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RESEARCH ARTICLE OPEN ACCESS

DEVELOPMENT AND IMPLEMENTATION OF AN INDUSTRIAL IOT-BASED REAL-TIME PROCESS MONITORING SYSTEM TO IMPROVE OVERALL EQUIPMENT EFFECTIVENESS (O.E.E.) OF BEARING MANUFACTURING PROCESS

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ABSTRACT

The research study presents the design and implementation of an IoT-based real-time monitoring system to enhance Overall Equipment Effectiveness (O.E.E) of External grinding process used in precision bearing manufacturing. The developed system continuously monitors critical parameters such as cutting temperature, machine vibration, noise and cycle time using calibrated sensors. These critical parameters are directly linked to Key Performance Indicators (KPIs) of O.E.E in terms of Availability, Quality and Performance. A systematic layered IoT architecture is developed to enable real-time data acquisition, cloud storage, visualization and alert generation through a customized web application. Controlled experiments were conducted on various batches of bearing races under fixed machining conditions with critical parameter thresholds defined based on ISO standards and historical production data. The system successfully identified deviations, enabling timely corrective actions and reducing unexpected breakdowns. The real-time dashboard and alert system provided actionable insights, improving operational decision-making and minimizing manual documentation. As a result, OEE improved from 86% to 94.70%, demonstrating an 8.70% increase. Additionally, reductions in breakdowns, defects, and downtime were observed. This study confirms that integrating IoT in manufacturing significantly enhances equipment performance and product quality through data-driven process control.

I. INTRODUCTION

Grinding is a abrasive machining process used to remove small amount of material from workpiece, there are two types of grinding process, precision and rough. In Bearing manufacturing precision grinding process is required to achieve markable surface finish in bearing parts as bearings are used in aerospace, automobiles, agriculture machineries, railways and rotary machines like turbine, pump and electric motors.The external grinding process is essential to produce bearing parts and carried out in external grinding machine. To achieve process efficiency and production proficiency, the monitoring of pre-decided optimum process parameters and machining conditions plays important role to achieve quality of bearing parts as well as productivity of external grinding process. In this research study the industrial IoT (Internet of things) web-based monitoring system has been developed to monitor the various production parameters. The process parameters are linked with concern factors of Overall Equipment Effectiveness (O.E.E.) i.e indicates correlation between Process parameters with quality of bearing part, Performance of system and Availability of machine.

The designed IOT based grinding system, sensors collects the data for all three O.E.E elements automatically and the data is visualized using IOT applications. O.E.E is a standard metric which represents the overall production capability, consistency, proficiency, and achievements after completion of manufacturing process. O.E.E represents the various factors i.e Quality, Availability and Performance which effectively evaluates the achievement of manufacturing system. O.E.E indicates in terms of percentage, As per world-class standard the O.E.E should be 85 % [1],less than 85 % OEE represents production inefficiencies. OEE is calculated by multiplying the three OEE factors so the equation will be OEE = Availability × Performance × Quality [2]. In which Availability is the ration of Run Time to Planned Production Time, Performance is calculated by (Ideal Cycle Time x Total Parts Produced)/Actual Operating Time and Quality is found by dividing Good parts count to Total parts count. The focus has been given to achieve maximum OEE by monitoring of critical parameters using IOT web-based system. The designed IOT system is multi-purpose, which can be used for condition monitoring, predictive maintenance, and In-process measurement. The Key Performance Indicators (KPIs) are identified for external grinding process by brainstorming, past production data, various quality, and productivity tools. The major quality measures of bearing parts are surface finish, dimensional accuracy, visual appearance and ovality.

It has been found from observation and past quality data taken from the bearing manufacturing industry that major defects among all defects are size variation and Surface finish, including surface scratches. The significant process parameters affecting parts' surface finish are cutting temperature [3], [4], machine vibration [3], [5], [6], [7], feed and cutting speed. Here, the most affected critical parameters, cutting temperature and machine vibrations are monitored during the entire external grinding process. The performance is a measure of how promptly the machine produces a part as compared to ideal machining time. The identified key performance indicators to monitor performance with an IoT-based system are grinding process time and inspection time. The key performance indicators of availability are machine uptime, machine downtime duration, mean time between failures, setup and changeover time, and number of unplanned downtimes. The machine's actual operating time is continuously monitored in the proposed IOT based system. In an external grinding machine, trail runs and experiments have been performed with IOT web-based monitoring system to improve and measure the O.E.E factors related with bearing manufacturing.Before performing trail runs and experimentation the past one year O.E.E of External grinding machine is calculated and it is 86 %.

II. LITERATURE STUDY

Using advanced technologies to constantly monitor equipment efficiency in the digitalization era, research suggests a digitalized, real-time OEE calculating system. Focusing on availability, performance, and quality measurements helps the system to improve organizational performance by automating manual processes and allowing real-time decision-making [2]. By allowing real-time data collecting and analysis via linked sensors, the IoT is absolutely essential in grinding process monitoring. By means of instantaneous feedback on machine performance, a real-time monitoring system improves production efficiency and enables timely adjustments to avoid failures. Improved product quality and less resource waste resulting from this integration help to maximize the grinding operation in manufacturing plants [7]. To continuously monitor the efficiency of manufacturing equipment, research presents a digital, real-time OEE calculation system that makes use of cloud computing, IoT sensors, and data analytics. The system lowers downtime through predictive maintenance, improves operational decision-making, and optimizes availability, performance, and quality metrics in industrial settings to improve product quality. It does this by automating manual data collection and enabling instant insights.[8]. Through real-time asset monitoring and data-driven insights, research conducted predictive maintenance (PdM) using IoT technology and Six Sigma Define, Measure, Analyse, Improve and Control (DMAIC) methodology, achieving a 95:5 Predictive Maintenance to Corrective Maintenance (PM-to-CM) ratio (from 84:16) and so reduced maintenance costs by 25–30%.

