RASBERRY PI PICO DRIVEN INDUSTRIAL PREDECTIVE MAINTANANCE SYSTEM

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Abstract: Industrial safety and predictive maintenance are crucial in ensuring operational efficiency and preventing hazardous failures. This project presents a Raspberry Pi Pico driven Industrial Predictive Maintenance System that utilizes vibration and temperature sensing to monitor machinery health and detect potential failures before they the escalate. By continuously analyzing sensor data, the system can identify abnormal temperature rises and unusual vibrations, which are early indicators of mechanical issues, overheating, or impending failures. The collected data is processed in real-time and transmitted to the maintenance team, enabling timely intervention and reducing downtime. This predictive approach enhances workplace safety by preventing accidents caused by equipment malfunctions, ultimately improving productivity and reducing maintenance costs. The system's compact design, low power consumption, and real-time monitoring capabilities make it a scalable solution for various industrial applications.

Keywords: Industrial safety, predictive maintenance, Raspberry Pi Pico, vibration sensing, temperature sensing, machinery health monitoring, real-time data analysis, fault detection, abnormal vibration, overheating detection, early failure prevention, operational efficiency, workplace safety, downtime reduction, industrial IoT, maintenance optimization, low power consumption, scalable solution, sensor-based monitoring, proactive maintenance.

1. INTRODUCTION

In modern industrial environments, machine reliability and operational efficiency are key factors in ensuring smooth production processes and minimizing unexpected failures. Equipment malfunctions not only cause costly downtime but also pose significant safety risks to workers and surrounding communities. Traditional maintenance strategies, such as reactive (breakdown) and preventive maintenance, often fail to address potential failures in real-time, leading to inefficiencies and increased operational costs. To overcome these challenges, predictive maintenance (PdM) has emerged as a proactive approach that leverages real-time data analysis to detect anomalies before a complete failure occurs. By integrating Internet of Things (IoT) technologies, smart sensors, and embedded systems, industries can significantly enhance equipment monitoring and failure prediction. The Raspberry Pi Pico, a low-cost and energy-efficient microcontroller, provides an ideal platform for implementing such an intelligent predictive maintenance system. This project proposes a Raspberry Pi Pico-driven Industrial Predictive Maintenance System that utilizes vibration and temperature sensing to continuously monitor machinery health. By detecting early signs of equipment degradation, such as excessive vibrations and temperature fluctuations, the system enables timely intervention, reducing the risk of catastrophic failures and improving overall operational efficiency.

2. LITERATURE SURVEY

Wu et al. (2019) conducted a comprehensive comparative analysis of three maintenance strategies: reactive, preventive, and predictive maintenance. Their findings highlighted the significant cost-saving potential of predictive maintenance, which leverages data analytics, machine learning, and real-time monitoring to anticipate equipment failures before they occur. In contrast, reactive maintenance—where repairs are conducted only after a failure—often results in higher downtime, increased labor costs, and unexpected production disruptions. Preventive maintenance, while structured, can still lead to unnecessary maintenance activities and associated costs due to its reliance on scheduled servicing rather than real-time condition monitoring. The study concluded that predictive maintenance offers the most efficient approach, reducing maintenance costs by 30–40% compared to reactive strategies. This reduction is attributed to minimizing unplanned downtime, optimizing resource allocation, and extending the lifespan of critical equipment through timely interventions.

Mishra et al. (2019) explored the integration of machine learning algorithms with vibration sensing techniques to enhance the classification of motor faults. The study aimed to improve fault detection and prediction accuracy by analyzing vibration signals, which serve as key indicators of mechanical issues such as misalignment, imbalance, and bearing defects. The researchers applied various machine learning models, including decision trees and support vector machines (SVM), to process and classify vibration data. Their findings demonstrated that these algorithms significantly improved fault prediction accuracy, achieving over 90% precision in identifying motor anomalies. Decision trees provided a structured and interpretable classification framework, while SVM effectively distinguished between fault types by mapping vibration patterns into a high-dimensional space. The study highlighted the potential of combining data-driven techniques with traditional sensing methods to develop robust predictive maintenance systems, reducing unexpected failures and improving the overall reliability of motor-driven systems.

