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Applied Internet of Things(IOT) In Temperature and Vibration Monitoring System for Milling Machine

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Abstract: Tool Condition Monitoring in the machine industry is considered vital for the preventive maintenance of the cutting tool, leading to technology improvement in Industrial Revolution 4.0. Especially in Small and Medium-sized Enterprise, it is challenging to implement monitoring system into their machine due to the high cost of development and expert handling the system. The need to have a well-developed system that is low cost and dependable for them to utilise in the shop floor becomes the key for this research. Two reliable sensors were tested: thermocouple to measure the temperature data and acceleration, ADXL335 to measure the vibration data during the end milling machining process. The relationship between these two sensors, together with the cutting speed and depth of cut, was recorded and observed. The research also proposed implementing Internet of Things in monitoring system for milling machine to help the working personnel monitor the machine tool condition in any location if it shared the same local network. The system also managed to operate and display real-time data through an online platform called Blynk. Through the mobile application, the user can monitor the sensors' data via smart device and be notified if there is unstable behaviour during the cutting process. Moreover, the effectiveness of the developed system had been validated through experimental testing using a three-axis vertical milling machine with a few machining parameters such as cutting speed, depth of cut and tool condition. Based on all parameters tested on the system, the cutting speed of 2600rpm with depth of cut of 0.9mm shown the highest temperature and vibration compared with the other parameters. Overall, the system managed to measure and transfer real-time data from the sensors and transmitted it to the online platform to interface the data.

Keywords: Internet of Things, Milling, Monitoring, Temperature, Vibration

1. Introduction

Machine monitoring is the process of connecting the machine at the shop floor to the medium that will gather and interpret data of the devices. While machine condition monitoring can be divided into two categories, machine condition monitoring and machine process monitoring [1]. It involved the

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installation of sensors on the factory machine. There are a lot of sensors that can be used, such as temperature sensors, accelerometers and gyroscopes. These sensors have its specific functions that can detect and gathered the required data. Through these sensors, real-time data can be continuously recorded from the machines for data records. This will assist the shop floor personnel in charge and executing proper and wise decisions for the industry to improve the performance of the manufacturing industry [2]. While in previous research, it mentioned that remote monitoring can reduce the excessive time and energy usage while monitoring the machines and allow more time to be spent on other critical tasks in the shop floor such as maintenance and optimization [2].

One of the essential components in a machining process is the cutting tool [3]. The error in machine tools caused approximately 40% to 70% from the total error [4]. It is proven that a good tool condition monitoring technology can decrease the downtime caused by human and machine factors up to 75 %. This will increase the efficiency of the production time up until 10 to 50%. If the replacement timing for the cutting tools is improved, it can save more time in the production. However, the lack of an efficient tool conditioning monitoring (TCM) device will inevitably lead to inaccurate product tolerances and peripheral damage to the computer and causing the machine to incur excessive maintenance costs and inferior quality products [3].

In addition, a Cloud-based remote monitoring system for industrial devices had been proposed previously by a researcher. The system aimed to demonstrate the implementation of the Internet of Things (IoT) concept in the machining process. This method utilised the sensors that been placed on the machine to monitor its condition. The data collected was sent to the Cloud storage for the record while also displaying the information to the other parties that have a connection with the Internet [5]. However, another novel design idea of remote monitoring and controlling system of the CNC machine using embedded Internet also once proposed by Zhai and Hu on 2010. The system had enhanced the communication system between the upper industrial control, the field monitoring host and the machines [6]. Having said that, a new proposed system that fused two sensors that more economical and easier to operate need to be done so that it can be implemented especially in Small and Medium Enterprise industry.

This study is primarily focused on establishing a monitoring system that applied Internet of Things (IoT) in the system for milling machine. Thermocouple and accelerometer sensors are integrated in one system to measure input data from the cutting process. Besides, milling machine had been chosen as experimental subject to test the functionality of the system with parameter of cutting speed, depth of cut and the tool condition. This developed system provides economical and flexible solution for Small and Medium Enterprise. It can also be improved to support wider manufacturing applications.

