AI-BASED INDUSTRIAL FAULT DETECTION AND IOT MONITORING SYSTEM USING FPGA

[1]KOMMULA ANJALI, [2]Mrs. V. TEJASWI, [3]BALNAGAR BALAJI, [4]BOBBILI DEVI AVINASH KARTHIKEYA, [5]ETEKELA ROHITH

[1,3,4,5]Students, Department of Electronics and Communication Engineering, Siddhartha Institute Of Technology & Sciences, Narapally, Telangana-501301, 23TQ5A0404@siddhartha.co.in, 24TQ5A0403@siddhartha.co.in, 23TQ1A0404@siddhartha.co.in, 23TQ1A0428@siddhartha.co.in

[2]Assistant Professor, Department of Electronics and Communication Engineering, Siddhartha Institute Of Technology & Sciences, Narapally, Telangana-501301, tejaswi@siddhartha.org.in

ABSTRACT

Industrial automation has become an essential component of modern manufacturing systems, where continuous equipment monitoring and rapid fault detection are critical for ensuring operational reliability, worker safety, and production efficiency. Unexpected equipment failures can lead to production downtime, increased maintenance costs, reduced product quality, and potential safety hazards. Conventional fault detection systems generally rely on periodic inspections or standalone monitoring devices, which often fail to identify faults at an early stage and provide limited remote monitoring capabilities. Recent advancements in Field Programmable Gate Arrays (FPGA), Internet of Things (IoT), embedded systems, and cloud computing have enabled the development of intelligent industrial monitoring systems capable of high-speed fault detection and real-time remote supervision. This project presents an FPGA-Based Industrial Fault Detection Using IoT, designed to continuously monitor industrial equipment and rapidly detect abnormal operating conditions. The proposed framework integrates an FPGA controller, temperature, vibration, current, voltage, and gas sensors, Wi-Fi communication, IoT cloud platform, and intelligent fault analysis algorithms into a unified industrial monitoring system. The FPGA processes multiple sensor inputs simultaneously through parallel hardware architecture, enabling rapid fault identification with minimal processing delay. The monitored data are transmitted to the IoT cloud platform for real-time visualization, historical storage, and remote monitoring. Whenever abnormal operating conditions such as overheating, excessive vibration, abnormal current, voltage fluctuations, or gas leakage are detected, the system immediately generates warning alerts and notifies maintenance personnel through cloud-based communication. Experimental evaluation demonstrates accurate fault detection, high-speed FPGA processing, reliable IoT communication, low response time, and stable system performance under different industrial operating conditions. The proposed framework significantly improves industrial safety, minimizes equipment downtime, supports predictive maintenance, reduces maintenance costs, and contributes to the development of intelligent Industry 4.0 manufacturing systems.

Keywords: FPGA, Internet of Things (IoT), Industrial Fault Detection, Industry 4.0, Predictive Maintenance, Temperature Sensor, Vibration Sensor, Current Sensor, Cloud Monitoring, Industrial Automation.

I. INTRODUCTION

Industrial automation has become one of the most important technological developments in modern manufacturing, enabling industries to improve productivity, operational efficiency, and product quality. Continuous operation of industrial machinery is essential for maintaining production schedules and minimizing manufacturing costs. However, unexpected equipment failures caused by overheating, excessive vibration, electrical faults, mechanical wear, or abnormal operating conditions can result in costly production downtime, equipment damage, and safety hazards for workers. Conventional fault detection systems mainly depend on periodic manual inspections or standalone monitoring devices, which often fail to identify equipment failures during their early stages. Consequently, industries require intelligent monitoring systems capable of continuously supervising equipment conditions and detecting faults before catastrophic failures occur. Recent advancements in embedded systems, Field Programmable Gate Arrays (FPGA), sensor technology, Internet of Things (IoT), and cloud computing provide effective solutions for developing high-speed industrial monitoring systems. Intelligent fault detection platforms enable continuous acquisition of sensor data, rapid fault identification, real-time remote monitoring, and predictive maintenance. These technologies significantly improve industrial safety, reduce maintenance costs, increase equipment reliability, and support the development of smart manufacturing environments aligned with Industry 4.0 principles [1–8].

