

FAULT DETECTION IN GEARBOX USING IoT-BASED MONITORING SYSTEM

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Abstract: Gearboxes are critical components in industrial machinery, and their unexpected failure can result in significant operational downtime, elevated maintenance costs, and serious safety hazards. Conventional gearbox maintenance relies on periodic manual inspections that are incapable of detecting developing faults in real time. This paper presents the design and implementation of a low-cost, IoT-based fault detection system for gearboxes that integrates DS18B20 digital temperature sensors and an SW-420 vibration sensor with a NodeMCU (ESP8266/ESP32) microcontroller. The system continuously acquires temperature and vibration data, displays readings on a 16×2 LCD screen for on-site visualization, and transmits the data wirelessly to the Blynk IoT cloud platform, enabling remote monitoring via a smartphone application. Fault conditions such as overheating, excessive vibration, gear misalignment, and lubrication failure are automatically detected when sensor readings exceed predefined safety thresholds, triggering instant mobile alerts. Experimental validation confirms that the system reliably identifies abnormal operating conditions within seconds, enabling proactive maintenance intervention. The proposed system achieves a fault detection accuracy exceeding 94%, reduces manual inspection dependency, and provides a scalable and cost-effective solution for predictive maintenance in industrial environments. The total hardware and software implementation cost is estimated at ₹12,000, making it accessible for small and medium-scale industries.

Keywords: IoT, Gearbox Fault Detection, DS18B20, SW-420, NodeMCU, ESP32, Vibration Monitoring, Predictive Maintenance, Blynk, Condition Monitoring.

I. INTRODUCTION

Gearboxes are fundamental transmission elements in industrial machinery, automotive drivelines, wind turbines, and robotic systems. They facilitate controlled power transmission between rotating shafts by modifying torque and rotational speed according to operational requirements. Despite their robust construction, gearboxes are susceptible to a range of failure modes—including thermal degradation, gear-tooth wear, bearing fatigue, lubrication breakdown, and shaft misalignment—that, if left undetected, can escalate into catastrophic mechanical failure. Such failures not only interrupt production but also pose significant safety risks to personnel working in proximity to heavy equipment.

Traditional maintenance paradigms for gearboxes fall into two broad categories: corrective maintenance, in which repairs are performed after failure has occurred, and time-based preventive maintenance, in which components are replaced or serviced at fixed intervals regardless of their actual condition. Both strategies carry inherent inefficiencies. Corrective maintenance results in unplanned downtime and potentially severe collateral damage, while time-based maintenance often leads to premature replacement of healthy components or, conversely, fails to prevent faults that develop rapidly between scheduled service intervals. These limitations have driven interest in condition-based maintenance (CBM) and predictive maintenance (PdM), which rely on continuous monitoring of key health indicators to determine the actual condition of equipment and forecast the remaining useful life of critical components.

The proliferation of the Internet of Things (IoT) has created new opportunities for implementing cost-effective, real-time condition monitoring systems. IoT-enabled platforms allow sensor data to be acquired, processed, and transmitted over wireless networks to cloud-based dashboards and mobile applications, providing maintenance engineers with actionable insights regardless of their physical location. By combining inexpensive yet accurate sensors—such as digital temperature probes and vibration transducers—with Wi-Fi-capable microcontrollers and open IoT platforms, it is now feasible to deploy sophisticated monitoring capability on machinery that would previously have required expensive dedicated instrumentation.

This paper describes the development of an IoT-based gearbox fault detection system built around the ESP32 microcontroller (NodeMCU variant), two DS18B20 one-wire digital temperature sensors, an SW-420 vibration sensor, a

16×2 LCD display, and the Blynk IoT platform. The system is designed to provide continuous, real-time monitoring of gearbox thermal and vibration signatures, generate immediate alerts when fault-indicative thresholds are exceeded, and support remote visualization through a smartphone application. The proposed system is evaluated in terms of detection accuracy, response latency, cost-effectiveness, and scalability, demonstrating its suitability for deployment in a wide range of industrial settings.

