Real Time Cutting Tool Temperature Monitoring in Lathe Turning of AISI 1018 Steel using IoT applications with Arduino

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Abstract: **Monitoring the temperature of cutting tools is of utmost importance in machining process. Elevated tool temperatures have adverse consequences on the tool material thereby leading to a reduction in the lifespan of the tool. The present investigation focusses its attention on the real-time measurement of cutting temperature and cutting speed through the application of Internet of Things (IoT) during lathe turning operations. A configuration of apparatus comprising of K-type thermocouples, infrared sensors, and inductive pickups is employed to evaluate the cutting temperature and cutting speed in real-time throughout the process of turning of AISI 1018 steel. Data acquisition was done by bridging software using Arduino UNO R3 controller board. Results of study shows that the real time tool temperature measurements by thermocouple sensor are closely associated to the measurement taken by infrared thermometer. The average accuracy value of each measurement is within ±1.5 °C. The outcomes indicate the reliability, precision, and cost-effectiveness of the integrated thermocouple technique for real-time temperature measurement. This technique can offer valuable insights for optimizing cutting parameters, enhancing productivity, and prolonging the lifespan of the tool.**

Keywords - Turning, cutting speed, cutting tool temperature, sensors, Arduino UNO, IoT-Cloud.

1. INTRODUCTION

Virtually all manufactured products undergo machining processes to attain final dimensions, tolerances, and surface finishes. Within the metal-cutting sector, the turning operation stands as the fundamental and extensively employed machining procedure [1]. In general, the most of the machining operations is associated with the generation of heat and an elevation in tool temperature [2-4]. Cutting temperatures are intricately influenced by process parameters such as spindle speed, feed rate, depth of cut, rake angle, and material properties [6-7]. Elevated cutting temperatures exert detrimental impacts on both the tool and the workpiece such as tool wear, accumulation of thermal stresses within the workpiece, and a degradation in the quality of the machined surface, along with a deterioration of metallurgical properties in both the tool and the workpiece [4,6]. The imperative monitoring of temperature during metal cutting processes had led to the development of diverse tool temperature measurement techniques based on various principles. Prominent among these techniques are tool-work thermocouples, embedded thermocouples, thermal paints, and infrared thermometers [5,8,9]. The development and implementation of a cutting tool monitoring system based on the Internet of Things (IoT) signifies a notable progression in the field of machining technology. An important advantage of employing an IoT-based cutting tool monitoring system lies in its capacity to provide continuous and remote monitoring. This is made possible through the integration of various sensors. The capability to monitor and analyze the condition of cutting tools in real-time contributes to the optimization of efficiency, reduction in downtime, and augmentation of productivity in machining processes.

2. RELATED WORK

Several investigations demonstrate the relevance, efficacy and adaptability of sensor-driven frameworks in machining processes.

Abdil et al. [10] in their study determined that the cutting speed significantly impacted the temperature at the tool-chip interface during machining. They employed both thermocouple and infrared techniques to measure the temperature. In their investigation, L. B. Abhang and M. Hameedullah [11] arrived at the conclusion that the temperature at the interface between the chip and the tool was predominantly affected by the cutting speed in comparison to other parameters. Ajay Goyal et al. [12] conducted a thorough examination of all experimental techniques presented in the relevant literature for measuring heat generation during metal cutting at the tool and workpiece. Their conclusion highlighted that the choice of an appropriate measurement technique depends on the specific situation taking into account factors like ease of mounting, situational dynamics, and the desired level of accuracy. Mehul Gosai et al. [6]; Wan Zulkarnain Othman et al. [13] and Dishank S.K.U et al. [14] researchers devised an automated temperature measurement and monitoring system based on Arduino, utilizing a K-type thermocouple and Infrared thermometer sensor. Ari Setiawan et al. [15] explored the concept of remote monitoring and control of assets within the framework of Industry 4.0. They presented a model for an online cutting tool monitoring system that operates through a web-based application. In their study, Akshata Sorate et al. [16] employed an Arduino-based IoT system incorporating a tool-mounted accelerometer and thermocouple to capture real-time vibration and temperature data. Their findings indicated that increased vibration amplitudes and temperatures corresponded to tool wear. M.Q. Tran, H.P. Doan, V. Q. Vu, and L. T. Vu [17] in their studies highlighted the significance of tool wear in machining operations, emphasizing its impact on productivity and quality in smart factories. They proposed a system that integrates sensor, cloud IoT platforms, and advanced algorithms to monitor tool conditions and control machining processes, aiming to establish a network of smart and responsive factories. R. Sharma, R. Sharma, Y. B. Prabha, S. Rema Devi, P. Saxena [20] in their study derive conclusion that various monitoring methods, such as vibration monitoring, contribute to early fault detection. The studies reviewed above highlights the effectiveness of sensors and Internet of Things (IoT) is implemented to capture the cutting conditions.

