Industrial Monitoring and Predictive Maintenance System Using IoT

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***Abstract*—Industrial monitoring is essential because even minor changes can lead to disastrous failures, serious safety risks, and substantial production losses. This paper outlines the design of an embedded industrial monitoring system using an ESP32 microcontroller, which employs vibration, humidity, and current sensors to track machine and environmental conditions in real time. The system compares these parameters to predefined thresholds; upon detecting any abnormalities, it activates a buzzer, halts the equipment, and sends alert notifications to the operator via Telegram. It offers both local and remote alerts, minimizing the need for human oversight. The solution is cost-effective and scalable to meet the needs of small and medium-sized industries.**

***Index Terms*—Industrial IoT (IIoT), ESP32 Microcontroller, Predictive Maintenance, Real-Time Monitoring, Embedded Systems**

I. INTRODUCTION

Contemporary manufacturing relies critically on continuous machinery performance, consistent power supply, and regulated environmental factors. Departures from standard operating parameters may signal an emerging malfunction or a hazardous condition. For instance, abnormal vibration can indicate loose components, misalignment, or mechanical wear. Excessive moisture can damage delicate machinery, accelerate rusting, or cause electrical failures. Unusually high current consumption can signal issues such as overload, blockage, short circuits, or motor strain. Failure to identify these problems promptly may lead to equipment failure, production stoppages, or safety hazards *[A. Banerjee, M. Singh, 2024].*

Many sectors still depend on traditional monitoring that involves either scheduled manual checks or isolated measurement tools. Such methods frequently fall short as they lack both ongoing monitoring and instant reaction capabilities. The risk of failure rises due to human mistakes, slow responses, and poor inter-system communication *[IJAREEIE,2023].* This issue is particularly acute in settings where machinery runs for extended periods without continuous oversight.

Embedded systems offer an effective remedy by integrating sensors, controllers, alarms, and communication units into a single, compact configuration. The ESP32 microcontroller is an ideal choice due to its robust processing power, extensive I/O pins, integrated analog and digital sensing, and native Wi-Fi capabilities *[Espressif Systems, 2024].* These capabilities enable the creation of a smart industrial monitoring system that detects anomalies, triggers automatic responses, and alerts users remotely.

This project aims to create an industrial management system that continuously tracks vibration, humidity, and current levels, automatically triggering corrective actions whenever unsafe conditions are identified. The system halts the machine as needed, triggers a local buzzer, and dispatches Telegram alerts to enable the operator to respond instantly from afar. This dual capability ensures the system is both proactive and reactive, a necessity for contemporary industrial safety.

II. LITERATURE REVIEW

Industrial monitoring systems have undergone substantial development throughout history. Initial systems relied heavily on manual processes, requiring operators to visually check both machinery and environmental conditions at set intervals. While straightforward, this approach relied heavily on human oversight and proved ineffective for identifying sudden failures *[IJAREEIE,2023].* With the rise of automation, sensor-based systems were implemented to enhance reliability and minimize the requirement for continuous human monitoring.

Early embedded monitoring systems generally relied on single sensors linked to simple microcontrollers. These systems identified specific hazards like gas leaks, temperature spikes, or vibrations, frequently activating a buzzer or LED once a set limit was exceeded *[P.Kumar, V.Yadav, 2023].* Although these systems offered an upgrade over manual checks, they remained constrained by their focus on just one or two metrics and a lack of remote alert capabilities.

The subsequent development phase introduced wireless monitoring using IoT microcontrollers like the ESP8266 and NodeMCU. These systems enabled the transmission of sensor data to cloud services or mobile devices. While accessibility increased, numerous designs continued to struggle with constrained processing capabilities, a scarcity of GPIO pins, and inadequate support for handling multiple concurrent sensor inputs *[F.A.Alrashdi, 2024].* In industrial settings, this proves limiting since numerous environmental and machine-specific variables must be tracked simultaneously.

Recent research and real-world applications demonstrate that the ESP32 serves as a superior platform for industrial IoT due to its enhanced processing speed, expanded pin count, and built-in Wi-Fi capabilities *[Espressif Systems, 2024]. [A. Banerjee, M. Singh, 2024].*

ESP32-based multi-sensor configurations enable the concurrent tracking of vibration, humidity, current, gas, temperature, and additional parameters with enhanced precision and faster response [7]. Such systems offer greater reliability by avoiding reliance on any single indicator to assess machine health. Conversely, they offer a more comprehensive perspective on the system's condition.

