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A Study of Implementing a Predictive Maintenance Software System for Conventional Machine Based on Internet of Things (IOT)

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Abstract: A predictive maintenance system is a form of maintenance system which can predict the need to maintain assets at a certain future period. The Internet of Things system may benefit manufactures from the data collection to advance the current manufacturing process which allowed devices to monitor physical processes. This paper is aiming to develop low-cost predictive maintenance system with an Internet of Things feature sensor to predict the condition of cutting tool and time decision on change the cutting tool to ensure the quality of products that allowing the tool life of cutting tool to be optimized. It is also studying the potential opportunity for install features to upgrade the old conventional machine. The operating cutting temperature of the cutting tool in metal cutting is influenced by cutting factors particularly during the machining operation. As the cutting temperature greatly affects the tool life, it is important to monitor an increase in cutting temperature using reliable techniques. In this study, two conditions of cutting tool whereas new tool with zero flank wear and a worn tool with 0.51mm flank wear was used. Average cutting temperature and maximum cutting temperature were investigated by placing a non-contact infrared MLX90614 temperature sensor. The data acquisition has been done with PLX-DAQ software and live monitoring system with Blynk application through ESP8266 NodeMCU controller board with Arduino IDE software. Experiments were performed and cutting temperature was recorded as well as results have been analysed. The correlation between cutting parameters and cutting temperature is clearly noticed. The predictive maintenance software system based on IoT technology with cutting temperature had a successful build-up to collect the data information of cutting temperature with a data acquisition system.

Keywords: Predictive Maintenance, Internet Of Things, Cutting Temperature

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1. Introduction

A predictive maintenance system used historical information to predict the trends, behaviour patterns and correlations to boost decision-making for sustaining maintenance activity to helps minimize machine downtime, reduce expenses, increase control and product quality [1]. It is a major challenge to assess machine maintenance time in the manufacturing industry to solve unexpected problems [2]. The maintenance effects account for a total of 15 to 60 percent of the total operating costs of all manufacturing activities [3]. The Internet of Things (IoT) is an important technology which makes it possible for real-time interaction and data sharing with embedded devices [4]. An Internet of Things maintenance system is able through real-time tracking of the operation state can transfer real-time information by installing a sensor to a data analysis module and could also send related updates to the maintenance department for the necessary steps [5][6]**.** Old machines can upgrade with suitable features which can be a stand-alone approach or part of the reconstruction or remanufacturing approach offers a quick, convenient and cost-effective solution [7].

The monitoring of tool deterioration is great importance as it determines the consistency of the finished surface and dimensional precision of the cuts with significant investments in replacing costly cutting tools due to breakage [8][9]. The friction between the tool and the workpiece can be increases by carrying on the machining operation with a worn tool. The worn tool can be modified in time with an efficient control device to prevents unexpected downtime and scrapped components [10]. This is critical as the worn tool produces less quality of finished products and dimension distortions during machining processes [11]. In the metal cutting process, tool condition monitoring system has the most significant because it specifically impacts the efficiency of the machined surface and dimensional precision [12] [13]. Tool life and product quality often rely on many other variables and there is major forms of tool wear whereas flank wear and the past researcher suggested to characterize flank wear with continuous sensory signals or data [14].

Sensing technologies are integrated into the manufacturing process to create an intelligent tool condition monitoring system to gain information about the condition of the tool [15] [16]. A high-speed infrared sensor with software designed for measuring transferred heat to the workpiece during high speed bronze alloy processing (HSM) was performed by [17]. Next, an infrared (IR) camera has been used to develop a process control methodology for the identification of the state of the tool during aluminium milling [18]. The use of an IR camera can correctly determine tool wear thus enabling better maintenance plans. In addition, a thermocouple was installed to measure the temperature of workpiece and the tool tip with high accuracy in the micro cutting process [19]. Maximum relative errors between the experimental and simulated tool tip temperatures and the workpiece surface range from 10% and 20%. According to the study [20], the thermal data is collected by heat sensor to form LSTM networks which are designed for thermal errors for adaptive compensation in this research. Practical case studies compared to processes without using the designed system have shown that the system has reduced transmitted data volume by 52.63% and improved process accuracy by 46.53%.

Nowadays, the manufacturing sector all around the world includes our country is facing the problem as their conventional machines were developed many years ago. A new modern conventional machine has a much higher mean time between failure than a legacy machine. Regarding this point, the manufacturing sector needs to maximize the availability of maintenance for legacy conventional machines. Decision making involving a large input of data and customization in the manufacturing process is faced by both machines and managers every day to maximize availability.

However, the old conventional machines often lead to small but frustrating problems with their reliability and programming complexity. It is difficult for technical workers to all-time monitoring the machine to avoid machine failure and control the quality of products. It is also important to study on prediction of the failure to reduce unplanned downtime with intelligent software systems as well as without human involvement. It can be said that one of the key challenges is the ability to predict the need for asset repair at a particular future period in this area [3].