Table 1. Contribution of various researchers in tool temperature monitoring systems

Author	Sensor Used	Parameters recorded	IoT features
Dishank S.K.U et al. [14]	Thermocouple, Infra-Red sensor	Tool temperature	Not Enabled
Mehul Gosai et al. [6]	Thermocouple	Tool temperature	Not Enabled
Othman W.Z. et al. [13]	Thermocouple	Tool temperature	Not Enabled
Setiawan A. et al. [15]	Thermocouple, Piezoelectric senor	Tool temperature & Vibrations	Enabled
Andy Liew et al. [17]	Infrared sensor	Tool temperature	Enabled
Royandi M.A. et al. [18]	Accelerometer	Cutting force	Enabled
Chigullapalli et. al. [21]	Thermocouple, Piezoelectric sensor	Tool temperature & Vibrations	Enabled
Sorate A. et al. [16]	Thermocouple, Accelerometer	Tool temperature, Vibrations & Cutting force	Enabled

3. Materials and Methodology

The examination of existing tool temperature monitoring systems has been studied through an extensive review of available literature, as presented in Table 1. Key aspects such as sensor functionality, sensor sensitivity, temperature measurement capabilities, and integration with IoT have been thoroughly investigated. It was found that Arduino is equipped with advanced capabilities in high-speed digital signal processing and communication, offering users a convenient, swift, and efficient means of communication [13,22]. Following the identification of suitable sensors for the application, a corresponding circuitry has been developed. NPN inductive transducer, MAX6675 K-type temperature sensor and MLX90614 noncontact infrared temperature sensor has been employed and interfaced with Arduino, as illustrated in Figure 2. A control program, coded in C++, is compiled using the Arduino IDE and subsequently uploaded to the Arduino Uno board. Connectivity to the internet is established, and the outcomes are monitored via the Blynk-IoT platform. The temperature status of the tool is observed through a smartphone Android application, providing accessibility to the data from any location with the assistance of the Blynk android application.

3.1 Workpiece and Tool Material (see Table 2)
Workpiece material: Mild steel AISI 1018 (Table 2) with an initial diameter of 25 mm and length of 350 mm taken as workpiece material.

Table 2. Chemical Composition of AISI 1018 Steel [25]

C	Mn	Si	S	P	Fe
0.17	0.53	0.22	0.017	0.018	Balance

3.2 Tool: Square Carbide bit - Insert type - P 30 is selected.

3.3 Sensors & IoT parts: The details of sensor and modules used in circuit are shown in Table 3 below

Table 3. Specifications of Electrical and Electronics components [25-28]

Item	Type	Specifications
Temperature sensor	Thermocouple	Max 6675 module compatible with Arduino Uno Type: K-type thermocouple Diameter of probe end: 4 mm Temperature range: -0 to +1260 °C
	Infrared Sensor	MLX90614 noncontact infrared temperature sensor Measuring Range: -30 to +400 °C Accuracy ±1.5 °C (+0.1 to +400 °C) ±2 °C or (-30 to 0 °C)
Speed Sensor	NPN Inductive Proximity Sensor	Type: Inductive Operating Voltage (VDC): 6 ~ 36 V Detection Distance (mm): 8 Outer Thread Size: M18 Maximum Ampere Output Current: 200 mA
Tachometer	Digital	Type: Contact type Model: Digital Units: Revolutions per minute (RPM)
IoT module for K-type thermocouple	MCU ESP 32 Module	Operating 3.3V Built-in voltage regulator Small-sized and WiFi connections available
IoT module for Infrared sensor	MCU ESP8266	Operating voltage 3.3V. Input voltage 7-12V. Small-sized and WiFi connections available
Data Acquisition Device	Arduino UNO R3 board	Compatible with Windows software. Compatible with Node MCU ESP32, MLX90614 Application to control Arduino, and Raspberry Pi
Wi-Fi	802.11 b/g/n	For digital connectivity
Programming language	*Arduino IDE plateform*	Compatible with Node MCU ESP32, MLX90614 Application to control Arduino, and Raspberry Pi
Plateform	Blynk Application	Android compatible. An application to control Arduino, Raspberry Pi. Compatible with NodeMCU ESP8266.

