Monitoring the Temperature and Wear of Arduino Uno-Based Lathe Tools Using MLX90614 Sensors in the Turning Process

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Abstract.
This study aims to design and implement an Arduino Uno-based lathe tool temperature monitoring system using MLX90614 sensors, analyze temperature changes in spindle speed variations, and determine the relationship between temperature and chisel wear. The research was carried out on the ST41 steel turning process using High Speed Steel (HSS) chisels with spindle speed variations of 190 rpm, 300 rpm, and 460 rpm. The temperature of the tool is measured non-contact using a MLX90614 sensor, while the wear of the tool is measured based on the flank wear (VB) value using an optical microscope. The data were analyzed using normality, homogeneity, One Way ANOVA, and Tukey HSD follow-up tests. The results showed that the monitoring system worked well with a sensor accuracy rate of 98.67% and an average error percentage of 1.33%. The variation in spindle speed had a significant effect on the chisel temperature with a significance value of 0.035 (<0.05). The increase in temperature was followed by an increase in chisel wear, with average wear of 0.170 mm at 190 rpm, 0.206 mm at 300 rpm, and 0.277 mm at 460 rpm. The developed system is able to monitor temperature in real-time and can be used as an initial indicator of tool wear conditions in the turning process.
Keywords: *Arduino Uno, MLX90614, chisel temperature, chisel wear and turning.*

I. INTRODUCTION

The turning process is one of the machining processes that are widely used in the manufacturing industry to produce components with dimensions and surface quality that are in accordance with specifications. The quality of the turning result is affected by various cutting parameters, such as spindle rotation speed, feeding motion (*Feed Rate*), depth of cut (*depth of cut*), the material of the workpiece, as well as the condition of the tool used [1]. During the turning process, there is contact and friction between the chisel, the workpiece, and the grinder, resulting in heat energy in the cutting area. Most of the mechanical energy during the cutting process is converted into heat energy which causes an increase in temperature at the end of the tool [2].

A high temperature increase in the cutting area can lead to a decrease in the hardness of the sculpting material, accelerate the wear rate, shorten the life of the workpiece, and reduce the surface quality of the resulting workpiece [2]. Therefore, the temperature of the tool is one of the important parameters that need to be monitored during the turning process because it is directly related to the performance of the tool and the efficiency of the machining process. Information about the temperature of the tool *real-time* It can also be used as an early indicator to detect wear and tear before it reaches more severe damage conditions.

In practice, the condition of the chisel in workshops and laboratories is generally still carried out visually after the turning process is completed. This method has limitations because it is not able to provide information about changes in the temperature of the chisel during the cutting process. As a result, the operator cannot know the thermal condition of the chisel directly, making the potential for premature wear difficult to detect. These conditions can result in a decrease in product quality, increased machine downtime, and increased production costs due to untimely tool replacement.

The development of microcontroller technology has allowed the development of a temperature monitoring system that is simple, economical, and easy to apply to the machining process. One of the most widely used microcontrollers is Arduino One, because it has ease of programming, a relatively affordable price, and is compatible with various types of sensors [3]. To take temperature measurements without direct contact with objects, infrared sensors are used MLX90614. This sensor works by detecting infrared radiation emitted by the surface of the object so that measurements can be made without interfering with the cutting process. In addition, the MLX90614 sensor has I2C-based digital communication that facilitates integration with the Arduino Uno [4].

Some previous studies have shown that MLX90614 sensors have a high level of accuracy in temperature measurements and have been successfully applied to various Arduino-based monitoring systems. Urbach and Wildian reported that temperature monitoring systems using MLX90614 sensors have an accuracy rate of up to 99.24% compared to standard measuring instruments [5]. Sudianto's Research *et al.* also shows that the sensor MLX90614 capable of taking temperature measurements automatically and *real-time* in the machining process *Milling* [6]. In addition, Inayah's research shows that MLX90614 sensors have the best accuracy at a measurement distance of 10–30 cm with an accuracy rate of 99.7% [7].

On the other hand, research on chisel temperature and wear shows that cutting parameters have an effect on the increase in temperature and the rate of chisel wear. Arifianti *et al.* report that the motion of eating (*Feed Rate*) and cutting depth have a significant influence on the chisel temperature in the turning process [8]. Manta Research *et al.* It also shows that increased cutting parameters lead to increased tool wear and decreased workpiece surface quality [9].

