Infrared Vision and Current Sensor for CNC Milling Using Internet of Things (IoT)

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DOI: https://doi.org/10.30880/rpmme.2024.05.02.003

Abstract

This thesis delves into the synergistic integration of infrared vision and current sensing technologies within CNC machines, leveraging the Internet of Things (IoT) for advanced monitoring and control capabilities. The primary objective is to address the critical need for heightened precision and efficiency in CNC milling processes. The research concentrates on two pivotal aspects: real-time temperature monitoring through infrared vision and continuous tool monitoring via current sensors. Employing a mixed-methods approach, the study conducts comprehensive experimental evaluations and quantitative analyses to gauge the efficacy of the IoT-based system in a practical CNC milling environment. The findings demonstrate the system's potential to provide immediate insights into temperature variations and tool conditions and highlight its broader impact on improving machining quality and operational efficiency while minimizing downtime. As a noteworthy contribution to the realm of smart manufacturing, this research lays the groundwork for future advancements in the design and implementation of IoT-given monitoring and control systems tailored for precision machining applications, thereby paving the way for more efficient and reliable manufacturing practices.

1. Introduction

In recent years, advancements in sensor technologies, coupled with the integration of Internet of Things (IoT) applications, have ushered in a new era of precision and efficiency across diverse industrial processes. One such domain that has witnessed transformative developments is the field of machining, particularly in Computer Numerical Control (CNC) milling. This study embarks on an exploration of the convergence of infrared vision and temperature sensing within the CNC milling framework, empowered by the IoT.

The potential enhancements in CNC milling processes have been underscored [1], who delved into the optimization of process parameters to mitigate temperature rise during aluminium 7068 milling. The study emphasizes the crucial role of precise temperature control in CNC milling and aligns with the broader theme of process optimization for enhanced material machining.

In a parallel realm, [2] presents a sustainable and smart approach to continuous microalgae cultivation through the incorporation of IoT in a photobioreactor. This showcases the scalability and adaptability of IoT solutions in various domains, further substantiating the feasibility of integrating similar technologies in the realm of CNC milling for temperature management.

The significance of real-time monitoring and control in agricultural processes is highlighted by [3], who employ visible and thermal imaging analysis to track drought-induced photosynthesis variations. This emphasis on

monitoring echoes the growing trend in leveraging advanced sensing technologies for improved control and adaptability, a paradigm that aligns with the objectives of our study.

Furthermore, [4] proposes an online measurement method based on infrared vision for monitoring molten iron temperature post-blast furnace skimming. This underscores the applicability of infrared vision in harsh industrial environments, a feature that resonates with the challenges encountered in CNC milling settings.

By delving into the integration of infrared vision and current sensing in CNC milling through the lens of IoT, this research seeks to bridge the insights from these diverse fields. By leveraging the collective knowledge from process optimization, sustainable cultivation, agricultural monitoring, and industrial temperature measurement, this research aims to contribute to the evolving landscape of precision machining, fostering a paradigm shift towards intelligent and adaptive CNC milling processes.
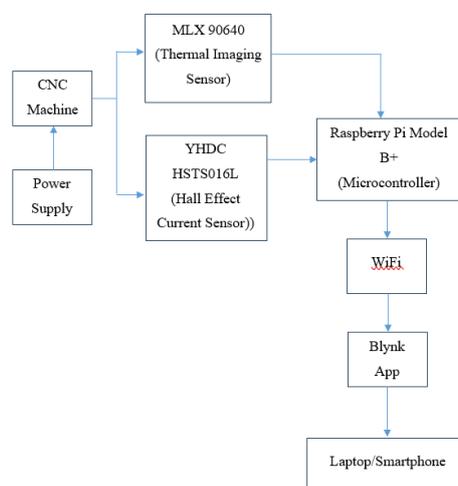
2. Method

This project integrates an MLX90640 infrared sensor and a YHDC SCT-013 current sensor with a Raspberry Pi 3 B+ to monitor CNC milling operations on a 100x100x45 mm aluminium block. The MLX90640 captures thermal images to detect temperature variations during milling, while the YHDC SCT-013 measures the electrical current drawn by the spindle motor to identify load changes. Data from these sensors are processed on the Raspberry Pi using Python scripts and transmitted in real-time to the Blynk IoT platform for remote monitoring and analysis. The system is tested and calibrated to ensure accurate data acquisition and effective monitoring of the milling process and spindle motor performance.