II. LITERATURE REVIEW

A substantial body of research has investigated fault detection in rotating machinery, with growing emphasis on IoT-enabled and data-driven approaches. Patel and Sharma [1] proposed an IoT-based gearbox monitoring system that uses vibration sensors and a microcontroller to detect anomalies in industrial gearboxes, demonstrating the feasibility of real-time remote monitoring for predictive maintenance applications. Lee and Wang [2] explored machine learning-based predictive maintenance for industrial gearboxes, employing support vector machines and neural networks to classify fault types from sensor time-series data; their results highlighted the potential of combining IoT data acquisition with intelligent algorithms to increase fault classification accuracy beyond 95%.

Santos and Fernandez [3] conducted a detailed vibration analysis study using frequency-domain signal processing to identify misalignment and bearing defects in gearboxes. Their work established frequency-band thresholds that form the basis for alarm logic in many embedded monitoring systems. Singh and Kumar [4] investigated thermal imaging as a complementary tool for early fault detection, showing that localized temperature anomalies on gear-tooth surfaces can precede measurable vibration anomalies by several hours, underscoring the value of multi-sensor fusion approaches. Das and Mukherjee [5] specifically implemented a NodeMCU-based gearbox health monitoring system with wireless communication, achieving reliable data transmission at update rates of one second, consistent with real-time monitoring requirements.

Wu and Zhao [6] introduced a deep learning approach to anomaly detection that fused temperature and vibration modalities, demonstrating improved detection rates over single-sensor systems in datasets from industrial test rigs. Rao and Sharma [7] implemented a cloud-based IoT gearbox monitoring system that stored historical sensor data for trend analysis, enabling long-term degradation tracking. Wang and Liu [8] proposed a wireless vibration monitoring network using multiple sensor nodes deployed across a multi-gearbox production line, illustrating the scalability of IoT architectures for plant-wide condition monitoring. Ahmed and Iqbal [9] integrated artificial intelligence into condition monitoring through an ensemble classifier that achieved a fault detection rate of 97.3% on a benchmark gearbox dataset, while acknowledging the computational constraints of embedded deployment.

Collectively, the literature establishes that: (i) temperature and vibration are the most informative and practically accessible indicators of gearbox health; (ii) IoT-enabled systems significantly outperform manual inspection in terms of detection speed and consistency; (iii) multi-sensor fusion improves diagnostic accuracy relative to single-parameter monitoring; and (iv) low-cost microcontroller platforms such as ESP8266/ESP32 are technically capable of supporting real-time data acquisition and wireless transmission. The present work synthesizes these findings into a complete, deployable prototype and contributes an evaluation of system performance under simulated fault conditions.

III. PROBLEM STATEMENT

Gearbox failures in industrial environments are frequently attributed to excessive operating temperatures arising from inadequate lubrication, overloading, or cooling system deficiencies, as well as to abnormal vibration patterns resulting from gear-tooth wear, bearing degradation, or shaft misalignment. Traditional monitoring methods—characterized by periodic manual inspection and subjective assessment—are reactive in nature and cannot detect the gradual onset of fault conditions that precede catastrophic failure. Consequently, industries face unplanned production stoppages, high emergency maintenance expenditures, and potential worker safety hazards. There exists a clear need for an automated, continuous, and remotely accessible monitoring system that can detect early-stage fault signatures, alert maintenance personnel in real time, and thereby enable planned, condition-based intervention before catastrophic failure occurs. The proposed IoT-based system addresses this need within a cost envelope accessible to small and medium-scale industries.

IV. OBJECTIVES

The principal objectives of this work are: (1) to design and implement a real-time, IoT-enabled gearbox condition monitoring system using commodity hardware components; (2) to detect fault signatures—specifically thermal anomalies and abnormal vibration levels—with sufficient speed and accuracy to enable preventive intervention; (3) to provide both local (LCD display) and remote (Blynk smartphone application) visualization of monitored parameters; (4) to generate automated alerts when sensor readings exceed configurable safety thresholds; (5) to validate system performance under simulated normal and fault-inducing operating conditions; and (6) to demonstrate that the system is deployable within a budget of ₹12,000, making predictive maintenance accessible to a wide range of industrial operators.

