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ARM-Based Industrial Monitoring and Safety Control System Using STM32 Microcontroller

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Abstract

In recent time, industries are facing safety issues such as gas leakage, fires, abnormal temperature rise and water leakage, which can cause huge losses to enterprises by damaging equipment or halting production and risk the life of workers working in that area. In industrial environment, such safety hazards can be avoided by using an ARM based industrial monitoring and safety control system with STM32F103C8T6 microcontroller. In this paper, the MQ135 gas sensor, LM35 temperature sensor, flame sensor and water leak sensor is used to continuously monitor the environmental and security parameters. The STM32 processes the data received from sensors and compares them to the safety threshold limits to detect any threat. In case of normal parameters system, relay-based safety systems get activated and sound signals through buzzer are produced whereas warning messages are displayed on LCD Screen. The other feature area included the implementation of a monitoring dashboard that shows the sensor outputs.

Keywords: Industrial Monitoring, STM32 Microcontroller, ARM-Based System, Gas Leakage Detection, Flame Detection, Temperature Monitoring, Water Leakage Detection, Industrial Safety.

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1. Introduction

The industrial environment has many processes and devices that operate under extreme condition. Gas leakage, fire outbreak, temperature rise and water leakage may occur during operation. If these parameters are ignored during the initial stages of implementation, they may end up causing damage to machines and other gear, stop production and compromise on the safety of human beings working inside or near factory premises. Therefore, there is an increasing need to develop a continuous monitoring and response system for modern industrial enterprises.

Previously, manual inspection and a single-parameter monitoring device were utilized to ensure safety in various industries. These techniques are now useless as they require human efforts each time and a delay of even few minutes can lead to an emergency situation. With advancements in technology apart from the embedded system design, smart systems are developed to allow observing many environmental parameters, analyze them and provide safety if needed.

ARM-based Microcontrollers are increasingly growing in realization of the industrial automation process with the effective computational skills, less power consumption, consistent performance, and favourable conditions for real-time functions. STM32F103C8T6 is one amongst many ARM-based microcontrollers (in fact, there are several other Arm based micros available) available but is a well-known and widely used ARM based microcontroller due to the built-in ADC module available along with communication interfaces, etc., which makes it capable of performing real time analysis of all types of sensor data.

The STM32F103C8T6 microcontroller is the main control unit of the proposed ARM based industrial controlling and safety monitoring. It consists of sensors to monitor the industrial surroundings, MQ135 gas sensor for gas monitoring; LM35 to detect temperature variation; flame sensor for identifying flames and fire hazards; water leakage sensor to check any unwanted presence of water.

Most importantly, if an abnormal situation is detected, the system will automatically activate safety features that actuate relay-based controls, and deliver alarms through a buzzer sound alarm and an LCD screen. In addition, a monitoring interface operators can clearly monitor the working state of the system and the environment. This would allow the system to act faster when a potentially life-threatening situation develops with minimal human intervention.

This research study intends to develop a low-cost yet efficient industrial safety supervision system capable of identifying different hazards and implementing suitable preventive measures. In this research, two or three methods of sensing will be combined in one ARM embedded platform to guarantee a safe work place and industrial systems.

2. Related Works

The necessity of the use of industry monitoring and safety systems has grown greatly in recent years with the increasing demands and necessity to ensure that both the equipment and personnel are safe. The embedded system based on ARM architecture with STM32 microcontroller plays a major role in reducing the power consumption.

Zhai et al. [1] proposed a motor online monitoring system, where ARM can employ an STM32 microcontroller to obtain continuous data on motor vibrations, temperature and environment. The wireless data transmission mode would help to provide information to the monitoring station, where the user can observe the data and receive alerts regarding possible malfunctions. This research helped to identify the benefits of ARM processor implementation for continuous monitoring of the operational status of equipment; however, it did not pay much attention to the aspect of security but focused on analyzing the state of motors. In their study, Kayan et al. [2] tried to analyze the problem of detecting anomalies in industrial robotic arms and offered an approach based on the edge-based IoT concept. Efficient data processing at the edge of the network is necessary for the proper functioning of the system. A system that monitored the environment conditions including temperature, humidity, gas level, and light intensity was proposed to be implemented through the use of sensor nodes. The LoRa technology was used to enable remote access and system security. The system was reliable, yet only concentrated on data collection and not any safety mechanisms.

