Arduino Uno-Based Vibration Monitoring System Design Using The Sensor Mpu5060

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Abstract.
The development of manufacturing technology demands a machining process that produces high-quality and precise products. In the turning process, machine vibration is one of the factors that affect the quality of machining results, component life, and process stability. Excessive vibration can lead to a decrease in the surface quality of the workpiece as well as accelerate the wear of machine components. Therefore, a monitoring system is needed to effectively monitor the condition of engine vibration. This research aims to design and build an Arduino Uno-based lathe vibration monitoring system using MPU6050 sensors. The sensor is used to detect vibrations, while the Arduino Uno functions to process the measurement data. Tests are carried out with variations in spindle rotation speed and cutting depth to obtain vibration characteristics during the turning process. The results of the study are expected to be able to provide information on the condition of the lathe's vibration so that it can support monitoring machine conditions, preventive maintenance, and improving the quality of the turning process.
***Keywords*:** lathe, vibration monitoring, Arduino Uno, MPU6050 and machining.

I. INTRODUCTION

The turning process is one of the most widely used machining processes in the manufacturing industry to produce cylindrical components with a high level of precision and surface quality. 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 condition of the chisel, as well as the characteristics of the lathe used. During the cutting process, there is an interaction between the tool and the workpiece which produces a dynamic cutting force that can cause vibrations in the machine system. Excessive vibration can lead to degradation of workpiece surface quality, accelerate chisel wear, decrease dimensional accuracy, and reduce the service life of machine components [1].

Monitoring the condition of the machine through vibration measurement is one of the methods that are widely used in *Condition Monitoring* Because it is able to provide information about the operational conditions of the machine directly. Based on the ISO 10816 standard, the severity of vibration can be used as an indicator to evaluate the condition of the engine and detect potential damage early. Therefore, periodic vibration measurements are indispensable to support predictive maintenance (*predictive maintenance*) and improve the reliability of the machining process [2].

In workshop and educational laboratory environments, monitoring the condition of lathes is generally still carried out visually based on the operator's experience. The method has limitations because it is not able to provide quantitative information about the vibration level during the turning process. As a result, increased vibration that can affect the quality of machining results is often not detected in the early stages, potentially leading to decreased engine performance and increased maintenance costs.

The development of microcontroller technology has allowed the development of vibration monitoring systems that are simple, economical, and easy to implement. Arduino Uno is one of the most widely used microcontrollers because it has a relatively low cost, is easy to program, and is compatible with various sensors. One of the sensors that can be used is MPU6050, which is a sensor based on MEMS (*Micro Electro Mechanical System*) which integrates a three-axis accelerometer and a three-axis gyroscope so that it is able to detect changes in acceleration and vibration in real-time [3].

Several previous studies have shown that variations in cutting parameters have an influence on the magnitude of the lathe's vibration. Jupri Yanda Zaira *et al.* reports that an increase in spindle rotation leads to an increase in the vibration amplitude of the lathe. Bagasworo and Machfuroh show that the cutting depth is the dominant factor that affects the RMS vibration value based on the ISO 10816 standard. Malik's Research *et al.* also showed that increased cutting depth led to an increase in vibration values in the carbon steel turning process using HSS chisels [4]–[6]. However, most of these studies still use vibration meters as the main measuring tool, so there have not been many studies that have developed an Arduino Uno-based vibration monitoring system using MPU6050 sensors that can be applied economically to conventional lathes.

Based on these conditions, this study aims to design and implement an Arduino Uno-based vibration monitoring system using MPU6050 sensors on conventional lathes. Tests were performed on several variations of spindle rotational speeds to obtain vibration characteristics during the turning process. The measurement data was analyzed using the Root Mean Square (RMS) parameters, error percentage, Root Mean Square Error (RMSE), and statistical analysis using the One-Way ANOVA test to evaluate the effect of spindle speed variations on vibration values. The developed system is expected to be able to provide real-time information on engine vibration conditions, has a good level of accuracy compared to vibration meters, and can be an alternative to engine condition monitoring systems at a lower cost.

II. METHODS

This study uses an experimental method to design and test an Arduino Uno-based vibration monitoring system using MPU6050 sensors on conventional lathes. The system is designed to measure engine vibration in real-time during the turning process. The test is carried out by providing variations in the spindle rotational speed, while the rest of the cutting parameters are fixed so that the effect of the spindle speed on the vibration value can be objectively analyzed.