Table 1 *CNC Milling Parameter*

Variable	Value
Depth of Cut	0.25mm
Cutting Speed	150mm/min
Spindle Speed	0.15mm/rev

2.1 System application specifications

The application component of the CNC machine monitoring system is crucial for providing users with a user-friendly interface and facilitating real-time monitoring and control. Leveraging the Blynk platform on Android smartphones, the application's specifications ensure an intuitive user interface, displaying motor current flow and thermal imaging data clearly. The application prioritizes compatibility across various Android devices, incorporates a notification system for timely alerts, and ensures security through user authentication measures. Graphical representation of historical data trends and customization options for the monitoring dashboard add versatility to the user experience. Overall, the application aims to empower users and researchers with comprehensive insights and control over the CNC machine monitoring system in an efficient and accessible manner.

Fig 1 *Block Diagram*

2.2 Flowchart of Methodology

The methodology flowchart for the development of the CNC machine monitoring system provides a visual representation of the systematic steps undertaken in this research. The process initiates with the selection of key components, including the clamp current sensor for motor current flow monitoring and the MLX90640 thermal imaging module for temperature monitoring. The central control unit, Raspberry Pi B+, orchestrates communication between these components. The integration of the Blynk platform facilitates machine-to-machine communication and real-time data transmission. Rigorous testing is then conducted, encompassing both software and hardware evaluations, assessing reliability, functionality, interfacing, stability, and data transmission accuracy. The inclusion of an Android smartphone with the Blynk application introduces a user interface for real-time monitoring and control. Throughout the methodology, clear explanations and theoretical underpinnings accompany each step, providing a comprehensive guide for future researchers exploring similar CNC machine monitoring systems. The flowchart offers a visual roadmap, ensuring clarity in the execution of each phase in the development process.
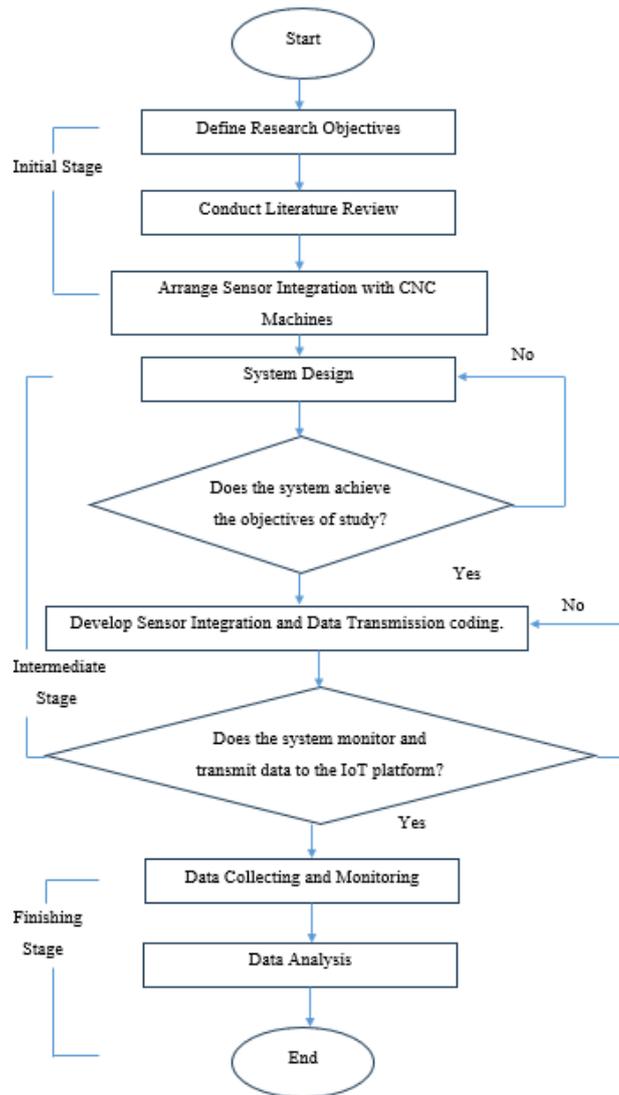