STM32-based control systems in mobile binocular vision platforms are proposed by Ma et al. [4]. The STM32F103 controllers were used as the primary elements for collecting environmental data and moving within environment. As a result of implementation of the proposed control system, the real-time monitoring of environmental data was carried out via CAN bus network. It should be noted that the experimental results proved the applicability of this design for real-time embedded control systems. The methodology for real-time monitoring and controlling marine loading arms has been suggested by Sastry et al. [5]. It is necessary to note that this model is able to improve the efficiency of operation through monitoring and controlling processes. The significance of such monitoring and control for industrial process has been proved in this study. As a solution for the problem of real-time monitoring in industry with ARM-based system and GPRS communications for industrial parameter transfer, the researchers from Nithya et al. [6] have suggested. The authors proved the possibility of designing wireless monitoring systems in industry with ARM-based devices, but at the same time their design was based on cellular technologies.

A wireless local area network-based SCADA system utilizing ARM technology has been introduced by Patle et al. [7]. The proposed system had capabilities to acquire parameters from the industrial processes in real time and control the processes remotely. The advantage of the solution proposed by the researchers was the possibility of wireless communication in the context of industrial automation applications. Another research article published by Shaikh et al. [8] described a security and safety system for base transceiver stations based on the implementation of ARM technology. The system consists of several sensors and alerts that are used for the detection of threats and intrusions. The wireless environmental monitoring system based on the use of STM32 has been implemented by Xilong et al. [9] and involved sensors for the acquisition of environmental parameters wirelessly. The findings have shown that the approach is applicable and provides reliable and efficient results. Hong et al. [10] developed an environment control system for agricultural environments using STM32 controllers. The controller will regulate the environment conditions based on the signals received from sensors.

Although there are many systems that have proven their capability and efficiency for industrial monitoring, environmental sensing, and equipment surveillance using ARM and STM32 platform, most of these systems tend to focus on data acquisition and remote monitoring. Only very few researches are available in the literature in terms of integrating industrial monitoring, hazard detection, safety controls automation, and real-time alarms in one single embedded system. This research work is an attempt to bridge this gap in the literature by developing an industrial monitoring and safety control system utilizing STM32 microcontroller.