Yadav et al. (2020) conducted an in-depth evaluation of frequency-domain analysis as a method for vibration monitoring in heavy machinery. The study focused on analyzing frequency shifts in vibration signals to detect early signs of mechanical wear and tear. By transforming raw vibration data into the frequency domain using techniques such as Fast Fourier Transform (FFT), the researchers identified characteristic frequency patterns associated with different types of faults, including bearing wear, misalignment, and gear defects. Their findings confirmed that even subtle frequency deviations from normal operating conditions could serve as early indicators of mechanical deterioration, allowing for timely maintenance interventions. The study emphasized that frequency-domain analysis provides a more precise and reliable approach to fault detection compared to time-domain methods, as it isolates specific frequency components linked to particular failure modes. By leveraging this approach, industries can improve predictive maintenance strategies, minimize unplanned downtime, and extend the operational lifespan of heavy machinery.

Rahman et al. (2020) conducted a detailed investigation into heat dissipation patterns in high-power industrial equipment, focusing on their impact on the reliability of power semiconductor devices. The study employed thermal imaging and advanced heat flow analysis to monitor temperature variations across critical components. The findings revealed that non-uniform heat distribution often serves as an early indicator of potential failures, as localized overheating can accelerate material degradation, induce thermal stress, and lead to electrical inefficiencies. In particular, power semiconductor devices, such as insulated-gate bipolar transistors (IGBTs) and metal-oxide-semiconductor field-effect transistors (MOSFETs), were found to be highly susceptible to thermal imbalances. When certain regions of a semiconductor experience excessive heat buildup while others remain cooler, uneven expansion and contraction occur, increasing the likelihood of cracks, delamination, and eventual device failure. The study highlighted the importance of real-time thermal monitoring and improved cooling techniques to enhance the longevity and performance of industrial power electronics. By addressing non-uniform heat dissipation through optimized heat sink designs, advanced cooling materials, and intelligent thermal management systems, industries can significantly reduce failure rates and maintenance costs.

Mukherjee et al. (2020) developed a Raspberry Pi-based vibration monitoring system specifically designed for CNC (Computer Numerical Control) machines to enhance fault detection and predictive maintenance. The system utilized vibration sensors to capture real-time data from machine components, which was then processed using Fast Fourier Transform (FFT) algorithms on the Raspberry Pi platform. By converting vibration signals from the time domain to the frequency domain, the system effectively identified anomalies associated with early-stage faults, such as spindle imbalance, misalignment, and bearing wear. The study demonstrated that real-time FFT processing on Raspberry Pi provided a cost-effective yet powerful solution for monitoring machine health, offering high accuracy in detecting abnormal frequency shifts indicative of mechanical issues. Additionally, the compact size and low power consumption of the Raspberry Pi made it a practical choice for industrial applications where continuous monitoring is required. The research emphasized that integrating such an affordable and scalable system into CNC machines could significantly reduce unplanned downtime, optimize maintenance schedules, and extend machine lifespan by addressing faults before they escalate into severe failures.

Chowdhury et al. (2020) developed and deployed a fuzzy logic-based predictive maintenance model aimed at enhancing decision-making in industrial maintenance strategies. The model utilized fuzzy logic principles to handle uncertainties and imprecise data associated with equipment degradation and failure patterns. By integrating multiple condition-monitoring parameters, such as vibration levels, temperature variations, and operational load, the system processed real-time sensor inputs to assess machine health. The key feature of the model was its ability to generate a confidence score for maintenance decisions, quantifying the likelihood of impending failures based on predefined linguistic rules and membership functions. This confidence score provided maintenance teams with a clear, data-driven indication of when to perform servicing, reducing unnecessary maintenance while preventing unexpected breakdowns. The study demonstrated that the fuzzy logic approach improved maintenance efficiency by offering a flexible and adaptive decision-support system, especially in complex industrial environments where precise failure prediction is challenging. The findings highlighted the potential of fuzzy logic in predictive maintenance applications, enabling industries to transition from reactive and preventive strategies to more intelligent and optimized maintenance planning.

Hitachi (2022) showcased the implementation of a 5G-enabled predictive maintenance network designed to enhance fault detection and response times in large-scale industrial environments. The system leveraged the high-speed, low-latency capabilities of 5G to facilitate real-time data collection from a vast network of IoT-enabled sensors embedded in critical machinery. These sensors continuously monitored key operational parameters such as temperature, vibration, pressure, and energy consumption, transmitting data to a centralized cloud-based analytics platform. By utilizing edge computing and AI-driven predictive models, the system rapidly processed sensor data to detect early signs of equipment failure and provided instant alerts to maintenance teams. The study revealed that the 5G network significantly improved fault detection response times compared to traditional wired and wireless communication systems, enabling proactive maintenance interventions before severe failures occurred. This approach minimized unplanned downtime, optimized resource allocation, and enhanced overall operational efficiency. Hitachi's findings underscored the transformative potential of 5G in industrial predictive maintenance, paving the way for smarter, interconnected manufacturing ecosystems with improved reliability and cost-effectiveness.