Based on previous research studies, most studies have only focused on testing the accuracy of MLX90614 sensors or the application of sensors to processes *Milling*. Other studies only discussed the relationship of cutting parameters to the temperature or wear of the tool without monitoring the temperature directly during the turning process. Thus, there are still limitations in research that integrates Arduino Uno-based MLX90614 sensors to monitor the temperature of the chisel *real-time* as well as connecting it to the level of tool wear in the ST41 steel turning process using High Speed Steel (HSS) chisels. These conditions become *Research gap* which underlies the implementation of this research.

Based on these problems, this study aims to design and implement an Arduino Uno-based tool temperature monitoring system using MLX90614 sensors, analyze the changes in tool temperature at spindle rotation speed variations, and examine the relationship between tool temperature and HSS tool wear level in the ST41 steel turning process. The results of the study are expected to provide information about the condition of the chisel *real-time* So that it can be used as a basis for determining the timing of tool replacement more precisely and supporting the development of a monitoring system in the machining process.

II. METHODS

This study used an experimental method to analyze the effect of spindle rotation speed variations on the temperature and wear of the tool in the ST41 steel turning process using a High Speed Steel (HSS) chisel. Temperature measurements are carried out in *real-time* using MLX90614 infrared sensors integrated with the Arduino Uno microcontroller, while the wear of the tool is measured based on *the flank wear* (VB) value using a digital microscope after the turning process is complete.

Tools and Materials

The equipment used in this study includes a conventional lathe C6240A, Arduino Uno, MLX90614 infrared sensor, laptops as a medium for monitoring and data storage, digital microscopes, and calipers. The material used is ST41 steel as a workpiece and High Speed Steel (HSS) chisel.

Table 1. Research Tools and Materials

No	Tools/Materials	Specification
1	Lathes	C6240A
2	Arduino One	ATmega328P
3	Sensors	MLX90614
4	Chisel	HSS
5	Material	Low ST41
6	Digital Microscope	Magnification 1000×

Research Variables

The independent variable in this study was the variation in spindle rotation speed, namely 190 rpm, 300 rpm, and 460 rpm. Bound variables include tool temperature and tool wear (Flank Wear). Control variables maintained during the study included workpiece material, chisel type, cutting depth, feeding motion, and cutting length.

Table 2. Cutting Parameters

Parameters	Value
Material	ST41
Chisel	HSS
DOC	1 mm
Feed Rate	0.2 (mm/rev)
Spindle Speed	190, 300, 460 rpm
Number of Repetitions	3 times

Data Analysis

The temperature data from the sensor measurements MLX90614 validated using standard measuring tools to obtain the error percentage value and the accuracy level of the sensor. Furthermore, the temperature and wear data of the tool were analyzed using IBM SPSS Statistics through the Shapiro–Wilk normality test, the Levene's Test homogeneity test, the One-Way ANOVA test, and the Tukey HSD follow-up test.

III. RESULT AND DISCUSSION

Results of Monitoring System Design

The temperature monitoring system was successfully designed using an Arduino Uno microcontroller and an infrared sensor MLX90614. The sensor is mounted facing the cutting area to measure the surface temperature of the tool Non-contact. The temperature data obtained by the sensor is transmitted to the Arduino Uno via I²C communication, then displayed in a real-time on a computer using Arduino IDE. Initial tests showed that all components of the system were able to work properly and were able to display temperature values stably during the turning process.

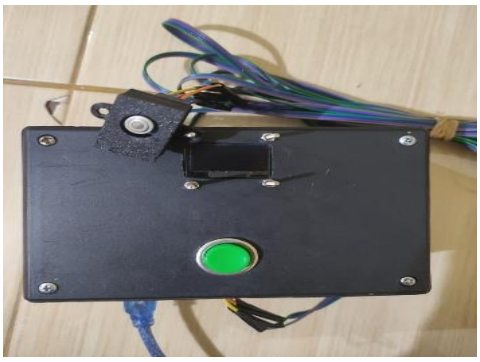

Fig. 4. Results of Temperature Monitoring System Design

After the system is successfully assembled, functional testing of each component is carried out to ensure that the sensor is able to read the temperature of the tool during the turning process. The test results show that the system can operate properly without interfering with the machining process.

Tool Temperature Test Results

Temperature testing was carried out on three variations of spindle rotational speeds, namely 190 rpm, 300 rpm, and 460 rpm. Each variation is carried out three times with the same cutting parameters so that the temperature difference that occurs is affected by the change in spindle speed.