3. Methodology

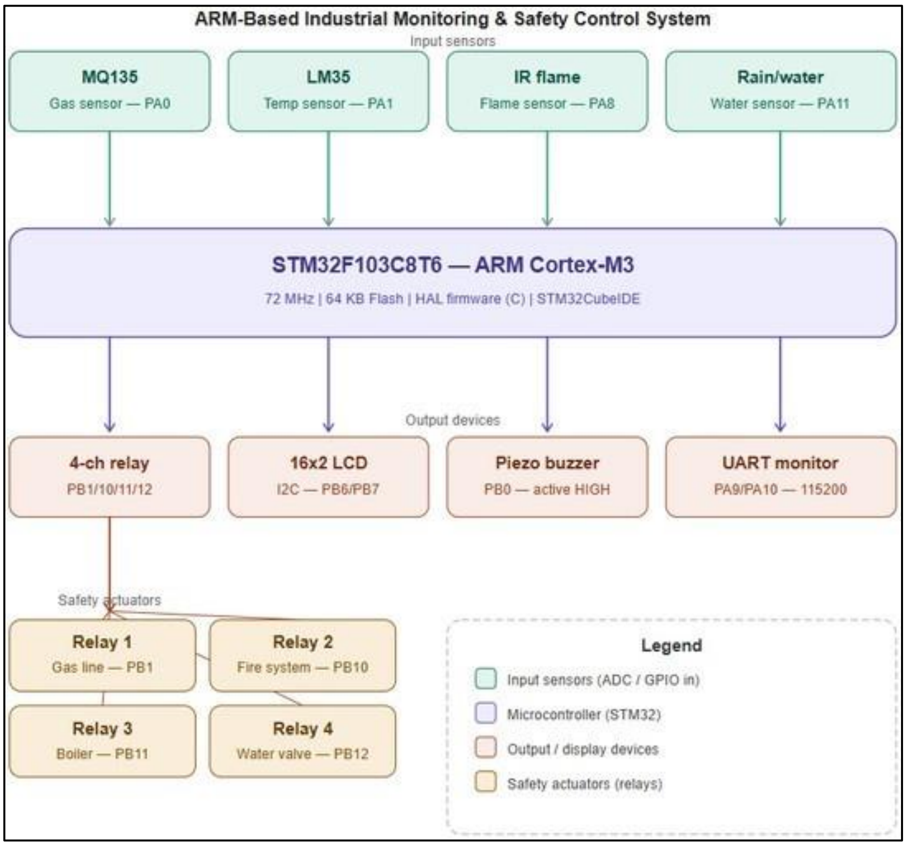

Figure 1. Block diagram of ARM-based industrial monitoring and safety control system

In Figure 1, the proposed ARM-based industrial monitoring and safety control system continuously monitor environment in addition to taking appropriate measures at the time of occurrence when any hazardous situation occurs. It uses a STM32F103C8T6 micro-controller to run the processing which makes it help in collecting data, reading environmental parameters and reacting by making appropriate action whenever an anomaly is encountered.

Table 1. Hardware components of the proposed system

Component	Model	Function
Microcontroller	STM32F103C8T6 (ARM Cortex-M3)	Central controller for sensor acquisition, processing, and safety control
Gas Sensor	MQ135	Detects harmful and combustible gases in the industrial environment
Temperature Sensor	LM35	Measures ambient temperature and detects overheating conditions
Flame Sensor	IR Flame Sensor	Detects fire or flame using infrared radiation

Water Leakage Sensor	Rain/Water Leakage Sensor	Detects water accumulation or leakage in industrial areas
Relay Module	4-Channel Relay	Controls safety devices based on detected hazards
LCD Display	16×2 I^2C LCD	Displays system status and warning messages
Alarm	Piezo Buzzer	Generates audible alerts during hazardous conditions

The proposed industrial monitoring system is implemented with the STM32F103C8T6 microcontroller based on ARM Cortex-M3 as the main processing unit. The sensing subsystem is composed of an MQ135 gas sensor for leakage detection, a thermal LM35 temperature sensor for measuring temperatures, an infrared flame sensor to detect fires and drip sensors that can identify how much liquid penetrates the environment. The controller repeatedly reads sensor values via its on-board ADC channels, and compares them with predetermined safety criteria. Whenever the IMU detects erratic conditions while working, it triggers the relay output secondary to that condition, and outputs a sound using piezo buzzer as well as visual alarm using 16×2 LCD. In addition, a monitoring interface based on a UART sends real-time sensor data to the web dashboard, enabling remote surveillance of industrial safety. The hardware elements and sensing modular tools used by the proposed system are listed in Table 1.

All sensor signals transmit to the STM32 microcontroller. The sensors continuously collect data, which is analyzed by the microcontroller. Specifically, analog sensor input is converted into digital signals through the internal ADC module of an STM32 microcontroller. Flame sensor flame infrared detection technique is used to detect fire in the system, and water leakage of the system is detected using a water leakage sensor.

To provide timely indication of hazardous circumstances, the system has been designed to feature not only a visual there also an audible alert. The buzzer alarm is triggered immediately after the detection of hazardous conditions to alert the people around about a possible danger. At the same time, a status message appears on the I2C LCD screen in real-time indicating what type of hazard detected. Under normal operation, the system status information is displayed on the LCD. Since all these functions run based on the same STM32 microcontroller, this system can fully meet the function and performance needs of industrial safety management.