Also eliminated 70–75% of breakdowns, so reducing downtime by 35–45% and so increasing production by 20–25%. The research mostly relies on IoT technology since it allows real-time and continuous data collecting through linked sensors and devices, so improving the accuracy and precision of the observations. In industrial and research environments, it automates data collecting, lowers manual intervention, and lets remote monitoring and predictive analytics possible, so improving operational efficiency, timely decision-making, and best use of resources [9]. In research article examining the development of Overall Equipment Effectiveness (OEE) as a key manufacturing KPI, this systematic literature review highlights growing academic interest, model changes, and new applications in logistics and services, so highlighting rising industrial KPI relevance. It underlines the importance of IoT integration since it improves operational efficiency, predictive maintenance, and real-time monitoring, so providing a strong basis for next studies and intelligent industrial machine control [10]. By allowing early fault discovery and predictive maintenance, the cost-effective IoT system for real-time temperature and humidity monitoring presented in this paper increases Overall Equipment Effectiveness (OEE). Combining edge computing, the system alerts and offers actionable insights by streaming data to a real-time OEE dashboard. This dashboard promotes smart manufacturing operations, enhances equipment availability and performance, and speeds decision-making for ongoing OEE improvement.

For immediate understanding of shop floor operations, shows real-time OEE scores including availability, performance, and quality criteria [11]. The research investigates how real-time monitoring and diagnosis made possible by IoT technologies might improve manufacturing Continuous Improvement (CI). It presents the Automatic Detailed Diagnosis (ADD) system, which tracks operator activity and equipment condition using low-power sensors, so increasing efficiency and lowering waste. In Lean Manufacturing systems, this integration of IoT supports improved problem-solving and decision-making.[12]. The researchers have found that real-time monitoring and data collecting made possible by the Internet of Things (IoT), manufacturing sector productivity is much improved. Condition monitoring, process optimization, and waste reduction made possible by this technology enable in the contactor manufacturing sector, for example, IoT deployment enhanced workplace productivity and safety as well as timely decision-making and knowledge-sharing among team members, so enabling cost savings and quality improvements [13]. Emphasizing the use of Kistler tri-axial accelerometers for vibration sensing in hostile environments, this work addresses the implementation of IoT-based monitoring for lathe machine performance. It describes local recording and cloud transmission as well as the significance of accelerometer data analysis of tool lifetime. Integration of cloud services like GE Predix improves analytics and data management capacities [14].

Track manufacturing efficiency, use real-time data to evaluate performance, quality, and availability, and the OEE monitoring system is absolutely vital. An OEE dashboard lets one quickly make decisions and adjust operations by offering graphic insights into these numbers. The dashboard KPIs allow one to keep a real eye on the current production status. IoT improves this system by means of data collecting from many machines, so promoting flexibility and production quality enhancement. Using IoT helps companies to reach operational excellence by means of ongoing process optimization and monitoring, so enhancing OEE results [15].

III. METHODOLOGY AND DESIGN OF IOT ARCHITECTURE

III.1 SENSORS AND DATA ACQUISITION

The selection of suitable sensors is essential for a cyber-physical system. The sensor should be highly accurate, and the appropriate data collection and data transmission are the most necessary things for any IoT-based system. The calibrated and accurate sensors were chosen for this research work.

Table 1: Details of selected sensors

Sr.No	Monitoring Parameter	Required sensor
1.	Cutting Temperature	Infrared Thermometer
2.	Machine work head, wheel head and bed Vibration	3-Axis Digital Accelerometer unit
3.	Machine Noise	Noise Sensor
4.	Bearing Part Detection	Proximity sensor

Source: Authors, (2026).

III.2 DETAILED NETWORK ARCHITECTURE, DATA STORAGE AND PROCESSING

There are four primary layers designed to establish IOT web-based monitoring system, first layer is Machine with sensors in which the sensors are attached in External Grinding machine to monitor machine conditions and process parameters, Second layer is perception layer in this Controller is designed to receive the data from sensors and takes appropriate actions if any abnormality generates. Third layer deals with network, in this layer, the data is stored in the cloud with using wifi module. The last one is application layer, in this, the O.E.E dashboard is designed and the production data can be visualized, analyzed, and monitored.

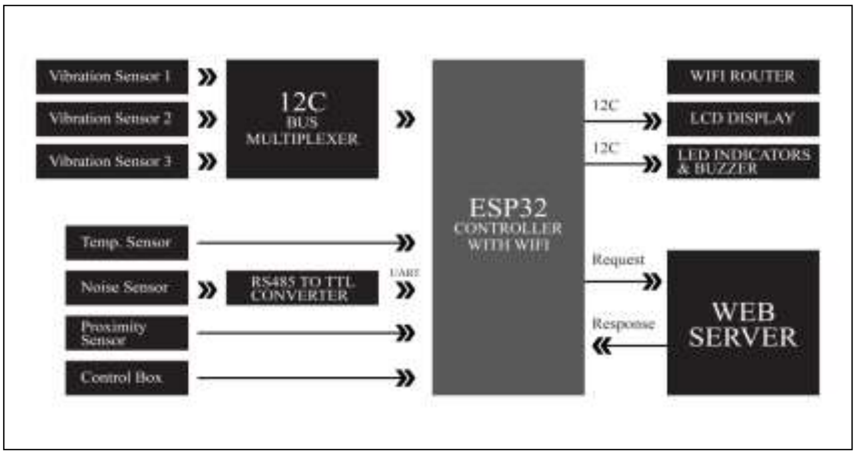


Figure 1: Basic Architecture and Hardware Interconnections.
Source: Authors, (2026).

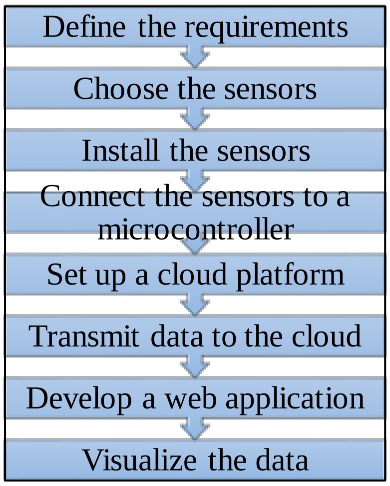


Figure 2: Steps to establish the setup of IOT web based monitoring system in the External Grinding machine.
Source: Authors, (2026).