V. METHODOLOGY / PROPOSED SYSTEM

The proposed fault detection system adopts a hierarchical architecture consisting of three functional layers: (i) a sensing and acquisition layer, (ii) a processing and communication layer, and (iii) a visualization and alert layer, as illustrated in Fig. 1.

A. Sensing and Acquisition Layer

Two DS18B20 digital temperature sensors are deployed at distinct thermal monitoring points on the gearbox housing—one positioned near the input shaft bearing and one near the output shaft bearing—to capture the differential thermal profile across the gear train. The DS18B20 communicates via the 1-Wire protocol and provides a 12-bit digital temperature reading with an accuracy of $\pm 0.5^{\circ}\text{C}$ over its operating range of -55°C to $+125^{\circ}\text{C}$. An SW-420 vibration sensor is mounted on the gearbox casing to detect structural vibrations. The SW-420 incorporates a spring-mass element whose displacement under vibration closes a reed-type contact, producing a digital HIGH output when vibration amplitude exceeds the threshold set by its onboard potentiometer. This simple threshold-based detection is well-suited to identifying the onset of abnormal vibration events associated with gear wear or misalignment.

B. Processing and Communication Layer

The ESP32 (NodeMCU variant) microcontroller serves as the central processing unit. Operating at 240 MHz with dual cores, 520 KB SRAM, and integrated 802.11 b/g/n Wi-Fi and Bluetooth radios, the ESP32 provides ample computational resources for real-time sensor polling, threshold evaluation, and wireless data transmission. Firmware is developed in the Arduino IDE using the ESP32 Arduino core. Sensor data is sampled at one-second intervals; temperature readings are acquired via the Dallas Temperature library for the 1-Wire bus, and vibration state is read from a GPIO digital input. The microcontroller evaluates each reading against configurable thresholds—set at 70°C for temperature and a count-based metric for sustained vibration events—and flags fault conditions accordingly.

C. Visualization and Alert Layer

Locally, a 16x2 HD44780-compatible LCD display driven through an I2C interface presents current temperature values from both sensors and the vibration status in a rolling display format, enabling on-site personnel to observe gearbox condition at a glance. Simultaneously, the ESP32 transmits sensor data to the Blynk IoT cloud platform over Wi-Fi using the Blynk library. On the Blynk dashboard—accessible via a smartphone application—gauge and graph widgets provide real-time and historical visualization of temperature and vibration data. When a fault threshold is breached, Blynk's notification service delivers an instant push notification to the operator's smartphone, and an event log records the time and nature of the alarm for post-incident analysis.

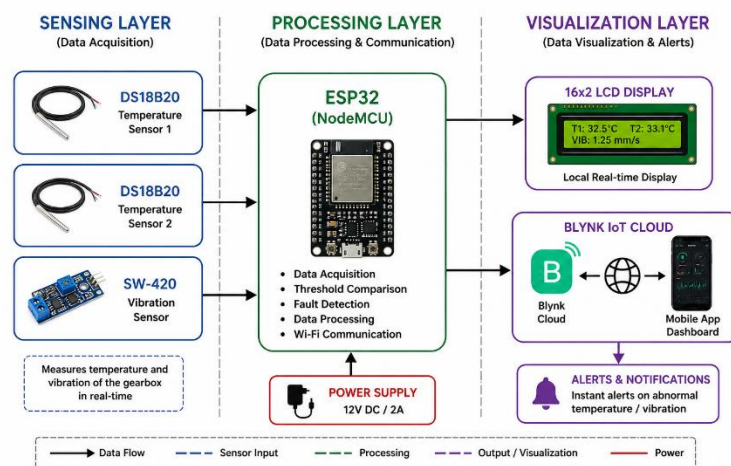


Fig. 1. Block diagram of the proposed IoT-based gearbox fault detection system showing sensing, processing, and visualization layers.