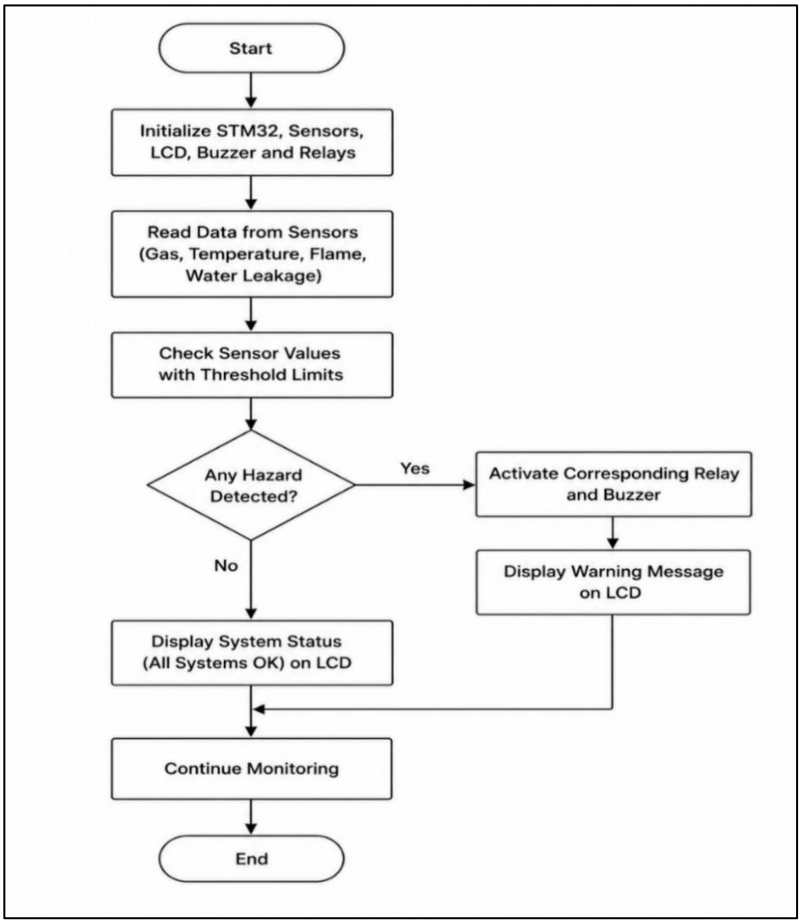

Figure 2. Workflow of the proposed ARM-based industrial safety monitoring system

The workflow of the proposed ARM-based industrial monitoring and safety control system is shown in Figure 2 starts as power supply is provided to the system. STM32 microcontroller initializes all the connected hardware parts such as gas sensor, temperature sensor, flame sensor, water leakage sensor, LCD display, buzzer and relay modules to perform monitoring and control functions. Then data acquisition phase comes in where we keep receiving data via connected sensors. The gas sensor acquires information on the presence of hazardous gases in the area and the temperature sensor acquires data about the surrounding temperature. Additionally, flame sensor detects first and the other is water leakage sensor which gets activated when there is any water stored in the area which is monitored. All these collected data will be processed by the STM32 microcontroller and compared against pre-defined threshold values. This allows one to determine if a industrial site contains any hazard. The threshold for any of the sensor values are breached, it determines hazard and then immediately act via STM32 control unit to trigger particular relay output and start the buzzer alarm to notify regarding same. The LCD display also provides a warning message on the detected hazard to inform users of the problem simultaneously. But in case if none of the sensors cross the safety threshold, then nothing will be happened but it will just display a normal state on LCD. The system this using either indicator and then goes back to monitoring mode, continuing to record sensor data. This will be continuously done to allow the real time monitoring of industrial operations and also for the rapid detection and response when any hazard comes along. This suggested system continuously repeats this process to ensure safer industries, less equipment damage and lesser manual monitoring.

