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Original Article

Development and Implementation of Real Time IoT-Enabled Cutting Temperature Monitoring System for Bearing Manufacturing Process

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Abstract *- Such excessive cutting temperature in external grinding has a detrimental effect on the surface finish, dimensional accuracy, and overall productivity in the manufacture of bearing components. This manuscript describes the design and industrial application of a real-time Internet of Things-enabled cutting temperature monitoring system developed for the use of cutting SAE 52100 bearing races in an external grinding machine. The system architecture has been integrated with a non-contact infrared temperature sensor, ESP32 microcontroller, wireless communications protocols, cloud-based data storage, and a web-based dashboard with utter threshold alerts to allow for in-process monitoring in a continuous fashion, proximal to the zone of grinding. Industrial additional validation was performed on a series of 259 bearing races at several production shifts. Revealed by empirical data was that there were stable grinding conditions maintained within a temperature band of 21.10°C to 24.95°C, and the highest recorded temperature was obtained at 26.31°C with resulting overall temperature variation of 4.58°C. Sustained presence of cutting temperature in the 20 - 25°C range invariably showed superior surface finish from 0.15 µm to 0.18 µm and dimensional accuracy with ± 0.01mm. To evaluate shift-wise process stability, the Thermal Stability Index (TSI) was introduced. The results validate the idea that the proposed system is a cost-effective, scalable, and industry-ready solution for real-time, quality-oriented monitoring of the grinding process and a basis for future predictive and adaptive control system applications.*

Keywords *- IoT (Internet of Things), Process monitoring, Temperature measurement, Thermal stability.*

1. Introduction

A bearing is a machine element used to reduce vibration and noise in a machine. Bearing also supports rotational parts. The manufacturing of bearings contains metal forming, cutting, machining, assembly, and heat treatment processes. Machining operations such as turning, grinding, and honing generate significant heat during the metal-removing process. Excessive cutting temperature leads to thermal damage, affects surface quality, [1-3] dimensional inaccuracy [3], and tool wear, which increases the chance of rejection during inspection. An external grinding process is required to finish the outer face of bearing parts. The outer race, Inner race, and rollers are externally ground to achieve surface finish and accurate outer dimensions. This process is carried out in an external grinding machine with the proper process parameters. During grinding, substantial heat is generated at the tool-workpiece interface due to plastic deformation and friction. The cutting temperature is one of the key parameters that affects the surface quality of bearing races in terms of surface finish and size accuracy. In the conventional bearing manufacturing process, the cutting temperature is often monitored indirectly; this approach is time-consuming and lacks real-time monitoring capability. It is needed to continuously monitor the cutting temperature during the external grinding process of bearings.

The development of an IoT-based in-process cutting temperature measurement system provides real-time readings of the working process. [4, 5] Using an IoT-enabled infrared thermometer, supporting electronic system and networking system, the cutting temperature monitoring experimental setup is developed. [6] Additionally, the web dashboard is developed, which continuously monitors the live status of the cutting temperature while the grinding process is performed. If the value of the cutting temperature exceeds the threshold value, an automatic notification will be generated in the dashboard as well as the networking platform mobile application.

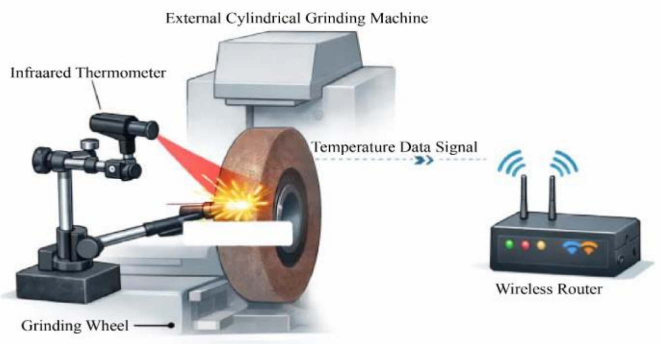


Fig. 1 In-Process temperature measurement

The threshold value of cutting temperature is 25°C, which is decided after performing experiments and observations during the external grinding process of bearings in industry. It is observed that with setting-controlled process parameters, the cutting temperature between 20°C and 25°C, a remarkable surface finish is achieved. The cutting fluid temperature is controlled at 20°C. The experimental setup is developed with a controller, sensor, Wi-Fi module, and necessary electronic materials. A web application is developed in which the threshold value of cutting temperature is customizable and can be set as a requirement. The data on cutting temperature is recorded and collected for the purpose of analysis.

The data analysis is carried out to decide how cutting temperature affects the surface finish and size accuracy of bearing races. The relationships between cutting temperature and surface finish, and between cutting temperature and dimensional accuracy, are established. The proposed system is validated by comparing sensor readings with a standard thermometer. The sensor is also calibrated for getting accurate readings. The study focuses on the development and implementation of a cost-effective IoT-based cutting temperature monitoring system for bearing operations. The operating voltage of the used infrared thermometer is 3.3V. The maximum sensing range is 10 CM, The Sensing Temperature is -40 °C to +85°C, and the accuracy is ±0.2°C over the wide temperature range. The sensor is calibrated in an accredited calibration laboratory and found suitable for use in experimentation.

Unauthorized access and data breaches can be seen as the risks that the proposed system may expose, since it uses cloud-based data storage. Such wireless communication protocols as Wi-Fi and MQTT can be subject to cyber-attacks unless properly secured. Lack of superior security tools, such as encryption of messages and a stringent authentication system, may impinge on system integrity. Secure network architecture is therefore necessary in order to defend against the interception or manipulation of real-time industrial data. Implementation must also include extensive structures on cybersecurity considerations, secure IoT architecture, and adherence to data privacy to provide secure and stable implementation of industries in the future.

The sources of error in IoT based system are sensor related errors like Noise in signal acquisition, Environmental interference (temperature, humidity, vibration), other source of error is data acquisition error like Sampling rate mismatch and quantization errors, third type of error source is Communication Errors such as packet loss in wireless communication and network latency and bandwidth limitations, In last hardware related errors like Microcontroller malfunction, power supply fluctuations and loose connections. To reduce the errors and for mitigation, the actions to be taken are to control the surrounding environment, calibration, and tests at regular intervals, and correct the installation and use of reliable instruments.