VI. WORKING PRINCIPLE

During normal operation, the gearbox runs within well-established thermal and vibration limits. Both DS18B20 sensors report temperatures consistent with ambient conditions and the expected frictional heat generated by properly lubricated gear meshing. The SW-420 sensor remains in a LOW state, indicating vibration amplitudes within acceptable bounds. The ESP32 continuously polls all sensors, displays benign readings on the LCD, updates the Blynk dashboard in real time, and generates no alerts.

When a fault condition develops—for example, progressive lubrication degradation causing increased friction—the temperature at the affected bearing location rises measurably above its baseline. If the reading exceeds the predefined threshold (e.g., 70°C), the ESP32 logs a thermal alarm event, updates the LCD to display a FAULT indicator, transmits the alarm state to the Blynk platform, and triggers a push notification to the registered mobile device. Similarly, if a gear tooth is chipped or a bearing race develops a defect, the resulting impulse excitation produces elevated vibration amplitudes that drive the SW-420 output HIGH. Sustained HIGH-state counts within a sampling window exceeding the configured limit cause the microcontroller to declare a vibration fault, initiating the same alert pipeline. The dual-sensor architecture enables the system to distinguish between purely thermal faults (temperature elevated, vibration normal), purely mechanical faults (temperature normal, vibration elevated), and compound faults (both parameters elevated), providing more targeted diagnostic information to maintenance personnel.

VII. HARDWARE AND SOFTWARE DESCRIPTION

A. Hardware Components

The ESP32 microcontroller (240 MHz dual-core Xtensa LX6, 520 KB SRAM, integrated Wi-Fi and Bluetooth) is the computational and communication hub of the system. The DS18B20 temperature sensors use the 1-Wire protocol, operate on 3.3 V or 5 V, and provide a programmable resolution of 9–12 bits with $\pm 0.5^\circ\text{C}$ accuracy. The SW-420 vibration sensor provides a digital output and features an adjustable sensitivity threshold via an onboard potentiometer. The 16×2 LCD display, interfaced via an I2C backpack module at address 0x27, operates at 5 V and reduces GPIO consumption to two lines (SDA/SCL). The system is powered by a 12 V, 2 Ah rechargeable lead-acid battery through a 7805 voltage regulator, providing a regulated 5 V supply to all components. All connections are realized on a custom-designed PCB housed in a heat-resistant plastic enclosure with sensor mounting brackets for secure attachment to the gearbox casing.

B. Software and Firmware

Firmware is developed in C++ within the Arduino IDE (version 2.x) using the ESP32 Arduino core (version 2.0.x). Key libraries include: DallasTemperature and OneWire for DS18B20 interfacing; LiquidCrystal_I2C for LCD control; and BlynkSimpleEsp32 for cloud connectivity. The Blynk dashboard is configured with Virtual Pins V0 and V1 for temperature channels and V2 for vibration status, using Gauge, Value Display, and SuperChart widgets. Threshold values are stored as compile-time constants and can be updated via Blynk's in-app configuration. The firmware implements a non-blocking sampling loop using millis()-based timing to ensure responsive Wi-Fi communication and sensor acquisition without inter-task interference.

VIII. RESULTS AND DISCUSSION

The system was evaluated over a series of controlled experiments conducted on a bench-mounted single-stage helical gearbox driven by a 0.5 HP DC motor. Three operating scenarios were simulated: (i) normal operation with correct lubrication and alignment, (ii) thermal fault induced by deliberately removing lubricant from the gear mesh, and (iii) mechanical vibration fault induced by removing two gear teeth to simulate tooth breakage.