Some companies with sufficient financial capabilities, they can afford to buy a new advanced machine to replace the old machine but some small-sized companies cannot afford it. A conventional machine can upgrade by adding new features to extend machine life and will not be eliminated. It is not rebuilding or remanufacturing which does not involve any major repairs to the machine. If it can find the best strategic method to upgrade the machine with the latest technologies, it will enhance the machine's overall performance.

The objective of this study is to study potential opportunities for install features to upgrade conventional machines on machinery manufactures and also construct a flexible and intelligent IoT technology system to monitor the machining process. It is also aiming to determine the effect of cutting parameters on temperature with a data acquisition system for predictive maintenance purposes.

2. Materials and Methods

The materials and methods section, otherwise known as methodology, describes all the necessary information that is required to obtain the results of the study.

2.1 System components

In this experimental study, the MLX90614 temperature sensor is contactless infrared (IR) digital temperature sensor to measure an object's temperature without physical contact and the range measured is from -70 to 382.2 degrees Celsius for the temperature of an object. Meanwhile, an ESP8266 NODEMCU is a low cost-effective open-source IoT platform. It originally included firmware that runs on the ESP8266 Wi-Fi SoC and hardware that was based on the ESP-12 module. In addition, I2C LCD screen is ideal for text or characters displays only to show the recorded cutting temperature. Figure 1 show the circuit connection of system component.

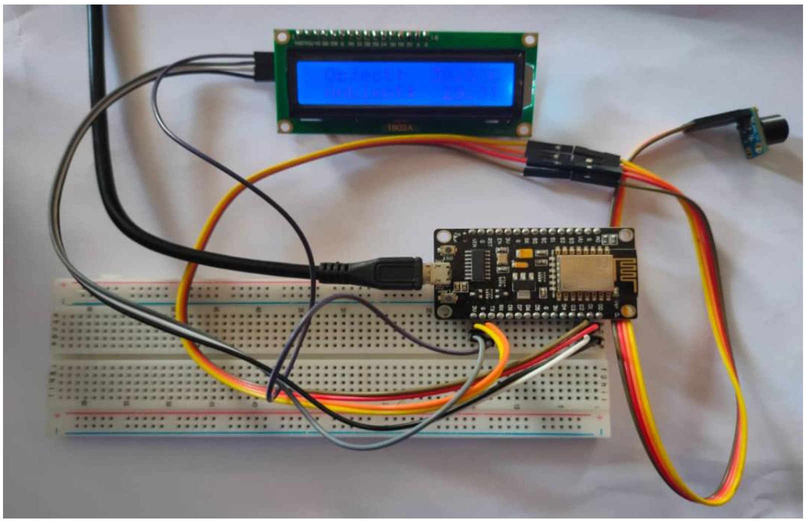

Figure 1: Circuit diagram of ESP8266NodeMCU and MLX90614 temperature sensor as well as I2C LCD display

2.2 Cutting tool and cutting parameters

There will two types conditions of turning inserts will used be and analysis their cutting temperature performance which are new turning inserts and worn turning inserts which are made high-speed steel (HSS). Form figure 2, it can see that the new cutting tools was sharp and zero flank wear. In comparison, it can see that the worn cutting tools was a little breakage and dull with 0.51mm flank wear from figure 3. The picture of flank wear is determined by an Olympus magnifier machine SZH10 with 15 enlargements at the material science lab of FKMP. Table 1 shows the cutting parameters of this study.

Table 1. Cutting parameters of turning experiment

Cutting parameters	Cutting speed, Vc (m/min)	Feed rate. f (mm/rev)	Depth of cut, dp (mm)
Values	14.14, 29.06, 42.41	0.049, 0.065, 0.081	0.1, 0.2, 0.3, 0.4, 0.5

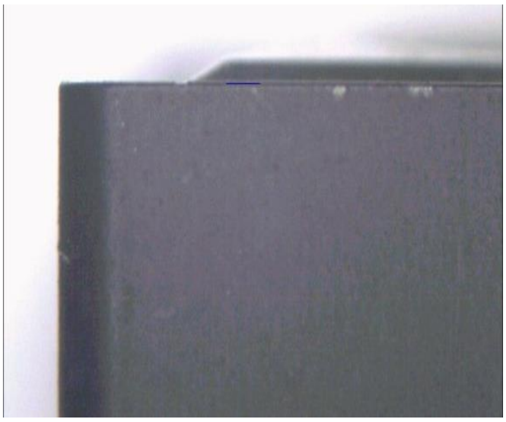

Figure 2: A new cutting tool with sharp and zero flank wear.