Table 3. Average Result of Tool Temperature

No	Spindle Speed (rpm)	Average Minimum Temperature (°C)	Average Maximum Temperature (°C)	Average Tool Temperature (°C)
1	190	31,33	44,17	36,04
2	300	34,17	49,5	41,09
3	460	36,4	47,82	40,5

Based on the test results, the chisel temperature increases as the spindle rotation speed increases. At the lowest spindle speed, the lowest average temperature is obtained, while at the highest spindle speed, the highest average temperature is obtained. The increase in temperature occurs because the higher the cutting speed causes the friction rate between the tool and the workpiece to be greater so that the heat energy produced also increases.

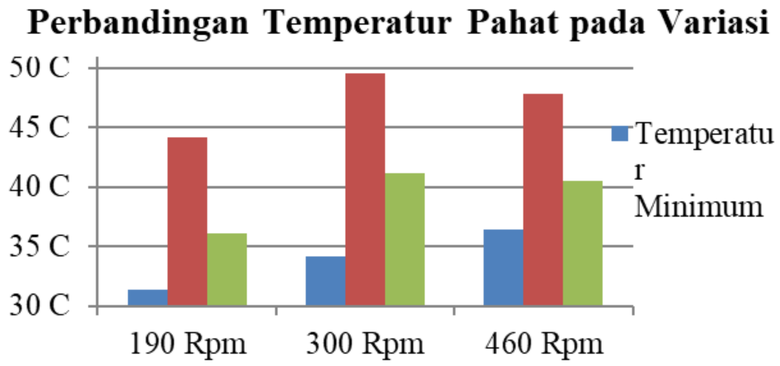

Fig. 5. Graph of Relationship of Spindle Speed to Tool Temperature

The graph in Figure 5 shows a consistent trend of temperature increase at each increase in spindle speed. These results show that spindle speed is one of the cutting parameters that affects the temperature of the tool during the turning process.

Tool Wear Test Results

After the turning process is completed, side wear measurements are carried out (Flank Wear or VB) using a digital microscope. Measurements are taken on each tool used in the test.

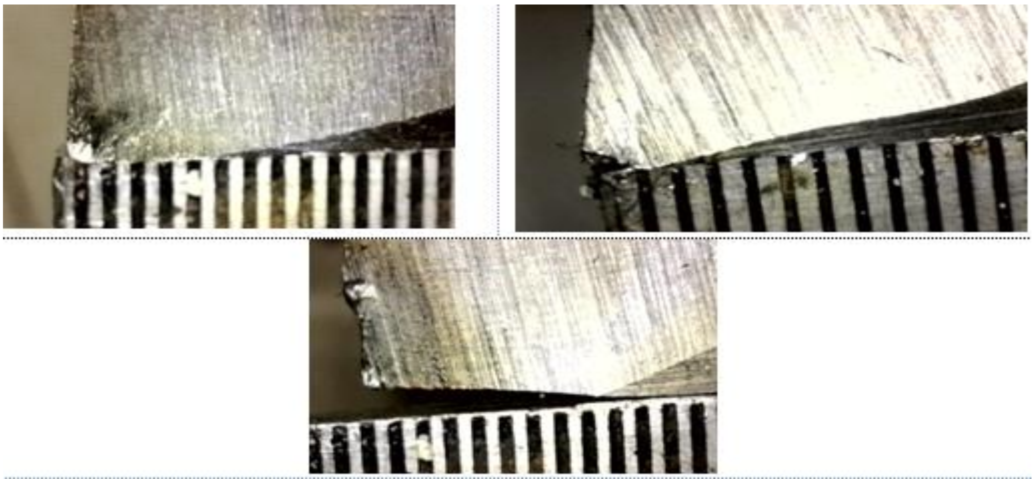

Fig. 6. Tool Wear Measurement Results Using Digital Microscope

Table 4. Tool Wear Value (VB)

Spindle Speed (rpm)	Average Tool Wear (VB) (mm)
190	0,170
300	0,206
460	0,277

The measurement results show that the wear value of the tool increases as the spindle speed increases. The highest VB value is obtained at a spindle speed of 460 rpm, while the lowest VB value is obtained at a spindle speed of 190 rpm. This condition suggests that the increase in temperature during the cutting process contributes to the acceleration of the chisel wear.

