



ORIGINAL CONTRIBUTION

IoT-Based Predictive Machine Health & Safety Monitoring System

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ABSTRACT

Industrial machines often exhibit warning signs such as excessive temperature and abnormal vibration before failure. This work presents a low-cost IoT-based machine health and safety monitoring system using an ESP32 controller. DHT22 and MPU6050 sensors monitor temperature/humidity and vibration, respectively. The data are processed locally and displayed on a 0.96-inch SSD1306 OLED, while LEDs and a buzzer indicate NORMAL, WARNING, and DANGER conditions. The system also supports Wi-Fi-based remote monitoring and can be extended with relay-based machine shutdown. Prototype readings demonstrate the transition from normal to hazardous conditions, establishing the system as a practical condition-monitoring and early-warning platform with scope for future predictive-maintenance development.

KEYWORDS: IoT, ESP32, Machine Health Monitoring, Predictive Maintenance, Vibration Monitoring, Industrial Safety.

1. INTRODUCTION

Industrial machines are continuously exposed to mechanical, thermal and electrical stresses during operation. Components such as motors, pumps, fans, compressors and hydraulic equipment may gradually develop abnormalities due to overheating, excessive load, vibration, electrical faults, poor lubrication or environmental conditions. If these abnormalities are not detected at an early stage, they can lead to machine failure, production downtime and safety hazards.

Traditional machine inspection generally depends on periodic manual observation or maintenance schedules. Such methods may fail to identify temporary or rapidly developing abnormalities occurring between inspections. Continuous monitoring provides a better approach because machine parameters can be observed while the equipment is operating.

The development of low-cost microcontrollers and IoT technologies has made continuous condition monitoring possible even at laboratory and small-scale levels. The ESP32 is particularly suitable because it provides sensor interfacing, processing capability and built-in wireless connectivity. A machine can continue operating even when its temperature, vibration or current consumption begins to increase. Without continuous monitoring, these changes may remain unnoticed until they develop into a serious fault.

Therefore, the proposed system aims to develop a

compact and low-cost monitoring unit capable of observing multiple machine parameters simultaneously and providing an immediate indication when abnormal conditions occur.

2. LITERATURE REVIEW

Jain et al. [1] investigated vibration monitoring of a milling machine using an MPU6050 sensor and Arduino, demonstrating that low-cost MEMS accelerometers can be used to measure machine vibration and support condition assessment.

Arciniegas et al. [2] developed an IoT-based motor-monitoring system using an MPU6050 and ESP32S3, applying vibration analysis and TinyML for detecting abnormal motor behaviour.

Macheso et al. [3] presented a low-cost ESP32-based system with a DHT22 sensor for real-time temperature and humidity monitoring, demonstrating the suitability of ESP32 for continuous sensor-data acquisition.

Supriyanto and Setiawan [4] developed an ESP32-DHT22 monitoring system with an OLED display and remote monitoring capability, showing the practicality of combining sensing, local visualization, and wireless communication.

Alsammarraie et al. [5] further demonstrated an ESP32-based environmental monitoring system integrating DHT22 and gas sensing with OLED and remote communication, highlighting the benefits of multi-parameter monitoring.

Ash Shiddiqi et al. [6] proposed an ESP32-based industrial monitoring system that combined vibration and temperature sensing with RMS and FFT analysis for condition-based maintenance.

Gomathi and Balaji [7] investigated vibration-based tool-condition monitoring for PCB milling, emphasizing the usefulness of vibration signals for identifying machine-tool conditions. Other related works are also presented in [8], [9], [10], [11], [12].

These studies demonstrate the effectiveness of low-cost embedded sensors for monitoring individual mechanical and environmental parameters. However, a clear gap remains in integrating vibration, temperature, and humidity sensing with local visualization in a single low-cost ESP32-WROOM-32 platform specifically aimed at early machine-condition warning. The proposed system addresses this gap by integrating the MPU6050, DHT22, and SSD1306 OLED with the ESP32-WROOM-32. The system focuses on multi-parameter condition monitoring and early warning rather than claiming fully validated predictive maintenance, since such performance requires machine-specific baseline data, calibration, controlled fault testing, and labelled datasets.