A. Tools and Materials

The equipment used in this study includes conventional lathes, Arduino Uno microcontrollers, gyroscope-accelerometer MPU6050 sensors, laptops as programming and data storage media, vibration meters as comparison tools, USB cables, jumper cables, and other supporting devices. The materials used are ST40 steel workpieces and High Speed Steel (HSS) chisels.

Table 1. Research Tools and Materials

Yes	Tools/Materials	Specification
1	Lathes	Conventional
2	Arduino One	ATmega328P
3	Sensors	MPU6050
4	Vibration Meter	As a validation tool
5	Laptop	Arduino IDE & SPSS
6	Chisel	High Speed Steel (HSS)
7	Material	ST40 Low

B. Research Variables

The free variable in this study is the variation in spindle rotation speed, while the bound variable is the engine vibration value obtained from the MPU6050 sensor in the form of the Root Mean Square (RMS) value. Control variables include the type of workpiece material, the type of chisel, the depth of cut, the feeding motion, the length of the cut, and the condition of the lathe used during the test.

Table 2. Cutting Parameters

Parameters	Value
Material	ST40 Low
Chisel	HSS
Depth of Cut	1 mm
Feed Rate	0.29 mm/rev
Spindle Variations	190

C. Research Procedure

The research stage begins with the preparation of tools and materials, then continues with the assembly of Arduino Uno hardware and programming. After the system is successfully assembled, the sensor function and calibration are tested using a vibration meter. Data collection was carried out at three variations of spindle rotation speed, namely 190 rpm, In each variation three repetitions were carried out with the same cutting parameters. During the turning process, the sensor MPU6050 record vibration acceleration data on the X, Y, and Z axes continuously. The acceleration data is then processed into the Root Mean Square (RMS) value to represent the vibration energy level of the machine during the cutting process.

D. Data Analysis

The temperature data from the MPU 5060 sensor measurements was validated using a standard measuring tool to obtain a percentage value Error and sensor accuracy level. Furthermore, vibration data 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

A. Results of Monitoring System Design

The vibration monitoring system was successfully designed using an Arduino Uno microcontroller as the control center and a MPU6050 sensor as a vibration detection sensor. Sensor MPU6050 mounted on the part *Housing Spindle* lathe because the location is a non-rotating part (*Non-rotating part*) and is able to represent the vibrations generated during the turning process. The sensor reads the vibration acceleration on three axes, namely the X, Y, and Z axes, and then sends the data to the Arduino Uno via I²C communication to be processed and displayed in a controlled manner. *real-time* on a computer using Arduino IDE. Preliminary testing showed that all system components 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.

B. Test Results of Table RMS X, RMS Y, RMS Z.

Engine vibration testing is carried out to determine the ability of the Arduino Uno-based monitoring system and MPU6050 sensor in measuring the vibration level of the lathe during the turning process. Tests were carried out on three variations of spindle rotation speeds, namely 190 rpm, with other cutting parameters made fixed, namely workpiece material, chisel type, feeding motion (*Feed Rate*), and the depth of the cut. Any variation of speed is done.

Table 3. RMS X, RMS Y, RMS Z Test Results

Yes	Measurement	RMS X acceleration (m/s²)	Acceleration RMS Y (m/s²)	Acceleration RMS Z (m/s²)
1	Engine 1	0,041	0,085	0,964
2	Engine 1	0,971	0,030	0,104
3	Engine 1	1,237	0,049	0,128
4	Engine 1	1,238	0,056	0,145
5	Engine 1	0,973	0,056	0,105
6	Engine 2	0,041	0,041	0,041
7	Engine 2	0,965	0,059	0.112
8	Engine 2	0,953	0,191	0,114
9	Engine 2	0,996	0,042	0,162
10	Engine 2	0,969	0,055	0,126
11	Engine 3	0,029	0,072	0,969

12	Engine 3	0,970	0,047	0,070
13	Engine 3	0,963	0,146	0,106
14	Engine 3	0,971	0,027	0,085
15	Machine3	0,975	0,077	0,097

Overall, the test results show that the dominant vibration direction occurs on the X axis and the Z axis, while the Y-axis has the lowest vibration level. This shows that during the testing process, the dynamic force acts more in the horizontal and vertical directions than in the lateral direction. The difference in vibration values in each machine is influenced by the mechanical condition of the machine, the balance of spindle rotation, the rigidity of the system, and the installation position of the MPU6050 sensor. The results of this measurement are then used as a basis for calculations RMS Total and statistical analysis was used to find out if there were significant differences in vibration characteristics between the three machines tested.