In the study, the IoT-based real-time cutting temperature monitoring system in the case of external grinding on an industrial scale is discussed. It proposes a parameter, the Thermal Stability Index (TSI), to measure stability in the process and combines quality configurations with temperature. There is a customized alert system and dashboard that improves quality control and decision-making. The architecture is a scalable and economical architecture based on non-contact sensing, cloud storage, and analytics. In a research study, the focus is on how to reduce the surface defects by controlling the cutting temperature.

The research study is very specific, with only one material (SAE 52100), and with control experiments and certain grinding conditions and process parameters, so it would be difficult to generalize the study. Only temperature cutting is monitored, whereas other important parameters, such as vibration, cutting force, and tool wear, are not. It depends on the Wi-Fi, which can impact stability within a fluctuating network setup. Validation using an experiment is done on a small dataset (259 components), and this might not reflect the long-term variation.

2. Literature Study

The systematic study of the development of grinding temperature and correlative surface integrity of quenched automotive transmission gears under form grinding was conducted in the current research study. The outcomes showed that the temperature of the grinding was rising over time with the varying feed speed, depth of cut, and spindle speed peaking to almost 290 °C, and as a consequence, caused a deposition of a white layer, stratification in the material structure, changes in hardness, and a roughness of the surface. This information provides some useful principles of reducing grinding burn as well as the optimum gear grinding parameters. [1]

This research presented an experimental study to examine the evolution of the cutting temperature in dry whirling milling of ball screws, using infrared thermal imaging. It measured the effect of cutting speed, depth of cut, number of tools, and thread geometry on the highest and the average temperature, and it developed both regression and back-propagation neural-network models; the maximum and average temperature prediction of the regression models was above 99.8 % and above. [2]

This paper was an experimental work that showed how cryogenic temperature in the form of liquid nitrogen significantly decreased cutting temperatures, tool wear, surface roughness, and dimensional variation in the turning of AISI-4037 steel. Compared to dry and wet machining, cryogenic machining demonstrated better chip tool interaction, tool life, and was found to confer better surface integrity and dimensional accuracy under industrial conditions of cutting. [3]

It was included in the current study, which proposed an in-process, workpiece-based temperature measurement of cylindrical grinding with a pyrometer of two wavelengths. This method made high-temporal-resolution measurement of underlying thermal fields more straightforward, and heating/cooling response during. Single rotations of workpieces and calculation of thermal load fields were made possible. As a result, the method provided the essential information about mitigation of grinding burns, assessment of the thermal damages, and validation of grind -hardening processes as well as finite-element thermal calculations. [4]

This research came up with a unique in-process ground surface temperature measurement procedure, which is implemented with an infrared thermometer utilizing small holes in a hollow rotating grinding wheel. The methodology made it possible to obtain periodic and high-resolution temperature data on both the grinding surface and the wheel, detect temperature increases due to clogging, and be applicable when dry CFRP grinding takes place under precision, rough, and highly efficient working conditions. [5]

The current research developed an Internet-of-things-based intelligent temperature control device that can be applied to machining processes that combines an MLX90614 infrared sensor and an ESP32 microcontroller. The system enabled real-time, non-contact measurements, data acquisition, and analytical processing of cutting temperatures, thus, on the basis of adaptive tool-path planning, improved surface integrity, diminished tool wear, and improved productivity in both traditional and Computer-Aided Machining tasks. [6]

This study has managed to develop, deploy, and test a complicated temperature sensing device utilizing Arduino and MLX90614 infrared sensor, to measure the dry milling of aluminium alloy AA6041. Comparative tests indicate that the temperature ratings made using this system have a striking similarity to those of the Fluke Ti400 reference apparatus, with the greatest variation being at most ±2°C. The system, therefore, has good data logging capabilities in real time, thermal continuity, and is practically viable to provide detailed machining process profiling and optimization, as mentioned in the reference. [7]

The research was able to come up with a high-speed infrared radiation biochromatic pyrometer that allows non-contact measurement of the cutting-edge temperature of end-mills. The system obtained a timely resolution of 0.01ms, good performance of noise reduction, and dependable temperature profiling, thus facilitating the correct determination of cutting mechanics, tool-chip test, and its application to both high-speed machining and tool-condition tracking. [8]

We conducted an experiment on relief grinding of gear milling teeth in this research after the Archimedes spiral, and our results showed the greatest impact of the velocity of the grinding wheel on the surface roughness and surface hardening. Taguchi-ANOVA modeling found quadratic relationships, which had high predictive power, providing quantitative information to choose the grinding wheel and cutting parameters to control the surface quality and the behavior of hardening. [9]

This work constructed a real-time monitoring device based on the Internet-of-Things, designed to measure the temperature of cutting tools used in filling steel AISI1018 lathe turning in the form of a thermocouple, infrared, and Arduino microcontroller. Quantitative analyses demonstrated that the sensing modalities have a strong correlation, with an accuracy in the measurement of ± 1.5 °C. As a result, the system will enable constant control, predictive maintenance, reasonable optimization of cutting parameters, and improved productivity, as well as increased tool life according to the recent discoveries in the control of manufacturing processes. [10]

The current study proposed a new in-process tool monitoring system based on the principles of cutting temperature changes, which was based on the impedance fluctuation represented by a dielectric-coated tool at the tool-chip interface. This allows a method of obtaining thermal measurements in real time without the use of auxiliary sensors and demonstrates a good impedance temperature relationship, and depicts the possible measurement of simultaneous contact conditions, vibratory behavior, and machining mechanics in operation during the cutting process. [11]

In this study, we made a comparative study of measurements of direct thermocouples and the infrared thermography to determine the cutting- zone temperature distribution during the surface grinding of C45 steel and Mo63 brass. The findings established that thermal imaging offered a better spatial-temporal resolution and a better temperature peak finding in comparison to the thermocouples that consistently underscored temperatures owing to the positioning errors, thus establishing infrared thermography as a dependable technique in the thermal analysis and evaluation of burns during grinding. [12]