Field Programmable Gate Arrays (FPGAs) have gained widespread attention in industrial automation because of their high-speed parallel processing capability, reconfigurable hardware architecture, and ability to process multiple sensor inputs simultaneously. Unlike conventional microcontrollers, FPGAs execute multiple operations concurrently, making them highly suitable for real-time industrial fault detection applications where rapid response is essential. Modern industrial monitoring systems integrate FPGA controllers with temperature sensors, vibration sensors, voltage sensors, current sensors, gas sensors, and wireless communication modules to continuously supervise equipment health. The

Internet of Things further enhances industrial monitoring by enabling secure communication between industrial equipment and cloud platforms. IoT-based dashboards provide real-time visualization of machine conditions, historical operating records, predictive maintenance analysis, and remote fault notifications. Experimental investigations demonstrate that FPGA-based IoT monitoring systems significantly reduce fault detection time, improve operational reliability, and enable proactive maintenance strategies that minimize equipment failures and production losses [9–17].

This project proposes an FPGA-Based Industrial Fault Detection Using IoT to provide intelligent, high-speed, and reliable monitoring of industrial equipment. The proposed framework integrates an FPGA controller, temperature sensor, vibration sensor, current sensor, voltage sensor, gas sensor, Wi-Fi communication module, and an IoT cloud platform into a unified industrial fault detection system. Initially, the sensors continuously monitor important operating parameters including machine temperature, vibration level, electrical current, supply voltage, and gas leakage. The FPGA receives all sensor inputs simultaneously and processes them using parallel hardware architecture to identify abnormal operating conditions with minimal latency. Whenever measured values exceed predefined safety thresholds, the FPGA immediately classifies the event as a fault and generates warning alerts. Simultaneously, operational data and fault information are transmitted to the IoT cloud platform for remote monitoring, historical storage, and predictive maintenance analysis. The effectiveness of the developed framework is evaluated using engineering parameters such as fault detection accuracy, processing latency, communication delay, sensor accuracy, response time, and overall system reliability. Experimental evaluation demonstrates that the proposed FPGA-based monitoring system accurately detects industrial faults, provides reliable cloud communication, minimizes maintenance downtime, improves equipment reliability, and supports the implementation of intelligent Industry 4.0 manufacturing systems [18–25].

II. SURVEY OF RESEARCH

1. FPGA-Based Industrial Monitoring Systems

2. Field Programmable Gate Arrays (FPGAs) have become an important platform for industrial automation because of their high-speed parallel processing capability and flexible hardware architecture. Researchers have implemented FPGA-based monitoring systems for continuously supervising industrial machinery and detecting equipment faults in real time. Unlike conventional microcontrollers, FPGAs execute multiple operations simultaneously, enabling rapid processing of sensor data with minimal latency. Modern FPGA-based systems integrate temperature, vibration, current, voltage, and pressure sensors for continuous equipment health monitoring. Experimental studies demonstrate that FPGA-based fault detection systems significantly improve processing speed, reduce equipment downtime, and increase industrial reliability. These investigations confirm that FPGA technology is highly suitable for Industry 4.0 applications requiring high-speed fault detection and intelligent automation **[1]**.

3. IoT-Based Industrial Equipment Monitoring

4. The Internet of Things (IoT) has transformed industrial automation by enabling continuous communication between industrial equipment and cloud-based monitoring platforms. Researchers have integrated IoT communication modules with industrial controllers to transmit machine operating parameters for remote supervision. Cloud dashboards provide real-time visualization of equipment status, fault history, maintenance records, and performance trends. IoT-based monitoring enables maintenance engineers to supervise industrial systems remotely while receiving immediate notifications during abnormal operating conditions. Experimental investigations indicate that IoT-enabled monitoring significantly improves maintenance efficiency, reduces inspection time, and supports predictive maintenance. These developments demonstrate the importance of IoT technology in modern industrial monitoring systems **[2]**.

3. Sensor-Based Fault Detection Techniques

Industrial fault detection systems rely on multiple sensors to continuously monitor machine operating conditions. Researchers have employed temperature sensors, vibration sensors, current sensors, voltage sensors, gas sensors, and pressure sensors to identify equipment abnormalities before severe failures occur. Continuous acquisition of sensor data enables intelligent monitoring systems to detect overheating, excessive vibration, electrical overload, voltage fluctuations, and hazardous gas leakage. Experimental studies demonstrate that multi-sensor monitoring significantly improves fault detection accuracy while reducing false alarms. The integration of multiple sensing technologies enables comprehensive machine health assessment and supports predictive maintenance in industrial environments **[3]**.