Nevertheless, numerous current systems primarily concentrate on identifying threats and issuing warnings but fail to automatically control machinery or integrate both local and remote responses *[R. Gupta and P. Rana, 2024]***.** While they frequently alert users to faults, they fail to automatically manage the machine or harmonize local and remote safety measures. Certain systems also lack continuous monitoring or appropriate threshold-based logic. This project overcomes those constraints by combining multi-sensor detection, automatic shutdown, buzzer alerts, and Telegram messaging into one embedded system. Consequently, the system becomes more comprehensive, practical, and well-suited for real-world industrial management.

III. METHODOLOGY

The project followed a structured workflow encompassing hardware integration, firmware development, threshold design, sensor calibration, and experimental validation.

The initial phase involved integrating the hardware. The ESP32 microcontroller was chosen as the primary processor due to its ability to manage multiple sensors concurrently and support wireless communication via Wi-Fi *[Espressif Systems, 2024].* The system linked to vibration, humidity, and current sensors. An industrial machine was simulated using a servo motor or motor-control output, with a buzzer providing local audio alerts. The prototype was first built on a breadboard to facilitate flexible testing and adjustments.

The next phase involved calibrating the sensors. Calibration is crucial since every sensor responds uniquely based on its environment and electrical configuration. The vibration sensor was calibrated to identify subtle mechanical disruptions without triggering spurious alerts. The humidity sensor was calibrated and verified based on standard specifications provided in manufacturer datasheets ***[****Adafruit Industries, 2025****]***. The current sensor was tested across different load conditions to verify detection of irregular current consumption *[A. Banerjee, M. Singh, 2024].*

The sensor was calibrated by recording a baseline during normal operation to flag any significant rise as abnormal.

The third phase involved developing the firmware. The firmware was developed in the Arduino IDE and then flashed onto the ESP32. The code perpetually processes every sensor input within a real-time cycle.

Vibration input is tracked via rapid detection, humidity levels are verified on a regular basis, and the current sensor is accessed through the analog input. Every value is evaluated against established limits. As long as the value stays within safe limits, the system proceeds with standard operation. Should a value breach either a warning or critical threshold, the system instantly switches to alert mode.

The fourth phase involved alert and control logic. Upon detecting a suspicious or critical condition, the system executes multiple actions simultaneously. It triggers a local buzzer, halts motor or servo activity for a set duration, and notifies the user via Telegram. How long the alert lasts is determined by how severe the condition is. Usually, suspicious circumstances lead to brief halts, whereas critical ones necessitate extended stops. This dual-response approach enhances system responsiveness, making it better suited for real-world industrial protection

The fifth step involved configuring wireless notifications. Telegram was chosen for its user-friendly interface, speed, and mobile compatibility *[C. Li and H. Zhang, 2024].* After establishing a connection, the ESP32 automatically transmits status updates and alerts to the operator. This enables remote oversight even when the operator is not physically near the equipment. Integrating Telegram introduces a vital communication layer to the embedded system. Telegram also has remote access to the system as the system can be powered on and off by sending command on telegram.

The concluding phase involved conducting experimental tests. Mechanical disturbances were applied to the setup to test the vibration sensor. The humidity sensor underwent testing by subjecting it to fluctuating environmental conditions. The existing sensor underwent testing across different load scenarios to verify its ability to identify irregular current consumption. Testing the buzzer, motor shutdown, and Telegram messaging simultaneously confirmed that the system responded accurately and without delay. Testing validated the system's ability to track several conditions in real time and trigger responses whenever limits were breached.

Fig1: flowchart


Fig:2: side view of sensors

V. RESULTS AND DISCUSSIONS

The ESP32-based Industrial Hazard Prevention System was tested against all simulated industrial hazards. The system monitored several environmental factors, including gas detected by the MQ-2 sensor, temperature and humidity from the DHT22 sensor, and vibration simulated by a push-button. Alerts were triggered when parameters exceeded set levels. All readings appeared on an OLED display. A buzzer and LEDs notified users of any industrial hazards. The MQ-2 gas sensor provided stable readings in clean air and gave immediate results as soon as lighter fumes entered the environment. The response time was about 2 to 4 seconds, which is typical for these sensors in smart monitoring systems *[P. Kumar, V. Yadav, 2023]*. Multiple readings taken by the DHT22 sensor to check its accuracy showed stable temperature readings with an average deviation of ±1°C and humidity readings with an average deviation of ±2% RH. These deviations are well within the tolerance levels outlined by the manufacturer ***[****Adafruit Industries, 2025****]***.