III.3 INTEGRATION WITH EXTERNAL GRINDING PROCESS

The attached sensors detect and measure the physical quantity, convert these values into an electric signal and transmit the data to the controller and the controller takes the decision about further required actions, if any abnormality is detected in machine conditions and process parameters. It is a close loop system in which feed is given to system about predefined process values. The data is transmitted through a Wi-Fi router and stored in the cloud. The data can be visualized using IOT applications.

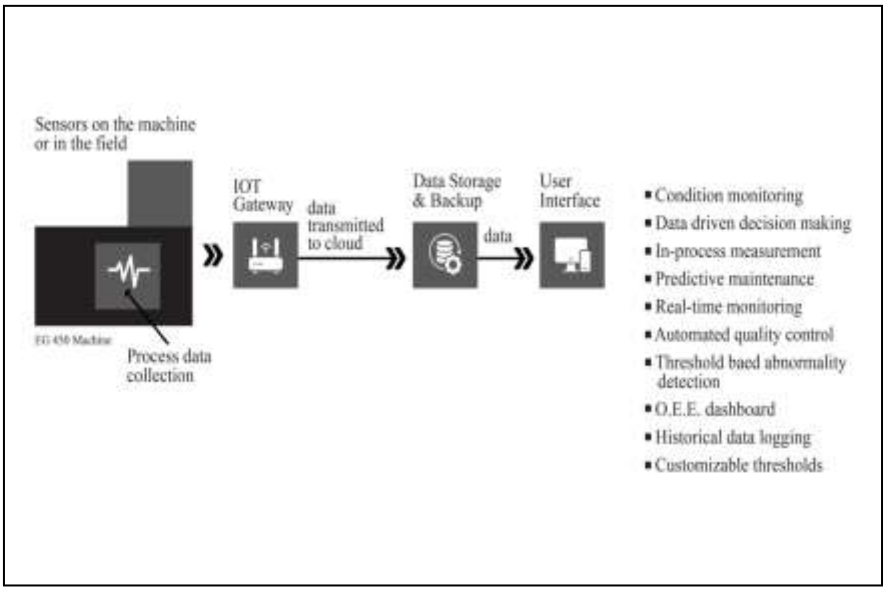
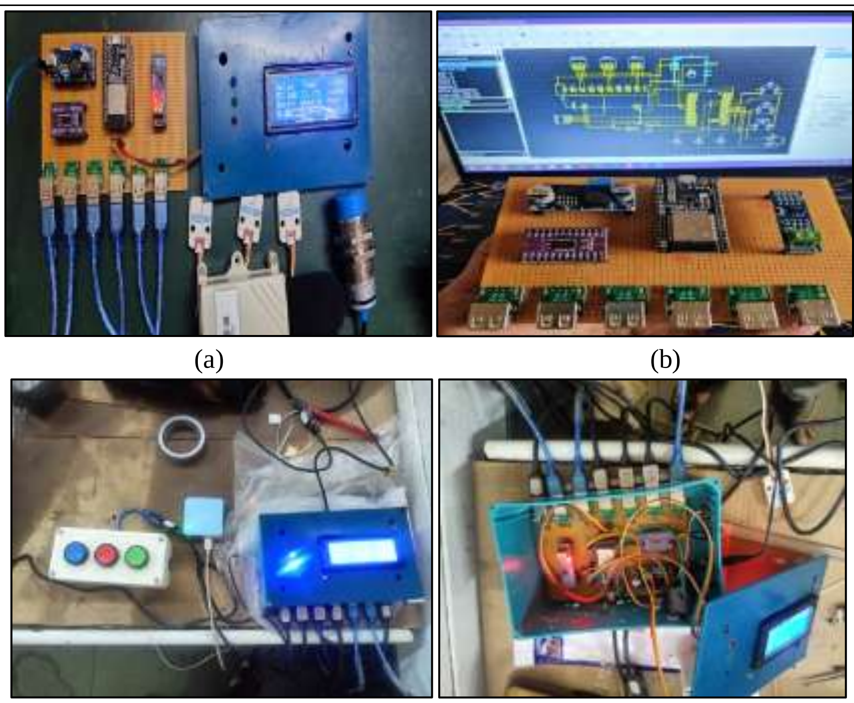


Figure 3: Data transmission pipeline in IoT-connected process systems
Source: Authors, (2026).

IV SYSTEM IMPLEMENTATION

IV.1 HARDWARE SETUP

The hardware elements, electronic components, control unit, wifi router, switches are interconnected and sensors have attached with machines to monitor process paramatrs and machine condition. Inter integrated circuit, Uart (Universal Asynchronous Receiver/Transmitter) and RS485 protocols are used for data communication between sensors and devices. The system is developed as if any abnormality is detected in machine or process parameters the notification will be sent to IOT web application for further improvements.



(a) (b) (c) (d)

Figure 4: a) Sensors connected with Microcontroller, b)Adapter Board with electronic devices ,c)Hardware unit Integration and d) Push Button Switch unit,Wifi router and control unit box with LCD screen
Source: Authors, (2026).

