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Condition Based Monitoring and Maintenance System for Underground Metro Stations

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Abstract: *Tunnel booster fans (TBFs) in underground metro stations, which vary in capacity, are essential for ventilation but pose significant maintenance challenges due to their infrequent operation and complex schedules. Traditional preventive maintenance requires extensive manpower and involves risks associated with working at heights. To address these issues, this project introduces a Condition-Based Monitoring and Maintenance (CBM) system designed to optimize maintenance activities and reduce associated costs. The CBM system will utilize an AI-based platform that integrates historical failure data, operational symptoms, parameter limits, and maintenance records. By analysing real-time data collected during mock drills, the AI system will compare it with historical data top redact maintenance needs and identify deviations from normal operation. This approach will enable targeted maintenance actions, thereby reducing unnecessary inspections and associated risks. The expected outcome is a more efficient maintenance process that leverages machine learning and behavioural analytics to proactively manage TBF conditions, ultimately enhancing equipment reliability and reducing overall maintenance costs.*

Keywords: *TBF, CBM, Condition based monitoring, underground metro station, maintenance.*

1. INTRODUCTION

This paper proposes a Condition-Based Monitoring and Maintenance System using ESP32 to ensure efficient operation and early fault detection in electrical and mechanical systems. The system continuously monitors key parameters such as temperature, vibration, and current using appropriate sensors. Under normal conditions, a fan remains operational to maintain airflow. However, when an abnormal condition is detected such as excessive temperature, unusual vibrations, or abnormal current levels, the system triggers a buzzer and a bulb as alert mechanisms. Additionally, the status of the system, including normal and abnormal conditions, is displayed on an LCD screen for real-time monitoring. The ESP32 serves as the central controller, processing sensor data and making real-time decisions. A relay module is used to control the buzzer and bulb, providing an immediate response to critical conditions. This system enhances predictive maintenance strategies, reducing the risk of equipment failure, improving safety, and increasing operational efficiency.

The Condition-Based Monitoring and Maintenance System is designed to ensure efficient operation and early fault detection in electrical and mechanical systems. Using ESP32 as the central controller, the system continuously monitors temperature, vibration, and current through sensors. Under normal conditions, a fan runs continuously to maintain airflow. However, when abnormal conditions such as high temperature, excessive vibration, or abnormal current are detected, the system triggers a buzzer and bulb as alerts to notify users. Additionally, an LCD screen displays real-time system status, providing instant feedback on the operating conditions. A relay module is used to control the buzzer and bulb, ensuring quick response to faults. This system enhances predictive maintenance by identifying potential issues early, reducing downtime, improving safety, and optimizing performance. With future expansions, the system can be integrated with IoT platforms for remote monitoring, AI-based predictive analysis, and wireless sensor networks to enhance its capabilities for industrial and commercial applications.

2. LITERATURE REVIEW

X. Zhou and L. Yang presented a comprehensive framework integrating Internet of Things (IoT) and machine learning (ML) for condition monitoring and predictive maintenance in industrial applications. The authors propose layered system architecture composed of sensing, network, and processing layers to capture equipment data, transmit it, and perform analytics. Various machine learning techniques such as decision trees, support vector machines, and neural networks are reviewed for predicting failures and assessing machinery health. The implementation case studies show improved operational efficiency and reduced unplanned downtimes. The authors highlight the role of data pre-processing and sensor fusion in achieving reliable predictions.

Cheng and Zhang discuss the application of IoT for real-time condition monitoring and predictive maintenance in smart manufacturing. The paper elaborates on a cloud-based IoT architecture that supports data collection from embedded sensors, analysis via edge devices, and remote monitoring interfaces. Predictive models are created using historical machine data to detect anomalies and anticipate equipment failures. They highlight a significant reduction in maintenance costs and downtime through early fault detection. The paper also discusses interoperability challenges and the importance of standardizing communication protocols in IoT-based industrial environments.

J. Lee and H. A. Kao explored the concept of Cyber-Physical Systems (CPS) as a foundational technology for predictive maintenance and service automation. The authors present an architecture that integrates physical machines with cyber infrastructure via sensors and embedded computing. The CPS system enables real-time data-driven diagnostics and decision-making. They emphasize the role of big data analytics and cloud computing in converting raw sensor signals into actionable maintenance strategies. The paper concludes with industry use cases demonstrating improved lifecycle management and service automation across different sectors.