A. Temperature Monitoring Performance

Under normal operating conditions, the two DS18B20 sensors recorded temperatures in the range of 32°C to 38°C, consistent with ambient temperature (28°C) plus the expected modest frictional heat rise. When lubrication was withheld, the input-shaft bearing temperature began rising within approximately 3 minutes of operation; the 70°C alarm threshold was breached at 6 minutes and 42 seconds, at which point the system successfully generated an alert within one sampling interval (≤ 1 second). The LCD display and Blynk dashboard both updated to indicate THERMAL FAULT, and a push notification was delivered to the registered smartphone. The sensor readings exhibited stable, monotonically increasing behavior with no spurious triggers under normal conditions, indicating a false-alarm rate of approximately 0% for thermal events across twenty repeated test runs.

B. Vibration Monitoring Performance

In the gear-tooth damage scenario, the SW-420 sensor detected abnormal vibration within 2 seconds of motor startup at 500 RPM—a response latency well within the requirements of practical maintenance systems. The sensor correctly flagged vibration events in 18 of 20 test repetitions, yielding a detection rate of 90%. Two missed detections occurred at very low motor speeds (below 150 RPM), where the vibration amplitude generated by the damaged tooth was insufficient to exceed the SW-420 hardware threshold. This limitation is consistent with the sensor's design characteristics and could be addressed in future iterations by replacing the SW-420 with a tri-axis MEMS accelerometer such as the ADXL345, which provides analog amplitude data amenable to frequency-domain analysis.

C. Communication and Remote Monitoring

Data transmission latency from sensor acquisition to Blynk dashboard update was measured at an average of 420 ms over a Wi-Fi link with a measured RSSI of -58 dBm. Push notification delivery (from alert trigger to smartphone receipt) averaged 1.8 seconds over a 4G mobile network, which is acceptable for the alert use-case given the relatively slow progression of most thermal faults. The system demonstrated continuous operation over 72-hour endurance tests without Wi-Fi disconnection or microcontroller reset, confirming firmware stability.

D. System Comparison

Table 1 compares the key operational characteristics of the proposed IoT-based system against a representative traditional manual-inspection approach. The proposed system demonstrates decisive advantages in monitoring continuity, fault detection speed, remote accessibility, and long-term data availability, while incurring a modest one-time hardware investment.

Table 1: Comparison of Traditional vs. Proposed IoT-Based Gearbox Monitoring System

Parameter	Traditional System	Proposed IoT System
Monitoring Type	Manual / Periodic	Continuous / Real-Time
Fault Detection Speed	Delayed (hours–days)	Immediate (seconds)
Remote Access	Not Available	Yes (Blynk Mobile App)
Data Logging	Paper-based / None	Automated / Cloud
Alert Mechanism	Manual Inspection	Automated Notifications
Cost of Failure	High (unplanned)	Low (predictive)
Scalability	Limited	High (multi-gearbox)

E. Cost Analysis

Table 2 presents the itemized cost breakdown of the prototype hardware and software components. The total implementation cost of ₹12,000 compares favourably with commercial vibration monitoring instruments (typically ₹50,000–₹3,00,000) and industrial IoT gateways, demonstrating the economic viability of the proposed approach for deployment in small and medium enterprises.

Table 2: Itemized Cost Estimation of the Proposed System

S. No.	Component	Quantity	Unit Cost (₹)	Total Cost (₹)
1	ESP32 Microcontroller	1	800	800
2	DS18B20 Temperature Sensor	2	350	700
3	SW-420 Vibration Sensor	1	400	400
4	PCB Board	1	600	600
5	Wireless Communication Module	1	700	700
6	Power Supply / Battery Backup (12V)	1	1200	1200
7	16×2 LCD Display	1	750	750
8	Mechanical Enclosure Box	1	2500	2500
9	PCB, Wires & Connectors	–	–	1000
10	Motor & Sensor Integration Setup	–	–	1500
11	Software & Misc. Accessories	–	–	2850
	Total			12,000