The results matched those found in a previous study on industrial IoT applications *[A. Banerjee, M. Singh, 2024].*

To evaluate the warning function of the vibration mechanism, we manually pressed the activation button. The system responded immediately with a buzzer and LED alert. The response time to press the button was less than 100 milliseconds, and the system reacted instantly, offering an early warning before unusual machine vibrations could cause damage. Quick alerts are vital in industrial settings *[A. Banerjee, M. Singh, 2024].*

A delay of even a few seconds can lead to machine failures or serious accidents. ESP32 has the built-in Wi-Fi capability, enabling one to transmit warning messages straight to the cloud. On the other hand, microcontrollers like the Arduino Uno require additional devices to facilitate communication. Past studies have proved that ESP32 provides better scalability and requires less hardware *[F.A.Alrashdi, 2024]*, *[A. Banerjee, M. Singh, 2024].*

Previous research on IoT shows that the ESP32 allows for more scalable designs while adding very little hardware overhead. Our results indicate that the system can effectively detect hazards early and is suitable for small to medium industrial safety environments. Its modular design makes it easy to add additional monitors with only software adjustments needed, ensuring the hardware remains relevant in the future

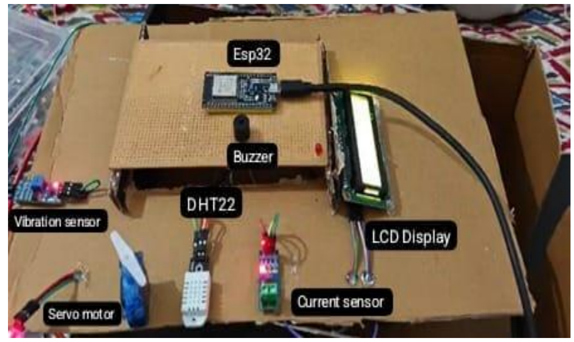

Fig3: System Top View While running

Fig:4 System Showing Humidity Alert

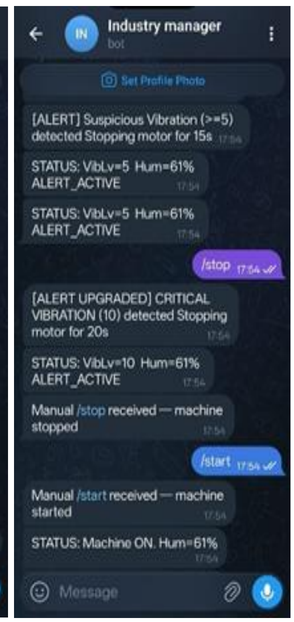

Fig:5 System Starting/ stopping at command

VI. CONCLUSION

This project showcases how an ESP32-driven industrial management system enables effective real-time monitoring and control. Integrating vibration sensing, humidity monitoring, and current measurement into one embedded platform enables the system to identify hazardous situations promptly and trigger automatic responses. Combining a buzzer, motor shutdown logic, and Telegram notifications and command control guarantees that both on-site and distant alerts are triggered whenever irregular activity is detected.

The system lessens reliance on manual checks and accelerates reaction times when hazards arise. Its affordable, modular, and wireless design makes it ideal for small and medium industries that require constant oversight but cannot justify the expense of full industrial automation. In conclusion, the project demonstrates that embedded systems offer a dependable, scalable, and intelligent solution for industrial management and safety.

VII. FUTURE SCOPES

While the existing system offers robust monitoring and alerting, it still holds potential for further enhancement. A primary area for future development involves integrating cloud capabilities. Linking the ESP32 to a cloud service enables the storage of sensor data over time, which facilitates long-term analysis of machine behavior, alert trends, and maintenance patterns.

A further enhancement involves the implementation of predictive maintenance. Rather than merely responding once a limit is breached, the system can be expanded to detect incremental shifts in vibration, current, or humidity, enabling failure prediction before it happens. Such an approach would enhance the system's intelligence and utility for industrial maintenance planning.

The system supports expansion with extra sensors, including those for gas, smoke, flame, temperature, or pressure. Such an approach would render the monitoring platform more robust and adaptable to a broader range of industrial safety applications. A mobile app can also be created to offer a specialized dashboard for real-time machine monitoring, alert logs, and remote operation.

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