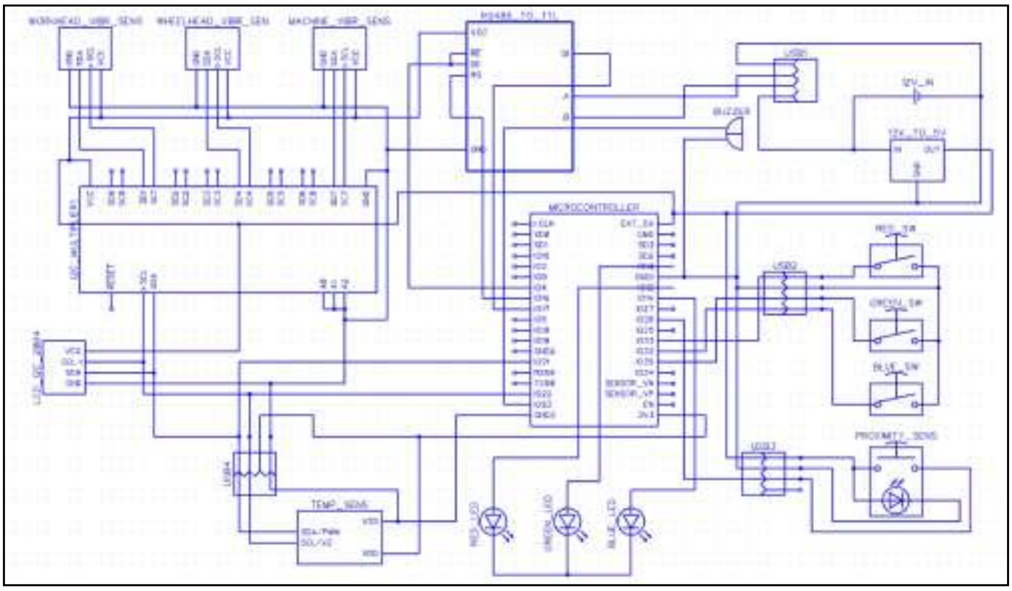


Figure 4: Schematic diagram of hardware interconnections and architecture.
Source: Authors, (2026).

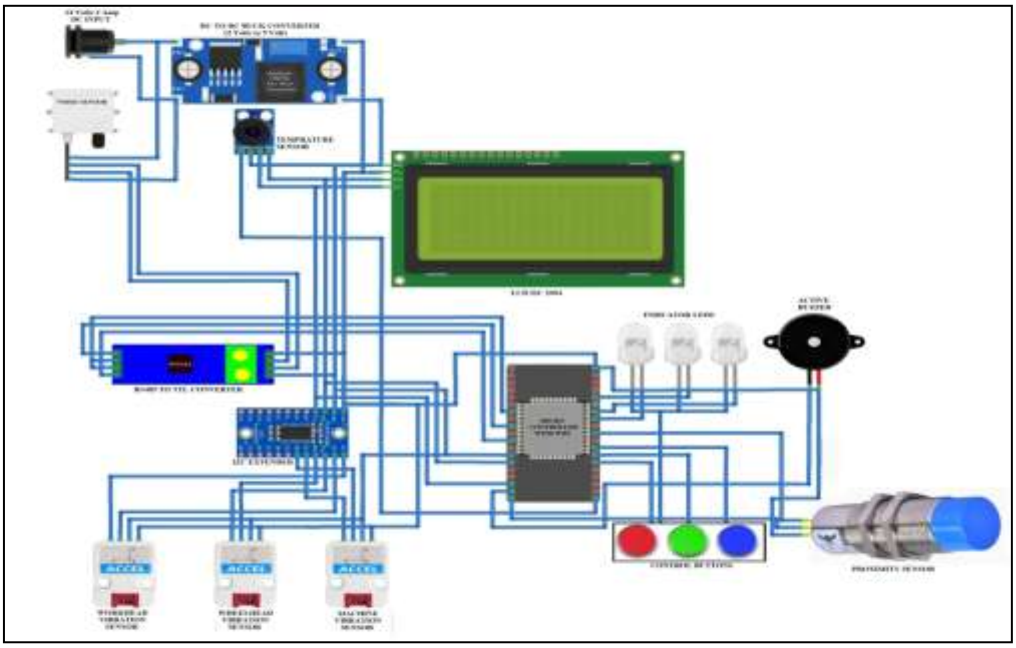


Figure 5: Circuit diagram of electronic hardware interconnections.
Source: Authors, (2025)

IV.2 EXPERIMENTAL SETUP AND TRAIL RUNS

The experimental setup has been developed by attaching sensors in machine to monitor external grinding process. The Control box, which contains a controller with voltage converters,I2C (Inter-Integrated Circuit) multiplier, RS485 signal to TTL (Transistor-Transistor Logic) converter, LCD, an active buzzer, Red and blue LED lights and a button Panel connector. Trail runs are conducted to check the response time, functionality testing, integration verification, usability, performance assessment, reliability, and stability of the developed IoT-based monitoring system. During trial runs, the problems faced related to incorrect sensor readings due to improper attachment with the machine, also corrected software bugs and compatibility problems related to IoT platforms, were not integrated smoothly with the machine tool. The experiments are performed after successful trial runs, Experiments are performed in various batches with groups of bearing races. Each batch contains total 38 bearing races. Experiments have been performed for two days with a total of five batches of 38 components. The method of experimentation is control experiments; it’s a scientific test in which all machining conditions and process parameters remain constant except for the variables being tested. The hypothesis is a prediction of experimental outcome and an assumption about the relationship between variables. The fig 6. explains the step-by-step procedure of controlled experiments.

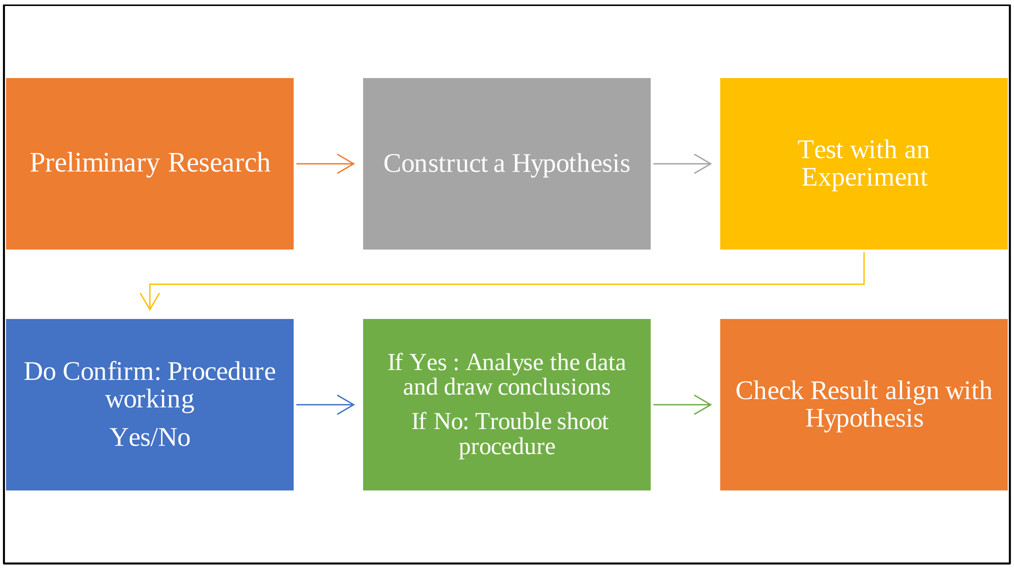


Figure 6: Controlled Experiment Procedure.
Source: Authors, (2026).