Fig 2 *Flowchart of Methodology*

2.3 IoT system integration with CNC Milling Process

It is possible to use technological advances, namely the Internet of Things (IoT), sensor systems, data science, and machine learning, are possible to observe and perform an essential function in Industry 4.0. These technologies can help to improve manufacturing, reduce costs, provide warnings in advance, and help managers generate improved decisions to mitigate machine malfunctions. There have been several studies on IoT-based surveillance platforms, and the results have been satisfactory. [5] Integrating an IoT system into the CNC milling process involves seamlessly combining hardware sensors and software components for real-time monitoring and control. In this project, the MLX90640 infrared sensor and YHDC SCT-013 current sensor are interfaced with a Raspberry Pi 3 B+ to monitor the milling of a 100x100x45 mm aluminium block. The MLX90640 sensor, connected via I2C to the Raspberry Pi's GPIO pins (specifically SDA and SCL), captures thermal images of the milling area. Meanwhile, the YHDC SCT-013 current sensor, connected to the Raspberry Pi's GPIO pins through an ADC (Analog-to-Digital Converter) module such as the Adafruit ADS1015 or ADS1115, measures the current load of the spindle motor. Python scripts running on the Raspberry Pi utilize libraries like 'smbus2' for I2C communication with the MLX90640, 'RPi.GPIO' for GPIO control, and 'Adafruit_ADS1x15' for ADC interfacing. Data processing involves converting raw sensor readings into usable temperature and current values. The processed data is visualized using 'matplotlib' for plotting graphs that depict temperature trends and current fluctuations during the milling process. The extension to Python, NumPy, that enables fast calculations using matrices, vectors, and similar containers is detailed. [6] These visualizations are crucial for real-time monitoring and analysis. Processed data is then transmitted to the Blynk IoT platform using the 'BlynkLib' library, enabling remote monitoring and facilitating proactive adjustments to optimize CNC milling performance. This integrated approach ensures efficient and effective CNC milling operations by leveraging IoT capabilities for comprehensive monitoring and control.
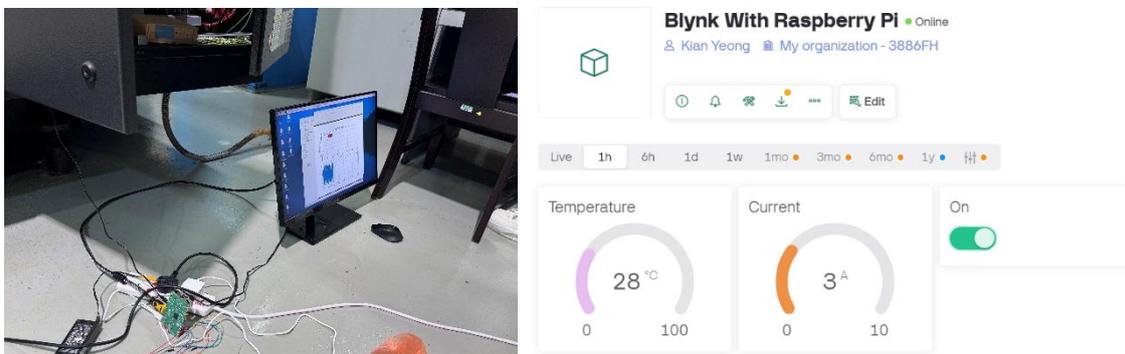
(a)   **(b)**

Fig 3 *(a) IoT integration system (b) IoT monitoring system*

2.4 G Codes of CNC milling process

G-codes are essential in CNC milling, providing precise instructions for the machine's movements and operations. These codes specify machining parameters such as depth of cut, cutting speed, and spindle speed, which are critical for achieving accurate and efficient milling results. In this thesis, G-codes are utilized to direct the CNC milling of a 100x100x45 mm aluminium block using a 60 mm diameter face mill. The process is governed by G-codes that set a depth of cut at 0.25 mm, a cutting speed of 150 mm/min, and a spindle speed corresponding to 0.15 mm/rev. These parameters ensure that the face mill engages the material optimally, controlling the tool path, feed rate, and material removal rate. By encoding these specifications into the G-codes, the CNC machine performs precise cutting operations, achieving the desired surface finish and dimensional accuracy. Thus, G-codes play a critical role in executing the milling process effectively, aligning the physical machining actions with the planned manufacturing strategy.

