MACHINE LEARNING FOR ENERGY OPTIMIZATION IN SMART FACTORIES

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Abstract— **The advent of smart factories, driven by Industry 4.0, has transformed traditional manufacturing by integrating advanced technologies such as IoT, AI, and real-time data analytics. This shift enables seamless automation, enhanced decision-making, and improved efficiency in production processes. Existing manufacturing systems rely on conventional monitoring methods, often leading to inefficiencies, unplanned downtimes, and reactive maintenance approaches. Traditional factories struggle with limited real-time insights, making it challenging to optimize resource utilization and predict failures. To address these challenges, smart factory solutions incorporating machine monitoring have been proposed to enhance operational efficiency and productivity. By leveraging interconnected sensors, automated data collection, and predictive analytics, manufacturers can track equipment performance in real time, minimize downtime, and proactively address maintenance needs. These improvements lead to optimized resource allocation, reduced operational costs, and enhanced product quality. Additionally, smart monitoring ensures compliance with safety standards, supports agile decision-making, and improves overall sustainability. The integration of IoT-enabled devices and intelligent analytics enables factories to adapt to dynamic market demands with greater flexibility. As a result, smart factories position themselves at the forefront of industrial innovation, offering a competitive edge by driving efficiency, cost savings, and improved production outcomes.**

***Keywords*— Smart factories, Industry 4.0, Real-time utilization, Predictive analytics, Productivity, Safety standards, Operational Costs**

I. INTRODUCTION

The rapid advancement of Industry 4.0 has driven the need for smart factory solutions that enhance efficiency, safety, and real-time monitoring. The integration of the Internet of Things (IoT) with industrial automation allows factories to operate more effectively by collecting and analyzing data to optimize performance. A Smart Factory Monitoring System using Node MCU leverages IoT technology to monitor critical parameters such as temperature, voltage, current, and oil leakage. This system ensures continuous tracking of key factory conditions, reducing downtime and preventing potential hazards.

The proposed system incorporates a thermal sensor, voltage and current measuring units, and an oil leakage detector, all connected through a Node MCU microcontroller. The collected data is transmitted to a cloud-based web application, where factory operators can monitor real-time sensor readings and receive alerts in case of anomalies. This allows for proactive maintenance, ensuring safety and operational efficiency. The use of wireless connectivity and data logging capabilities enables quick response to irregularities, reducing the risk of equipment failures and energy wastage.

By implementing this smart monitoring system, industries can benefit from enhanced automation, predictive maintenance, and improved energy management. The ability to monitor multiple parameters remotely ensures cost savings and increased productivity while reducing manual inspections. This project demonstrates how IoT-powered solutions can revolutionize industrial monitoring by providing real-time insights and intelligent decision-making, ultimately leading to a safer and more efficient factory environment.

This Paper flows Section 2 Literature Survey, Section 3 Existing System, Section 4 Proposed System, Section 6 Result, Section 7 Conclusion and future Enhancement and finally References.

II. LITERATURE SURVEY

[1] This article introduces Event-Dependent Process Planning (EDPP) to promote time-efficiency in smart factories. EDPP automatically plans activities according to previous results and matches them with customer demand through intelligent measuring tools. Recurrent learning is used to provide continuous improvement of process planning. The strategy is implemented on the delivery and production layers of manufacturing automation. Experimental results demonstrate significant improvements, such as less processing time, delay in delivery, and blocking rate, as well as an enhanced response ratio.

[2] This research examines the determinants of smart factory adoption in Korean manufacturing SMEs. It emphasizes that the efficiency of current production systems greatly enhances firms' intention to implement smart factories. Top management support for information systems does not have significant effect. The research further discovers that production system in-house development enhances the mechanism of adoption. The discoveries provide strategic knowledge for companies transitioning into smart manufacturing.