Industrial monitoring system collects environmental data continuously from the MQ135 gas sensor, LM35 thermal environment sensor, flame sensor, and water leakage sensor by STM32F103C8T6 microcontroller. The controller receives and processes coupled sensor values based on other safety thresholds to produce the appropriate monitoring condition. The dashboard application receives the sensor data that is processed in the gateway and transmitted serially through a communication interface to the monitoring computer. The dashboard refreshes the sensor readings and the system status in real time, providing operators with live data to monitor gas concentration, ambient temperature, flame detection, water leakage status, relay operation and alarm conditions with remote access. When a hazard is detected, the dashboard will immediately be updated with this new knowledge while triggering the local relay, buzzer and LCD warning mechanisms; this means local and remote monitoring are always synchronous.

The software stack consists of the following: STM32CubeIDE for firmware development and programming of the STM32 microcontroller; Embedded C to implement interfacing with sensors and control logic; Web-based dashboard developed using standard web technologies to visualize real-time sensor measurements and relevancies of system status. Table 2Summarizes the software tools utilized for the realization of the suggested system Dashboard gives a dashboard to the end-users that is used to monitor the industrial condition and also monitoring as well seeing if all sensors are operation.

Table 2. Software tools used in the proposed system

Software Tool	Purpose
STM32CubeIDE	Firmware development and programming of the STM32 microcontroller
Embedded C	Sensor interfacing, data acquisition, threshold evaluation, and safety control logic

STM32 HAL Library	Hardware abstraction for peripheral configuration and sensor communication
Serial Communication Interface (UART)	Transmission of processed sensor data to the monitoring computer
Web-Based Dashboard	Real-time visualization of sensor readings, relay status, and safety alerts

4. Results and Discussion

The implemented hardware prototype measures the gas leakage, temperature change, flame detection and water leakage. It is a system that combines multiple sensors with an STM32 microcontroller to survey the surroundings and provide instantaneous corrective measures when an unsafe condition occurs.

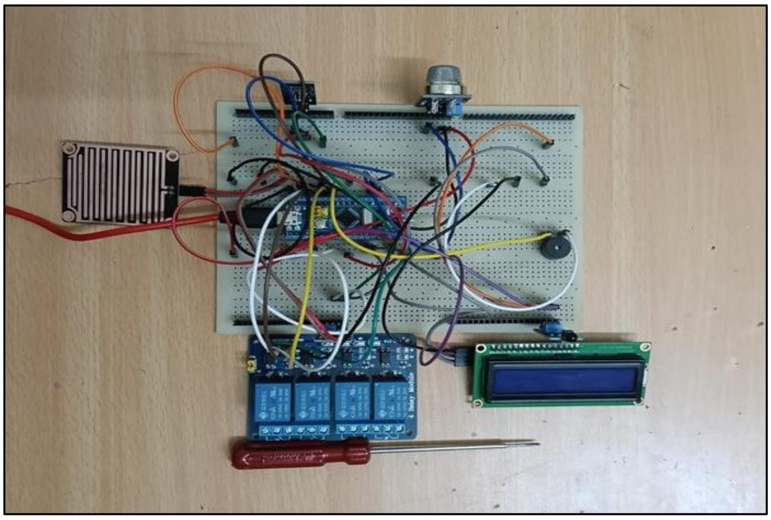

Figure 3. Hardware setup — ARM-based industrial monitoring and safety control system

The developed hardware model is shown in Figure 3. All the required hardware components, like the STM32F103C8T6 microcontroller, gas sensor, temperature sensor, flame sensor, water leakage sensor, relay module, buzzer, and LCD display, were integrated into one system. The hardware design proved to be a success, with an established connection between the sensors and the microcontroller. The sensors sensed the surroundings and passed the information to the microcontroller, which processed it further. The LCD display showed information about the functioning of the system, while the buzzer and relay acted as emergency measures.

The gas sensor was capable of detecting such gases and giving out an alarm in case such gases had levels above the set threshold. Also, the temperature sensor was responsible for detecting the temperature in the surrounding area. In addition, the flame detector would detect any fire in the surroundings, while the water leakage sensor was responsible for detecting any water in the surrounding areas. All these sensors were capable of providing total monitoring of industrial hazards.