2. Materials and Methods

2.1 Materials

The prototype for the developed system that been fabricated using two types of sensors which are thermocouple type-k and accelerometer, ADXL335, ESP8266 NodeMCU, OLED display, two different color of LED and online platform data interface, Blynk. The hardware components connection will be placed inside a secure cover box to protect it from the cutting chips during machining. The list of components that is used for the system fabrication is stated as in Table 1 together with their function and Figure 1 shows the circuit connection of the system hardware.

Table 1: List of Component Used

No.	Name	Function	Component
1.	ESP8266 NodeMCU	Microcontroller is used to control the functions of embedded systems in system.	
2.	Thermocouple Type-K	Temperature sensor is used to measure temperature data.	
3.	ADXL 335	Vibration sensor is used to measure vibration data.	
4.	OLED Display	Display screen is used to interface the data input from sensors	
5.	LED	LED is used as precautions every time the system detects unusual condition during machining.	

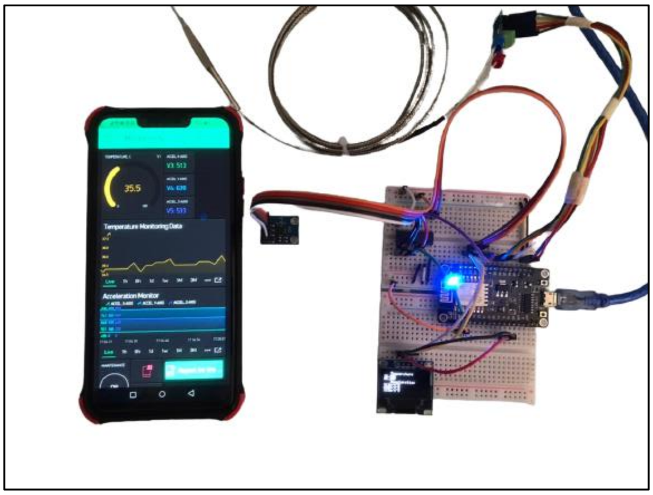

Figure 1: Prototype of the System

2.2 Methods

The component is selected due to the its compatibility to Arduino and be rated to the following specifications which are the economical, easy to operate, sensitivity and easy to set up. The morphological chart is used to allow the systematic exploration of many possibility for the design solutions of the system. It also helps to incorporate several conceptual design solutions for the proposed system. The rating method is a quantitative method used to classify the various set of options to make it easier to choose from. The rating method applying rating value from range between 1 to 5 which represent into very poor, poor, neutral, good and very good respectively. The rating is based on the specification which are economical, easy to operate, sensitivity and easy to set up for the system. The resultant score from this technique will reveal the decision for the component selection for the system.

The developed system is fabricated with the connection of a few components which are battery as power supply, related sensors, and microcontroller with Wi-Fi module. The sensors that been applied in this system are temperature sensor to measure the temperature and accelerometer to measure the vibration of the cutting tools. The system also is controlled using ESP8266 NodeMCU microcontroller. The architecture of the system consists of three major processing steps as illustrated in Figure 2. In step 1, the data collected from the sensors will be collected using programmable microcontroller and transfer it to the Blynk Cloud Storage. Next step is the features extraction where the input data been monitored and if it exceeds the threshold set in the system, it will give output of the warning remainder for unusual behaviour of the machining process. The system also been tested in experimental condition where a few different parameters had been applied to the experimental work.

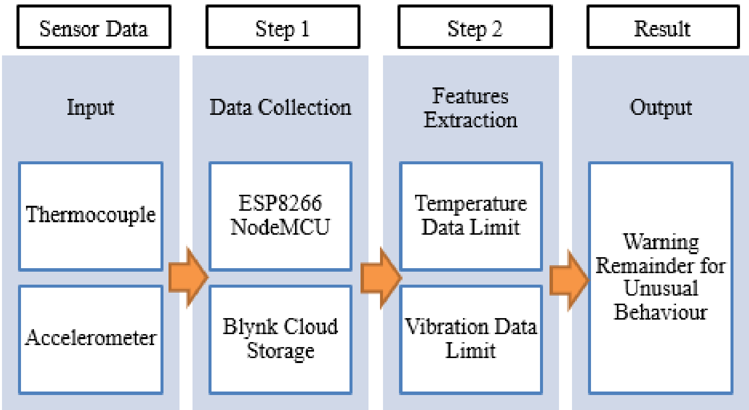

Figure 2: Overview of the System Architecture

2.3 Taylor's Equations Applied for Validation

The fabricated system is tested in an experiment that include the temperature sensor and accelerometer to monitor the cutting tool during the milling process. The recorded data from the experiment were analysed using Taylor's equation, as shown below.