In this review, the author explores how Industry 4.0 technologies support the sustainable manufacturing sector through more efficient use of resources, minimization of waste, and transparency in the supply chain. It finds that, although such technologies enhance the environmental, economic, and social performance, issues like energy consumption and job displacement require concerted technological, policy, and organizational approaches in implementing them sustainably. [13]

The review examines how IoT facilitates a smart factory in Industry 4.0 by enhancing real-time monitoring, predictive maintenance, energy savings, and optimization of a supply chain. It concludes that IoT increases productivity, quality, and sustainability and demands improved progress in the field of security, interoperability, and intelligent decision-making systems. [14]

The research article summarizes wireless communication protocols that allow IoT in the Industrial sphere and smart manufacturing, reviews their protocols, applications, and specifications. It concludes that although the current technologies are suitable to monitor and control the factories, other solutions like 5G can meet the problems of latency, reliability, and scalability in future factories. [15]

This study examines Industry 4.0 as a redefinition of the systemic change brought about by AI, IoT, CPS, and optimization, not limited to manufacturing but also to the fields of healthcare, logistics, and smart cities. It concludes that effective adoption involves a combination of technological innovation and ethical governance, sustainability, and human-centered development to create resolute socio-economic systems. [16]

Highlights the progress in Industry 4.0 of smart manufacturing using AI, IoT, and digitalization, and identifies efficiency, sustainability, and competitiveness as its most significant upgrades. It also structures the findings that issues like cyber security, modernization of the workforce, and sustainability demand a paradigm shift to Industry 5.0 with its focus on resilience, human-friendliness, and balanced incorporation of technological advancements. [17]

The study indicated that the assessment of Industry 4.0, considering automation and supervision systems, looks at definitions, enabling technology, and architectures. It concludes that standardization and interoperability are one of the most important requirements of IoT, AI, and decentralized architecture implementation, as they create flexibility and efficiency. [18]

The paper will analyze the integration of Industry 4.0 technologies, namely, IoT, AI, big data, cloud computing, robotics, and their advantages to efficiency, flexibility, and sustainability in smart manufacturing. It draws a conclusion that, among the advantages, issues such as high costs, skills gap, and information security need to be planned and coordinated. [19]

This paper examines how the Internet of Things will evolve in 2025, the adoption of AI, 5G, and edge computing in all industries, including smart manufacturing. It concludes that IoT increases efficiency and innovation by providing sophisticated business models, whereas the IoT security concerns, such as cybersecurity, interoperability, and privacy, need to be addressed by powerful technological and strategic tools. [20]

This research creates an IoT-based smart manufacturing platform that incorporates AI, robotics, and cloud computing and has shown great advances in efficiency, cost-saving, and quality of products. It concludes that Industry 4.0 can improve operational performance and ROI, but issues such as security, costs, and skill gaps need to be addressed with a strategy. [21]

The article suggests a multi-layer architecture of an Industrial Data Management System (IDMS) based on IoT in order to acquire, process, and store heterogeneous industrial data efficiently. The findings show better real-time monitoring, efficiency in handling data, and predictive maintenance features in smart manufacturing setups. [22] The research study describes a framework of the Internet of Things approach with a digital twin as the IoT energy management system in smart manufacturing, with real-time monitoring, adaptive control, and energy optimization (via the simulation-supported validation procedure). Findings have shown high energy savings, reliability, higher battery duration, and lowered latency, showing scalable and efficient system behavior. [23]

In the presented article, the study related to the introduction of smart manufacturing through Industrial IoT (IoT), including architecture, communication protocols, applications, and security challenges; the article has discussions about the enhanced productivity, real-time monitoring, and cost-effectiveness, with the general challenges of security threats, integration, and future research areas of scalable smart industry implementation. [24]

The paper constructs a conceptual framework of how Industry 4.0 technologies provide strategic and business model innovation by identifying organizational and contextual preconditions as dynamic moderators that create a virtuous cycle, facilitating a transformation process or a vicious cycle leading to technological inertia and resulting in firms' value creation and competitive advantage. [25]

2.1. Research Gap

- Some existing literature looks more towards laboratory-scale temperature measurements, and do not involve a real-time implementation in bearing grinding processes.
- Very limited literature highlights the integration of cutting temperature monitoring to specific quality parameters like dimensional accuracy and surface finish.
- Continuous in-process monitoring in the form of IoT and an automated threshold-based alert mechanism has not been highlighted in some previous literature.
- Adequate investigation of thermal behavior in a shift-wise scenario and stability of the process in an industrial setting is observed in very few past studies.
- The majority of literature does not have a standardized index to assess thermal stability, such as the Thermal Stability Index (TSI), when studying thermal consistency in machining operations.

Table 1. Comparison of the IoT system with the traditional system

Parameter	Traditional system	IoT Enabled
Alarm generation	No	Yes
Process monitoring	Periodic	Continuous
Decision making	Experience-based	Data-driven
Reporting time	At the End of Shift	Instant
Visualization	None	Real-time dashboard
Data acquisition	Manual	Fully Automatic

3. System Architecture and Methodology

- Sensing Layer: Thermal Sensor: Infrared Thermometer installed near cutting zone, Workpiece, and Tool Holder.
- Data Acquisition and Edge Layer: Micro Controller (ESP32), Signal Conditioning, and Real-time data sampling.
- Communication Layer: Wireless Protocols Wi-Fi, MQTT, RS 485, and Data Transmission Cloud data storage.
- Application Layer: Dashboard for Temperature data visualization and analytics, Data Logging, Threshold alerts, and trend analysis.

The system is designed to continuously monitor cutting temperature during the external grinding process. A modular approach is adopted to ensure scalability and ease of industrial implementation. The first layer of IoT based system is the infrared thermometer with a magnetic stand attached to the machine work head. The second layer is the perception layer, in which the controller receives the data from sensors and takes prompt action if the temperature value exceeds the threshold value. The third layer is the network layer, which stores the temperature readings data in the cloud using a Wi-Fi module. The fourth layer is the application layer, in which the dashboard is developed for visualization and monitoring of cutting temperature data. The thermal sensor measures physical quantities and converts these values into an electric signal, and transmits the data to the controller, which decides further actions. If the value of the cutting temperature exceeds the threshold value, the notification regarding abnormality is generated and sent to the web application and the communication platform mobile application. The regular DC Power supply is given to the sensor and controller for stable and smooth operation.