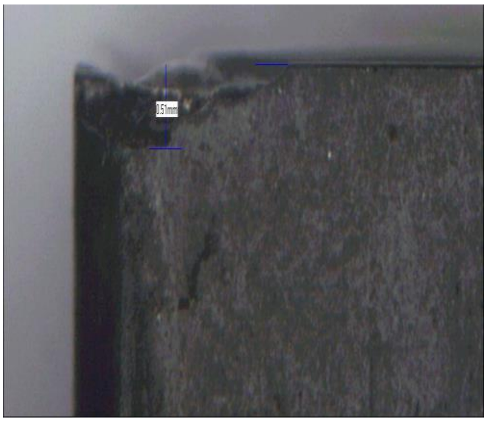

Figure 3: A worn cutting tool with blunt and 0.51mm flank wear.

2.3 Experimental setup

The study conducts at Machining Lab of FKMP UTHM and the feasibility of monitoring the cutting tool for predictive maintenance is demonstrated using a lathe machine M300 for turning machining process. The lathe machine M300 is already served from years 1995 which had 26 years. The workpiece was mild steel with a cylindrical bar with a diameter of Φ25mm. The machine settings and process parameters are kept changed with different parameters in all measurements and the workpiece is changed frequently. In order to monitor the cutting temperature data with conventional machine characteristics, the built-in MLX90614 temperature sensor is used in this study to acquire the cutting temperature of cutting tool. The data transfer can be achieved wireless by using the built-in ESP8266 NODEMCU microcontroller which responds to instructions from Arduino IDE to I2C LCD displays and Blynk application for live monitoring on mobile phone. Because Arduino IDE software was not functional for data analysis so adds in Parallax Data Acquisition tool (PLX-DAQ) software which Arduino IDE software can straight transfer the data to PLX-DAQ system for data acquisition on Microsoft Excel for data acquisition. Figure 4 had shown the block diagram for experimental procedures and figure 5 had shown the schematic diagram for predictive maintenance system with IoT sensor.

2.4 Placement of MLX90614 non-infrared sensor with tool

The temperature sensor is placed above the cutting tool with a suitable angle at a distance of 2cm away from cutting tool. In this position, the cutting temperature information is directly obtained by sensor. The MLX90614 temperature sensor was built in on the top of the cutting tool which does not affect the efficiency of the cutting performance of the machine as showed in figure below. The head of MLX90614 temperature sensor was facing the contact point between the workpiece and cutting tool. Besides that, it also needs to fix up the MLX90614 temperature sensor when we embed it because we found the temperature readings change a lot when moving only a few centimetres from the object. Figure 6 had shown the position of the temperature sensor to record the temperature data.

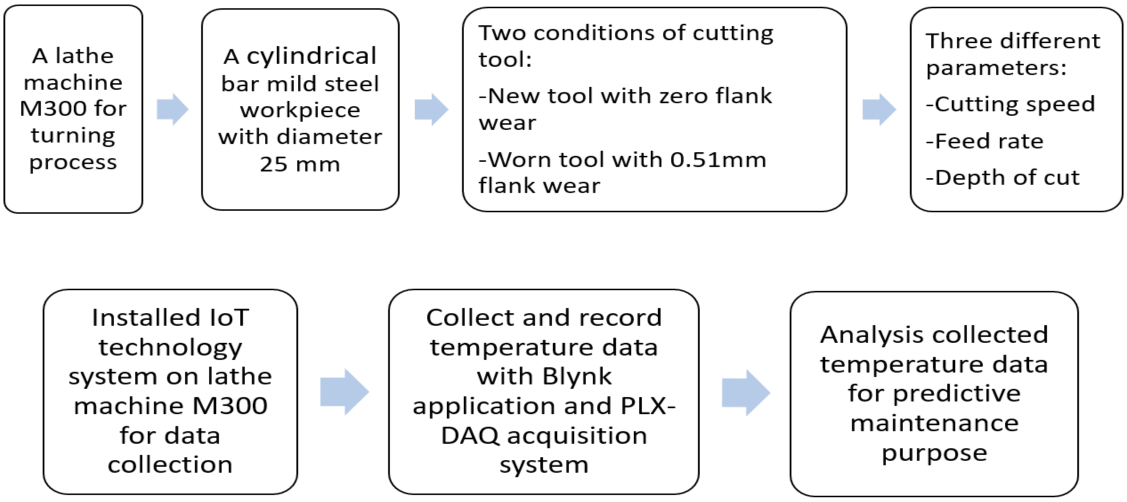

Figure 4: A block diagram for experiment procedures with predictive maintenance system with IoT sensor