$$V_c T^n \times a_p V_f = C \qquad \text{Eq. 1}$$

According to FW Taylor, the increasing of depth of cut and the feed rate of will influenced the tool life the most. So, this equation was be used to assess the capability of the developed system towards real-time data. To calculate more accurate prediction on tool life, an extended Taylor's tool-life approximation model also been applied in experimental result estimation[7]. In the extended formula, more machining variables need to be gathered. A researcher once highlighted that the expending of the model may resulting unreliable data result when various parameter is changing over time. The common tool wear prediction models can be divided into empirical model, finite element model and mathematical model. Taylor tool life model is the typical empirical model (ISO3685 for turning and ISO8688 for milling). It can predict the tool life at various cutting parameters and the coupling coefficient is determined [8]. Overall, the Taylor's equation mentioned before this still been used in this study.

2.4 Experimental Testing

The experimental work was conducted on mild steel workpiece with dimension of 73 x 30 x 20 mm. The time taken for each milling process was 60 seconds with depth of cut mentioned in the parameter table. Other than that, the cutting speed also been manipulated as it was elevated 400rpm which time the depth of cut had finished cutting 0.5mm, 0.7mm and 0.9mm respectively. All the parameters used in the experimental work is gathered into Table 2.

Table 2: Cutting Parameter and Condition for the Experiment

Machining Process		End Milling
Condition during experiment	Workpiece material	Mild Steel
	Cutting Tool	M42 ST/SHK 4 Flute Endmill 104mm
	Machine Tool	Vertical milling machine
	Cutting Condition :	
	Cutting Speed, v	1.884-2.721 m/s
	Feed f_z	0.007-0.01 mm/tooth
	Depth, a_p	0.5-0.9 mm

The system during experimental testing is shown in Figure 3. All the experiments had been conducted on Argo 3VH Vertical Milling Machine using 4 Flute Endmill 104mm milling cutter to machine mild steel block.

Figure 3: Sensors Arrangement for Experimental Testing

3. Results and Discussion

3.1 Results of System Execution

The sensors arrangement was shown in Figure 3 and the placement for both sensors were changed compared with the initial planned arrangement. The experiment finding reveals that the thermocouple can be placed on the workpiece to measure the temperature during the milling process. The data gathered is acceptable together with the sensitivity of the sensor. In addition, the vibration sensor also placed on top of the workpiece, inspired by the previous studies that focus on vibration data measurement [9]. Next, the input data from the sensors will be sent from the NodeMCU ESP8266 to the Internet using Wi-Fi. The device that connected with the same local network operate the system using a mobile application called Blynk. This mobile application has its own cloud storage that will receive the data from the microcontroller and will interface it via application in smart devices such as smartphone and tablet. By establish using local network, it allows user to connect with the system when they are in same location. The data that been display on the OLED display was correspondent with the information output at the Blynk mobile application. The results of the output data were then tabulated into graph as shown in result for experimental testing.

3.2 Result for Experimental Testing

The result from the experiment were illustrated into graph. From the graph in Figure 4, the cutting speed shown an increment of 0.42 m/s, and the result is taken started from 1800rpm until 2600rpm. Other than that, the dept of cutting also increases by 0.2mm in each test. Based on the results, it can be seen that the temperature of the surface of the workpiece is rising as the cutting speed is increased. The same behaviour also can be seen in the difference in depth of cut. It shown that as the dept of cut increase, the temperature will also increase. The highest temperature, which is 82 ℃, is recorded while cutting speed of 2.721m/s and cut, with a depth of cut, and is 0.9mm. In contrast, the lowest temperature is 34 ℃ which taken at 1.884m/s cutting speed and 0.5mm depth of cut.