R. Srinivasan and S. Venkataraman critically examined IoT-based systems for condition-based maintenance (CBM) in industrial environments. It categorizes various CBM solutions into sensor technologies, communication frameworks, data analytics, and user interface layers. The authors highlight recent trends in smart maintenance, such as edge computing, AI-driven diagnostics, and self-healing systems. Key challenges identified include cyber security, energy efficiency, and integration with legacy equipment. They also propose a unified framework for designing future-ready CBM systems that are adaptive, scalable, and autonomous.

R. Sivaraman and V. Sharma propose the development of intelligent monitoring systems that leverage IoT sensors for predictive maintenance. The system architecture includes real-time sensor data acquisition, cloud-based analytics, and automated alert systems. Several case studies are presented, focusing on rotating equipment, HVAC systems, and motors. Key contributions include the integration of vibration and temperature sensors with predictive algorithms such as ARIMA and random forest. The results demonstrate improved reliability and significant cost savings due to proactive maintenance scheduling.

H. Alemzadeh and M. Gholami focused on the role of IoT sensors in condition monitoring and fault diagnosis within industrial automation systems. The authors survey sensor technologies and their deployment in various industries such as manufacturing, oil & gas, and energy. Machine learning algorithms like k-NN and deep neural networks are explored for identifying anomalies in equipment behavior. The integration of sensor networks with SCADA and PLC systems is discussed in detail. Emphasis is placed on system reliability, low-latency data processing, and real-time diagnostics.

3. PROPOSED METHODOLOGY

ESP32: ESP32-WROOM-32 is a powerful, generic Wi-Fi + BT + BLE MCU module that targets a wide variety of applications, ranging from low-power sensor networks to the most demanding tasks, such as voice encoding, music streaming and MP3 decoding. The core of this module is the ESP32-D0WDQ6 chip. The chip is designed to be scalable and adaptive. There are two CPU cores that can be individually controlled, and the CPU clock frequency is adjustable from 80 MHz to 240 MHz. The user may also power off the CPU and make use of the low power coprocessor to constantly monitor the peripherals for changes or crossing of thresholds.