4. Cloud Computing for Predictive Maintenance

5. Cloud computing has become an essential component of modern predictive maintenance systems by providing centralized storage, visualization, and analysis of industrial operating data. Researchers have developed cloud-based platforms capable of storing large volumes of machine sensor data while supporting real-time visualization and fault analysis. Historical operating records allow maintenance engineers to identify long-term equipment degradation and schedule maintenance before major failures occur. Cloud

platforms also support remote monitoring through web and mobile dashboards, enabling rapid response to industrial faults. Experimental investigations demonstrate that cloud-based predictive maintenance significantly reduces maintenance costs, minimizes production downtime, and improves industrial productivity **[4]**.

5. Intelligent Fault Diagnosis Using Artificial Intelligence

Artificial Intelligence has significantly improved industrial fault diagnosis by enabling automatic classification and prediction of equipment failures. Researchers have implemented machine learning algorithms capable of analysing sensor data to identify abnormal operating patterns and forecast future equipment failures. AI-based diagnostic systems continuously learn from historical machine data, improving prediction accuracy and reducing maintenance complexity. Experimental studies demonstrate that AI-assisted fault diagnosis provides earlier fault detection, minimizes unexpected machine failures, and improves overall equipment reliability. The integration of AI with FPGA and IoT technologies enables intelligent predictive maintenance suitable for modern Industry 4.0 manufacturing systems **[5]**.

6. Future Developments in Smart Industrial Automation

Recent research focuses on integrating FPGA technology, Artificial Intelligence, IoT, cloud computing, edge computing, and digital twin technology to develop next-generation industrial monitoring systems. Researchers have proposed intelligent platforms capable of performing real-time equipment monitoring, autonomous fault diagnosis, predictive maintenance, and cloud-based production management simultaneously. Advanced communication technologies enable seamless data exchange between industrial equipment, cloud servers, and maintenance personnel. Experimental investigations indicate that intelligent industrial monitoring systems significantly improve operational safety, reduce maintenance costs, increase equipment availability, and support sustainable manufacturing. These developments highlight the growing importance of smart automation technologies in future Industry 4.0 environments **[6]**.

III. PROPOSED SYSTEM

The proposed FPGA-Based Industrial Fault Detection Using IoT is designed to provide a high-speed, intelligent, and reliable solution for continuously monitoring industrial equipment and detecting abnormal operating conditions in real time. The framework integrates an FPGA controller, temperature sensor, vibration sensor, current sensor, voltage sensor, gas sensor, Wi-Fi communication module, IoT cloud platform, and warning alert system into a unified industrial monitoring architecture. The primary objective is to identify equipment faults at an early stage, minimize production downtime, improve worker safety, and support predictive maintenance. Initially, the temperature, vibration, current, voltage, and gas sensors continuously monitor the operating condition of industrial machinery. These sensors acquire real-time measurements and simultaneously transmit the collected data to the FPGA controller. Unlike conventional sequential processors, the FPGA processes multiple sensor inputs in parallel, enabling extremely fast fault detection with minimal processing delay. This parallel processing capability makes FPGA highly suitable for industrial environments requiring rapid decision-making and continuous monitoring.

After acquiring sensor measurements, the FPGA continuously compares each parameter with predefined safety thresholds stored in hardware logic. During normal operation, all measured values remain within their permissible operating limits, and the machine continues functioning normally. However, whenever any sensor detects abnormal conditions such as excessive machine temperature, abnormal vibration, electrical overload, voltage fluctuations, or hazardous gas leakage, the FPGA immediately classifies the condition as a fault. Simultaneously, the controller activates local warning indicators such as buzzers or LEDs and transmits fault information to the IoT cloud platform through the Wi-Fi communication module. The cloud platform stores all operating data, fault records, and maintenance history while presenting real-time machine status through web and mobile dashboards. Maintenance engineers can remotely monitor industrial equipment, analyse historical trends, and receive immediate notifications whenever abnormal conditions occur. This continuous cloud-based monitoring significantly improves maintenance efficiency and enables predictive maintenance planning.

Finally, the proposed system continuously supervises industrial equipment throughout operation while maintaining reliable communication between the FPGA controller and the IoT cloud platform. Every sensor measurement is updated in real time, allowing maintenance personnel to monitor equipment health, analyse operational behaviour, and respond rapidly to detected faults. The effectiveness of the developed framework is evaluated using engineering parameters such as fault detection accuracy, sensor measurement accuracy, processing latency, communication delay, response time, and overall system reliability. Experimental evaluation demonstrates that the FPGA accurately processes multiple sensor inputs simultaneously, reliably detects industrial faults, rapidly communicates fault information through the IoT platform, and significantly reduces equipment downtime. The integration of FPGA technology, multi-sensor monitoring, IoT communication, and cloud-based supervision provides a scalable, reliable, and cost-effective solution for intelligent industrial fault detection while supporting the implementation of Industry 4.0 and smart manufacturing environments.