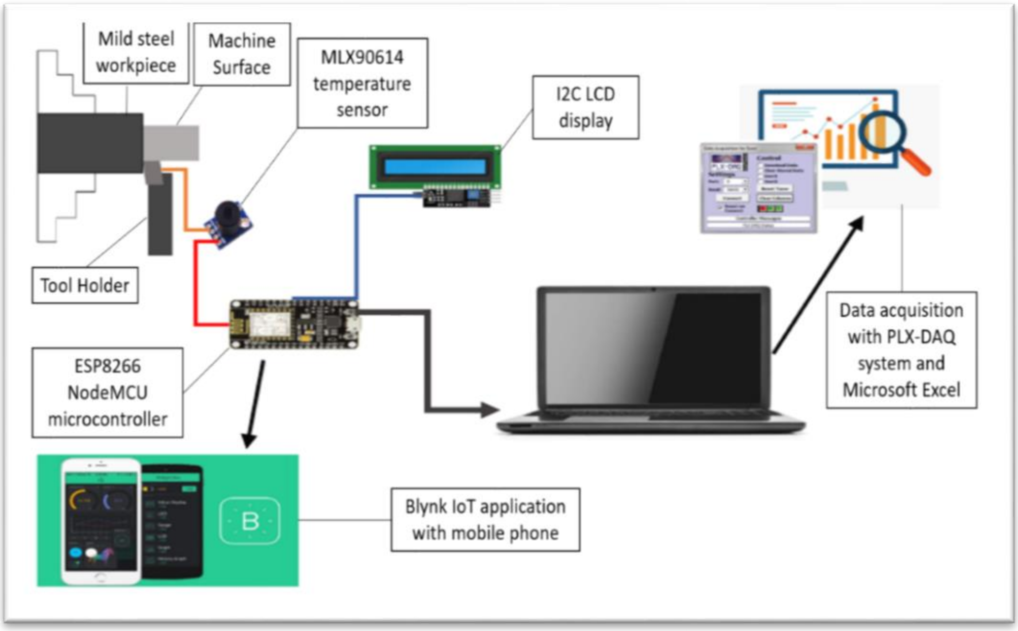

Figure 5: Schematic diagram for predictive maintenance system with IoT sensor.

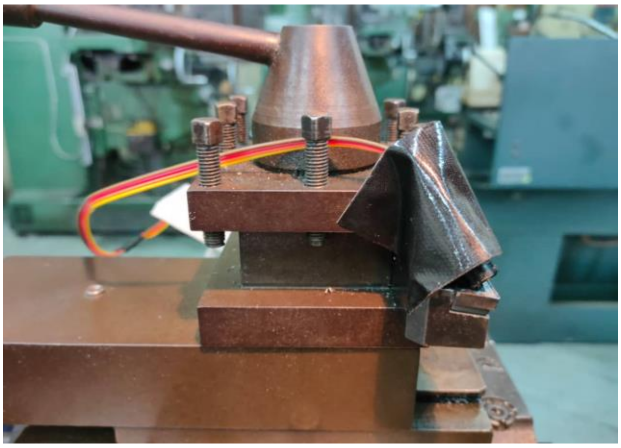

Figure 6: MLX90614 temperature sensor embed above the cutting tool.

3. Results and Discussion

The result obtained from the turning process with a conventional lathe machine in the machinery lab with the IoT-based system with different flank wear of cutting tool was compared and analysed based on different parameters with cutting speed, feed rate and depth of cut and compared with past research. It is necessary to know the impact of the cutting parameters on the cutting variables for a better define of the relationships. It is necessary to know the impact of the cutting parameters on the cutting variables for a better define of the relationships. Different levels of cutting speed, feed rate and depth of cut were used to compose the experimental study during turning of mild steel workpiece with new cutting tool and worn cutting tool respectively to determine the correlation of cutting parameter with cutting temperature. The performance of the main effects is shown in every combination of parameters that were analysed.

3.1 Cutting speed

The cutting speed for experimental was 14.14 m/min, 29.06 m/min and 42.41 m/min respectively. This experimental was designed to use different cutting speed cut the workpiece while maintaining 5 different depth of cut which are 0.1mm, 0.2mm, 0.3mm, 0.4mm and 0.5mm as well as the same of cutting length per min which is 30 mm/min.