The pre-defined optimum threshold values for process parameters and machining conditions have been decided based on ISO standards and past production quality data records. The values of machining time and inspection time are chosen by the standard procedure of industrial engineering. With concerning controlled experiments the Independent variables (Controls during the experiment) are Vibration of Work head, Wheel head and Machine Bed, Cutting Temperature, and Noise. The Dependent Variables (Measured during the experiment) are surface finish, size accuracy, machine working time, machining time, and inspection time. The controlled variables Controlled Variable (Need to be constant for accurate results) are Feed, cutting speed, and depth of cut.

Table 2: Threshold values during experiment.

Sr. No	**Critical Parameter**	**Threshold values**	**Reference**
1	Maximum Cutting Temperature	25°C	---
2	Machine Vibration (Wheel head, work head and machine Bed)	1.8 mm/sec	ISO 10816-1
3	Noise	85 db	[16]
4	Cycle Time	126 sec.	--
5.	Inspection Time	4 sec.	--

Source: Authors, (2026).

The parameters mentioned in Table No.2 are monitored by IoT web-based monitoring system during the external grinding process for a bearing race. If the value exceeds the threshold, there is a chance of poor bearing race quality as well as machine inaccuracy and abnormal conditions.

Table 3: Machining Conditions that remain constant during controlled experiments.

Sr. No	**Parameter**	**Value**
1	Grinding Wheel RPM	2200
2	Work Piece RPM	16
3	Depth of Cut	0.05 mm
4	Material of Grinding wheel	RAA120L5VF8/60
5	Material of Work Piece	SAE 52100
6	Cutting Fluid Flow rate	20 Liter/Min
7	Feed	0.05 mm per pass
8.	Cutting Speed	46.05 m/s

Source: Authors, (2026).

Figure 7: Experimental setup.
Source: Authors, (2026).

The bearing race holds in work holding device of the external grinding machine. during external grinding, the cutting temperature is monitored, as well as the vibration and noise of the machine is monitored. After completion of the grinding operation, the machining time and inspection time are noted by a proximity sensor. The bearing size accuracy is measured by a measurement setup using a dial gauge. At last, the quality of the part is confirmed by pressing the Green or Red button push switch.

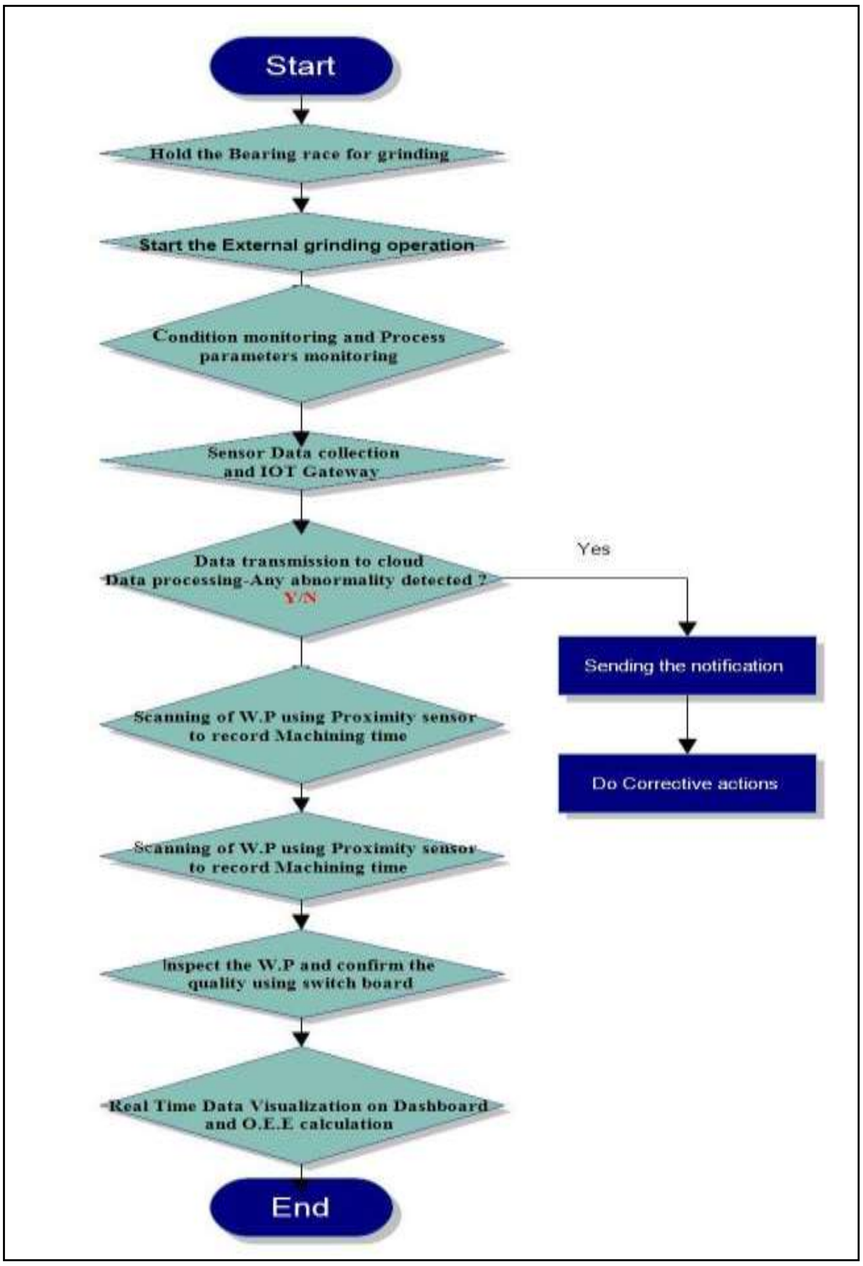


Figure 8: Flow chart of Experimental procedure.
Source: Authors, (2026).