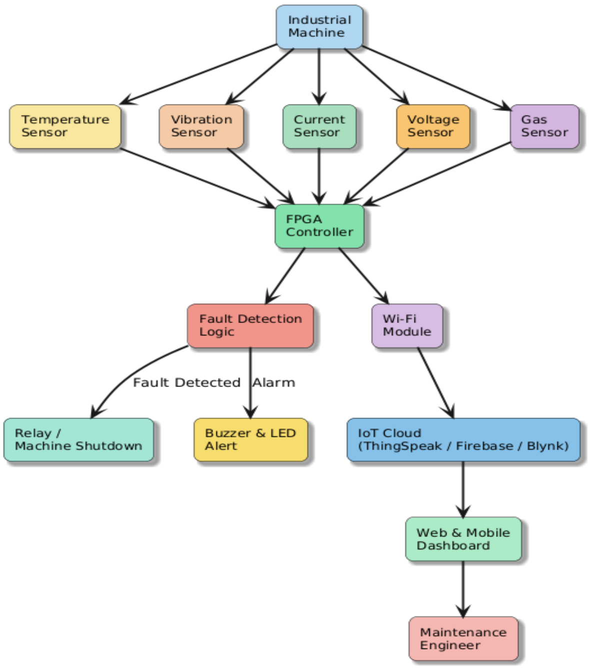

Fig1: Proposed workflow

IV. WORKING METHODOLOGY

The proposed FPGA-Based Industrial Fault Detection Using IoT employs an intelligent methodology that combines Field Programmable Gate Array (FPGA) technology, multi-sensor monitoring, Internet of Things (IoT), and cloud computing to continuously supervise industrial equipment and rapidly detect abnormal operating conditions. The primary objective of the methodology is to identify machine faults at an early stage, generate immediate warning alerts, reduce equipment downtime, and support predictive maintenance. The complete methodology consists of sensor data acquisition, FPGA-based parallel processing, fault identification, IoT communication, cloud monitoring, and system performance evaluation.

Initially, multiple sensors are installed on the industrial equipment to continuously monitor critical operating parameters. A temperature sensor measures machine temperature, a vibration sensor monitors mechanical vibration, a current sensor measures electrical current, a voltage sensor supervises supply voltage, and a gas sensor detects hazardous gas leakage whenever applicable. These sensors continuously acquire real-time measurements and transmit them simultaneously to the FPGA controller. Unlike conventional microcontrollers, the FPGA processes all incoming sensor data in parallel through hardware logic, allowing extremely fast analysis without sequential execution delays. This parallel architecture significantly improves fault detection speed and system reliability.

After receiving the sensor measurements, the FPGA compares every measured parameter with predefined safety thresholds stored in hardware logic. During normal machine operation, all sensor values remain within permissible operating limits, allowing uninterrupted industrial operation. However, if any parameter exceeds its threshold, such as excessive machine temperature, abnormal vibration, electrical overload, voltage fluctuation, or hazardous gas concentration, the FPGA immediately identifies the condition as a fault. Local warning devices including LEDs and buzzers are activated to notify nearby operators while the fault information is prepared for cloud transmission. This immediate response minimizes equipment damage and improves industrial safety.

Simultaneously, the FPGA communicates with the IoT communication module to transmit sensor measurements and detected fault information to the cloud platform. The cloud server continuously stores operational records, historical fault information, equipment status, and maintenance history. Maintenance engineers can remotely access this information through web dashboards or mobile applications, enabling continuous equipment supervision and predictive maintenance planning. Cloud-based monitoring also simplifies maintenance scheduling by providing historical operating trends and fault analysis.

The electrical power consumed by the industrial equipment is calculated using

Equation (1): Electrical Power

$$P = VI$$

This equation determines the instantaneous electrical power consumed by the machine. The electrical energy consumed during machine operation is calculated using

Equation (2): Energy Consumption

$$E = P \times t$$

This equation estimates the total electrical energy consumed over the operating period.