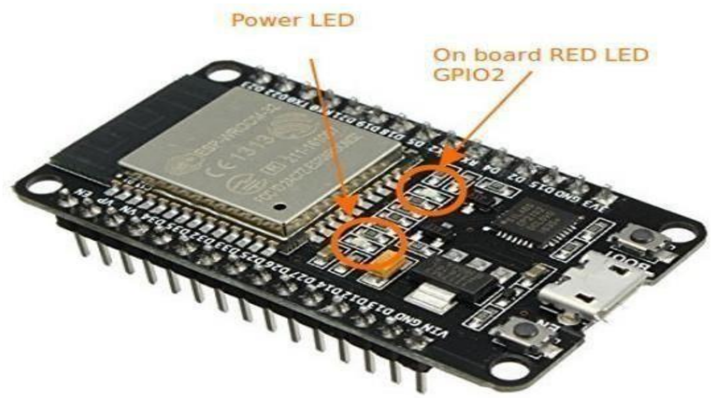

FIGURE 1. ESP32 Module

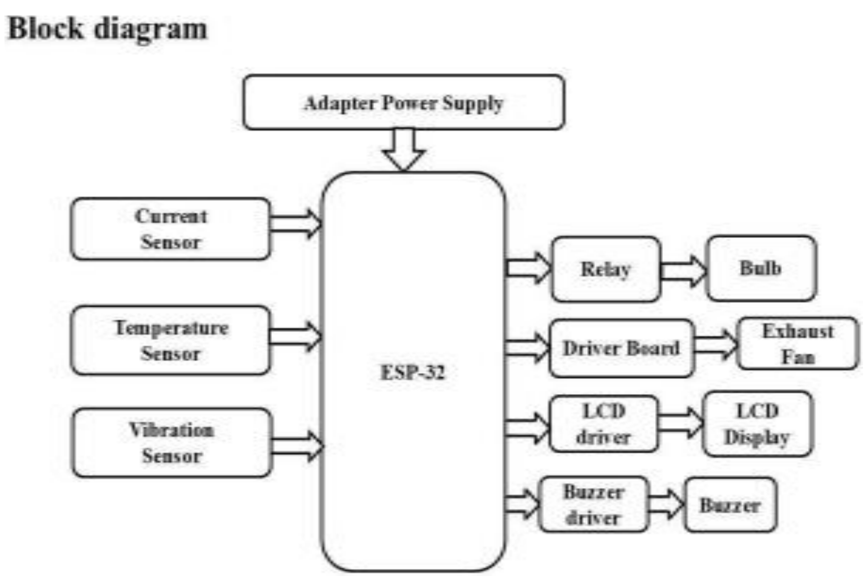

FIGURE 2. Block Diagram

The main blocks of this project are:

- Power Supply
- ESP32
- Temperature Sensor
- Current Sensor
- Vibration Sensor
- Driver Board with Exhaust Fan
- LCD Display

LED: A light-emitting diode (LED) is a semiconductor light source. LEDs are used as indicator lamps in many devices, and are increasingly used for lighting. Introduced as a practical electronic component in 1962, early LEDs emitted low-intensity red light, but modern versions are available across the visible, ultraviolet and infrared wavelengths, with very high brightness. The internal structure and parts of an LED are shown in figure.

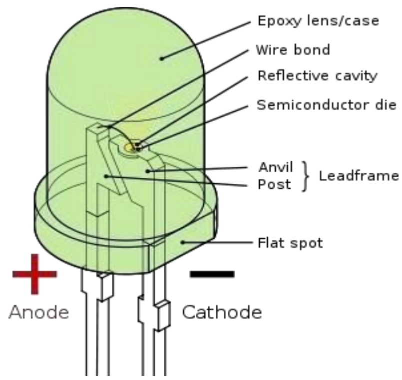

FIGURE 3. LED

LCD Display:

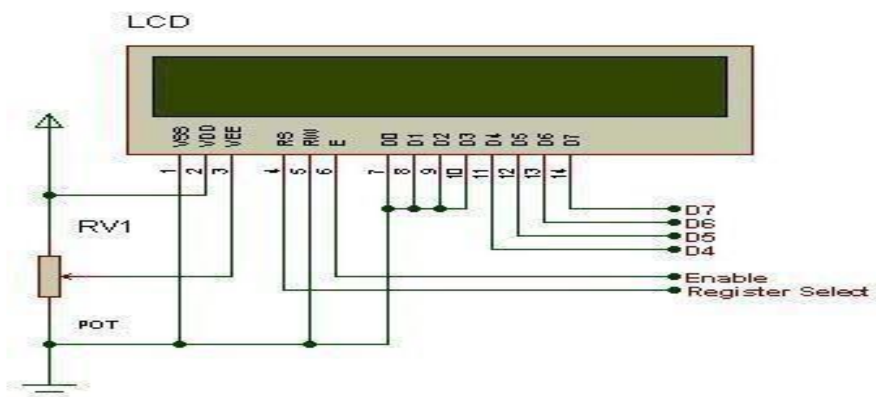

FIGURE 4. LCD Display

The LCD requires 3 control lines as well as either 4 or 8 I/O lines for the data bus. The user may select whether the LCD is to operate with a 4-bit data bus or an 8-bit data bus. If a 4-bit data bus is used, the LCD will require a total of 7 data lines (3 control lines plus the 4 lines for the data bus). If an 8-bit data bus is used the LCD will require a total of 11 data lines (3 control lines plus the 8 lines for the data bus)

Relay: A relay is an electrically operated switch. Many relays use an electromagnet to operate a switching mechanism, but other operating principles are also used. Relays find applications where it is necessary to control a circuit by a low-power signal, or where several circuits must be controlled by one signal. The first relays were used in long distance telegraph circuits, repeating the signal coming in from one circuit and re-transmitting it to another. Relays found extensive use in telephone exchanges and early computers to perform logical operations. A type of relay that can handle the high power required to directly drive an electric motor is called a contactor. Solid-state relays control power circuits with no moving parts, instead using a semiconductor device triggered by light to perform switching. Relays with calibrated operating characteristics and sometimes multiple operating coils are used to protect electrical circuits from overload or faults; in modern electric power systems these functions are performed by digital instruments still called "protection relays".