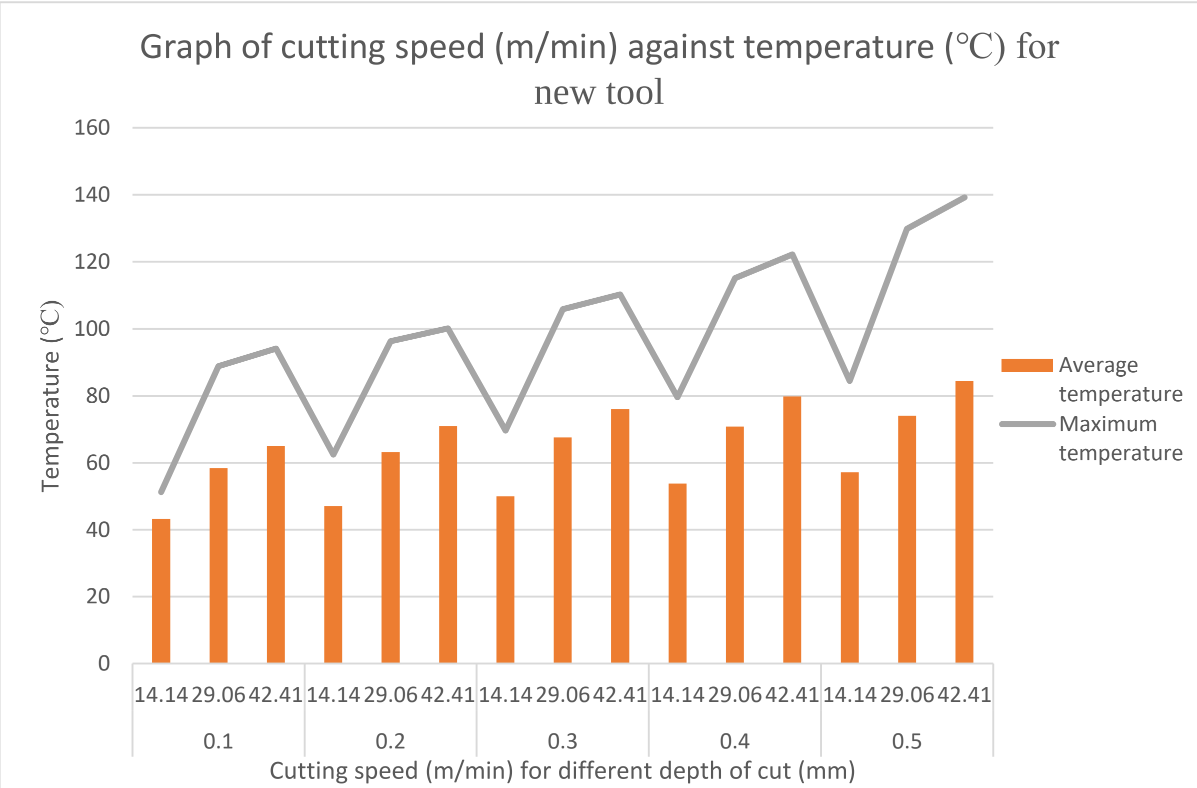

Figure 7: The graph of average cutting temperature against different cutting speed for new tool

It is noted that the average temperature and maximum temperature increase when the cutting speed increase from figure 7. The chart and lines have shown a similar increase trend when the experiments are kept constant with the same depth of cut throughout all different depth of cut which are 0.1mm, 0.2mm, 0.3mm, 0.4mm and 0.5mm. It can observe that the slowest cutting speed (14.14 m/min) for 5 different of the depth of cut had recorded the lowest cutting temperature compared with 29.06 m/min and 42.41 m/min. For observation above, it can conclude that when cutting speed increases, there will be an increase cutting temperature. This behaviour kept constant for worn cutting tool.

3.2 Feed rate

The feed rate was set to 0.049 mm/rev, 0.065 mm/rev and 0.081 mm/rev in this experiment and it was designed to use different feed rate cut the workpiece while maintaining 5 different depth of cut which are 0.1mm, 0.2mm, 0.3mm, 0.4mm and 0.5mm as well as the same of cutting speed which is 29.06 m/min.

Continuous cutting experiments have been carried out with various depth of cut and feed rate. Figure 8 shows the relationship of different feed rate while maintaining five identical depth of cut (0.1 mm, 0.2 mm, 0.3 mm, 0.4 mm and 0.5 mm). It can observe that the cutting temperature increases proportionally with feed rate from the data information obtained by build-in IoT system. The average temperature shows a similar trend with a uniform increase bar graph with five different depth of cut. It has been noted that the highest feed rate with 0.081 mm/rev had the highest average temperature among 0.065 mm/rev and 0.049mm/rev. From this point of view, it can say that the feed rate was statistically significant for the cutting temperature. However, the line graph which represents maximum temperature does not show a similar trend with five different depth of cut and it shows inconsistent pattern start for 0.3mm, 0.4mm and 0.5mm. This may be due to the feed rate of lathe machine M300 is cut manually by hand and not performed consistently compared with automatically machine. Once again, this behaviour kept constant for worn cutting tool.