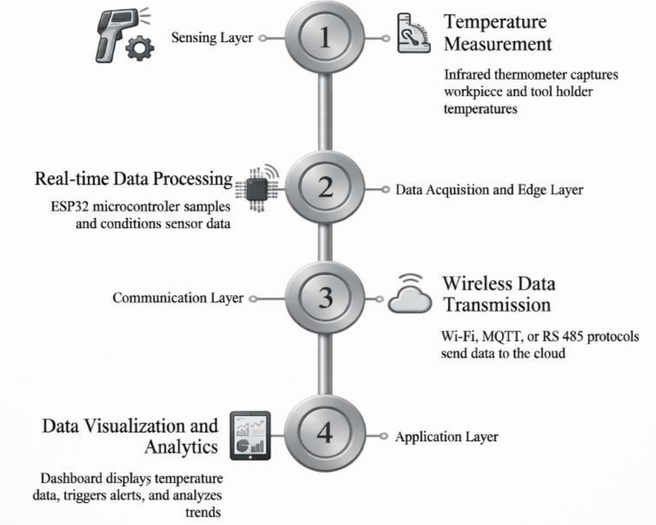


Fig. 2 Different layers of the IoT system

The hardware units, electronic components, sensors, and wi-fi router are interconnected to monitor cutting temperature data. The inter integrated circuit, Universal Asynchronous Receiver, and RS-485 protocol are used for communication between devices. The infrared thermometer is fitted in a magnetic stand, and the magnetic stand is attached to the machine work head. The thermal sensor is positioned closer to the external grinding process for monitoring of cutting temperature. Figure 2 shows the hardware interconnections and circuit diagram of the developed system.

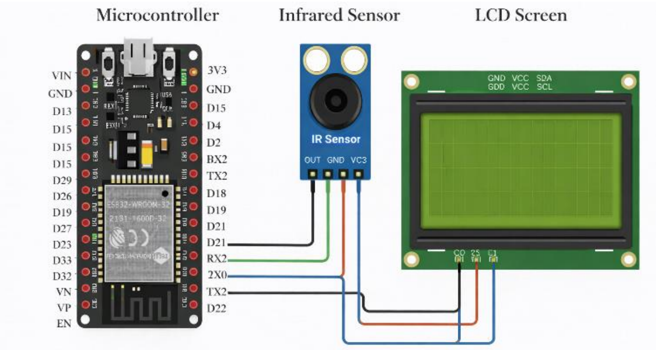


Fig. 3 Hardware interconnections

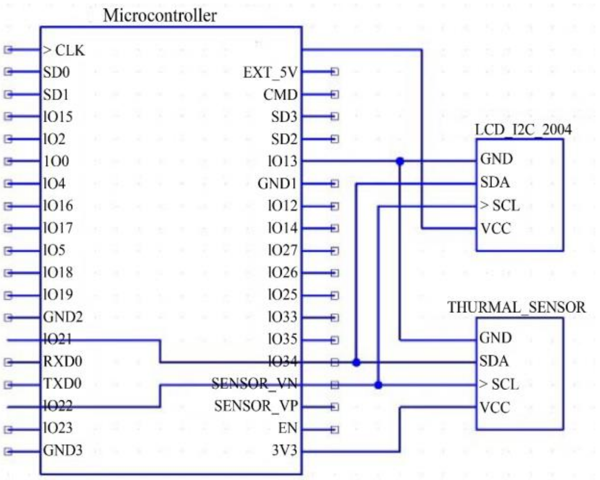


Fig. 4 Circuit diagram

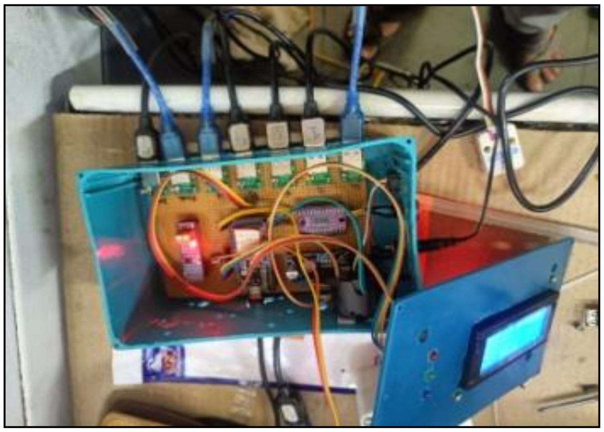


Fig. 5 Control unit box with LCD screen

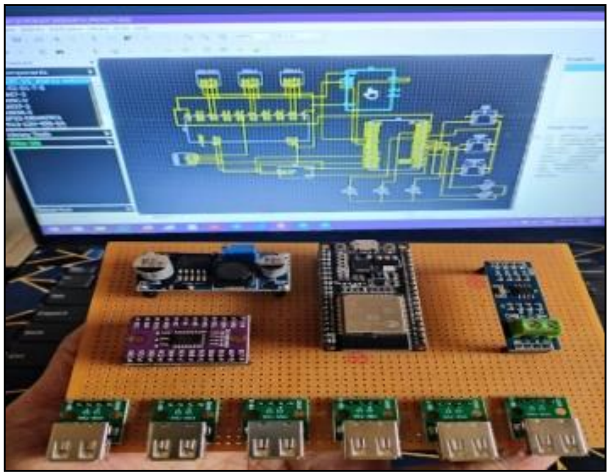


Fig. 6 Adapter board with electronic devices

4. Implementation in the Bearing Manufacturing Industry

The developed IoT-enabled system is implemented in the external grinding process carried out in the bearing manufacturing industry. The sensor is attached nearer to the cutting zone. The experiment trials are conducted to monitor cutting temperature and establish a relation between cutting temperature, surface, and finish size accuracy. A Control Experimentation method is a scientific method and an appropriate approach in which experimental trials are conducted in a controlled environment while maintaining constant variables. By keeping maximum constant machining conditions, it becomes easier to evaluate the performance of the system. Repeated tests under the same conditions, ensuring that the system provides consistent results, which is crucial for trust in real-time monitoring. It will be easy to compare the performance of IoT-enabled and conventional systems. Maintaining constant parameters in the machine, the controlled experimentation procedure is carried out to ensure system stability, reliability, and accurate micro-level analysis. Here, the feed, cutting speed, depth of cut, and cutting fluid flow rate remain constant during the entire experimentation process. During Pre-experimentation work, the cutting temperature was recorded, and it was observed that a remarkable surface finish up to 0.15 µm can be achieved if the cutting temperature remains between 20°C and 25 °C.