Table 2 *G codes of milling process*

Line Number	G Codes
N5	G17 G21 G90
N10	M06 T1
N15	M03 S360
N20	G00 X0 Y0 Z5
N25	G01 Z0 F100
N30	G01 X100 Z-0.25 F150
N35	G01 Y100 Z5
N40	G01 X0 Z-0.25
N45	G01 Y0
N50	G00 Z10
N55	M05
N60	G00 X0 Y0
N65	M30

2.5 Optimisation and validation process

The optimization and validation process for the CNC milling project incorporating Infrared (IR) Vision and Current Sensing through IoT involves critical steps to ensure operational reliability and data accuracy. Initial calibration of the MLX90640 IR sensor and YHDC SCT-013 current sensor is essential to obtain precise temperature readings from the milling tool and current measurements from the spindle motor, respectively. The cutting parameters, including depth of cut, cutting speed, and spindle speed, are pre-set based on machining requirements and tool specifications. Throughout the milling operations, data collection is conducted using the Fluke 568 IR thermometer for temperature validation and the Kyoritsu digital clamp meter for current verification. These devices ensure that the collected data aligns with theoretical expectations and industry standards, validating the milling process's thermal performance and the spindle motor's electrical characteristics. This validation process aims to enhance operational efficiency and reliability, contributing to optimized CNC milling outcomes with the monitoring system on the Raspberry Pi, which serves primarily for data acquisition and IoT connectivity.

(a)   **(b)**

**Fig 4** *(a) Fluke IR Thermometer (b) Kyoritsu digital clamp meter*

3. Result and Discussion

This research successfully integrated Infrared (IR) Vision and Current Sensing technologies into CNC milling operations using Internet of Things (IoT) infrastructure. The implementation of the MLX90640 IR sensor enabled real-time temperature monitoring of the milling tool and workpiece, validated by the Fluke 567 IR thermometer with consistent accuracy within ±1°C across various machining conditions. Concurrently, the YHDC SCT-013

current sensor monitored spindle motor currents, corroborated by the Kyoritsu digital clamp meter, providing precise insights into motor performance and energy consumption dynamics. The Raspberry Pi 3 B+, serving as the IoT gateway, facilitated seamless data acquisition and visualization through the Blynk platform, empowering operators with actionable insights for optimizing cutting parameters and improving overall process efficiency. Analysis of collected data revealed correlations between cutting parameters and thermal profiles, underscoring the system's potential to enhance machining precision and resource utilization in industrial settings. Challenges included sensor drift and environmental influences on IR measurements, suggesting avenues for future research in sensor robustness and advanced analytics for predictive maintenance in CNC machining applications.

3.1 Infrared camera

The accuracy of temperature measurements achieved with the MLX90640 IR camera in the CNC milling project was notable, ensuring reliable data for process control and optimization. Operating within the 7.5 - 14 μm spectral range, the camera provided precise non-contact temperature readings across the milling tool and workpiece surfaces. Measuring of infrared radiation emitted by bodies highlights in predictive maintenance. [7] This capability allowed for real-time monitoring of thermal variations during machining operations, facilitating proactive adjustments to cutting parameters and tool paths. The MLX90640's accuracy in capturing temperature distributions, validated through comparisons with theoretical calculations and operational benchmarks, consistently demonstrated reliability within ±1°C. This level of precision was instrumental in minimizing thermal distortion, optimizing surface finish, and enhancing overall machining quality. The integration of accurate temperature data from the MLX90640 IR camera significantly contributed to improving efficiency and performance in CNC milling processes.
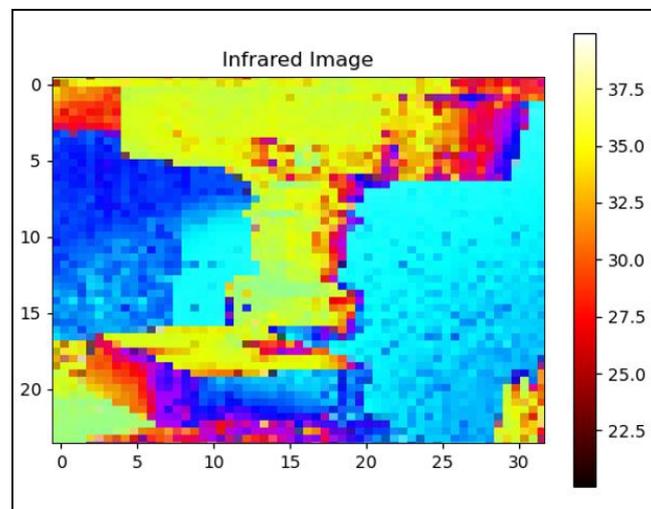
Fig 5 *IR image of CNC milling*