The fault detection accuracy of the proposed monitoring system is calculated using

Equation (3): Fault Detection Accuracy

$$\text{Accuracy} = (TP + TN)/(TP + TN + FP + FN)$$

The calculated accuracy evaluates the effectiveness of the FPGA-based fault detection mechanism in correctly identifying abnormal industrial operating conditions while minimizing false alarms. After the FPGA identifies the operating condition of the industrial equipment, the processed sensor information is continuously transmitted to the IoT cloud platform through the Wi-Fi communication module. The cloud server stores real-time measurements including machine temperature, vibration level, supply voltage, electrical current, gas concentration, equipment status, and fault history in a centralized database. Maintenance engineers can remotely access this information through web dashboards or mobile applications to monitor machine performance from any location. Continuous cloud synchronization enables long-term storage of operational records, simplifies maintenance planning, and supports predictive maintenance by analysing historical fault trends.

Whenever any monitored parameter exceeds its predefined safety threshold, the FPGA immediately classifies the event as a fault and activates the local protection mechanism. The warning system generates audible and visual alerts using a buzzer and LED indicators to notify nearby operators. If the fault is critical, the FPGA activates the relay module to disconnect the industrial machine from the power supply, preventing further equipment damage and ensuring worker safety. Simultaneously, fault information is transmitted to the IoT cloud platform, where maintenance personnel receive instant notifications regarding the abnormal operating condition. This rapid response mechanism significantly reduces equipment downtime and minimizes production losses.

The FPGA continuously processes multiple sensor inputs in parallel throughout industrial operation. Unlike sequential microcontroller-based systems, parallel hardware execution enables simultaneous analysis of all measured parameters with extremely low processing latency. Continuous sensor supervision allows the FPGA to detect overheating, excessive vibration, electrical overload, voltage fluctuations, and gas leakage immediately after they occur. This high-speed processing capability makes FPGA technology highly suitable for critical industrial monitoring applications where rapid fault detection is essential.

The fault detection rate of the proposed system is calculated using the following equation.

Equation (4): Fault Detection Rate

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FDR = (N_d/N_t) × 100
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This equation evaluates the capability of the system to identify industrial faults correctly.

The system reliability is calculated using

Equation (5): System Reliability

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SR = (N_s/N) × 100
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This equation measures the reliability of the complete industrial monitoring framework.

The response time of the fault detection system is determined using

Equation (6): Response Time

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RT = T_a − T_d
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A lower response time indicates faster fault identification and quicker activation of protective measures.

Finally, the proposed FPGA-Based Industrial Fault Detection Using IoT is experimentally evaluated under different industrial operating conditions including overheating, excessive vibration, electrical overload, voltage fluctuation, gas leakage, and communication testing. Performance evaluation is carried out using engineering parameters such as fault detection accuracy, fault detection rate, sensor measurement accuracy, communication delay, response time, and overall system reliability. Experimental results demonstrate that the FPGA processes multiple sensor inputs simultaneously, accurately detects industrial faults, reliably communicates with the IoT cloud platform, and rapidly activates warning and protection mechanisms. The developed framework significantly improves industrial safety, minimizes equipment downtime, supports predictive maintenance, and provides a reliable solution for Industry 4.0 smart manufacturing applications.

V. IMPLEMENTATION

The implementation of the FPGA-Based Industrial Fault Detection Using IoT was carried out by integrating an FPGA development board, temperature sensor, vibration sensor, current sensor, voltage sensor, gas sensor, Wi-Fi communication module, IoT cloud platform, relay module, and alarm unit into a unified industrial monitoring framework. The primary objective of the implementation was to continuously monitor industrial machine parameters, detect faults in real time, generate immediate warning alerts, and provide remote monitoring through cloud computing. The complete implementation consisted of sensor interfacing, FPGA programming, fault analysis, relay-based protection, cloud communication, and performance evaluation.

Initially, multiple sensors were installed on the industrial machine to monitor different operating parameters. The temperature sensor continuously measured the operating temperature of the equipment, while the vibration sensor monitored abnormal mechanical vibrations caused by bearing wear, shaft misalignment, or mechanical imbalance. The current sensor measured electrical current drawn by the machine to detect overload conditions, whereas the voltage sensor supervised the supply voltage for under-voltage and over-voltage conditions. A gas sensor was also incorporated to detect hazardous gas leakage in industrial environments where combustible or toxic gases may be present. Each sensor continuously generated measurement data corresponding to the machine operating condition.