3. PROPOSED SYSTEM

3.1. System Architecture

The proposed system is organized into five functional units: a sensing unit, processing and control unit, display and alert unit, machine interface unit, and IoT communication unit. DHT22 and MPU6050 sensors acquire thermal and mechanical information. The ESP32 receives these signals, processes them against predefined operating conditions, and determines the machine state. The result is shown locally on the OLED and through LEDs and a buzzer, while Wi-Fi provides the foundation for remote monitoring.

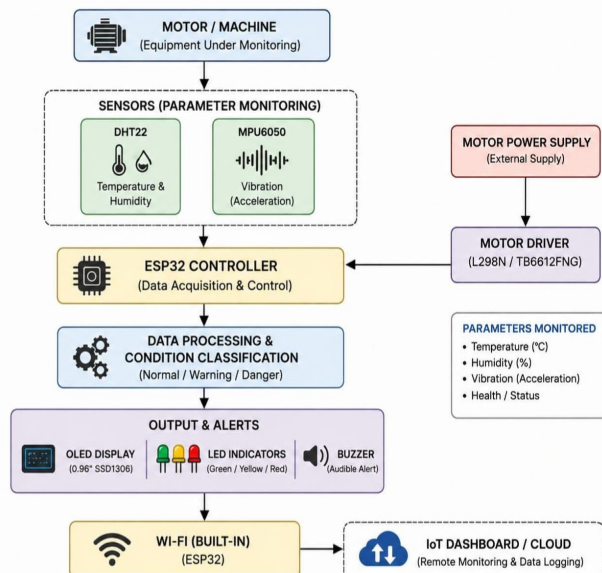


Figure 1: Overall block diagram of the proposed IoT-based machine health monitoring system.

In figure 1, the block diagram shows the signal flow from the monitored machine and sensors to the ESP32 controller, condition classification stage, local alerts, and Wi-Fi/IoT monitoring. It also indicates the separate motor power and driver path used in the prototype.

3.2. Hardware Components

Table I. Hardware Components and Functions

Component	Function / Role
ESP32 DevKit V1	Central controller, sensor acquisition, local logic, and Wi-Fi communication.
DHT22	Temperature and relative-humidity measurement.
MPU6050	3-axis accelerometer and 3-axis gyroscope for vibration/motion monitoring.
0.96-inch SSD1306 I ² C OLED	Local display of measurements and machine condition.
Buzzer	Audible warning/alarm.
Green LED	NORMAL condition indication.
Yellow LED	WARNING condition indication.
Red LED	DANGER/fault condition indication.
220 Ω resistors	Current limiting for LEDs.

3.3. Control and Condition Classification Unit

The ESP32 acts as the central processing unit. It collects the sensor readings and compares them with predefined operating conditions. When monitored parameters remain within the defined range, the system reports NORMAL. When one or more parameters enter an abnormal range, the system reports WARNING. Severe or multiple abnormal conditions produce the DANGER state and activate the red indication and buzzer.

3.4. Display, Alert and IoT Communication

The SSD1306 I²C OLED provides local display of sensor values and machine status. A green LED indicates NORMAL, a yellow LED indicates WARNING, and a red LED indicates DANGER or fault. The buzzer provides audible warning, with intermittent operation for WARNING and continuous alarm for DANGER. The ESP32 Wi-Fi interface can transmit collected data to a remote dashboard or cloud platform in an expanded implementation.

4. METHODOLOGY

The operational logic follows a continuous sense-process-classify-alert cycle.

- 1) **Initialization:** On power-up, the ESP32 initializes the connected sensors, OLED display, alert outputs, and communication functions.
- 2) **Sensing:** The DHT22 and MPU6050 acquire temperature/humidity and motion/vibration information.
- 3) **Data Processing:** The ESP32 receives and processes the sensor readings. The measurements are compared with predefined operating conditions.
- 4) **Condition Classification:** The system assigns NORMAL, WARNING, or DANGER according to the monitored conditions.
- 5) **Local Alerting:** The OLED displays the current condition. The corresponding LED is activated and the buzzer provides the required audible indication.
- 6) **IOT Communication:** The ESP32 Wi-Fi interface provides a foundation for transmitting sensor information to a remote monitoring platform. The complete operating sequence can therefore be represented as: Machine → Sensors → ESP32 → Data Processing → Condition Classification → OLED + LED + Buzzer → Wi-Fi/IoT.