There was any danger in hazardous situation within the environment, then the STM32 controller would activate the relay and buzzer alarm accordingly. Furthermore, there would be a warning displayed in the LCD, showing that the dangers have been identified in the environment. Therefore, it would ensure that if there was any hazardous situation, there would be an instant response. When the abnormality is gone, then the monitoring process will be done automatically.

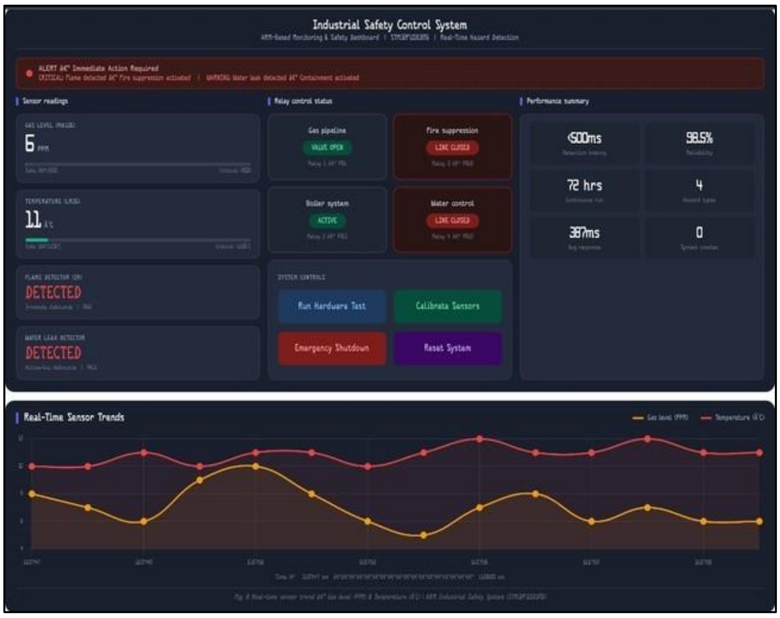

Figure 4. Real-time web dashboard — industrial safety control system monitoring interface

The developed real time monitoring dashboard is shown in Figure 4. The real time monitoring dashboard displays live data collected by the sensors of the system. The interface helps the operator understand what goes on in the factory environment. The user can access important information about gas level, temperature, flames, water leakages, and relays. It also enables operators to remotely monitor the system and identify any malfunctions without the need for checking the physical structure of the system.

The real-time monitoring interface adopted in this research is user-friendly. Through this interface, an operator can monitor the information received from the sensors in real time. Besides, local alarms, which consist of buzzers and LCD monitors, combined with the real-time monitoring interface, make the entire safety management process much more efficient.

From the experiment results mentioned above, it is clear that the system design has been shown to be capable of monitoring the industries continuously, detecting any potential hazards that may occur and then taking the necessary safety steps. From the integration of the different sensors, relays, alarms, and dashboard displays, it is clear that the proposed system is a feasible solution for industrial safety.

5. Conclusion

This research study has presented the design and development of ARM based industrial monitoring and safety control system, which employs STM32F103C8T6 microcontroller. It was capable of viewing critical industrial processes, such as the presence of gas leakages, temperature variations, flames or water leaks because of the integration of different sensors into a single system. The monitoring system also indicated the hazardous situation generated from monitoring via relay outputs, buzzers and LCD display of alerts. During the tests performed, the prototype carried out continuous monitoring of the parameters related to environmental cleanliness and automatically detected any incidents that arose. The real time dashboard made monitoring even easier since we had a place to see the current state of the system. Hence, based on the above analysis, it can be concluded that the proposed system as a low-cost, affordable and permanent solution for industry safety management. This system can be utilized in factories, processing plants, warehouses and other locations, where constant monitoring is needed. Future extensions may involve remote access via IoT, cloud solutions for notifications and data storage.

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