4.1. Setting of Process Parameters

Table 2. Materials and process parameters

Workpiece material and size	Material Grinding wheel	Work piece RPM	Cutting Fluid Type and Temp.
SAE 52100 with 70.10 mm OD	RAA120L 5VF8/60	16	Hicut Bio 150 Water Soluble fluid 20 °C

Table 3. Machining conditions

Depth of Cut	Cutting Fluid Flow Rate	Grinding wheel RPM	Feed
0.10 mm	20 Liter/Min.	2200	0.05 mm/min

Fig. 7 IR Thermometer sensor attached near the cutting zone

Fig. 8 Experimental Setup, (1) Bearing race (2) IR Thermometer (3) Magnetic stand (4) Control unit with screen (5) Wi-fi router [4, 5, 7]

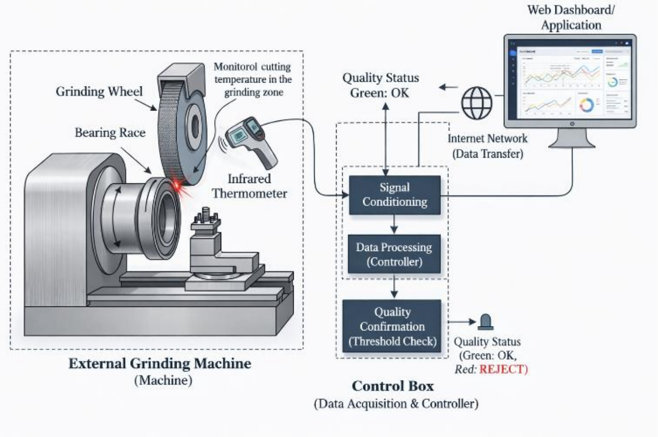
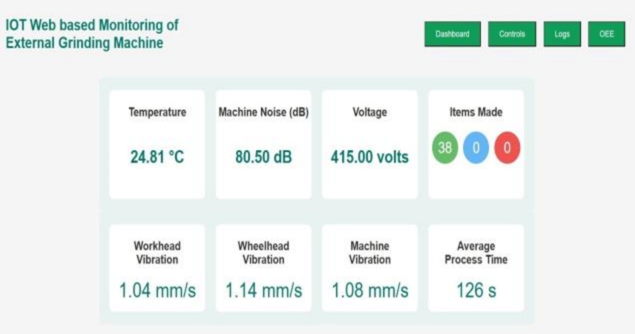


Fig. 9 Schematic diagram of experimental setup

The experiments are performed in various shifts, the temperature data have been collected in 8 production slots, and a total of 259 bearing races of 70.10 mm diameter were externally ground in an external grinding machine located in the bearing manufacturing industry. The recorded response time of the sensor is 2 seconds for each temperature reading. The screen of the control unit indicates the real-time temperature status of the grinding process. The alert notification is generated when the value of the cutting temperature exceeds the threshold value 25°C. The notification can be seen in the mobile communication platform and web dashboard.



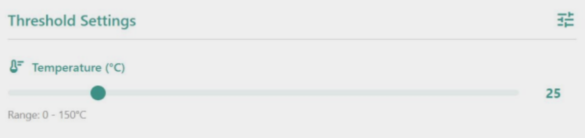
IOT Web based Monitoring of External Grinding Machine

Temperature: 24.81 °C
Machine Noise (dB): 80.50 dB
Voltage: 415.00 volts
Items Made: 38 0 0
Workhead Vibration: 1.04 mm/s
Wheelhead Vibration: 1.14 mm/s
Machine Vibration: 1.08 mm/s
Average Process Time: 126 s

Fig. 10 IoT-Enabled web dashboard

Date Time	ID	Quality	Temperature
28/12/25 13:37:45	S4D001	Yes	22.47 °C
28/12/25 13:40:11	S4D002	Yes	22.91 °C
28/12/25 13:42:48	S4D003	Yes	23.39 °C
28/12/25 13:45:34	S4D004	Yes	23.36 °C
28/12/25 13:48:22	S4D005	No	26.29 °C
28/12/25 13:51:02	S4D006	Yes	22.79 °C

Fig. 11 Temperature data logs



Threshold Settings

Temperature (°C): 25

Range: 0 - 150°C

Fig. 12 Threshold setting option

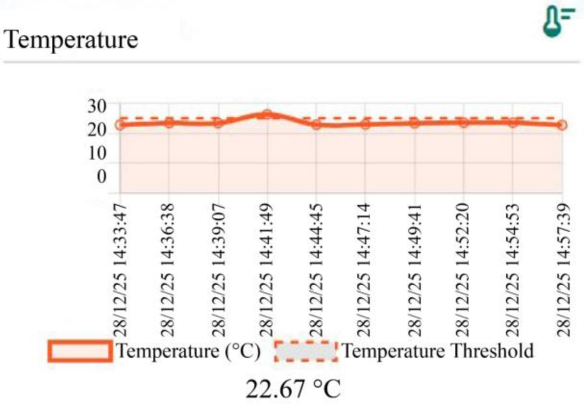
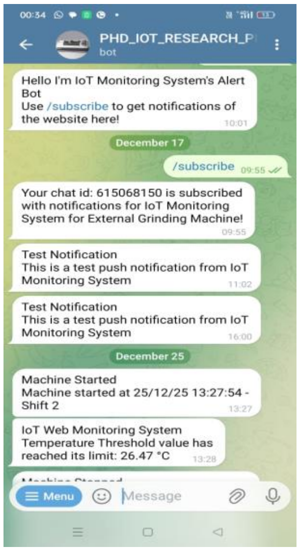