5. IMPLEMENTATION

The prototype is assembled around an ESP32 DevKit V1/ESP32-WROOM-32, a small DC motor representing the machine-under-test, and the two sensing modules. The DHT22 and MPU6050 are connected to the ESP32 for acquisition of the required parameters. The motor driver provides the interface between the controller and the laboratory motor, while the OLED is connected through the I²C interface. The OLED and three LEDs provide direct visual feedback, and the buzzer provides an audible warning. The motor power path is kept separate from the ESP32 logic supply through an external motor supply as specified in the prototype design. A breadboard and jumper wires are used for the low-cost laboratory implementation. **The ESP32 processes the acquired sensor data and continuously monitors the operating condition of the motor. The sensed parameters are displayed locally on the OLED for real-time observation. This arrangement enables simple and low-cost evaluation of the prototype under different motor operating conditions.

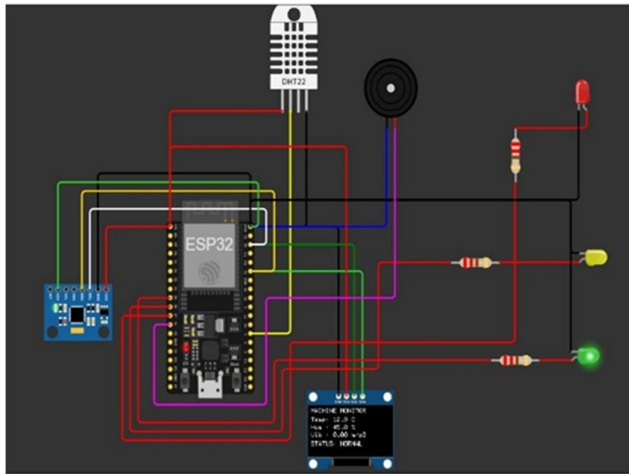


Figure 2: Prototype circuit in NORMAL operating mode.

In figure 2, the NORMAL-state image shows the ESP32, DHT22, MPU6050, OLED, buzzer and three LED indicators interconnected on the prototype. The green indicator is active while the warning and danger indicators remain inactive.

6. RESULTS AND DISCUSSION

The prototype successfully demonstrates three operating states based on temperature and vibration conditions. The OLED displays the corresponding machine status, while the buzzer provides an audible warning when abnormal conditions are detected. The system provides a simple and effective indication of machine health and can be further improved through calibration and controlled testing.

LED Output Indication:

- **Green LED:** NORMAL condition — continuously ON/slow blinking; buzzer OFF.
- **Yellow LED:** WARNING condition — blinking; buzzer gives intermittent beeps.
- **Red LED:** DANGER condition — rapidly blinking/ON; buzzer gives a continuous alarm.

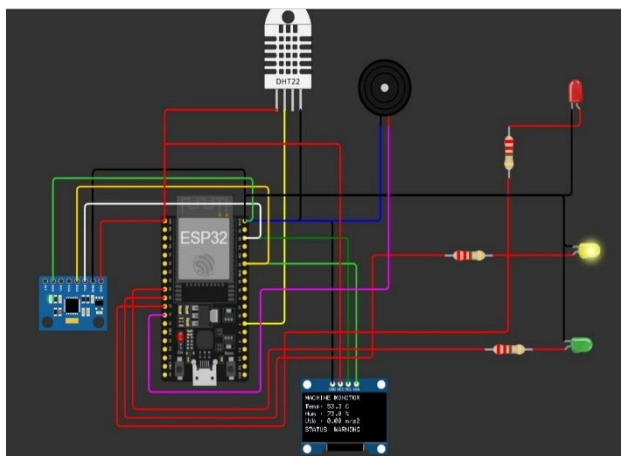


Figure 3: Prototype circuit in WARNING operating mode.

In figure 3, the WARNING-state image shows the same hardware configuration with the yellow indicator activated. This represents an abnormal but non-critical operating condition in the classification logic.