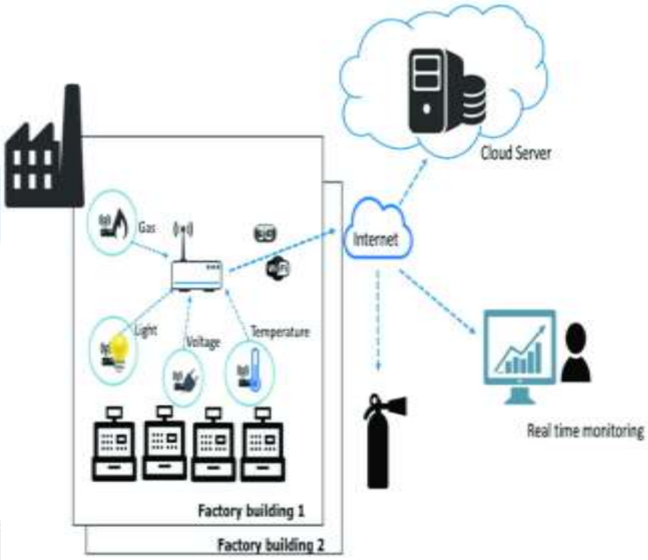
[3] The work suggests a new smart factory structure for converting traditional factories to digital ones based on open-source software. It unifies six primary components: cyber-physical systems, edge computing, AI, cloud computing, data analytics, and cybersecurity. A proof of concept using a model for a pick-and-place Tangram puzzle assembly proved the system's flexibility and responsiveness. Key performance metrics validated successful integration and repeatability. The structure is a feasible solution for small and medium factories with goals of digitization.

[4] This paper introduces Ultra-Wideband air-to-ground wireless measurements made in an actual factory environment to investigate UAV-aided applications in smart factories. It investigates narrow and wide band radio channel properties at different heights and positions within the 3.1-5.3 GHz range. The work offers link budget, interference, and time dispersion insights for aerial communications. Comparison is made with ground measurements, and differences and benefits are outlined. The results confirm the establishment of intelligent, wireless, UAV-integrated factory systems. Actical solution for small and medium factories toward digitization.

[5] This paper discusses recent developments in strain sensor technology as a central enabling technology for the next generation of smart machines and intelligent tools. As Industry 4.0 emerges, there is a critical need to harvest real-time data from manufacturing operations, and strain sensors provide an effective means of achieving greater insight into machines. The review discusses mature, ready-for-industrial-use strain sensing technologies, examining parameters such as sensitivity, power supply, connectivity, and resilience. It highlights the necessity of "technology-solution fit" for efficient implementation. The paper acts as a manual to researchers and industrialists to make intelligent, data-driven machines.

III. EXISTING SYSTEM

The research paper discusses the challenges and improvements: The integration of IoT-enabled intelligent measuring devices has transformed factory monitoring through automated data acquisition and enhanced real-time analysis. Smart factories utilize networked sensors and predictive analytics to monitor equipment performance, detect possible failures, and optimize resource allocation. Introducing Event-Dependent Process Planning(EDPP) makes operations more efficient by scheduling operations



dynamically with historical data and customer needs. This shift reduces downtime, enhances production planning, and provides smooth monitoring at all levels of manufacturing. Centralized monitoring systems enable industries to attain increased productivity, lowered operation expenses, and improved quality levels in production.

Conversely, the report identifies challenges such as infrastructure integration is a huge barrier since the old systems have to undergo heavy modifications to be compatible with state-of-the-art IoT technologies. The hefty up-front investment in sensors, networks, and automation equipment may deter numerous industries. Additionally, greater dependence on cloud-based monitoring and connectivity is worrying from the data security and cyber-attack front, calling for stringent protective protocols. Besides, the labor force has to accommodate these technologies, and the employees have to undergo a lot of training to translate real-time data and run automated systems. Accomplishing this is necessary for industries to realize the full potential of smart factories.

The shift towards smart factories improves efficiency through real-time tracking, predictive maintenance, and optimization of resources. Although integration complexity and cybersecurity threats pose challenges, the advantages surpass the disadvantages. IoT-facilitated technologies will be important to the future of industrial automation.

IV. PROPOSED METHODOLOGY

The proposed **Smart Factory Monitoring System** utilizes a **NodeMCU microcontroller** to enable real-time monitoring of industrial environments through an **IoT-based web application**. This system integrates multiple sensors, including a **thermal sensor** for detecting temperature variations, a **voltage and current sensor** to measure electrical parameters, and an **oil leakage detector** for identifying potential hazards. The collected data is transmitted wirelessly to a **cloud-based platform**, where it is analyzed and displayed in an intuitive web interface. This allows factory operators to monitor **equipment conditions remotely**, receive **instant alerts** for abnormal readings, and take **proactive maintenance actions** to prevent failures. The system enhances safety, improves operational efficiency, and reduces downtime through predictive maintenance.

1) System Architecture

The system is built using a multi-layer structure to ensure it's easy to manage, scalable, and can handle data efficiently. It has four main parts:

A. Sensor Data Acquisition Layer

Sensors continuously monitor temperature, voltage, current, and oil leakage. The Node MCU collects sensor data at regular intervals.