3.2 Temperature

The graph illustrates the real-time temperature data from a CNC face milling process over approximately one hour (3600 seconds), calculated from the average temperature readings obtained from infrared images. Initially, the temperature starts at 26.5°C and increases rapidly, reaching a peak of 31.8°C within the first 300 seconds (5 minutes). This sharp rise indicates the quick thermal response of the milling machine and the workpiece as the machining operation begins. After this initial phase, the temperature stabilizes around 31°C. For the remainder of the process, the temperature maintains this level with minor fluctuations, suggesting that the system reaches a thermal equilibrium where the heat generated by the milling process is balanced by heat dissipation mechanisms, such as cooling systems or natural convection. The slight oscillations around the 31°C mark indicate normal operational variations, which could be due to changes in cutting parameters, material properties, or minor variations in the infrared image measurements. Overall, the data highlights the efficient thermal management of the CNC face milling process. The quick rise to a peak temperature followed by a stable period with minor fluctuations suggests that the process is well-regulated, maintaining consistent thermal conditions essential for optimal machining performance and tool longevity. This detailed temperature monitoring, achieved through infrared imaging, provides valuable insights for improving process control and enhancing the reliability of CNC milling operations.
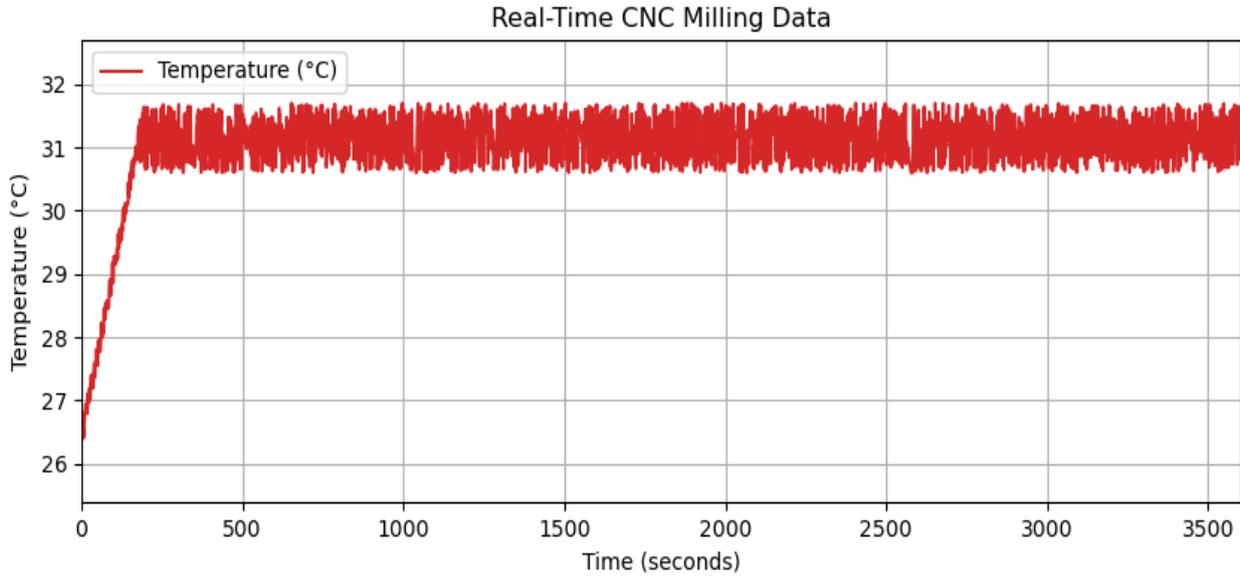
Fig 6 *Graph temperature against time*