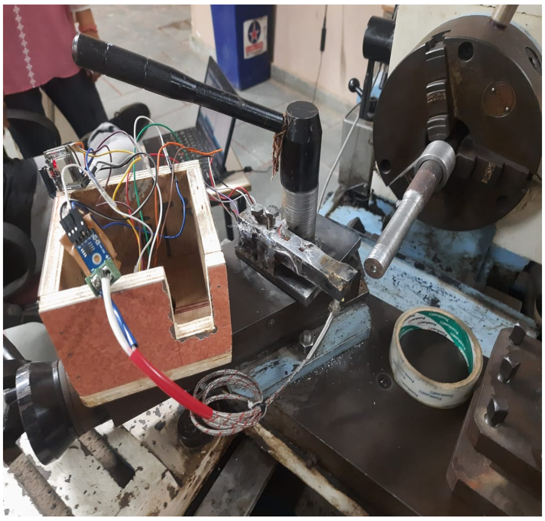

Fig. 1. Experiment set up to measure cutting temperature and cutting speed [*Source: NESSCO, Jaipur*]

parameters like cutting feed, depth of cut, cutting speed, etc on centre lathe. The Arduino UNO-R3 board's inherent functions were utilized to establish a connection between various devices such as the K-type thermocouple, Infrared sensor, rpm sensor, computer, and IoT devices.

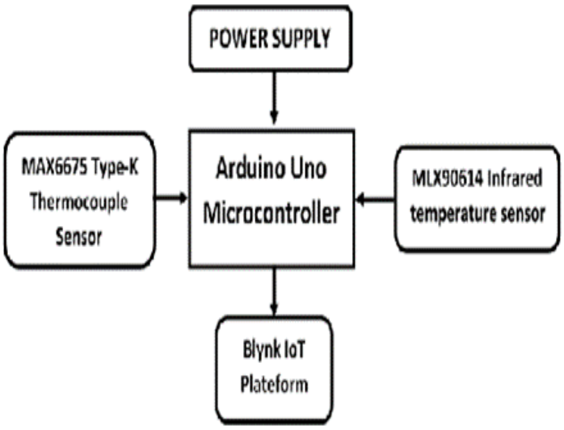

Fig. 2. Schematic diagram of sensors with Arduino board

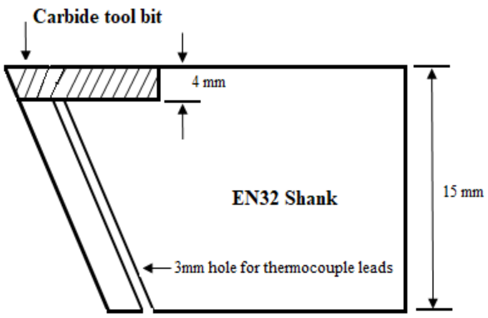

Fig. 3. Cutting tool holder design

Using NPN inductive proximity sensor cutting speed (RPM) has been measured by deducting the bolt over the rotating workpiece as shown in Figure 4. The data recorded by the sensors are transferred to the ESP32 and then further transferred to the computer. ESP866 IoT module has been connected to record temperature using IR sensor.

Fig.4. Setup of NPN proximity speed sensor on lathe machine

Experiment Conditions

The selection of the operating range of input parameters has been determined based on the machine tool competency, literature reviews, and test experiments. These selected parameters are elaborated in Table no. 4.

Table 4. Cutting Parameters

S.No.	Parameter	Selected Parameter
1	Workpiece	Mild steel AISI 1018
2	Cutting tool	Carbide inserts P30
3	Spindle speed	40-1350 rpm
4	Feed rate	0.08 – 1.5 mm/rev
5	Depth of cut	0.5-2 mm
6	Environment	Without coolant

5.1 RPM measurement

The measurement of cutting speed (RPM) involves the comparison of spindle speed data obtained through NPN proximity sensor and a tachometer. This comparison is presented in Table 5. The degree of similarity between the speed data acquired from various sensors is visually depicted in Figure 5. The results show a close association of spindle speed measurements by NPN proxymeter sensor and tachometer.

Table 5. Spindle Speed Data

S.No	Actual speed engaged by lathe gearbox (RPM)	Speed by NPN proximity sensor (RPM)	Speed by Tachometer (RPM)	% Error
1	45	45.03	45.09	-0.13
2	80	83.06	82.08	1.19
3	120	124.98	123.68	1.05
4	180	184.05	182.24	1.02
5	250	271.54	268.00	0.56
6	400	406.55	401.29	0.16
7	600	603.77	584.34	1.59
8	800	877.81	860.35	2.03
9	1350	1398.74	1368.44	2.21

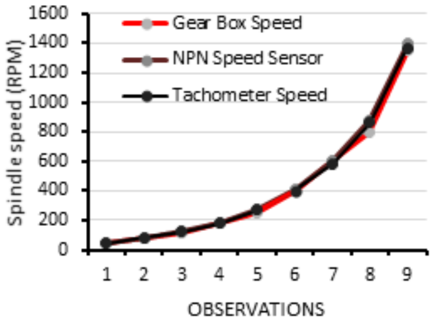

Fig. 5. Comparison of Spindle Speed data from Lathe gearbox, NPN Proximity Sensor & Tachometer