B. Data Processing & Communication Layer

Data is processed on the Node MCU and sent to the cloud via Wi-Fi (MQTT/HTTP Protocols). Alerts (via buzzer/LEDs) are triggered locally if any parameter exceeds predefined thresholds.

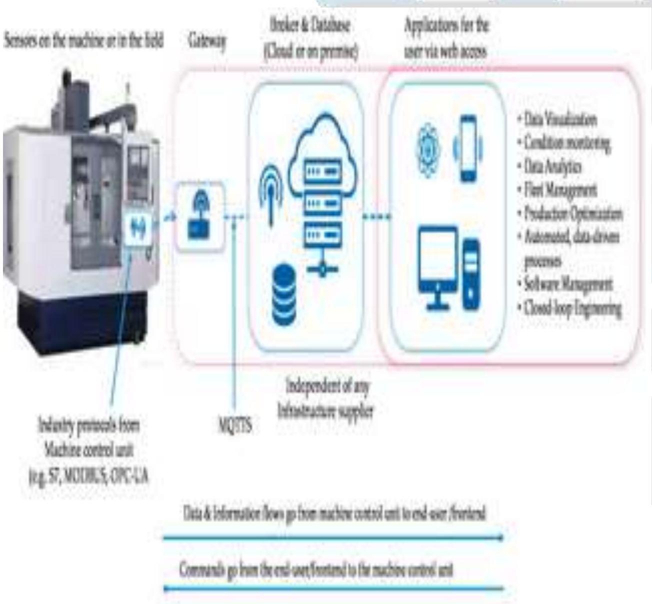
C. IoT Web Application & Dashboard Layer

The IoT web application (hosted on Firebase, ThingsBoard, or Blynk) displays real-time sensor data. • Users can access historical trends, receive alerts, and remotely monitor factory conditions.

D. Alert & Notification System

If any parameter crosses its threshold, notifications are sent via Email/SMS/Push notifications. The system logs critical events for future analysis.

2) Data Flow Diagram



3) Tools and Technologies

A. NodeMCU (ESP8266/ESP32) - Central Control Unit

The Node MCU (ESP8266/ESP32) is the core processing unit responsible for collecting sensor data, processing it, and transmitting it to the cloud for real-time monitoring. It acts as a bridge between sensors and the IoT platform, enabling remote access and automated alerts. With built-in Wi-Fi capabilities, the NodeMCU ensures seamless communication between the hardware components and the web application. It is programmed using Embedded C in the Arduino IDE, allowing for efficient control of multiple connected devices. The module ensures high-speed data transmission and is capable of executing real-time commands for immediate responses to critical situations.

B. Thermal Sensor Module

The thermal sensor module continuously monitors temperature variations in factory environments. It utilizes temperature sensors like MLX90614, DHT11, or DHT22, depending on the accuracy and range required. This module is crucial in preventing overheating of industrial machines by continuously tracking temperature levels and sending alerts when predefined thresholds are exceeded. Overheating detection is vital to avoid potential equipment failures, fire hazards, and energy inefficiencies. The temperature data is displayed in real-time on the IoT dashboard, allowing operators to take proactive measures to maintain optimal working conditions.

C. Voltage and Current Measurement Module

This module ensures that factory machinery operates within safe voltage and current limits. It uses voltage sensors such as ZMPT101B and current sensors like ACS712 to continuously measure and monitor electrical parameters. The system can detect power fluctuations, short circuits, and overloading conditions, preventing potential electrical failures. If any abnormality is detected, an alert is triggered via the IoT platform, ensuring that immediate corrective actions can be taken. Additionally, the module helps optimize power consumption by providing insights into energy usage patterns, which can be used to implement cost-saving measures.

D. Oil Leakage Detection Module

Oil leaks in machinery can lead to major operational hazards, including fire risks, environmental contamination, and costly equipment damage. The oil leakage detection module employs sensors such as MQ-3, TGS 822, or custom-built oil spill sensors to identify the presence of oil leakage in pipelines and machinery. When leakage is detected, an alarm is triggered, and an alert is sent to the IoT web application for immediate action. This early detection system helps prevent hazardous accidents and reduces maintenance costs by allowing timely repairs. The collected data can also be used to assess trends and prevent future leaks.