Fig. 13 Real-Time temperature graph



Hello I'm IoT Monitoring System's Alert Bot
Use /subscribe to get notifications of the website here! 10:01

/subscribe 09:55

Your chat id: 615068150 is subscribed with notifications for IoT Monitoring System for External Grinding Machine! 09:55

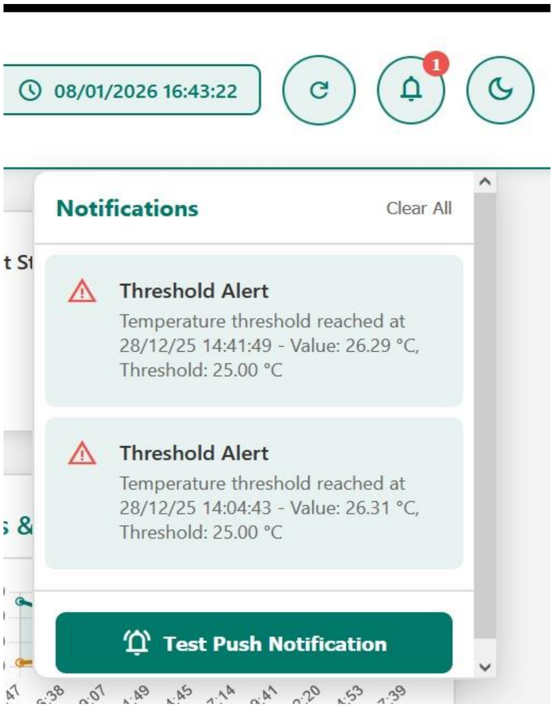
Test Notification
This is a test push notification from IoT Monitoring System 11:02

Test Notification
This is a test push notification from IoT Monitoring System 16:00

Machine Started
Machine started at 25/12/25 13:27:54 - Shift 2 13:27

IoT Web Monitoring System
Temperature Threshold value has reached its limit: 26.47 °C 13:28

Fig. 14 Threshold exceed limit notification in mobile application



Threshold Alert

Temperature threshold reached at 28/12/25 14:41:49 - Value: 26.29 °C, Threshold: 25.00 °C

Threshold Alert

Temperature threshold reached at 28/12/25 14:04:43 - Value: 26.31 °C, Threshold: 25.00 °C

Fig. 15 Threshold alert notifications in web dashboard

Table 4. Shift wise average temperature reading

Date and Shift	Total Components produced in Shift	Avg.Cutting Temperature	Temperature Spread	Avg. Surface Finish achieved	Size accuracy achieved
27/12/25 S1	33	23.64 °C	± 1.96 °C	0.15 µm	± 0.01 mm
27/12/25 S2	32	23.32 °C	± 2.27 °C	0.17 µm	± 0.01 mm
27/12/25 S3	33	23.59 °C	± 1.46 °C	0.16 µm	± 0.01 mm
27/12/25 S4	33	23.52 °C	± 1.43 °C	0.18 µm	± 0.01 mm
28/12/25 S1	32	23.64 °C	± 1.96 °C	0.15 µm	± 0.01 mm
28/12/25 S2	32	23.06 °C	± 2.29 °C	0.18 µm	± 0.01 mm
28/12/25 S3	33	22.96 °C	± 1.50 °C	0.16 µm	± 0.01 mm
28/12/25 S4	31	23.45 °C	± 2.14 °C	0.17 µm	± 0.01 mm

5. Results and Discussion

The cutting temperature of SAE 52100 bearing races has been continuously monitored during the external grinding process. The temperature range is observed between 21.10 °C and 26.31 °C. The normal operating temperature range is 21.10 to 24.95°C. The highest temperature recorded is 26.31°C. The overall largest temperature variation recorded is 4.58 °C.

The abnormality notification is shown when the cutting temperature is generated above the threshold limit of 25 °C. The remarkable surface finish is achieved between 0.15 µm and 0.18 µm. The size accuracy is achieved up to ± 0.01 mm. The average temperature data gathered is mentioned in Table 3. The process control plan for maintaining the temperature is shown in Table 4.

Table 5. Process control plan for maintaining cutting temperature

Real Time Temperature Reading in °C	Notification Sent	Corrective actions required
25.01	Yes	Reduce cutting fluid temperature. Regulate feed rate, [9] cutting speed, and depth of cut.
25.75	Yes	
25.18	Yes	
25.01	Yes	
25.80	Yes	
25.68	Yes	
26.29	Yes	
26.31	Yes	
26.29	Yes	