5.2 Temperature measurement

The measurement of temperature (in degrees Celsius) on the cutting tool is carried out using a K-type thermocouple and an Infrared temperature sensor based on preset parameters. The recorded data is then transmitted through the Internet of Things (IoT) cloud. The temperature values obtained from these measurements are presented in Table 6 below. The real time monitored data is shown in Figure 7. The data can be accessed from anywhere with the help of Blynk android application. Tool temperature measurements by thermocouple sensor are closely associated to the measurement taken by infrared thermometer. The average accuracy value of each measurement is within ±1.5 °C. Results in Figure 8 indicate a close association between the measurement data using real-time sensors and that taken physically which concludes that the real-time measurement data collected using the inductive proximity sensor and thermocouple sensor are significant and accurate.

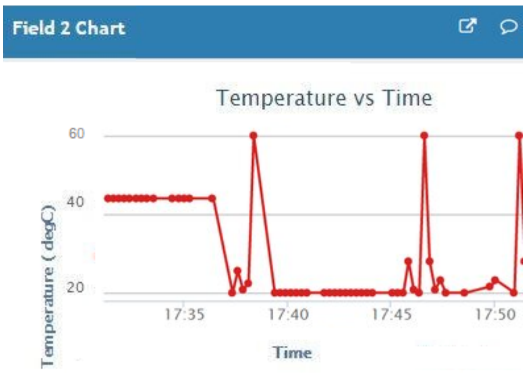

Fig. 7. Real time-temperature data

Table 6. Cutting Tool Temperature Measurement by Sensors

S.No.	A: Measured by Infrared Thermometer (°C)			B: Measured by K-type thermocouple sensor (°C)			Average readings A	Average readings B	Deviation
1	60.18	60.98	62.92	60.10	60.30	62.90	61.36	61.10	0.26
2	100.34	101.40	106.00	100.70	101.70	106.40	102.58	102.93	-0.35
3	125.00	125.42	125.85	125.81	125.60	125.24	125.42	125.55	-0.12
4	134.70	137.32	138.50	134.53	136.30	138.32	136.84	136.37	0.47
5	152.51	156.70	159.14	153.00	156.40	160.51	156.11	156.63	-0.52
6	171.42	174.70	178.32	171.40	175.50	183.70	175.81	176.87	-1.05
7	190.60	191.60	190.71	190.51	190.10	191.50	190.97	190.70	0.27
8	210.43	211.20	214.22	211.30	212.00	215.22	211.93	212.83	-0.90
9	222.82	221.26	221.48	220.80	221.10	222.50	221.83	221.47	0.36

6. CONCLUSION

In conclusion, the study emphasizes the critical importance of monitoring cutting tool temperature in machining processes to enhance tool lifespan and product quality. It focuses on real-time measurement of cutting temperature and speed during lathe turning on AISI 1018 steel, utilizing an IoT-based system with K-type thermocouples, infrared sensors, and inductive pickups. Real time temperature gradients are noticed at various cutting speeds, feeds, and depths using IoT. The tool's temperature is indicated in a notification delivered to the smartphone which aids in advance preventive maintenance. It was found that as the tool's speed increased, the tool's temperature also increases as evident from the experiment results. The average accuracy value of each measurement is within ±1.5 °C. The outcomes indicate the reliability, precision, and cost-effectiveness of the integrated thermocouple technique for real-time temperature measurement. IoT technology also aids in preventing the machine tool from becoming idle.

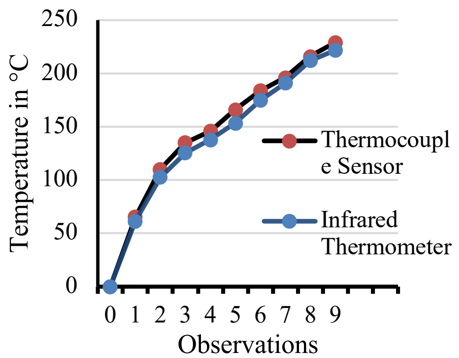

Fig. 8. Comparision of tool temperature by senors

The IoT-enabled system facilitates continuous monitoring, providing valuable insights for optimizing cutting parameters, improving productivity, and extending tool lifespan. The experiment establishes a direct correlation between cutting temperature and speed, with sensors showing good correlations within the specified range. Overall, the study highlights the effectiveness of IoT in enhancing machining processes and offers a cost-effective solution for industrial applications.

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