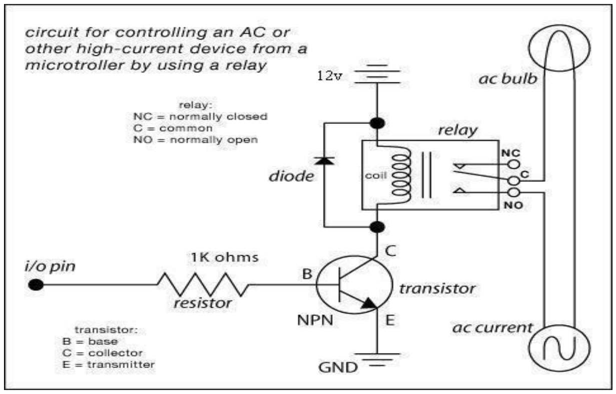

FIGURE 5. Relay Module

Current Sensor: In practice, a current transformer can be used as a current sensor. The current sensor is to be connected in series with the transmission lines. When current in a circuit is too high to directly apply to measuring instruments, a current transformer produces a reduced current accurately proportional to the current in the circuit, which can be conveniently connected to measuring and recording instruments. A current transformer also isolates the measuring instruments from what may be very high voltage in the monitored circuit. The primary of the current transformer is to be connected to the transmission lines and the secondary is to be connected to the microcontroller.

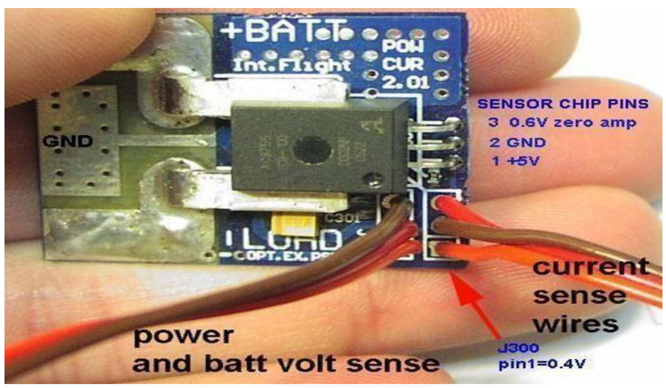

FIGURE 6. Current Sensor Module

Buzzer: Basically, the sound source of a piezoelectric sound component is a piezoelectric diaphragm. A piezoelectric diaphragm consists of a piezoelectric ceramic plate which has electrodes on both sides and a metal plate (brass or stainless steel, etc.). A piezoelectric ceramic plate is attached to a metal plate with adhesives. Applying D.C. voltage between electrodes of a piezoelectric diaphragm causes mechanical distortion due to the piezoelectric effect. The distortion of the piezoelectric element expands in a radial direction. And the piezoelectric diaphragm bends toward the direction. The metal plate bonded to the piezoelectric element does not expand. Conversely, when the piezoelectric element shrinks, the piezoelectric diaphragm bends in the direction. Thus, when AC voltage is applied across electrodes, the bending is repeated, producing sound waves in the air.

FIGURE 7. Buzzer

4. RESULTS AND DISCUSSION

The Condition-Based Monitoring and Maintenance System successfully monitors temperature, vibration, and current in real-time using ESP32. Under normal conditions, the fan runs continuously, while in abnormal conditions, the buzzer and bulb are activated as alerts. The LCD screen displays system status, ensuring clear visibility of faults. This system effectively enables early fault detection, enhances predictive maintenance, improves safety, and reduces manual monitoring efforts, making it a reliable and efficient solution for equipment maintenance.

