. In cracker manufacturing factories, various chemicals and explosive materials are used during production, which may produce dangerous gases if leakage occurs. Early detection of these gases is essential to prevent accidents and ensure worker safety.

The gas sensor operates by measuring the concentration of gas particles in the air. When gas molecules interact with the sensing element of the sensor, a change in electrical resistance occurs. This change is converted into an analog voltage signal, which is then sent to the Arduino microcontroller for processing.

3. Fire Sensor

The fire sensor is used to detect the presence of flames or fire in the working environment. Fire hazards are one of the most critical risks in cracker manufacturing factories because of the highly flammable materials used in the production process. The fire sensor helps in identifying fire outbreaks at an early stage so that immediate action can be taken.

The sensor typically works by detecting infrared radiation emitted by flames. When fire is present, the sensor detects the characteristic infrared light produced by the flame and generates a signal that is sent to the Arduino microcontroller.

4. Smoke Sensor

The smoke sensor is used to detect the presence of smoke particles in the air. Smoke is often an early indicator of fire, overheating, or chemical reactions occurring in industrial environments. By detecting smoke at an early stage, the system can provide timely warnings before the situation becomes dangerous.

The smoke sensor works by detecting changes in air quality caused by the presence of smoke particles. When smoke enters the sensing chamber of the sensor, it alters the electrical properties of the sensing element. This change is converted into an electrical signal and transmitted to the Arduino microcontroller.

5. Temperature Sensor

The temperature sensor is used to measure the surrounding environmental temperature in real time. In industrial environments such as cracker factories, temperature monitoring is very important because excessive heat can lead to equipment malfunction, chemical reactions, or fire hazards.

The temperature sensor converts thermal energy into an electrical signal that can be measured by the Arduino microcontroller. The microcontroller reads the temperature values and continuously compares them with predefined safe limits.

6. LCD Display

The LCD display module is used to provide a visual interface for displaying system information and sensor readings. In this system, a 16×2 LCD display is commonly used because it is simple, cost-effective, and easy to interface with the Arduino microcontroller.

The LCD module displays real-time data such as gas levels, temperature readings, smoke detection status, and fire alerts. It also shows warning messages when abnormal conditions are detected. This allows workers and supervisors to quickly understand the current environmental conditions without requiring additional monitoring devices.

7. IoT Communication Module

The IoT communication module enables the system to connect to the internet and transmit sensor data to remote monitoring platforms. In this project, the communication functionality can be achieved using Wi-Fi connectivity available in microcontroller-based systems.

Through IoT connectivity, sensor data such as gas concentration, temperature levels, smoke detection, and fire alerts can be transmitted to cloud servers. Supervisors or safety officers can monitor this data remotely using computers or mobile devices. This remote monitoring capability improves industrial safety management by enabling quick responses to hazardous situations.

8. Power Supply

The power supply unit provides the electrical energy required to operate the entire safety monitoring system. It ensures that all components such as sensors, microcontroller, display modules, and communication units receive stable voltage and current for proper functioning.

Typically, the system operates using a regulated DC power supply. Voltage regulators are used to maintain constant voltage levels and protect electronic components from fluctuations or power surges. A stable power supply is essential to ensure reliable system performance and continuous monitoring operation.

V. Result and Discussion

The proposed AI and IoT based industrial safety monitoring system was experimentally evaluated in a controlled environment to analyze its sensing performance, hazard detection accuracy, real-time alert response, and remote monitoring capability. The evaluation focused on four major aspects: environmental hazard detection, alert response behavior, IoT communication reliability, and overall system stability.

A. Gas and Smoke Detection Performance

The gas and smoke sensing modules were tested under controlled exposure conditions to evaluate their detection capability. The sensors were initially calibrated under normal environmental conditions to establish baseline threshold values. During testing, controlled gas exposure and artificial smoke conditions were introduced near the sensors to observe their response.

Experimental observations showed that the sensor output values increased proportionally with the concentration of gas or smoke present in the environment. When the sensor readings exceeded the predefined safety threshold levels, the microcontroller successfully detected the hazardous condition and triggered the alert mechanism. Multiple test cycles were conducted to ensure consistency and repeatability of the results.