3. PROPOSED METHODOLOGY

This project introduces an Industrial Predictive Maintenance System using Raspberry Pi Pico with vibration and temperature sensing, integrating fire, gas, temperature, and vibration monitoring to enhance industrial safety. The system continuously monitors environmental and machine parameters and triggers alerts via buzzer, LED indicators, and IoT notifications when abnormal conditions are detected.

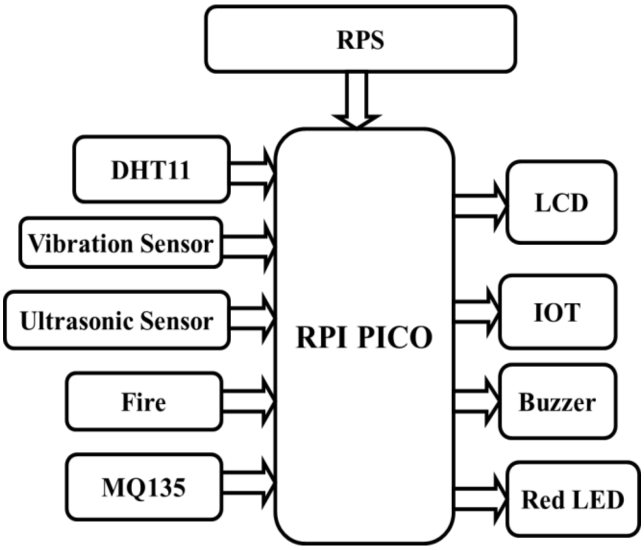


Figure 1: Proposed system.

Fires in industries can be catastrophic, leading to equipment damage, human casualties, and financial losses. To mitigate fire risks, the system includes a fire sensor (Flame Sensor Module) to detect flames and sudden temperature surges. If a fire is detected: A buzzer is activated to alert nearby personnel. A red LED indicator is turned on as a visual warning.

An IoT-based notification is sent to responsible authorities for immediate action. This real time monitoring ensures quick response times and minimizes fire hazards in industrial environments.

Many industries utilize flammable and toxic gases, which, if leaked, can cause explosions or health hazards. The project integrates an MQ-series gas sensor (e.g., MQ-2, MQ-5, or MQ-135) to detect the presence of harmful gases such as methane, LPG, carbon monoxide, or ammonia. If gas leakage is detected. The buzzer sounds an alarm to alert workers.

The red LED lights up as a warning signal. An IoT alert is sent to notify maintenance teams or 11 safety officers. This feature ensures early detection of gas leaks, preventing industrial accidents and ensuring worker safety.

Industrial machines generate significant heat, and extreme temperatures can cause overheating, insulation failure, or fire hazards. The system incorporates a DHT11 sensor to measure both temperature and humidity levels.

When temperature or humidity exceeds a predefined threshold value: A buzzer is activated to signal abnormal conditions.

The red LED is turned on as a visual alert. An IoT notification is sent, allowing remote monitoring and preventive maintenance. This real-time monitoring helps industries prevent overheating issues, ensure optimal working conditions, and protect sensitive machinery.

Industrial machinery is prone to mechanical failures, such as bearing wear, misalignment, or structural damage. Additionally, strong vibrations can indicate potential earthquakes or structural instability in industrial buildings.

The system uses a vibration sensor to detect abnormal vibrations. If excessive vibrations are recorded: The buzzer sounds an alarm for immediate awareness.

The red LED is turned on to indicate the issue. An IoT-based warning is sent, allowing remote monitoring and proactive maintenance.

This feature ensures early fault detection in machinery, reducing downtime and preventing severe industrial failures.

This Raspberry Pi Pico-driven predictive maintenance system integrates fire, gas, temperature, humidity, and vibration monitoring to ensure industrial safety.

The system enhances real-time monitoring and automates alert mechanisms via buzzers, LEDs, and IoT notifications.

By implementing this solution, industries can prevent major accidents, reduce maintenance costs, and ensure worker safety through automated, real-time, and data-driven decision-making.

4. EXPERIMENTAL ANALYSIS

The below figure shows the complete output of the project before the device is powered on. It includes all the main components: Raspberry Pi Pico, a regulated power supply, and various sensors and modules, including a fire sensor, smoke sensor, vibration sensor, DHT11 temperature and humidity sensor, ultrasonic sensor, ESP8266 Wi-Fi module, and IoT module.