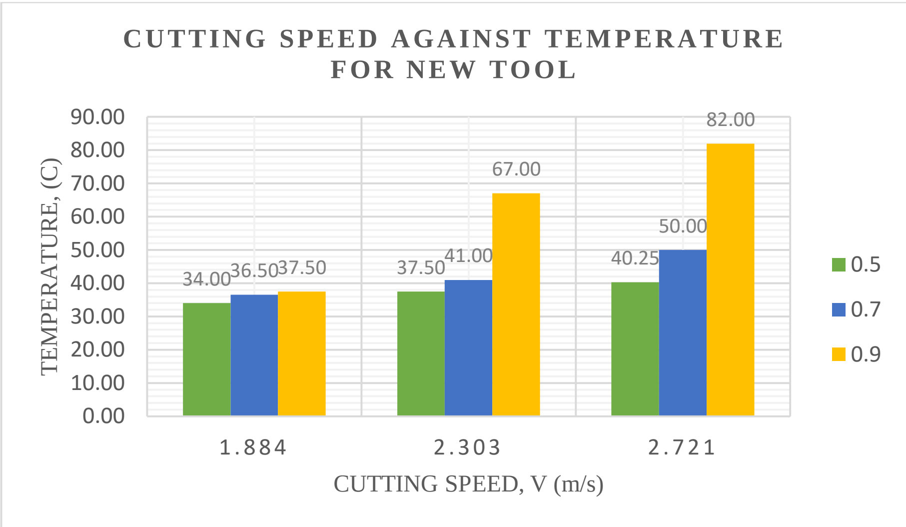

Figure 4: Graph of Cutting Speed against Temperature for New Tool

Therefore, using the similar parameter difference, such as the cutting speed and the depth of cut, is also applied to the worn tool testing for the system in Figure 5. The data showed a positive increment to all three cutting speeds. At a cutting speed of 1.884m/s, the temperature is increased from 35 ℃ to 40.25 ℃. Other than that, the temperature recorded at 1.884 The highest temperature at cutting speed 2.721m/s is 86 ℃ while the lowest at this speed is 45 ℃. Then, at speed 2.303m/s, it has shown the same behaviour with the other two cutting speeds. The temperature also improved from 40.74 ℃ to 68.50 ℃ as the depth of cut increased from 0.5mm to 0.9mm. The important finding in these results is on the increasing of cutting temperature when the cutting speed and depth of cut is increasing over time. Comparing between the new tool and the worn tool also shown significant difference where the worn tool display higher temperature than the new cutting tool.