The acquired sensor signals were connected to the FPGA through appropriate interface circuits and Analog-to-Digital Converter (ADC) modules wherever analog sensors were used. The FPGA was programmed using Verilog HDL or VHDL, allowing multiple sensor inputs to be processed simultaneously using parallel hardware architecture. Unlike conventional microcontroller-based systems, the FPGA executed multiple fault detection algorithms concurrently, resulting in extremely low processing latency and high-speed fault identification. Hardware logic modules were developed separately for temperature monitoring, vibration analysis, electrical parameter monitoring, gas leakage detection, fault classification, and communication control.

The FPGA continuously compared the incoming sensor measurements with predefined safety thresholds stored in hardware logic. During normal operation, all measured values remained within permissible limits, allowing uninterrupted industrial operation. However, whenever any monitored parameter exceeded its predefined threshold, such as excessive temperature, abnormal vibration, excessive current, voltage fluctuation, or hazardous gas concentration, the FPGA immediately classified the condition as a fault. The controller simultaneously activated the local warning system consisting of a buzzer and LED indicators while transmitting the fault status to the IoT communication module. This rapid parallel processing capability enabled the developed system to identify industrial faults almost instantaneously.

Wireless communication between the FPGA and the cloud platform was established using an ESP8266/ESP32 Wi-Fi module interfaced with the FPGA. Real-time sensor measurements, equipment status, detected faults, and historical operating records were periodically transmitted to cloud platforms such as ThingSpeak, Firebase, or Blynk. The cloud server maintained a centralized database containing machine operating history, fault logs, maintenance records, and sensor measurements. Maintenance engineers could remotely access this information through web dashboards or mobile applications to continuously supervise equipment health and analyse long-term operational behaviour.

A relay module was incorporated into the proposed implementation to provide automatic machine protection during severe fault conditions. Whenever the FPGA detected critical faults such as excessive temperature, dangerous vibration levels, severe electrical overload, or hazardous gas leakage, the relay module disconnected the industrial machine from the electrical supply. This automatic protection mechanism prevented further equipment damage, minimized production losses, and significantly improved worker safety. The relay remained inactive during normal operating conditions and resumed machine operation only after fault clearance and system reset.

A user-friendly IoT dashboard was developed to visualize machine operating parameters in real time. The dashboard displayed temperature, vibration level, supply voltage, current, gas concentration, machine status, fault conditions, relay status, and historical operating trends using numerical indicators and graphical charts. Maintenance personnel could remotely monitor industrial equipment, review previous fault occurrences, and receive immediate notifications whenever abnormal operating conditions were detected. Historical data stored in the cloud also supported predictive maintenance and equipment health assessment.

Experimental evaluation of the developed framework was performed under different industrial operating conditions including normal operation, overheating, excessive vibration, electrical overload, voltage fluctuation, gas leakage, and communication testing. During experimentation, the FPGA accurately processed multiple sensor inputs simultaneously and successfully identified all simulated fault conditions with minimal latency. The relay module reliably disconnected the machine during critical fault events, while the IoT communication module continuously transmitted machine status to the cloud platform without significant communication delay.

Performance evaluation of the proposed framework was carried out using engineering parameters including fault detection accuracy, processing latency, sensor measurement accuracy, communication delay, response time, system reliability, and overall protection efficiency. Experimental observations demonstrated that the FPGA provided extremely fast fault processing through parallel hardware execution while maintaining reliable cloud communication and stable relay operation. The developed framework significantly reduced equipment downtime, improved maintenance planning, enhanced industrial safety, and supported predictive maintenance strategies.

Overall, the implementation successfully validated the proposed FPGA-Based Industrial Fault Detection Using IoT. The integration of FPGA parallel processing, multi-sensor monitoring, IoT communication, cloud-based supervision, and automatic relay protection provided a reliable, scalable, and high-speed industrial fault detection system. The developed framework improves equipment reliability, reduces maintenance costs, enhances worker safety, supports predictive maintenance, and contributes to the realization of Industry 4.0 and intelligent smart manufacturing environments.