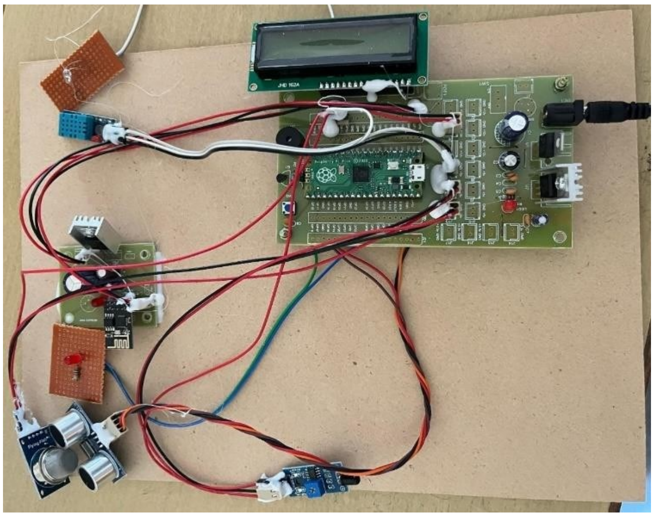


Figure 2: IoT-Based Industrial Monitoring System with Raspberry Pi Pico

The below figure shows the complete project which after the devices is turn on and the LCD screen display the Industrial Predective Maintenance.

Figure 3 :Industrial Predictive Maintenance System Using IoT

The figure shows the module connecting to the network, allowing the LCD screen to display sensor values, which indicate that the module has successfully connected to the network, **PSNR**

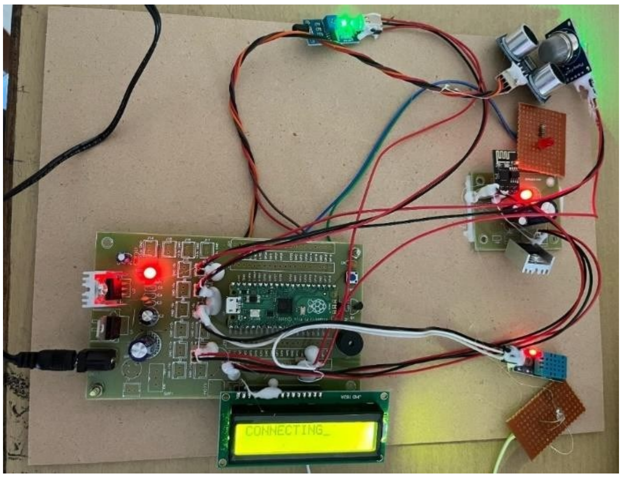


Figure 4 :Module is connecting to network

The below figure shows the values from the DHT11 temperature and humidity sensor and the ultrasonic sensor. The DHT11 sensor provides temperature and humidity readings for a particular factory, while the ultrasonic sensor measures the distance of a person from the machines. The remaining sensors, such as the fire sensor, vibration sensor, and smoke sensor, remain off by default and activate only when they detect fire, smoke, or vibrations. When activated, the LCD screen displays which sensor has been triggered, and the buzzer will beep to alert about potential danger. Additionally, the data is uploaded to the IoT server, allowing real-time monitoring of the machine's status.

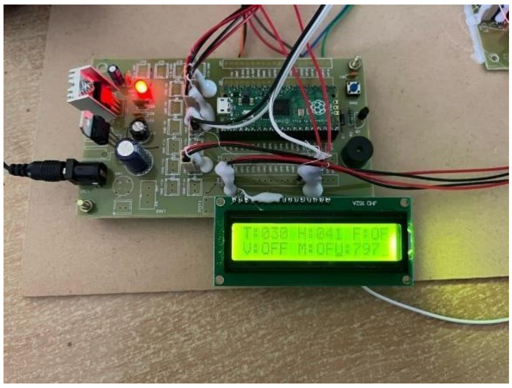
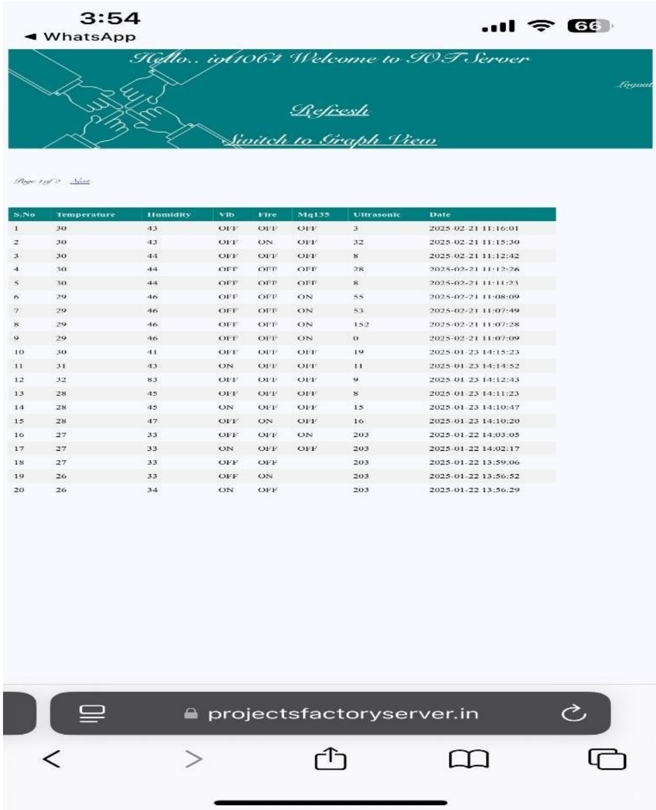