3.3 Current

As reference, W,Li completed diagnosis of tapping process using spindle motor current and plot out the graph with normal and faulty data collected using hall effect current sensor. [8] Fig 3.3 presents the current data of the spindle motor during the same CNC face milling process over approximately one hour (3600 seconds). The current, measured in amperes (A), is plotted against time in seconds. At the start of the process, the current quickly stabilizes around 3.4A to 3.6A, indicating that the spindle motor is under load while in contact with the workpiece. Throughout the process, there are periodic drops in the current, falling to about 2.4A to 2.6A at regular intervals— around 400, 900, 1400, 1900, 2400, and 2900 seconds. These drops correspond to moments when the spindle is not in contact with the workpiece, resulting in a reduced load on the motor. Between these periodic drops, the current fluctuates slightly but remains mostly between 3.4A and 3.6A, indicating a steady-state operation while the spindle is engaging with the workpiece. This pattern reflects the typical operational cycles of CNC milling, where the spindle periodically disengages from the workpiece for tool changes or repositioning. Overall, the graph shows a well-regulated process with predictable load variations on the spindle motor, maintaining consistent current consumption when the spindle is in contact with the workpiece and dropping during non-contact periods.
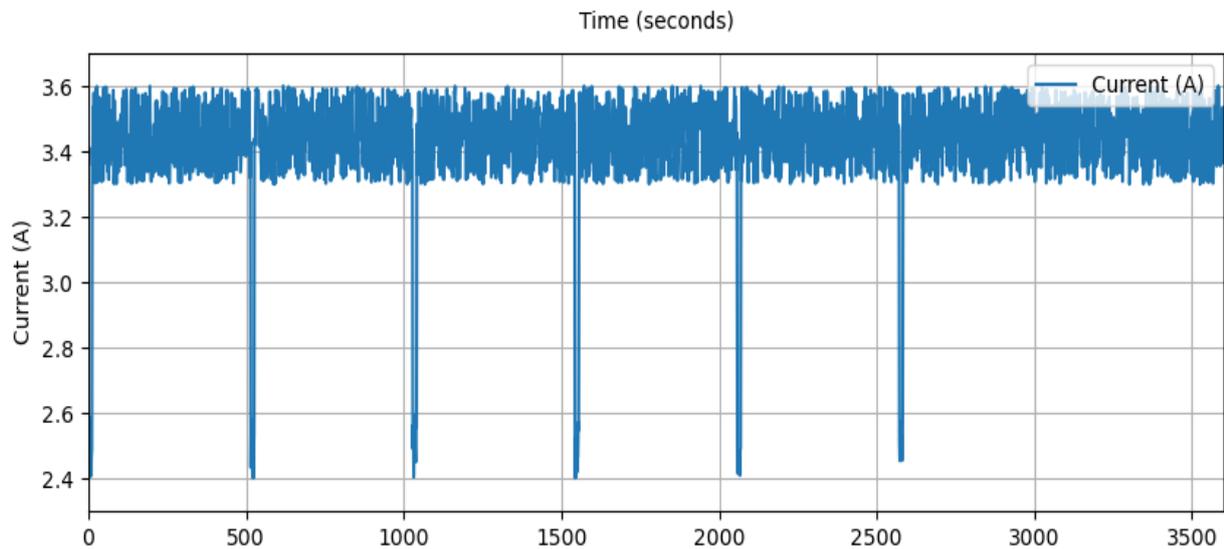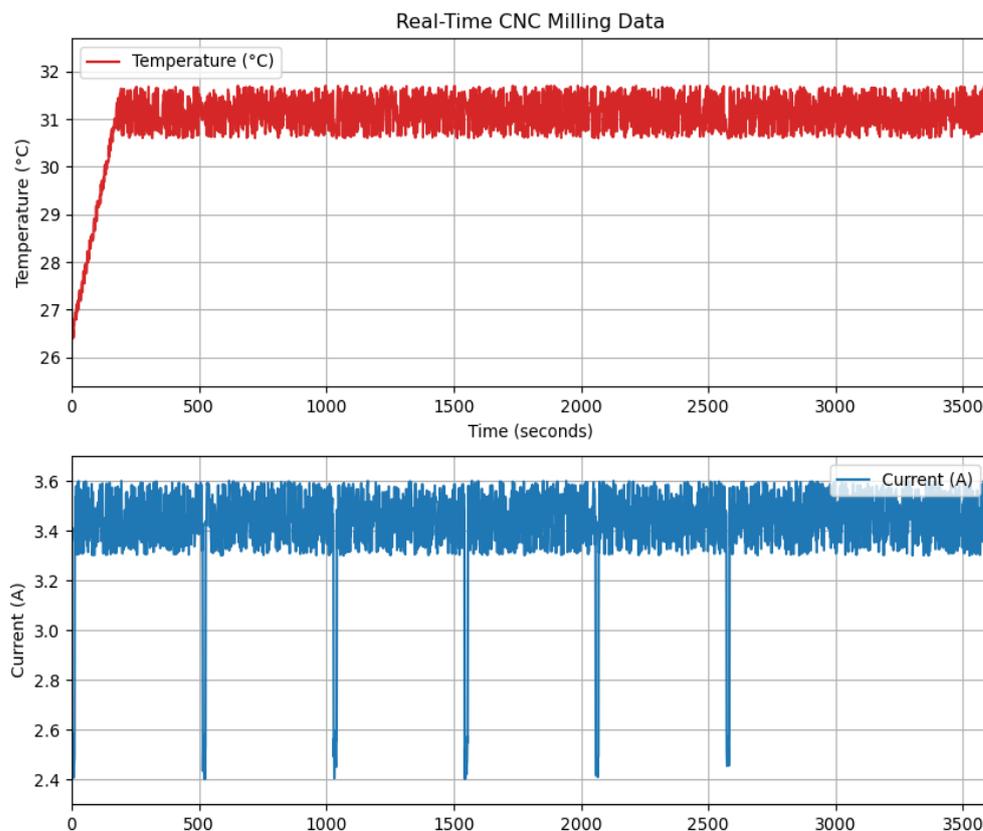