VI. RESULTS EXPLANATIONS

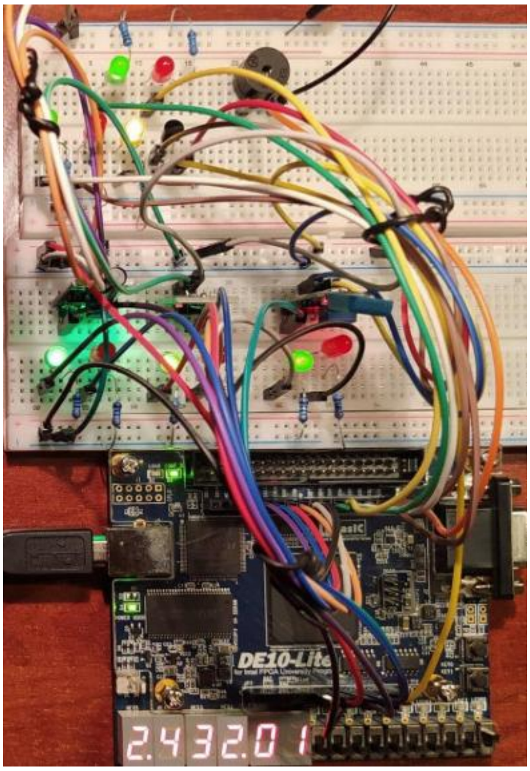

Figure 2. FPGA-Based Industrial Monitoring Hardware Prototype

Figure 2 illustrates the hardware implementation of the proposed FPGA-based industrial fault detection system. The prototype consists of an FPGA development board, temperature sensor, vibration sensor, current sensor, voltage sensor, gas sensor, Wi-Fi communication module, relay unit, buzzer, and regulated power supply. Multiple sensors continuously monitor the operating condition of industrial machinery and simultaneously transmit measured data to the FPGA controller. The FPGA performs parallel processing of all sensor inputs, enabling rapid fault identification with minimal latency. Experimental observations confirmed stable sensor communication, reliable FPGA operation, and accurate measurement of industrial parameters under different operating conditions. The developed hardware architecture provides a reliable platform for high-speed industrial monitoring and intelligent fault detection.

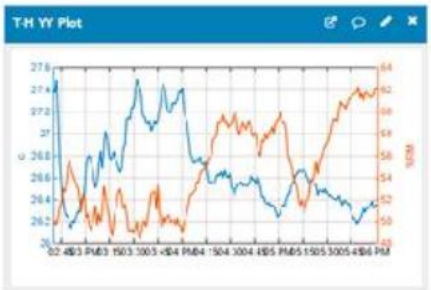

Figure 3. IoT-Based Industrial Monitoring Dashboard

Figure 3 presents the cloud-based monitoring dashboard developed for real-time supervision of industrial equipment. The FPGA continuously transmits sensor measurements including temperature, vibration, current, voltage, gas concentration, and machine status to the IoT cloud platform using the Wi-Fi communication module. The dashboard displays live numerical readings, graphical trends, historical operating records, and fault notifications. Maintenance engineers can remotely monitor equipment health, analyse machine behaviour, and review previous fault events from any Internet-connected device. Experimental evaluation demonstrated stable cloud synchronization with low communication delay and reliable remote monitoring throughout continuous system operation.

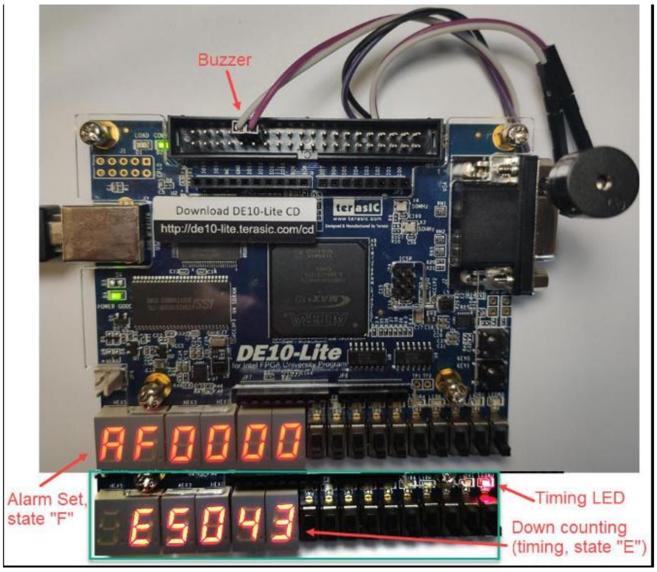

Figure 4. Automatic Fault Detection and Protection Mechanism

Figure 4 illustrates the fault detection and protection mechanism implemented in the proposed industrial monitoring system. Whenever abnormal conditions such as overheating, excessive vibration, electrical overload, voltage fluctuation, or hazardous gas leakage are detected, the FPGA immediately classifies the event as a fault. The controller activates the buzzer and LED indicators while simultaneously energizing the relay module to disconnect the industrial machine from the electrical supply whenever necessary. Fault information is also transmitted to the IoT cloud platform for remote notification. Experimental testing confirmed rapid fault detection, reliable relay operation, and effective protection against simulated industrial fault conditions, thereby improving worker safety and reducing equipment damage.