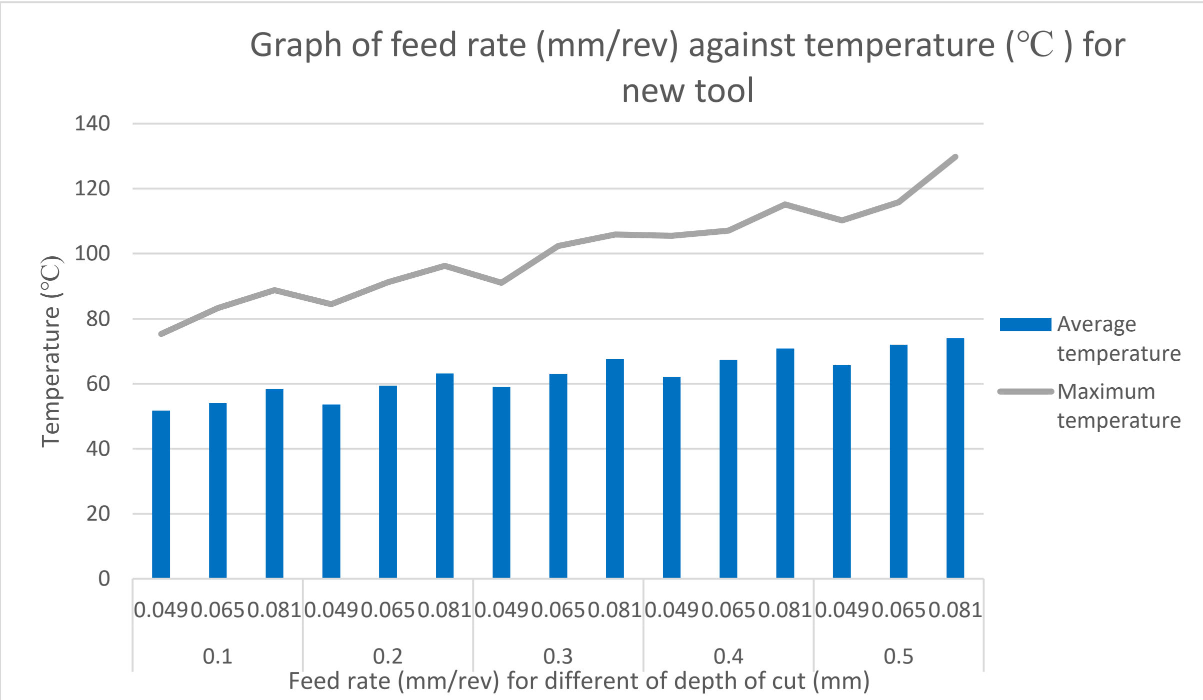

Figure 8: The graph of average cutting temperature against different feed rate for new tool

3.3 Depth of cut

There are five different depth of cut was conducted were as 0.1mm, 0.2mm, 0.3mm, 0.4mm and 0.5mm in this experimental to relate the average and maximum temperature with depth of cut. The cutting speed is kept constant with 14.14 m/min, 29.06 mm/min and 42.41 mm/min.

It can observe that the average temperature and maximum temperature obtained by the lowest depth of cut with 0.1mm are the lowest among the other depth of cut parameters for new tools and worn tool in figure 9. In contrast, the highest depth of cut with 0.5mm had the highest average temperature and maximum temperature. Furthermore, the maximum temperature also had the same similar trend as average temperature. It can conclude that the cutting temperature increases as the depth of cut increased for both cutting tool based on the observation above. This behaviour also kept constant for worn cutting tool.