Relationship of Tool Temperature to Tool Wear

The relationship between temperature and tool wear is analyzed based on the average temperature value as well as the value of the Flank Wear (VB) on each spindle speed variation.

Spindle Speed (rpm)	Average Temperature (°C)	Average Wear (VB) (mm)
190	36,04	0,170
300	41,09	0,206

460	40,50	0,277

Table 5. Relationship of Tool Temperature to Tool Wear

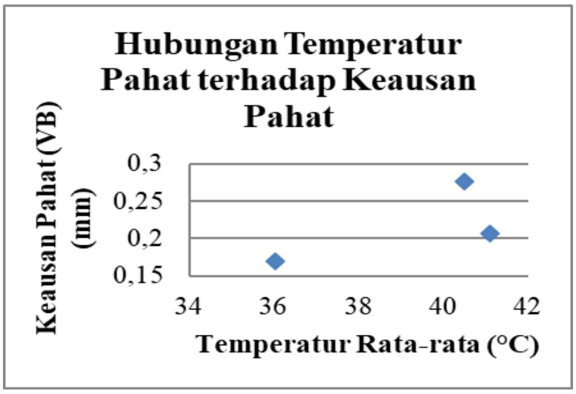

Fig. 7. Relationship of Tool Temperature to Tool Wear

The graph in Figure 7 shows a tendency that the higher the chisel temperature, the more the chisel wear value increases. This shows that temperature is one of the factors that affect the rate of tool wear during the turning process. The increase in temperature causes a decrease in the hardness of the tool material, thus accelerating the occurrence of wear on the free plane (Flank Wear).

Results of Statistical Analysis

The temperature data obtained was then analyzed using IBM SPSS Statistics software. Before the hypothesis test was carried out, the data was tested for normality and homogeneity to ensure that the data met the assumptions of parametric analysis.

Table 5. Shapiro–Wilk Normality Test Results

Spindle Speed	Statistics	Sig.
190 rpm	0,975	0,695
300 rpm	0,975	0,696
460 rpm	0,997	0,887

Table 6. Levene's Test Homogeneity Test Results

Living Statistic	df1	df2	Sig.
0,892	2	6	0,445

The test results showed that the data was normally distributed and had a homogeneous variance so that it was eligible for the One-Way ANOVA test.

Table 7. ANOVA One-Way Test Results

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	34,311	2	17,155	6,135	0,035
Within Groups	16,779	6	2,797		
Total	51,090	8			

The results of the ANOVA One-Way test showed a significance value of 0.035 ($p < 0.05$), which means that the variation in spindle rotation speed exerts a significant influence on the temperature of the chisel. Thus, the hypothesis that the spindle speed affects the temperature of the tool is acceptable.

Next, a follow-up test was carried out by Tukey HSD to find out the group pairs that had significant differences.

Table 8. Tukey HSD Advanced Test Results

Spindle Speed Comparison	Mean Difference (°C)	Sig.	Remarks
190 rpm – 300 rpm	-2,0633	0,086	No significant difference
190 rpm – 460 rpm	-3,5233	0,037	Significant differences
300 rpm – 460 rpm	-1,4600	0,781	No significant difference

The results of the Tukey HSD test showed that there was a significant difference in a given spindle speed pair, indicating that the increase in spindle speed resulted in a noticeably different change in tool temperature.

IV. CONCLUSION

Based on the results of the study, the Arduino Uno-based tool temperature monitoring system uses an infrared sensor MLX90614 was successfully designed and implemented to monitor the temperature of the tool in *real-time* during the ST41 steel turning process using a High Speed Steel (HSS) chisel. The developed system is able to take temperature measurements without direct contact with the tool so that it does not interfere with the machining process. The test results showed that the increase in spindle rotation speed caused the tool temperature to increase further, where the highest temperature was obtained at the spindle speed variation of 460 rpm and the lowest temperature at 190 rpm. The increase in temperature is followed by an increase in the value of the tool wear (*flank wear*), which indicates a relationship between the temperature of the tool and the wear rate during the turning process. The results of statistical analysis using *the One-Way ANOVA* test showed that the variation in spindle speed had a significant effect on the chisel temperature with a significance value of 0.035 ($p < 0.05$). In addition, the validation results showed that the MLX90614 sensor had an average error percentage of 1.33% with an accuracy rate of 98.67%, so the monitoring system developed is suitable for use as a tool for *real-time tool temperature monitoring* and has the potential to support the more precise determination of tool replacement time to improve the efficiency of the turning process.

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