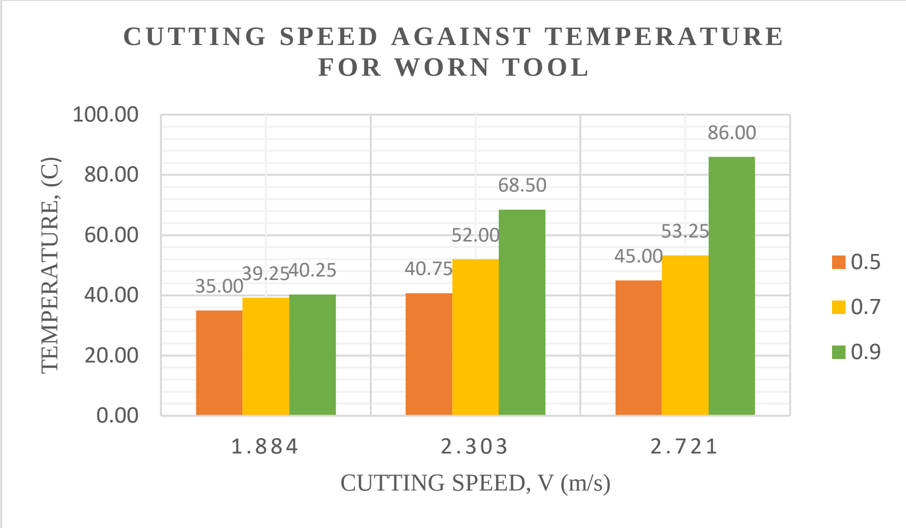

Figure 5: Graph of Cutting Speed against Temperature for Worn Tool

Among the other manipulated variables of cutting speed, 2600rpm shown the most significant compared with the other two. An experiment that applying cutting speed of 2600rpm, had been executed to collect data, and it illustrated into graph in Figure 6. The total acceleration at the cutting depth of 0.5mm shows an irregular pattern for all the data recorded during the cutting time. The data decrease and increase irregularly, especially the depth of cut, 0.9mm. The critical point for cut, 0.5mm is when the acceleration falls to 4.924g $m/s^2$and rises to the peak, which is 6.454g m/s^2. Comparing the line graph with the depth of cut 0.7mm, the acceleration at 0.5mm is more lively compared with their accelerations. The significant point on this line graph is when the acceleration was dropped rapidly at the second 50 and climbing back to the next peak, which is 6.715g m/s^2. The summit of the acceleration value is at a cutting depth of 0.9mm, which was 8.776g m/s^2.

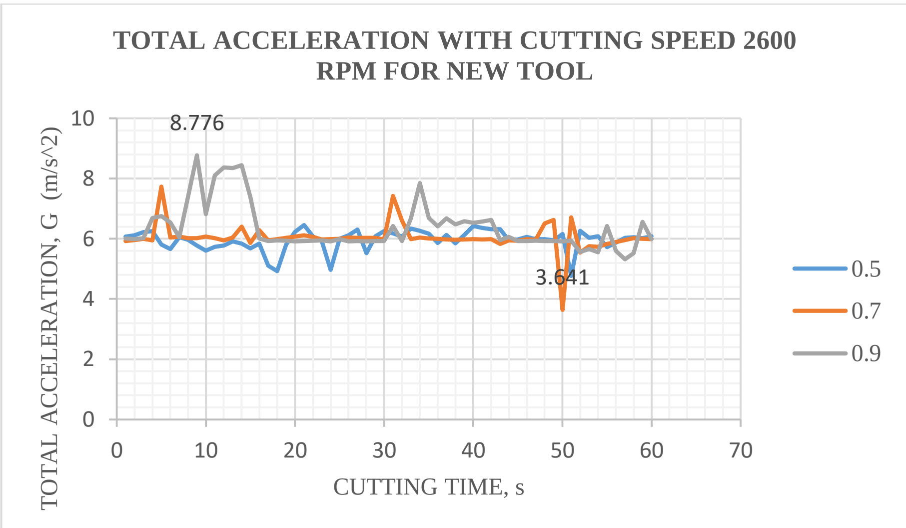

Figure 6: Total Acceleration for Cutting Speed 2600rpm for New Tool

Along with the temperature data, the total acceleration for the cutting speed 2600rpm for worn cutting tool is performed into a line graph shown in Figure 7. The most significant trend that can be understood in the graph is the highest peak of vibration data for depth of cut 0.9mm with vibration value of 15.891g m/s^2. This vibration data also is the highest compared with the other three cutting speed parameter that been discussed before. Both depth of cut 0.5mm and 0.7mm shows same behaviour compared with the other cutting speed. From the experimental results of new tool for vibration, it had confirmed that the depth of cut and the cutting speed will influence the vibration data, as well as leading to early tool life damage if not monitor accordingly. Corresponding with the finding in the vibration results, it can be accepted that the system developed can be used to monitor the vibration data throughout the milling process.