Figure 5 :Sensor Data Display

In this figure, we can observe the recorded values of temperature, humidity, vibration, fire (both on and off conditions), and the ultrasonic sensor readings. Additionally, the figure displays the login date and time, ensuring proper tracking and monitoring of the system's status in real time. This allows for efficient analysis and timely response to any detected anomalies.



S.No	Temperature	Humidity	Vib	Fire	Mq135	Ultrasonic	Date
1	30	43	OFF	OFF	OFF	3	2025-02-21 11:16:01
2	30	43	OFF	ON	OFF	32	2025-02-21 11:15:30
3	30	44	OFF	OFF	OFF	8	2025-02-21 11:12:42
4	30	44	OFF	OFF	OFF	28	2025-02-21 11:12:26
5	30	44	OFF	OFF	OFF	8	2025-02-21 11:11:23
6	29	46	OFF	OFF	ON	55	2025-02-21 11:08:09
7	29	46	OFF	OFF	ON	53	2025-02-21 11:07:49
8	29	46	OFF	OFF	ON	152	2025-02-21 11:07:28
9	29	46	OFF	OFF	ON	0	2025-02-21 11:07:09
10	30	41	OFF	OFF	OFF	19	2025-01-23 14:15:23
11	31	43	ON	OFF	OFF	11	2025-01-23 14:14:52
12	32	83	OFF	OFF	OFF	9	2025-01-23 14:12:43
13	28	45	OFF	OFF	OFF	8	2025-01-23 14:11:23
14	28	45	ON	OFF	OFF	15	2025-01-23 14:10:47
15	28	47	OFF	ON	OFF	16	2025-01-23 14:10:20
16	27	33	OFF	OFF	ON	203	2025-01-22 14:03:05
17	27	33	ON	OFF	OFF	203	2025-01-22 14:02:17
18	27	33	OFF	OFF		203	2025-01-22 13:59:06
19	26	33	OFF	ON		203	2025-01-22 13:56:52
20	26	34	ON	OFF		203	2025-01-22 13:56:29

Figure:6 IoT Server Data Log for Sensor Monitoring

5. CONCLUSION

The Raspberry Pi Pico-Driven Industrial Predictive Maintenance System enhances safety, reliability, and efficiency in industrial environments by integrating vibration, temperature, fire, and gas leakage sensing. Traditional maintenance methods are often reactive and inefficient, leading to unexpected failures, increased downtime, and higher operational costs.

This project addresses these limitations by providing a real-time, IoT-enabled monitoring system that detects potential hazards before they escalate into major accidents.

The system uses fire sensors to detect flames, MQ-series gas sensors to identify harmful gas leaks, DHT11 sensors to monitor temperature and humidity variations, and vibration sensors to detect machinery faults or earthquakes. When abnormal conditions are detected, immediate alerts are triggered through buzzers, LED indicators, and IoT notifications, ensuring timely preventive action.

By leveraging Raspberry Pi Pico, this system offers a low-cost, scalable, and efficient predictive maintenance solution. The integration of IoT technology enables remote monitoring, reducing the need for manual inspections and improving industrial safety, equipment lifespan, and maintenance efficiency.

In conclusion, this project provides a smart, real-time predictive maintenance system that can significantly reduce industrial risks, enhance worker safety, and optimize operational performance.

With further advancements in AI and cloud-based analytics, this system can be expanded to provide automated fault diagnosis and predictive insights, making industries more resilient and proactive in maintaining their critical machinery.

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