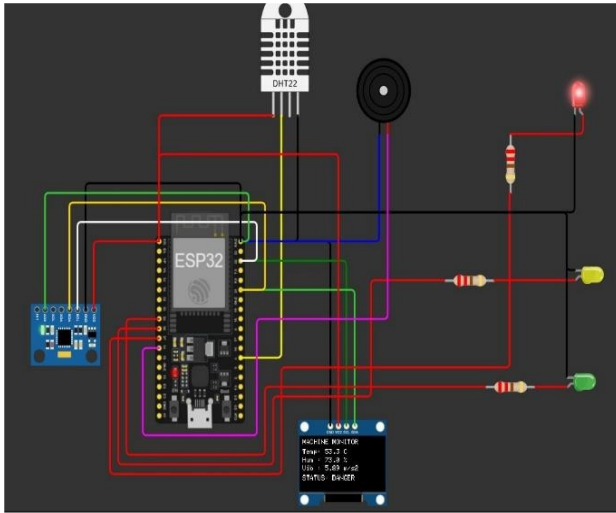


Figure 4: Prototype circuit in DANGER operating mode.

In figure 4, the DANGER-state image shows the red indicator activated, representing a severe or multiple abnormal condition. The buzzer provide the alarm.

7. CONCLUSION

This paper presented a low-cost IoT-based machine health and safety monitoring system using a temperature/humidity ESP32 and with vibration sensing. The system processes sensor data and classifies the machine condition into NORMAL, WARNING, and DANGER states, providing immediate feedback through an OLED display, LEDs, and buzzer.

The prototype demonstrates the effectiveness of multi-parameter condition monitoring as an early-warning mechanism. By continuously observing important machine parameters, the system can help identify abnormal operating conditions at an early stage and reduce the risk of unexpected machine failure or unsafe operation. The proposed approach also provides a foundation for continuous monitoring, remote data acquisition, and future predictive-maintenance applications.

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REFERENCES

- [1] V. Jain and S. K. Pradhan, "Vibration monitoring of ball nose end mill tool during milling of sculptured surfaces using MPU6050 sensor," *Materials Today: Proceedings*, vol. 27, pp. 2477–2486, 2020, doi: 10.1016/j.matpr.2019.09.222.
- [2] S. Arciniegas, D. Rivero, J. Piñan, E. Diaz, and F. Rivas, "IoT device for detecting abnormal vibrations in motors using TinyML," *Discover Internet of Things*, vol. 5, art. no. 41, 2025, doi: 10.1007/s43926-025-00142-4.
- [3] P. Macheso, P. Chombo, and M. M. Nyirenda, "Design of standalone asynchronous ESP32 web-server for temperature and humidity monitoring," *International Journal of Computer Applications*, 2021.
- [4] Supriyanto and N. D. Setiawan, "Rancang bangun sistem real-time monitoring suhu dan kelembaban menggunakan ESP32," *Elkom: Jurnal Elektronika dan Komputer*, vol. 18, no. 1, pp. 447–457, 2025, doi: 10.51903/elkom.v18i1.3064.
- [5] M. J. A. Alsammarraie, A. H. Ali, A. A. Al-Hilali, H. Q. M. Monir, M. S. Jabbar, and H. B. Qasim, "Implementation of a long range-based monitoring system for environmental remote safety schemes," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 32, no. 3, pp. 1462–1475, 2023.
- [6] A. Ash Shiddiqi, L. S. Wasitova, and D. H. Nugroho, "IoT-based real-time vibration and temperature monitoring system for industrial machinery using ESP32 and MQTT," *International Journal of Engineering Continuity*, vol. 5, no. 1, pp. 53–71, 2026, doi: 10.58291/ijec.v5i1.519.
- [7] K. Gomathi and A. Balaji, "Tool condition monitoring of PCB milling machine based on vibration analysis," *Materials Today: Proceedings*, 2020.
- [8] N. Tandon and A. Choudhury, "A review of vibration and acoustic measurement methods for the detection of defects in rolling element bearings," *Tribology International*, vol. 32, no. 8, pp. 469–480, 1999.
- [9] Espressif Systems, *ESP32-WROOM-32 Datasheet*, version 3.6, Espressif Systems, 2025.
- [10] TDK InvenSense, *MPU-6000 and MPU-6050 Product Specification*, document no. PS-MPU-6000A-00, rev. 3.4.
- [11] Aosong Electronics, *AM2302/DHT22 Digital Relative Humidity & Temperature Sensor*, datasheet.
- [12] Solomon Systech, *SSD1306 128 × 64 Dot Matrix OLED/PLED Segment/Common Driver with Controller*, datasheet.