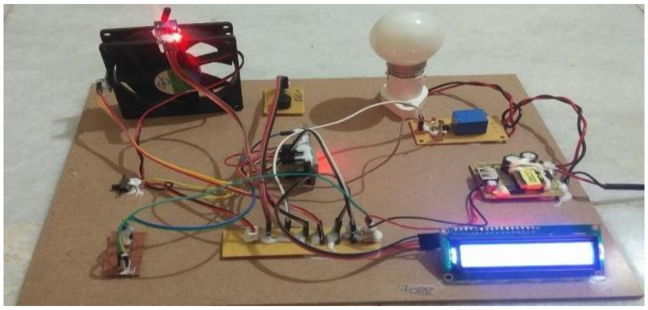

FIGURE 8. Output Execution

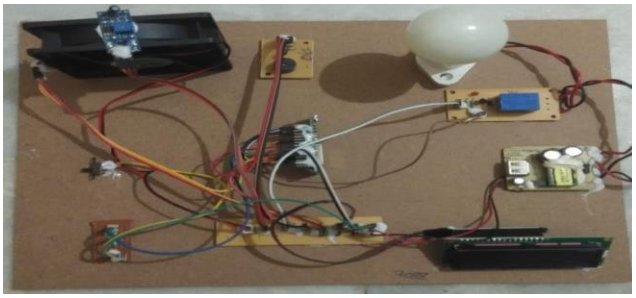

FIGURE 9. Output Execution

FIGURE 10. Output Execution Display on LCD Screen

Applications:

- Industrial Equipment Monitoring
- HVAC Systems
- Motor Maintenance
- Home Automation

Advantages:

- **Early Fault Detection**: Prevents equipment failure by identifying abnormal conditions in real time.

- **Automated Monitoring:** Reduces manual inspection efforts by continuously tracking temperature, vibration, and current.
- **Improved Safety:** Alerts through buzzer and bulb help prevents potential hazards.
- **Real-Time Status Display:** LCD provides instant system condition updates for easy monitoring.
- **Cost-Effective Maintenance:** Helps in predictive maintenance, reducing repair costs and downtime.
- **Energy Efficiency:** Ensures optimal functioning of devices like fans, reducing unnecessary energy consumption.
- **Reliable Operation:** ESP32 provides fast and efficient data processing for real-time control.
- **Scalability:** Can be expanded to monitor additional parameters or integrated with IoT platforms.

Disadvantages:

- Potential inaccuracies due to saturation, cost limitations, and space constraints, particularly with magnetic core-based sensors.
- It can be costly to implement, requiring specialized equipment and personnel.
- It may also lead to unpredictable maintenance scheduling and false alarms, potentially causing operational disruptions.
- While beneficial for certain types of equipment and industries, it may not be universally applicable or effective.

5. CONCLUSION AND FUTURE SCOPE

This system is a proactive maintenance approach that uses real-time data from sensors to assess the health of equipment and predict when maintenance is needed. It monitors various parameters like vibration, temperature, and pressure to detect changes that could indicate a developing fault, allowing for timely maintenance and preventing costly downtime.

The future scope of this system includes expanding its capabilities to monitor additional parameters such as humidity, pressure, and air quality. Integration with cloud-based platforms for remote monitoring and data analysis can provide more insights and enhance decision making. Advanced machine learning algorithms could be implemented for more accurate predictive maintenance. Additionally, the system can be further optimized for scalability, enabling it to be used in large-scale industrial operations, smart cities, and IoT-based environments for broader applications in automation and efficiency.

REFERENCES

[1]. X. Zhou and L. Yang, "Condition monitoring and predictive maintenance for industrial applications using IoT and machine learning," *J. Manuf. Process.*, vol. 35, pp. 358–368, 2018.
[2]. M. Senthil Kumar and M. Gopinath, “An Efficient Polynomial Pool-Based Scheme for Distributed Heterogeneous WSNs”, *International Journal of Modern Engineering Research (IJMER)*. (Vol.3, Issue 6, Nov-Dec.2013, PP 3328-3335, ISSN: 2249-6645).
[3]. Senthilkumar Meyyappan and N. Selvamuthukumaran, “Network Selection in Heterogeneous Wireless Systems using GRA Method”, *Journal on Electronic and Automation Engineering*, Vol. 4(1), March 2025, pp. 127-132.
[4]. Senthilkumar Meyyappan, A. Bharath Naik, A. Uma Sai and Ch. Keerthi, “Improving Weather Forecasting Accuracy Using Machine Learning”, *Journal on Electronic and Automation Engineering*, Vol. 2(4), December 2023, pp. 9-18.
[5]. M. Senthil Kumar, R. Karthik and I. Rabeek Raja, “An Efficient Approach for Increasing Power Optimization in Mobile Ad-Hoc Networks”, *International Journal of Engineering Research and Technology (IJERT)*. (Vol.3, Issue 2, February 2014).
[6]. Z. Cheng and Y. Zhang, "Internet of Things-based condition monitoring and predictive maintenance in manufacturing systems," *Int. J. Adv. Manuf. Technol.*, vol. 92, no. 9–12, pp. 3841–3853, 2017.
[7]. M. Senthil Kumar and L. Praveen, “An Assuring Approach for Tree-Based Routing Topology in WSNs”, *International Journal of Emerging Trends in Engineering and Development (IJETED).* (Issue 3, Vol.6, November 2013, ISSN: 2249 – 6149).