E. IoT Web Application Module

The IoT web application serves as the centralized monitoring and control interface. It is built using modern web technologies, including HTML, CSS, and JavaScript for the frontend, with backend support from Node.js, Firebase, or ThingSpeak. The web dashboard provides real-time data visualization, logs historical sensor readings, and allows users to configure threshold values for alerts. The application enables remote monitoring, allowing factory operators and engineers to access data from anywhere and take necessary actions based on real-time insights. With features such as user authentication, role-based access control, and mobile-friendly UI, the web application enhances operational efficiency and security.

F. Communication and Data Transmission

Seamless data transmission between sensors, the NodeMCU, and the cloud is essential for real-time monitoring and decision-making. This module uses Wi-Fi, MQTT (Message Queuing Telemetry Transport), and HTTP protocols to ensure continuous data flow. MQTT is a lightweight messaging protocol designed for IoT applications, ensuring low-latency and efficient data transfer. The NodeMCU collects data from sensors, processes it, and transmits it to the cloud-based IoT platform. The web application retrieves this data, visualizes it, and triggers alerts when needed. This reliable communication mechanism enables industrial automation, predictive maintenance, and remote fault detection.

V. FEATURE OF SMART FACTORIES

A. *Real-Time Equipment Monitoring*

The system continuously tracks temperature, voltage, current, and oil leakage using IoT-enabled sensors, providing a live status of factory machinery and environmental conditions. These sensors send data to a central control unit, which processes and analyzes the readings in real time. If the system detects irregularities such as overheating, excessive power consumption, or oil spills, it instantly triggers an alert to notify operators. This proactive monitoring prevents unexpected machine breakdowns, fire hazards, and production halts, ensuring that operations run smoothly without costly delays. Furthermore, historical data from real-time monitoring helps identify long-term performance trends, allowing for data-driven maintenance planning.

1) *Sensor:*

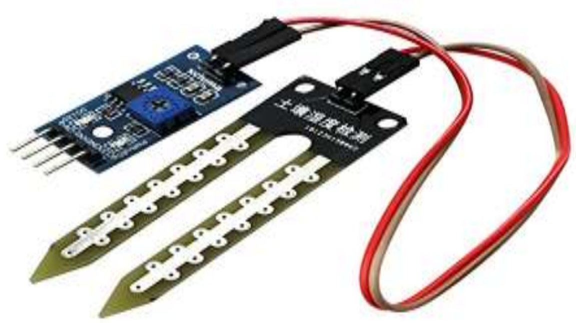


Fig 1.
Moisture Sensor

Moisture Sensors quantify the volumetric water content of. As direct gravimetric measurement of free moisture involves removal, drying, and weighing of a sample, moisture sensors indirectly measure the volumetric water content using some other characteristic of the, e.g., electrical resistance, dielectric constant, or neutron interaction, as a surrogate for the moisture content.

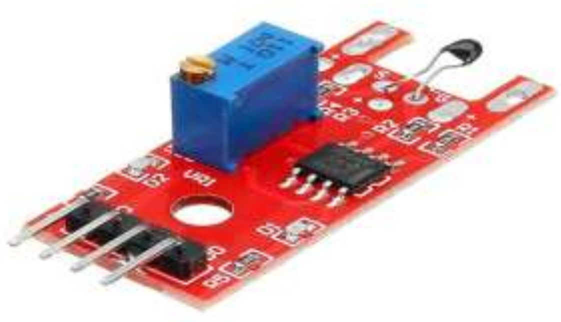


Fig 2
MLX90614 Thermal Sensor

Measures the temperature of machinery and surroundings in the factory. Helps in preventing overheating and ensures an optimal working environment.

Fig 3
TGS 822 Oil Detection Sensor

Detects oil leakage in factory equipment and pipelines. Prevents hazards such as fire risks, contamination, and equipment damage.

B. *Remote Monitoring Through IoT Web Application*

The system includes a cloud-based IoT dashboard that allows factory managers and engineers to monitor real-time sensor data, alerts, and system performance from any location. Built using HTML, CSS, JavaScript, and Node.js, the dashboard offers a responsive and interactive interface, accessible via desktop, tablet, or smartphone. Users can view live sensor readings, check historical trends, and receive alerts instantly. Additionally, the dashboard allows operators to configure sensor thresholds, generate reports, and track system logs. Remote access to factory conditions eliminates the need for manual supervision, ensuring that decision-makers can respond to emerging issues promptly, even when off-site.