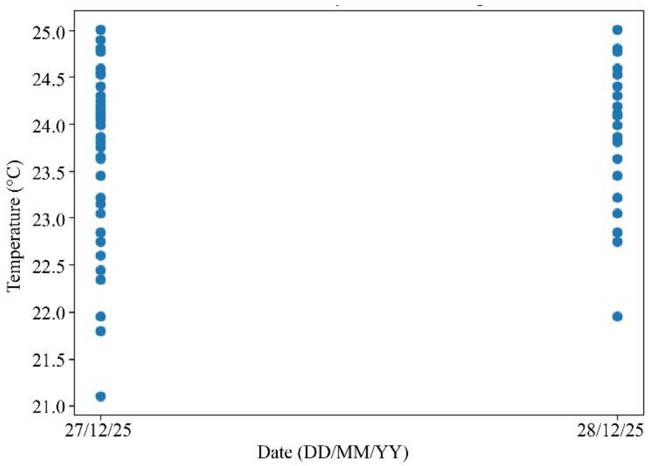


Fig. 16 Shift-wise temperature trend

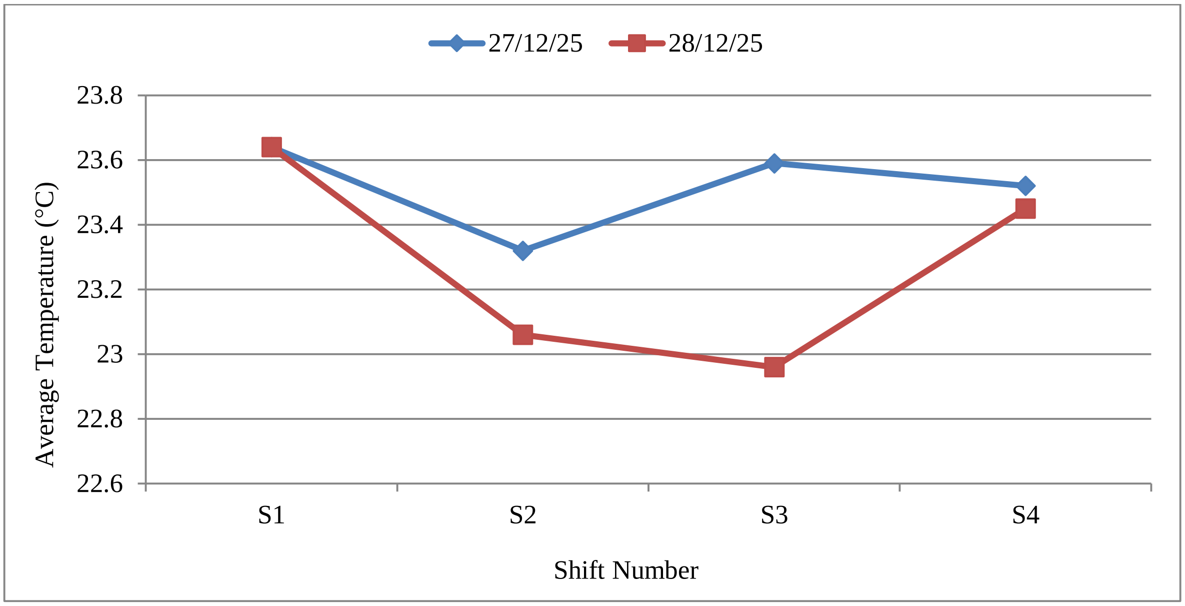


Fig. 17 Combined scatter plot of temperature readings

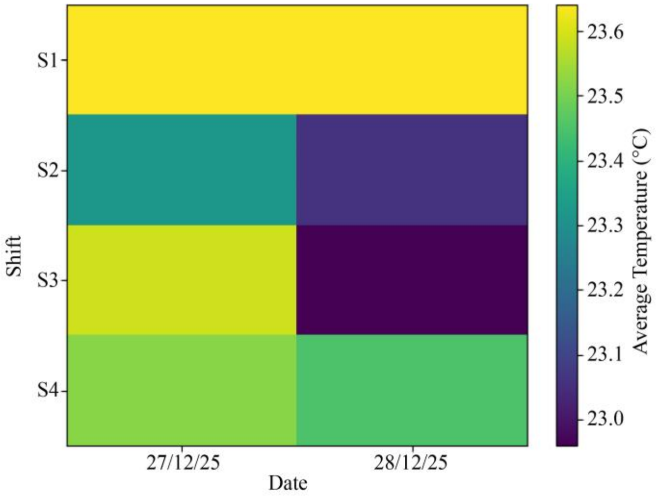


Fig. 18 2D heat map of date and shift-wise average temperature

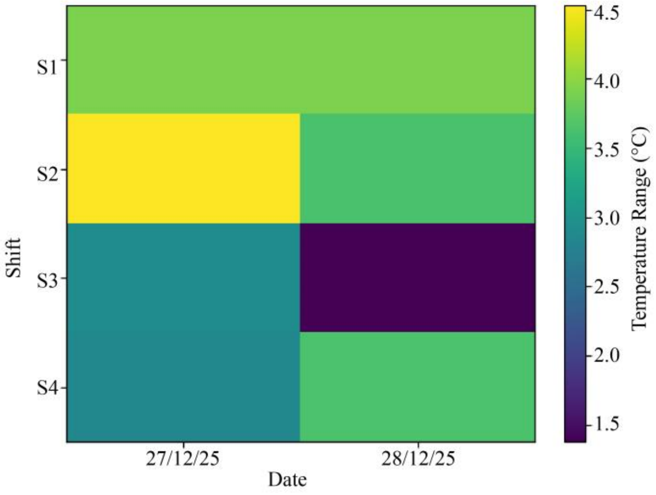


Fig. 19 2D heat map of date and shiftwise temperature range

Separate day-wise temperature trend analysis reveals that Shift-2 exhibits the highest thermal fluctuation on both 27/12/2025 and 28/12/2025, with temperature excursions beyond 25 °C, whereas Shift-1, Shift-3, and Shift-4 maintain comparatively stable thermal behavior.

The 2D heat map analysis reveals that Shift 1 shows high thermal stability across both dates, Shift 3 on 28/12/2025 exhibits a lower average temperature, which indicates cooler process conditions. Shift 2 on 27/12/2025 has the largest thermal swing, while shift 3 on 28/12/2025 shows the smallest temperature range. Shift 1 maintains consistent ± variation on both days, which indicates good thermal repeatability.

The Thermal Stability Analysis (TSI) reveals clear shift-wise and day-wise variations in the thermal behavior of the external grinding process carried out on bearing races. A significant improvement in thermal stability is observed in shift-3 on 28/12/2025, which indicates better thermal control and process consistency. The shift-2 exhibits a comparatively lower TSI value, which shows that thermal management is required for smooth operations.