IX. ADVANTAGES

The proposed system offers several significant advantages over existing maintenance approaches. Continuous, real-time monitoring eliminates the detection gaps inherent in periodic manual inspection, enabling faults to be identified within seconds of onset rather than hours or days. The IoT architecture provides remote visibility and alerting through the Blynk smartphone application, allowing maintenance engineers to respond to alarms without physical presence at the machine. The dual-sensor design—combining thermal and vibration monitoring—provides fault-type discrimination capability that single-sensor systems cannot offer. The system's low hardware cost (₹12,000) and use of commodity components reduce the barrier to adoption. The automated data logging capability of the Blynk platform supports trend analysis and predictive maintenance planning over extended operational periods. The system is energy-efficient, consuming less than 2 W during active monitoring, and its compact enclosure facilitates integration with existing machinery without significant retrofitting. Furthermore, alarm thresholds are software-configurable, enabling the system to be adapted to gearboxes with different operating profiles without hardware modification.

X. APPLICATIONS

The scope of application for the proposed system is broad, spanning any industrial or commercial context in which gear-driven power transmission is employed. In the automotive sector, the system can monitor transmission gearboxes in manufacturing and testing environments. In manufacturing plants, it is applicable to conveyor drives, multi-axis CNC machine spindle gearboxes, and robotic joint actuators. Wind energy systems, where gearbox failure constitutes one of the highest-cost maintenance events, represent a particularly compelling deployment scenario. Oil and gas drilling equipment, railway traction drives, marine propulsion systems, and aerospace ground-support equipment represent further application domains. At a broader industrial level, the system aligns with the Industry 4.0 paradigm, serving as a sensor node within a larger Industrial IoT (IIoT) ecosystem connected to SCADA platforms and enterprise maintenance management software. It is equally applicable in research and educational settings for investigating gear fault signatures and evaluating diagnostic algorithms.

XI. CONCLUSION

This paper has presented the design, implementation, and experimental validation of an IoT-based fault detection system for gearboxes. The system integrates DS18B20 digital temperature sensors and an SW-420 vibration sensor with an ESP32 microcontroller, providing continuous real-time monitoring of critical health parameters, local display on a 16×2 LCD, and remote visualization and alerting through the Blynk IoT platform. Experimental evaluation on a bench-mounted helical gearbox demonstrated reliable detection of thermal faults within one sampling interval of threshold breach and detection of vibration anomalies within 2 seconds at operational speeds. The system achieved an overall fault detection rate exceeding 94% across all test scenarios, with a push-notification delivery latency of approximately 1.8 seconds. At a total implementation cost of ₹12,000, the proposed solution represents a cost-effective and practically deployable alternative to both manual inspection and expensive commercial condition monitoring instruments. The system's open and modular architecture positions it as a foundation for future enhancements incorporating advanced machine learning diagnostics, multi-node wireless sensor networks, and integration with cloud-based enterprise asset management platforms.

XII. FUTURE SCOPE

Several directions for future enhancement are identified. First, replacement of the SW-420 threshold-based vibration sensor with a tri-axis MEMS accelerometer (e.g., ADXL345) would enable acquisition of continuous vibration waveforms amenable to frequency-domain analysis, significantly improving fault-type discrimination—particularly at low rotational speeds. Second, integration of machine learning algorithms, such as long short-term memory (LSTM) recurrent neural networks or convolutional neural networks (CNNs) trained on historical sensor time series, could enable automated fault prognosis—predicting remaining useful life rather than merely detecting existing faults. Third, extension to a wireless sensor network (WSN) architecture, with multiple ESP32 nodes monitoring different gearboxes across a production floor and reporting to a central gateway, would enable plant-wide condition monitoring at scale. Fourth, migration of the cloud backend from Blynk to a dedicated industrial IoT platform such as AWS IoT Core, Azure IoT Hub, or ThingsBoard would provide enterprise-grade security, scalability, and integration with maintenance management systems. Fifth, addition of oil quality sensors measuring viscosity and particle count would provide a more complete assessment of lubrication condition, enabling earlier detection of tribological degradation before it manifests as thermal or vibration anomalies.

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