[8]. M. Kavitha, T. Maheshwaran and M. Senthil Kumar, "Secure Routing in MANETs with Key Management", *International Journal on Engineering Technology and Sciences (IJETS).* (Vol.1, Issue 6, October 2014, ISSN (P): 2349 – 3968, ISSN (O): 2349 - 3976).
[9]. J. Lee and H. A. Kao, "Cyber-physical systems for predictive maintenance and service automation," *CIRP Ann.*, vol. 63, no. 2, pp. 707–730, 2014.
[10]. M. Senthil Kumar, "Energy Efficient Techniques for Transmission of Data in Wireless Sensor Networks", *Journal of Computing Technologies (JCT)*. (Vol.5, Issue 2, February 2016, ISSN: 2278 – 3814).
[11]. C.I. Vimalarani and M. Senthil Kumar, "Energy Efficient PCP Protocol for k-Coverage in Sensor Networks", *IEEE International Conference on Computational Intelligence and Computing Research, IEEE Proceedings, 2010*.
[12]. M. Subashinidevi, S. Castro and M. Senthil Kumar, "Efficient Anonymous Transfer of Data in Wireless Networks", *International Journal on Engineering Technology and Sciences (IJETS)*. (Vol.1, Issue 6, October 2014, ISSN (P): 2349 – 3968, ISSN (O): 2349 - 3976).
[13]. R. Srinivasan and S. Venkataraman, "Condition-based maintenance for smart industrial applications: A review of IoT-based systems," *J. Ind. Inf. Integr.*, vol. 18, p. 100124, 2020.
[14]. M. Senthil Kumar and C. Sridhathan, "Impact of Mobility on the Routine of Enhanced – DSDV Protocol in Mobile Ad-hoc Networks", *International Journal of Applied Engineering Research (IJAER)*. (Vol.13, No.14, 2018, PP 11674-11679, ISSN: 0973-4562).
[15]. M. Senthil Kumar and Ashish Chaturvedi, "Energy-Efficient Coverage and Prolongs for Network Lifetime of WSN using MCP*", European Journal of Scientific Research (EJSR).* (Vol.95, No.2, January 2013, ISSN: 1450 – 216X / 1450 – 202X).
[16]. Senthilkumar Meyyappan, G. Lava Kumar, G. Niharika and G. Chakradhar, "Cellular Network Signal Strength Analyser", *Journal on Electronic and Automation Engineering*, Vol. 4(1), March 2025, pp. 165-174.
[17]. R. Sivaraman and V. Sharma, "Development of smart monitoring systems for equipment using IoT sensors for predictive maintenance," *Sens. Actuators A Phys.*, vol. 296, pp. 374–382, 2019.
[18]. M. Senthil Kumar and Ashish Chaturvedi, "A Novel Enhanced Coverage Optimization Algorithm for Effectively Solving Energy Optimization Problem in WSN", *Research Journal of Applied Sciences, Engineering and Technology (RJASET).* (Issue 4, Vol.7, January 2014, ISSN: 2040 – 7459 & e-ISSN: 2040 – 7467).
[19]. M. Kavitha, T. Maheshwaran and M. Senthil Kumar, "Ensure Data Transmission in Mobile Ad-Hoc Networks", *International Journal on Engineering Technology and Sciences (IJETS)*. (Vol.2, Issue 4, April 2015, ISSN (P): 2349 – 3968, ISSN (O): 2349 - 3976).
[20]. H. Alemzadeh and M. Gholami, "Application of IoT sensors for condition monitoring and fault diagnosis in industrial automation," *J. Autom. Control Eng.*, vol. 9, no. 1, pp. 42–51, 2021.