Table 6. Day and shift-wise thermal stability index

Date	**Shift**	**Min. °C**	**Max °C**	**Range °C**	**TSI (Thermal Stability Index) TSI=** $\frac{1}{T.max-T.Min.}$
27/12/25	1	21.10	25.01	3.91	0.256
27/12/25	2	21.22	25.75	4.53	0.221
27/12/25	3	22.04	24.95	2.91	0.344
27/12/25	4	22.04	24.89	2.85	0.351
28/12/25	1	21.10	25.01	3.91	0.256
28/12/25	2	22.18	25.80	3.62	0.276
28/12/25	3	22.25	23.63	1.98	0.725
28/12/25	4	22.67	26.31	3.64	0.275

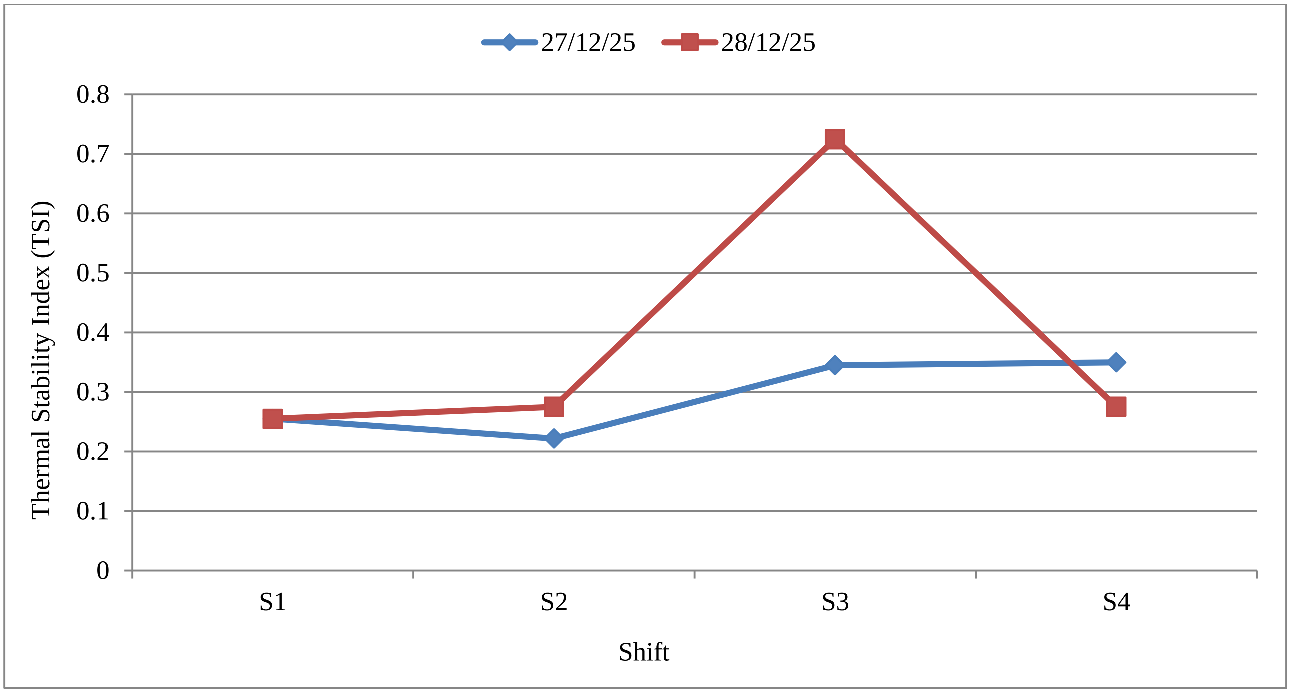


Fig. 20 Line diagram of Thermal Stability Index (TSI)

Table 7. Validation details

Test Parameter	**Acceptance Limit**	**Observed**
Data Loss Rate (%)	< 5 %	1.2%
Communication Delay	< 2 seconds	1.5 seconds
Cloud Uptime	> 99 %	99.7 %
Packets Sent vs Received	> 95 %	99.1 %
Temperature Graph Update	10 Sec.	5 Sec.
Threshold Notification Alert	5 Sec. (Event-based)	4 Sec.

5.1. Validation of IoT based System

The functional, accuracy, and reliability validation has been performed to ensure consistency of experimental results. In controlled experiments, the stability of the IoT system is most required. Before starting the experiments, the infrared thermal sensor was calibrated with a reference instrument, and the value of both were compared; no major uncertainty was observed.

6. Conclusion

This study has successfully developed and implemented a real-time IoT-enabled cutting temperature monitoring system for external grinding of SAE 52100 bearing races and thereby allowed the continuous non-contact and in-process cutting temperature measurement directly at the grinding zone. The system incorporates an infrared sensor, an ESP32 controller, cloud connectivity, and a web-based dashboard, and thus provides a cost-effective and scalable solution for bearing manufacturing industries. Experimental validation on 259 bearing races proved that the cutting temperature was mainly controlled within a range of 21.10°C to 24.95°C of stable cutting temperature, and a maximum cutting temperature reached 26.31°C. The overall temperature variation was between 4.58°C, which confirmed the reliable thermal monitoring based on a (2-second) response time, which is useful to perform real-time industrial applications. Quantitative results confirmed that there is a definite relationship between cutting temperature and product quality. When the temperature was controlled within the optimum temperature range of 20°C to 25 °C, better surface finish of 0.15 - 0.18 µm and dimensional accuracy of ± 0.01 mm were consistently obtained. Exceeding the threshold of 25°C resulted in automatic alerts, allowing corrective action to be taken in time, such as adjusting the feed rate, reducing speed, depth of cut, and temperature of coolant. The proposed Thermal Stability Index (TSI) was a successful way of assessing process consistency. The maximum thermal stability (TSI = 0.725) was recorded in Shift-3, 28/12/2025, while the low values of TSI in Shift-2 provided evidence that thermal control needs to be improved. This shows the ability of the system to aid in data-driven decision-making and process optimization.

The novelty in this work is the industrial-scale realization, the customizable threshold-based alerts, the integration of temperature data with the quality metrics, and the real-time visualization using an IoT dashboard, which are hardly practiced together in the study of traditional grinding temperature. The overcutting temperature directly affects the quality of the surface; it may damage the surface, producing defects like surface burn, chattering, and improper surface finish.

Future work should focus on the integration of machine learning models for together predicting the surface finish, tool wear, and thermal anomalies, monitoring vibration and power signals, and enabling closed-loop adaptive control of grinding parameters. Industrial implementation of the proposed system can help reduce the rejection rate directly, improve the stability of the process, and support predictive maintenance strategies.

The developed IoT-based cutting temperature system can be implemented in Lathe, Milling, Pedestal grinder, Shaper machine, Hacksaw, metal cutting machine, where the real-time monitoring of cutting temperature affects the quality of parts, but it is needed to check the feasibility, and a deep study is required to define the maximum cutting temperature value (Threshold limit).

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