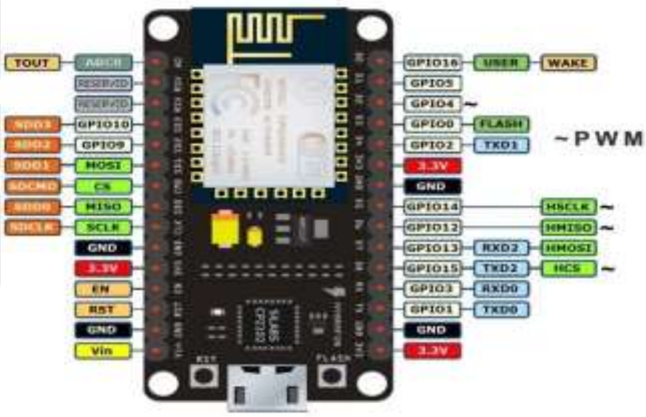


Fig 4. Node MCU V3 Pinout

Node MCU V3 comes with a number of GPIO Pins. There is a candid difference between Vin and VU where former is the regulated voltage that may stand somewhere between 7 to 12 V while later is the power voltage for USB that must be kept around 5 V.

Fig 5. LCD Display

A liquid crystal display (LCD) is a flat panel display, electronic visual display, or video display that uses the light modulating properties of liquid crystals. Liquid crystals do not emit light directly.

C. Instant Alerts and Notifications for Anomalies

Whenever an anomalous condition is detected, the system generates immediate alerts via SMS, email, push notifications, and on-screen warnings. These alerts ensure that operators can respond quickly to prevent potential disasters. The system categorizes alerts based on severity levels, prioritizing critical failures such as electrical faults, overheating, or hazardous leaks over minor warnings. Additionally, operators can customize notification preferences to receive alerts based on their roles or responsibilities. This ensures that emergency situations are handled by the appropriate personnel, preventing costly damage, production delays, and safety risks.

D. Energy Optimization and Power Efficiency

Factories often experience high electricity costs due to unmonitored power usage, inefficient machine operation, and energy wastage. The system integrates voltage and current sensors (ZMPT101B & ACS712) to track power consumption trends in real time. By identifying excessive energy use, power surges, and underutilized equipment, the system helps factory managers implement energy-saving strategies. This data-driven approach allows industries to reduce electricity expenses, enhance sustainability, and prevent overloading-related damage. Additionally, AI-driven energy analysis helps detect anomalies in power consumption patterns, enabling predictive energy management and reducing overall carbon footprint.

E. Workplace Safety and Hazard Prevention

Factory environments often involve high-risk machinery, hazardous chemicals, and potential fire hazards. This system enhances workplace safety by monitoring overheating, oil leaks, voltage irregularities, and current fluctuations. In the event of a critical safety risk, the system immediately triggers alarms, shuts down affected machinery, and notifies emergency personnel. By automating safety monitoring, the system ensures that factories comply with workplace safety regulations, reducing accident risks and legal liabilities. Additionally, the data collected can be used for risk assessments and future safety planning, improving overall hazard prevention strategies.

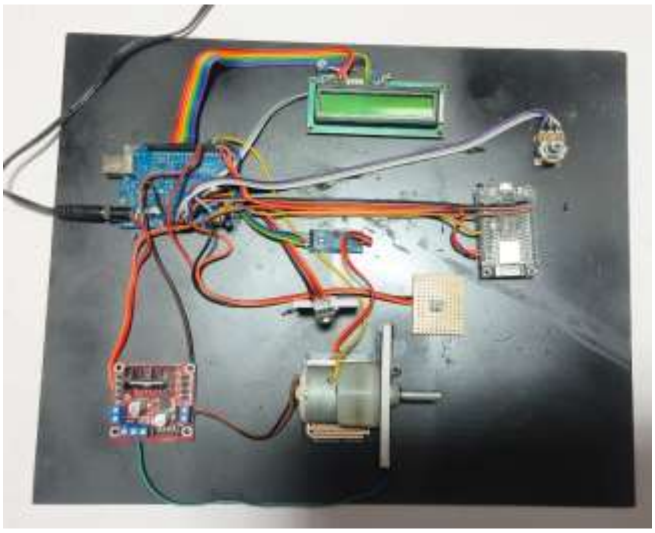


Fig 6. Monitoring System

F. Secure Wireless Communication and Cloud Storage

To ensure reliable data transmission, the system uses Wi-Fi-based communication via MQTT and HTTP protocols. This allows real-time data synchronization between factory machines and cloud storage platforms like Firebase, AWS, or ThingsBoard. Cloud storage provides scalability, backup security, and long-term data access, making it an ideal solution for multi-factory management. Additionally, end-to-end encryption is implemented to secure sensitive machine data from cyber threats and unauthorized access. By leveraging cloud-based architecture, factories can integrate multiple production sites into a single monitoring system, enabling seamless remote factory management.