IV.3 REAL-TIME MONITORING AND O.E.E DASHBOARD

The process variables are monitored by IoT-based system, and if any abnormality is detected, the notification will be mentioned on IOT web application.

IV.4 PROCESS CONTROL PLAN

Table 4: Process Control plan for IoT-based External Grinding Process.

KPI	Thresh-old Values	Relevant O.E.E.Factor	Required Corrective actions (If variable values exceed threshold values)
Cutting Temperature	25°C	Quality	Maintain cutting fluid temperature.
Vibration of the Machine bed, wheel head, and work head	1.8 mm/ sec	Quality and Availability	Balance machine parts, repairing Spindle misalignment, Repairing Loose machine parts, managing cutting speed, and feed.
Machine Noise	85 db	Availability	Controlling friction, unbalancing, overloading, malfunctioning, and misalignment between machine parts.
Process Time and Inspection Time	126 sec. and 4 sec.	Performance	Continuous improvement, corrective actions and standardizing working procedures.

Source: Authors, (2026).

IV.5 IOT WEB APPLICATION AND O.E.E DASHBOARD

The IoT web application is developed to analyze, monitor, and visualize the real-time production data. The stored data from the cloud is sent to the web application through the wi-fi module. The O.E.E Dashboard is developed to monitor the O.E.E of the external grinding process. O.E.E. is visible after the completion of a shift. The record of past production data and O.E.E. is visible in the web application.

IV.6 FEATURES OF IOT WEB APPLICATION

1) Real-time production data monitoring for data-driven decision making
2) A facility to customize threshold values of each critical parameter.
3) Threshold-Based Abnormality Detection notification.
4) O.E.E. dashboard and historical data Logging.
5) Notification and alert system on Mobile Phone.

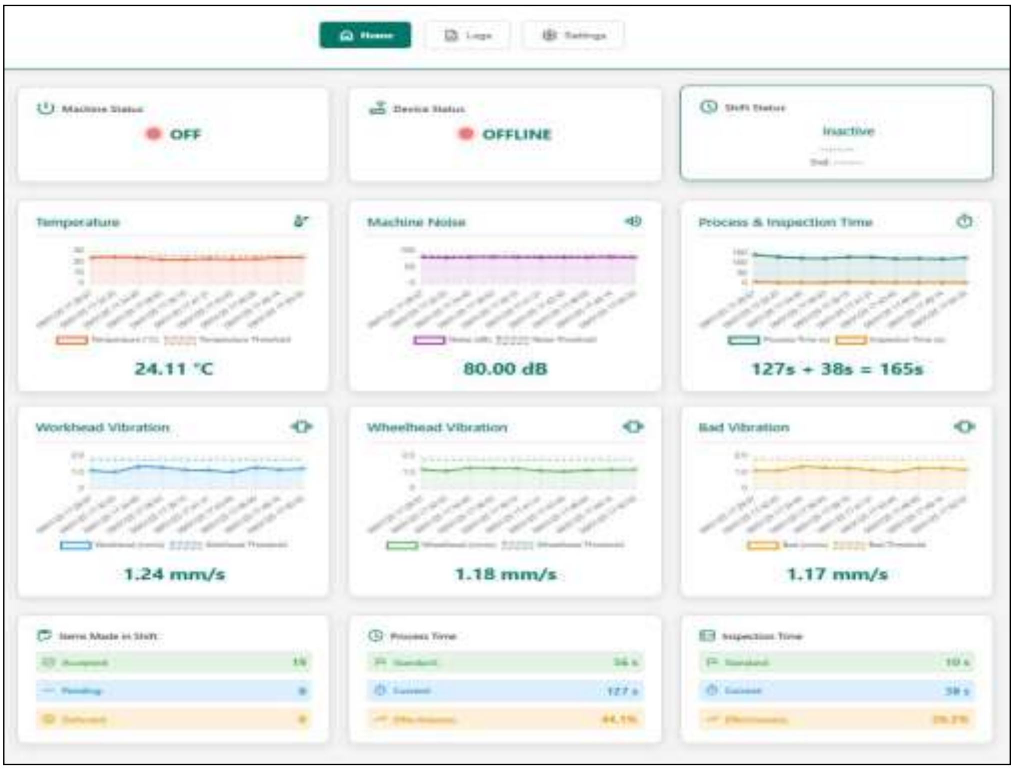


Figure 9: Real-time data Dashboard.
Source: Authors, (2026).

Figure 10: Data Logging and shift-wise KPI records.
Source: Authors, (2026).