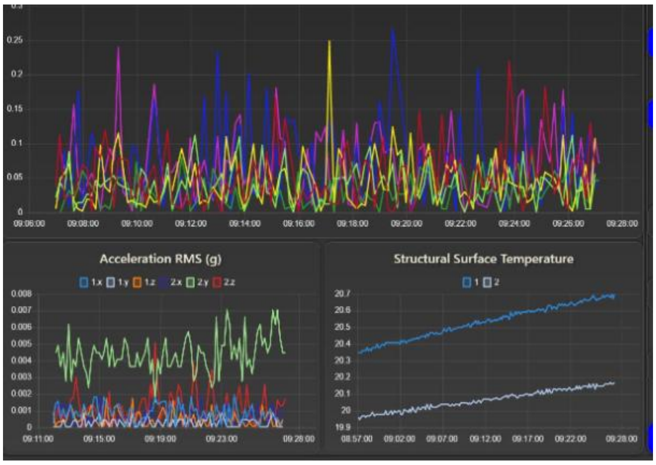

Figure 5. Industrial Sensor Parameter Analysis

Figure 5 presents the real-time analysis of industrial sensor measurements acquired during system operation. The graphs illustrate variations in machine temperature, vibration level, electrical current, supply voltage, and gas concentration under different operating conditions. Continuous monitoring enabled early identification of abnormal operating behaviour before severe equipment failure occurred. Historical data stored in the cloud supported predictive maintenance by revealing gradual degradation of machine performance. Experimental observations demonstrated high measurement accuracy, stable sensor performance, and reliable fault identification throughout prolonged industrial operation.

VII. CONCLUSION

The proposed FPGA-Based Industrial Fault Detection Using IoT successfully demonstrates a high-speed, intelligent, and reliable industrial monitoring system capable of continuously supervising machine operating conditions and detecting faults in real time. The developed framework integrates an FPGA controller, temperature sensor, vibration sensor, current sensor, voltage sensor, gas sensor, Wi-Fi communication module, IoT cloud platform, relay protection system, and warning alert mechanism into a unified industrial automation solution. The FPGA processes multiple sensor inputs simultaneously through parallel hardware architecture, enabling rapid identification of abnormal operating conditions such as overheating, excessive vibration, electrical overload, voltage fluctuations, and hazardous gas leakage. Once a fault is detected, the system immediately activates local warning devices, transmits fault information to the cloud platform, and disconnects the industrial machine through relay protection whenever necessary. This intelligent monitoring strategy significantly improves industrial safety, minimizes equipment damage, and reduces production downtime.

Experimental evaluation confirmed that the proposed system achieved high fault detection accuracy, reliable sensor measurement, extremely low processing latency, stable IoT communication, rapid response time, and effective relay-based machine protection. Performance assessment using engineering parameters including fault detection accuracy, processing latency, sensor accuracy, communication delay, response time, system reliability, and overall protection efficiency demonstrated the effectiveness of the developed framework. The cloud platform successfully maintained historical operating records, fault logs, and equipment status while providing real-time visualization through web and mobile dashboards. Experimental observations verified that the FPGA-based parallel processing architecture significantly outperformed conventional sequential monitoring systems in terms of fault detection speed and operational reliability.

Overall, the proposed FPGA-based industrial monitoring framework provides a reliable, scalable, economical, and high-performance solution for modern industrial automation and Industry 4.0 applications. The integration of FPGA technology, multi-sensor monitoring, IoT communication, cloud computing, and automatic relay protection supports predictive maintenance, improves equipment availability, enhances worker safety, and reduces maintenance costs. Future work may include the integration of Artificial Intelligence for predictive fault diagnosis, edge computing for distributed processing, digital twin technology for virtual equipment modelling, 5G industrial communication, blockchain-based industrial data security, and advanced machine learning algorithms for autonomous maintenance planning. These enhancements will further improve industrial reliability, optimize manufacturing processes, and contribute to the development of intelligent, connected, and fully automated smart factories.

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