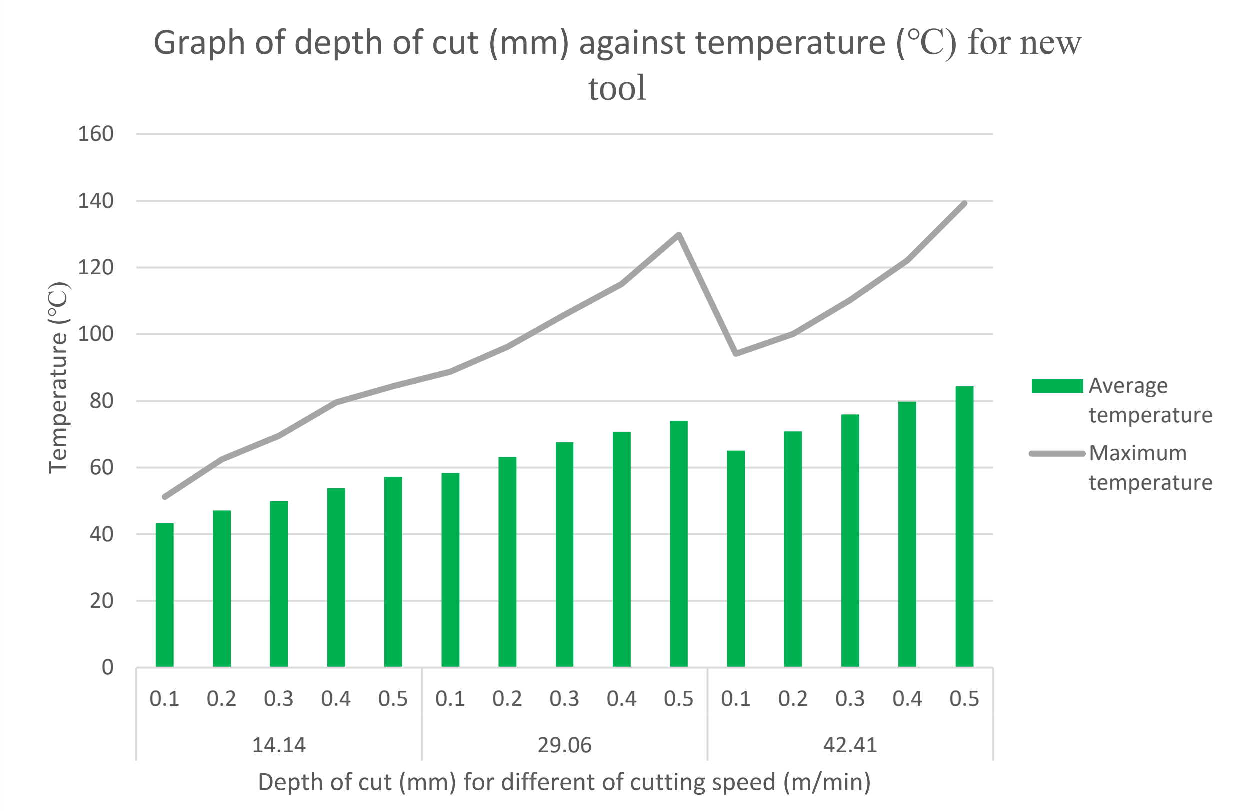

Figure 9: The graph of average cutting temperature against different depth of cut for new tool

With compared all the graphs above, it can conclude that all the parameter includes cutting speed, feed rate and depth of cut were noted with an increasing exponentially graph which the same result with the past research [21]. The increase in the depth of cut, increase the friction between the tool and workpiece as well as will increase the energy generated and the temperature in the deformed area. A higher depth of cut leads to increased cutting forces and higher cutting temperatures. The results agree with previous studies [22].

Moreover, the low feed rate and cutting speed that generates low cutting temperature has been confirmed in other research [23] and high cutting temperature have been generated with high feed rates and cutting speed during dry turning process. The higher feed rates and cutting speed were resulting in higher material removal which would induce greater energy for the extra removal rate therefore higher cutting temperatures. Most of the heat is normally dissipated as the chip carries away most of the heat generated during the cutting process. During metal cutting, the material is subject to extremely high strain and elastic deformation constitutes a very small portion of the total deformation. There is thus the possibility of converting all energy into heat. [24].

For comparison purposes, it is observed that the cutting speed affects the cutting temperature the most because the curves in these graphs are greater in inclination for both tools. When analysing the influence of all cutting variables, it looks that cutting speed is the most significant because by raising the cutting speed by almost 200% (from 14.14 m/min to 42.41 m/min) with the cutting temperatures increases 34%. Meanwhile, an increase of 65% (from 0.049mm/rev to 0.081mm/rev) on the feed only produces an increase of 11.34% on average temperature and a rose of 400% (from 0.1mm to 0.5mm) on the depth of cut produces an increase of 26.80% on the average temperature. It can conclude that all the cutting temperature demonstrate increasing behaviour under different cutting speed, depth of cut and feed rate values at the specified experiment.

3.4 Influence of flank wear of tool on the cutting temperature

This experiment has modified to the situation of the small and mid-size enterprises manufacturing company with a conventional turning machine. The new tool has represented the tool without any flank wear and will have high efficiency to produce high quality of the workpiece. Meanwhile, the worn tool has represented the tool that cut innumerable times and causes the tool to have flank wear as well as may product unperfect surface finish at workpiece.