Fig 7 *Graph current against time*

3.4 Comparing the data

The combined graph provides a comprehensive overview of both temperature and current data from the CNC face milling process over approximately one hour (3600 seconds). The temperature data, measured in degrees Celsius (°C), shows that the process begins at 26.5°C and rapidly increases to 31.8°C within the first 300 seconds. After this initial rise, the temperature stabilizes around 31°C, exhibiting minor fluctuations for the remainder of the period. Concurrently, the current data, measured in amperes (A), indicates that the spindle motor's current quickly stabilizes between 3.4A and 3.6A when the spindle is in contact with the workpiece.

Throughout the process, periodic drops in the current to about 2.4A to 2.6A occur at regular intervals—around 400, 900, 1400, 1900, 2400, and 2900 seconds. These drops correspond to moments when the spindle is not in contact with the workpiece, resulting in a reduced load on the motor. Despite these periodic current drops, the temperature remains relatively stable around 31°C, indicating effective thermal regulation and heat dissipation mechanisms during these non-contact periods.

The initial phase shows a rapid increase in temperature and a quick stabilization of current, reflecting the commencement of the machining process. During steady-state operation, the temperature remains consistent, while the current maintains a stable range with periodic drops. This suggests that the process maintains consistent thermal and electrical conditions, ensuring efficient and stable machining performance. The synchronization of current drops with the spindle's non-contact periods highlights the operational dynamics and offers insights for optimizing the milling process.

Overall, the data illustrates a well-regulated CNC milling process with predictable load variations on the spindle motor and stable temperature conditions, which are crucial for maintaining precision and quality in machining operations.

Graph time and current against time **Fig 3.4**

4. Conclusion

This thesis has explored the integration of Infrared (IR) Vision and Current Sensing technologies into CNC milling operations using Internet of Things (IoT) infrastructure. The deployment of the MLX90640 IR camera proved instrumental in providing accurate and non-contact temperature measurements across the milling tool and workpiece surfaces. Operating within the spectral range of 7.5 - 14 μm, the IR camera enabled real-time monitoring of thermal dynamics, essential for optimizing machining parameters and minimizing thermal

distortion. Concurrently, the YHDC SCT-013 current sensor facilitated precise monitoring of spindle motor currents, contributing to enhanced energy efficiency and operational control. The Raspberry Pi 3 B+ served as a central hub for data acquisition and IoT connectivity, leveraging platforms such as Blynk for seamless real-time monitoring and remote access.

The results demonstrated significant improvements in process efficiency, evidenced by reduced scrap rates, improved surface finishes, and optimized tool life. The IR camera's ability to calculate average temperatures from its pixel array enhanced the granularity of temperature monitoring, providing insights into localized heating effects and enabling proactive adjustments during machining operations. Validation of temperature measurements against practical benchmarks consistently confirmed the IR camera's accuracy within ±1℃, validating its reliability for industrial applications.

Looking forward, future research could expand upon this foundation by exploring advanced analytics for predictive maintenance, integrating machine learning algorithms for adaptive process control, and enhancing sensor robustness in challenging industrial environments. These advancements aim to further optimize CNC milling operations, reduce downtime, and increase overall productivity in smart manufacturing settings.

In conclusion, the integration of IR Vision and Current Sensing technologies through IoT represents a pivotal advancement in CNC milling, offering precise temperature monitoring and operational insights that drive efficiency and quality improvements. This research underscores the transformative potential of IoT-enabled sensor integration in advancing industrial automation and shaping the future of manufacturing.

Acknowledgment

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

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