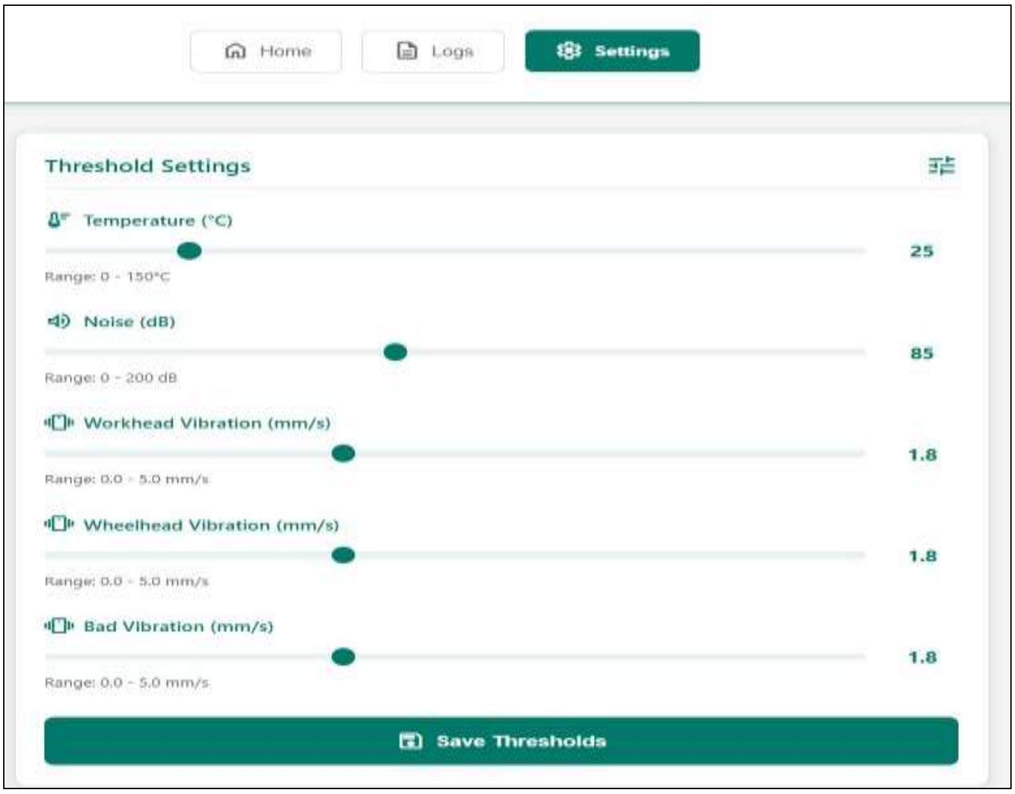


Figure 11: Customizable thresholds for each critical parameter.
Source: Authors, (2026).

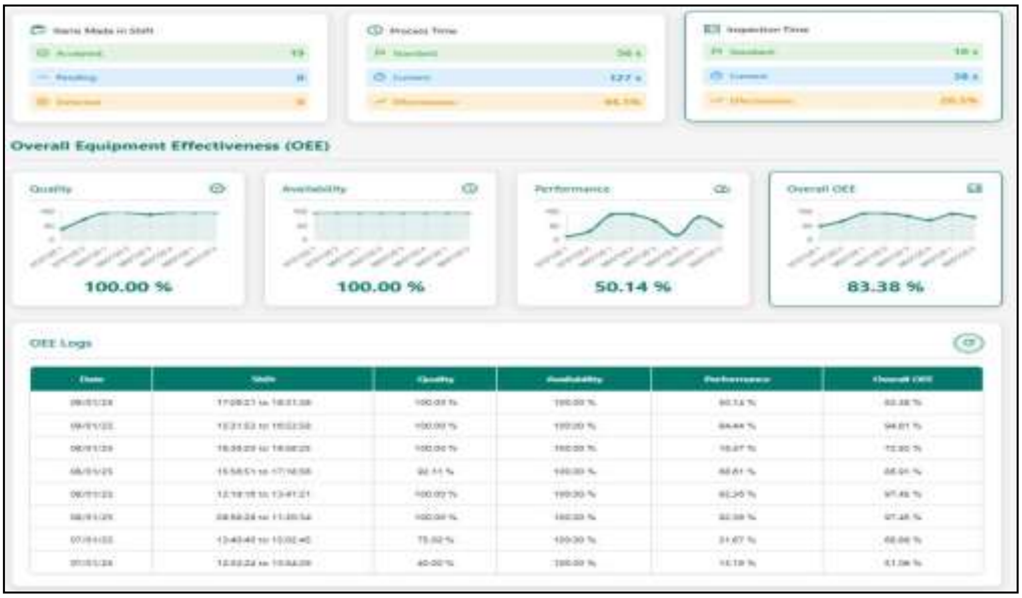


Figure 12: O.E.E Dashboard.
Source: Authors, (2026).

V. RESULTS AND DISCUSSION

After performing experiments, it is observed that if the values of critical parameters like cutting temperature and vibration do not exceed their threshold values, the bearing's remarkable surface finish and accurate size can be achieved. The sudden breakdown of the machine is reduced due to the detection of an abnormality in the early stage. The notification and alert system helps to provide attention to the supervisor by providing the condition monitoring system. The following notifications have been generated during experiments.

Table 5: Notification and alert system Observation during experiments.

Shift and Date	Critical Parameter	Values exceed the Threshold?	Notification and alert generated?
Shift 1 8/1/2025	Bed Vibration	Yes	Yes
Shift 2 8/1/2025	Bed Vibration	Yes	Yes
Shift 3 8/1/2025	Cutting Temperature	Yes	Yes
Shift 2 9/1/2025	Noise	Yes	Yes

Source: Authors, (2026).

After getting a notification from IoT web-based monitoring system, corrective actions have been taken to achieve the quality and reduce the chances of breakdown. The sudden breakdowns are eliminated by the live monitoring and alert system. The paperwork is eliminated by implementing an IoT-based system, as all production records have been digitized, so it helps to promote environmentally conscious and sustainable practices. After monitoring the O.E.E. of each shift it is observed that the O.E.E. of the external grinding process is improved. The past one-year production data of O.E.E without implementing IoT system was collected, and after implementing IOT system, the O.E.E is calculated. A notable improvement observed in O.E.E is 8.70%. Fig.13 shows a significant improvement in the quality of bearing parts as well as an improvement in performance and availability of the machine.

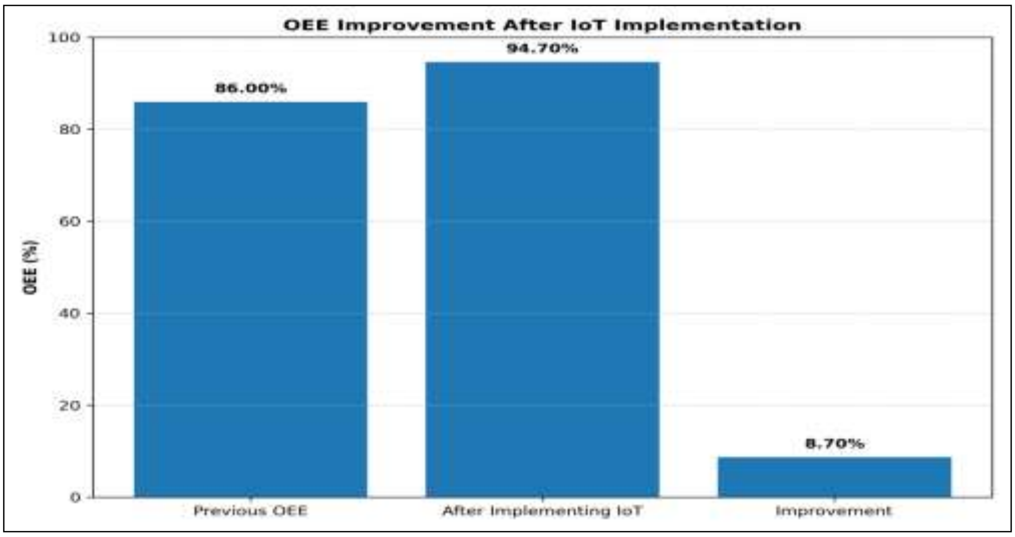


Figure 12: O.E.E before and after implementing the IoT-based monitoring system.
Source: Authors, (2026).