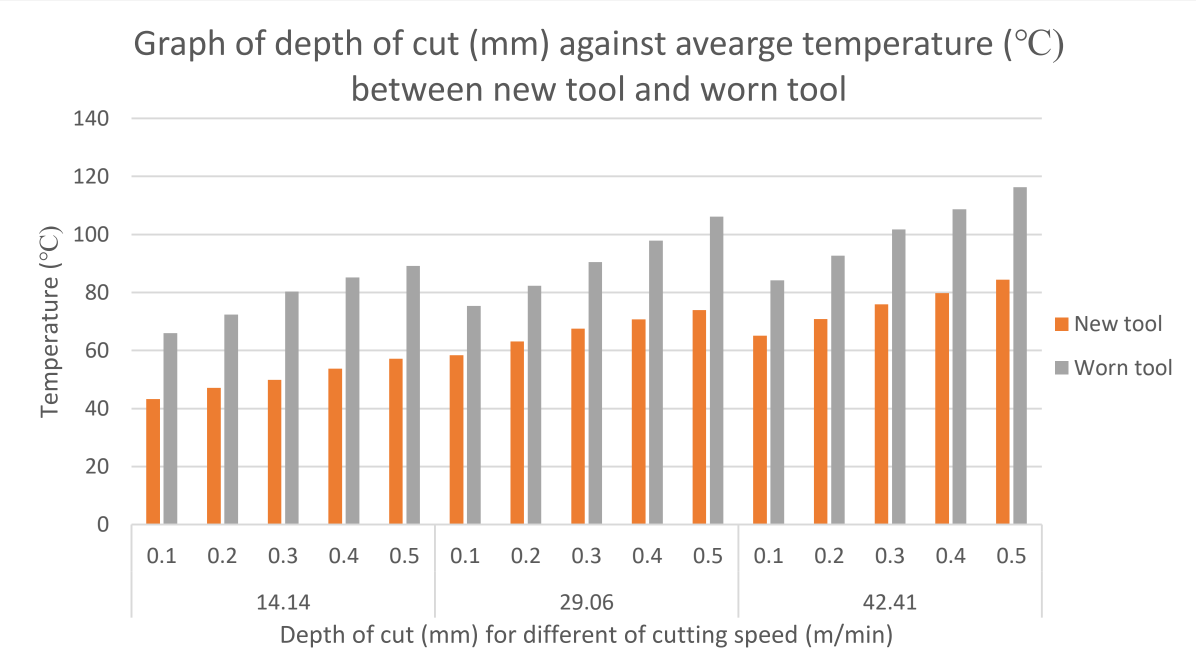

Figure 10: Bar chart for comparison for average temperature between new tool and worn tool

It was observed from the capture data by temperature sensor during the turning process that increase in depth of cut while maintain same cutting speed increase the average temperature at the cutting zone based on figure 10. It also can see that the average cutting temperature obtained with a worn cutting tool are much higher than average cutting temperature obtained with new cutting tool for the performance of cutting speed. In order to determine the influence of flank wear on tool tip temperature, the relationship between tool tip and flank wear of tool during the cutting process is investigated. This same behaviour has kept constant for maximum temperature.

The author [25] mentioned that the major cause of accelerated wear and deterioration of the surface quality is high temperature generation in the cutting area. Normally, the workpiece is subjected to plastic deformation during cutting material to generate a surface that results in progressive wear of the tools. The formation of a chip continues over this period and the contact of tool-workpiece affects the mechanical characteristics of the surface and cutting tool. Mechanical energy is converted into heat energy in the deformation zones. As a result, plastic deformation heat increases and the temperature of the cutting tool on the rake face increases. The factors that increase plastic deformation in the workpiece ensure the removal of the chip on the one hand and also increase the tool wear.

Maximum temperatures steadily increasing on the side or rake of the cutting tool reduce the life of the tool. The quality of the machined surface also depends on both the tool and the workpiece's maximum temperature and average temperature [26]. The surface finished of a workpiece cut by new tool is in good quality meanwhile when conducted the experimental with worn cutting tool, the workpiece is founded that with bad quality of surface finished on the workpiece and it came out with smoke and spark during turning process.

In this study, a data-driven method predictive maintenance is used based on the historical results to make changes on cutting tool. From the data obtained above, it can set the notifications for the Blynk IoT application with 163°C which is higher than maximum cutting temperature (139.25°C) of new tool condition but also less than maximum average cutting temperature of worn tool. The minimum flank wear is 0.40mm and the flank wear was 0.51mm in this study so it can take the suitable maximum temperature to notice and alert that the cutting tool may reach the minimum requirement of flank wear. It is to remind the cutting tool was on unhealthy condition on the same condition of cutting parameter during turning process.

4. Conclusion

A low-cost predictive maintenance with IoT feature sensor with the development of a data acquisition system for the measurement of cutting temperature used for turning process was successful implement. The system has proven to be easy to use and provided high accuracy results for data analysis purposes that achieve the objective in this study. When increasing the cutting speed, feed and depth of cut, the measured average and maximum cutting temperature increase. For comparison purposes, it is observed that the cutting speed affects the cutting temperature the most because the curves in these graphs are greater in inclination for both tools. The cutting speed raising the cutting temperatures with 34%. The average temperature of worn tool has recorded higher than the average temperature of new tool at depth of cut with a range 20%-30% when increase depth of cut. Other than that, the infrared non-contact temperature sensor can help enhance the authenticity of the measured cutting temperature. The sensor can accurately measure the cutting temperature and can be recorded simultaneously with the varying cutting time. It can conclude that a convenient, effective and economical methodology for accurately measuring cutting temperature in the cutting zone for predictive maintenance based on IoT technologies system was successful and it is sustainable with reduce the wastage of raw material and prolong the machine life of conventional machine.

Recommendations are added with the requirements and suggestions to improve further studies with similar aims. Great recommendations can lead toward better results and even open up opportunities for further research. It can be considered to conduct the turning experimental with one cutting insert and analyse the effect of cutting parameters from zero flank wear to maximum flank wear under different cutting environments. This can observe the revolution of condition for cutting tool and the cutting temperature with different cutting environments. Beside. It also can study the turning performance with an uncoated and coated carbide tool. The cutting temperature with an uncoated and coated carbide tool can be study and can make a comparison for both carbides insert in terms of relationship of cutting parameter with cutting temperature. Lastly, it also can conduct the turning experimental under different materials of workpiece. Different materials have its mechanical properties and chemical compositions. The cutting temperature with different material of workpiece can be study.

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