G. Customizable User Interface and Configurable Alerts

The system provides a flexible user interface, allowing operators to customize sensor threshold values, set alert preferences, and generate reports based on factory-specific requirements. Users can define specific warning levels for different machines, ensuring that critical alerts receive immediate attention, while less severe warnings are logged for further review. Additionally, the system supports multi-user roles, allowing factory managers, engineers, and maintenance teams to access role-based dashboards with tailored insights. This customization ensures that the system is adaptable to different manufacturing industries, production scales, and safety regulations.

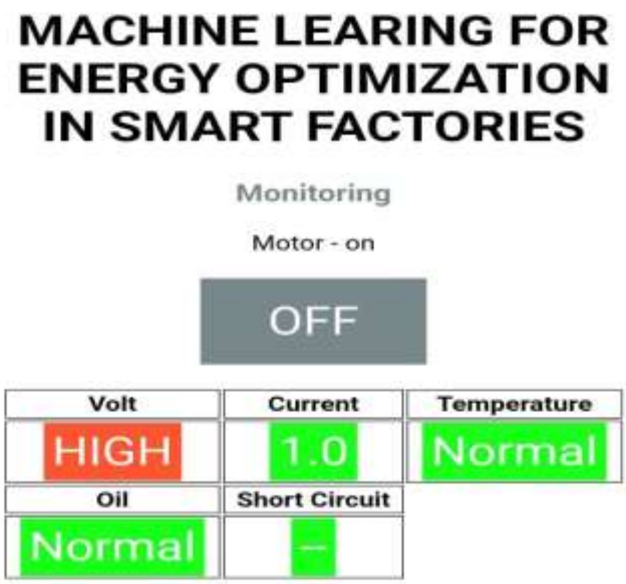


Fig 7. Desired Output

VI. Result

The implementation of the Smart Factory Monitoring System integrates multiple sensors with a Node MCU microcontroller, leveraging IoT technology to track critical factory parameters. It includes thermal sensors for temperature variations, voltage and current sensors for power monitoring, and an oil leakage detector for hazard detection. The Node MCU processes and wirelessly transmits collected data to a cloud-based IoT web application for real-time monitoring. Programmed using Arduino IDE and utilizing the

MQTT protocol, the system ensures secure and efficient data transmission. A web-based dashboard displays sensor readings, enabling remote monitoring and alerting factory personnel to abnormal conditions for quick responses. Designed for adaptability in industrial settings, the system features strategically placed sensors, stable DC power, and data logging capabilities, improving operational efficiency and workplace safety.

Conclusion

In conclusion, the Smart Factory Monitoring System using Node MCU through an IoT web application provides a comprehensive and efficient solution for real-time industrial monitoring. By integrating thermal sensors, voltage and current measurement modules, and an oil leakage detector, the system enhances safety, improves operational efficiency, and minimizes downtime. The use of IoT technology enables remote monitoring, allowing factory managers to receive instant alerts and take proactive measures to prevent potential failures. This smart system not only optimizes resource utilization but also contributes to a safer and more reliable industrial environment, making it a valuable innovation for modern manufacturing facilities

VII. FUTURE ENHANCEMENT

To further enhance the system's capabilities, several advancements can be integrated:

A. *AI and Machine Learning Integration*

Incorporating AI and ML algorithms can enhance predictive maintenance, reducing unexpected failures and operational costs by analyzing historical data and identifying patterns.

B. *Expanded Sensor Network*

Adding sensors for vibration analysis, gas leakage detection, and humidity monitoring can improve safety, efficiency, and overall factory performance.

C. *Cloud-Based Data Analytics*

Utilizing cloud platforms for data storage and real-time analytics can provide better trend analysis, helping industries optimize production and maintenance strategies.

D. *Real-Time Dashboards*

Implementing user-friendly dashboards with real-time visualization of machine performance and alerts can aid in quicker decision-making.

E. *5G Connectivity Integeration*

Integrating 5G technology will enhance data transmission speed and reliability, ensuring seamless remote monitoring and control of factory operations.

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