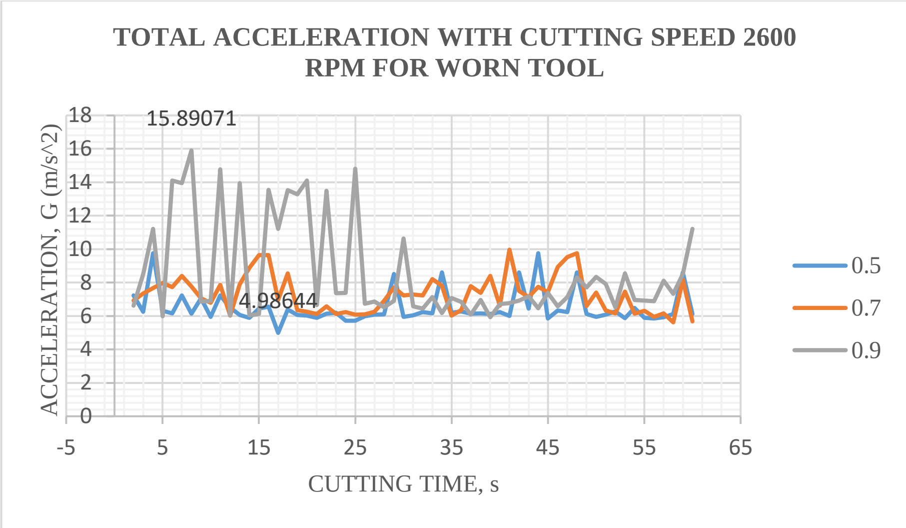

Figure 7: Total Acceleration of Cutting Speed 2600rpm for Worn Tool

Similarly, as discussed in the new tool condition for the vibration results, the analysis from the worn tool data shown equivalent findings and discussion. The same pattern of data can observe from the graph illustrated for the other parameters. Likely, the system developed with Internet of Thing can be used to monitor real-time data like temperature and vibration to monitor the unwanted scenario happen during milling process.

3.3 Discussions

The discussion for the finding of the temperature result is focusing on the pattern of the data recorded from the experimental and theoretical evaluation. The difference between the theoretical and the experimental may be affected by the execution of the process. The placement of the sensors and the sensitivity of the sensors can become one of the reasons of the irregular output. But the trend of the data can be seen and analysed for this study. Normally, in down milling the generated heat continuously increases during a single cut, leading to a localization of heat with decreasing undeformed chip thickness [10].

In addition, the finding from the vibration results it shows irregular acceleration in every cutting speed and depth of cut. The most significant behaviour can be observed from cutting speed 2600rpm and depth of cut 0.9mm. The relationship of preferred response and independent variables for input are represented in the appropriate form as follows. Feed rate, cutting speed, depth of cut, different hardness levels (independent variables) which vary during the experiments [11]. Furthermore, excessive vibration, pressure or temperature usually because of the poor condition of machine and cutting tool. In term of statistics, the mechanical vibrations influenced by the failure rate of over 60% for various reasons.

Based on the overall finding from the both experimental results and the theoretical results, it can be summarized that the system can interface the similar data trend compared with the estimation value from tool life model. The trend which are declining of tool life as the cutting speed and depth of cut were increase can be monitor using the developed system. In addition, the vibration data also can be observed together with the temperature data and shows the similar data pattern. This was because the output from both sensors show appropriate corresponding reaction as the parameters were increase. This finding is supported by previous study that stated that the cutting tool temperature with increasing speed, feed and depth of cut owing to the generation of large amount of friction heat from the contact surface on the workpiece [12]. From the finding, it reveals that the tool life can be affected with the changes in speed and depth of cutting during the machining and the temperature sensor can be used along with vibration sensor to monitor the tool condition using the system that been fabricated.

4. Conclusion

The study can conclude that the system that been developed can perform as in promises and therefore dependable and reliable. In order to validate the system output, experimental testing had been conducted using different parameter which are the cutting speed, depth of cut and also the tool conditions. The experimental results of the study shown these parameters will affect the workpiece temperature and vibration and should be monitored so that preventive maintenance can be made beforehand to avoid disturbing the machining process due to the damage of tool. It also confirms that the relationship between all the stated parameters and the system manage to be interface its real time data as the cutting process happen. The theory that mentioned when the cutting speed is increase it will also affect the temperature is applied in the developed system. It also the same for the depth of cut that lessen the tool vibration when the depth of cut is increase.

In addition, it also revealed that the improvise system that have two sensors can perform better at detecting initial tool wears and let the user to decide either to conduct maintenance or continuing the machining. With the application of Internet of Thing in this monitoring system, it allows the operating personnel to receive real-time update of the machining without attending the machine all the time. In another hand, the components chosen in fabricating the system hardware also economical and easier to operate. The system also shown a positive relationship between cutting temperature and vibration with the cutting parameter during machining process and reliable to utilize it for temperature and vibration monitoring during milling process. The sustainability of the system will help to reduce operation cost and workforce to operate the machine.

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