B. Fire and Temperature Detection Response

The fire sensor and temperature sensor were tested to analyze their responsiveness in identifying heat and flame conditions. Controlled flame sources and temperature variations were introduced near the sensors to simulate potential fire hazards that may occur in cracker manufacturing environments.

The fire sensor successfully detected infrared radiation emitted by the flame source and generated a signal that was immediately processed by the microcontroller. Similarly, the temperature sensor continuously monitored environmental temperature and detected abnormal temperature rise beyond the predefined safe limit. The response time between hazard detection and system alert activation was observed to be very fast, typically within a few milliseconds.

C. IoT Data Transmission and Remote Monitoring

The IoT communication module was tested to verify the reliability of real-time data transmission from the monitoring system to the remote monitoring platform. Sensor readings including gas levels, smoke detection status, fire alerts, and temperature values were transmitted periodically through the Wi-Fi communication interface.

The experimental evaluation showed that the system successfully transmitted sensor data to the IoT platform without communication failure when stable network connectivity was available. The delay between sensor detection and remote data update was observed to be within a few seconds, depending on network conditions. This remote monitoring capability enables safety supervisors to continuously observe factory environmental conditions from remote locations.

D. System Stability and Power Performance

During experimental testing, the power supply stability and overall system reliability were carefully observed. The monitoring system was operated continuously for extended durations to ensure stable performance without hardware or software failures.

The inclusion of proper voltage regulation and filtering components ensured stable power supply to the sensors, microcontroller, and communication modules. No unexpected resets or system crashes were observed during continuous operation. The sensors maintained consistent readings, and the microcontroller processed data efficiently without delay.

E. Overall System Evaluation

The experimental results confirm that the proposed system accurately detects hazardous environmental conditions such as gas leakage, smoke presence, fire detection, and abnormal temperature rise. It provides fast response and real-time warning alerts when unsafe conditions are detected, displays environmental information clearly through the LCD monitoring interface, successfully transmits real-time data to remote monitoring systems using IoT connectivity, and operates reliably with stable power performance and continuous monitoring capability.

VI. Conclusion and Future Scope

A. Conclusion

This paper presented the design and implementation of an AI and IoT based industrial safety monitoring system developed to enhance worker protection in hazardous environments such as cracker manufacturing factories. The proposed system integrates multiple environmental sensors, a microcontroller-based processing unit, and IoT communication technology to continuously monitor critical safety parameters including gas leakage, smoke presence, fire detection, and temperature variations.

The system uses the Arduino Uno microcontroller as the central control unit to collect and process data from the connected sensors. The collected environmental data is analyzed in real time and compared with predefined safety thresholds to identify hazardous conditions. When abnormal conditions are detected, the system immediately generates alerts and displays warning messages through the LCD module. In addition, the integration of IoT communication enables real-time data transmission to remote monitoring platforms.

Experimental evaluation demonstrated that the proposed monitoring system successfully detects hazardous environmental conditions and provides timely alerts. The results confirm that the proposed system is cost-effective, reliable, and suitable for real-time industrial safety monitoring applications.

B. Future Scope

Although the proposed system demonstrates effective industrial safety monitoring capabilities, several improvements can further enhance its functionality, intelligence, and scalability. Future developments may include the integration of advanced Artificial Intelligence algorithms for predictive hazard detection and intelligent decision-making. By analyzing historical sensor data, AI models can identify abnormal patterns and predict potential safety risks before they occur.

The system can also be enhanced by incorporating additional environmental sensors such as humidity sensors, vibration sensors, and air quality monitoring sensors. Integration with wireless communication technologies such as Wi-Fi, Bluetooth, or cellular networks would further improve remote accessibility and real-time monitoring capabilities.

Another potential improvement is the implementation of cloud-based IoT platforms for long-term data storage and analysis. Cloud integration would enable real-time dashboards, automated alert notifications, and data analytics for industrial safety management. With these future enhancements, the proposed safety monitoring system can evolve into a more intelligent, scalable, and fully automated industrial safety management solution suitable for modern smart factory environments.

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