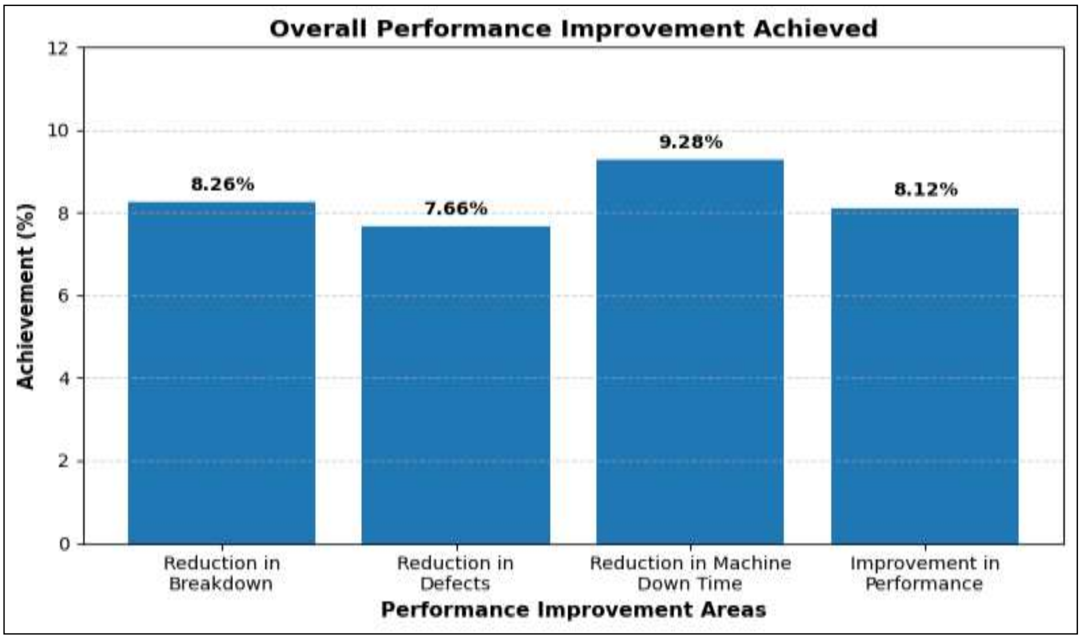


Figure 13: Achievements after implementing an IoT-based system.
Source: Authors, (2025)

VI. CONCLUSION

The research demonstrates the development and implementation of an IoT-based web monitoring system aimed at improving the O.E.E. of an external grinding process used in the precision manufacturing of bearing components. The results from experiments highlight the effectiveness of IoT-based real time monitoring system for improving O.E.E with enhancing quality, reducing breakdowns, reducing machine downtime and promoting sustainable practices in the manufacturing process by eliminating the usage of papers.The integration of real-time monitoring and data analytics plays an important role in process improvement. The developed system utilizes calibrated sensors for data collection and monitoring of critical process parameters such as cutting temperature, machine vibration, noise levels,cycle time which are linked with key performance indicators and these factors directly influence the OEE elements in terms of quality, availability, and performance. Through controlled experiments, the system was tested for its reliability, accuracy, and responsiveness. When deviations from threshold values were detected, the system generated immediate notifications, allowing timely corrective actions to prevent quality defects and machine downtime.

The significant improvement in O.E.E was observed, rising from 86 % to 94.70 % after implementing IOT web based real time monitoring system. After performing experimentation during various manufacturing shifts at bearing manufacturing industry the 8.26 % reduction in breakdown,7.66 % reduction in manufacturing defects,9.28 % reduction in machine downtime and 8.12 % improvement in machine performance is observed. Furthermore, the adoption of digital manufacturing approach minimised paperwork, reduced production bottlenecks and supports data-driven decision-making on the production shop floor. This approach confirms the practical benefits of adopting IoT technologies in manufacturing operations particularly in high-precision processes like external grinding.Future work may focus on expanding the system's capabilities to other machining processes and incorporating advanced analytics and machine learning for predictive insights. Overall, this IoT-based solution represents a scalable and cost-effective approach to achieving operational excellence in smart manufacturing environments.

VII. AUTHOR’S CONTRIBUTION

Conceptualization: Manan Bhavesh Raval, Hirenkumar Indravadan Joshi, Bharat Khatri and Janak Valaki.
Methodology: Manan Bhavesh Raval, Hirenkumar Indravadan Joshi, Bharat Khatri and Janak Valaki.
Investigation: Manan Bhavesh Raval, Hirenkumar Indravadan Joshi, Bharat Khatri and Janak Valaki.
Discussion of results: Manan Bhavesh Raval, Hirenkumar Indravadan Joshi, Bharat Khatri and Janak Valaki.
Writing – Original Draft: Manan Bhavesh Raval, Hirenkumar Indravadan Joshi, Bharat Khatri and Janak Valaki.
Writing – Review and Editing: Manan Bhavesh Raval, Hirenkumar Indravadan Joshi, Bharat Khatri and Janak Valaki.
Resources: Manan Bhavesh Raval, Hirenkumar Indravadan Joshi, Bharat Khatri and Janak Valaki.
Supervision: Manan Bhavesh Raval, Hirenkumar Indravadan Joshi, Bharat Khatri and Janak Valaki.
Approval of the final text: Manan Bhavesh Raval, Hirenkumar Indravadan Joshi, Bharat Khatri and Janak Valaki.

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