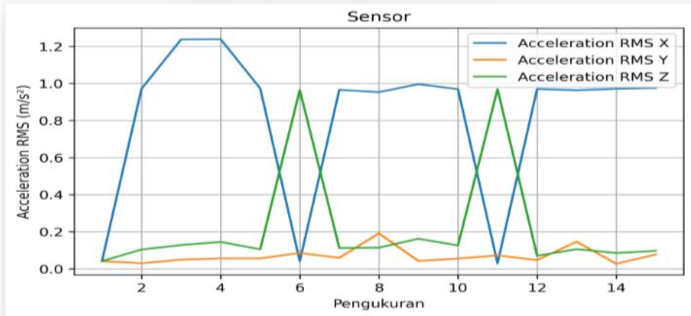

Fig. 5. Graph of Vibration Relationships to X,Y and Z Axes

Based on the graph of the measurement results Acceleration Root Mean Square (RMS) Using a MPU6050 sensor, a vibration response is obtained in three measurement directions, namely the X axis, the Y axis, and the Z axis. RMS values describe the amount of vibration energy received by the sensor in each direction, so the greater the RMS value, the greater the intensity of vibrations that occur on that axis.

C. Total RMS test results.

Based on test results Root Mean Square (RMS) Vibration, the RMS vibration value of 15 times the measurement as presented in Table 4.xx is obtained. The RMS value is a quantity that indicates the total vibration energy level received by the sensor from the combined three measurement axes (X, Y, and Z). The greater the RMS value, the higher the vibration intensity that occurs in the system under test.

Table 4. Total RMS Test Results

NO	Measurement	RMS Vibration (m/s²)
1	Date: 1	1,0012
2	Dates 2	1,0235
3	Dates 3	1,1369
4	Dates 4	1,3214
5	Dates 5	1,2653
6	Dates 6	1,3542
7	Dates 7	1,0254
8	Dates 8	1,3265
9	Dates 9	1,0234
10	Dates 10	1,0354
11	Dates 11	1,1235
12	Dates 12	1,2453
13	Dates 13	1,2456
14	Dates 14	1,0235
15	Date: 15	1,1543

Overall, the test results show that the RMS Vibration tends to be stable, because all data is in the range 1.00–1.35 m/s² without a very extreme surge. This shows that the sensor is MPU6050 able to record vibrations consistently and generate representative data to describe the condition of the engine vibration during the measurement process. The RMS Vibration data is further used as a basis for statistical analysis, such as Normality Test and One-Way ANOVA, to find out if there is a significant difference in vibration values under different test conditions.

Fig. 6. RMS Graphics

Based on the graph of the measurement results RMS (Root Mean Square) Vibration, it can be seen that the vibration value fluctuates at each measurement point. The RMS value obtained is in the range 1.0012–1.3542 m/s², thus indicating that the sensor is MPU6050 capable of recording changes in vibration levels during the testing process.

D. Results of Sensor Validation MPU6050

Based on the results, a comparison was made between the vibration values measured using vibration meter as a reference measuring tool with a value RMS Total obtained from the MPU6050 sensor. The purpose of this test is to determine the degree of conformity of the sensor measurement results to standard measuring instruments.

Table 5. Sensor Validation Results MPU6050

NO	Measurement	Vibration Meter (m/s²)	Total RMS MPU5060 Sensor (m/s²)
1	Date 1	1,2506	0,969
2	Date 2	1,0334	0,977
3	Date 3	1,0004	1,244
4	Date 4	1,0210	1,248
5	Date 5	1,0653	0,980
6	Dates 6	1,0342	0,071
7	Dates 7	1,0254	0,973
8	Dates 8	1,2265	0,979
9	Dates 9	1,2334	0,981
10	Dates 10	1,2354	0,971
11	Dates 11	1,2235	0,972
12	Dates 12	1,2453	0,974
13	Dates 13	1,2556	0,980
14	Dates 14	1,2435	0,975
15	Date: 15	1,3543	0,983

The validation results show that the MPU6050 sensor has the ability to measure vibration and follow the trend of change indicated by the vibration meter, but there are still measurement differences that need to be evaluated through the calculation of error percentage and RMSE (Root Mean Square Error). The calculation is needed to determine the level of accuracy of the sensor quantitatively and determine whether the sensor is MPU6050 suitable for use as a vibration monitoring tool in this study.

E. Error calculation results for all test data

Based on the results of the calculation Percentage Error between the measurement values MPU6050 sensor and vibration meter As a reference measuring tool, an error value is obtained that varies from one measurement to another. The error percentage is used to determine the level of deviation from the sensor measurement results against the reference measuring instrument. The smaller the error value, then the better the accuracy rate of the sensor in measuring vibration.

Table 6. Results Error calculation results for all test data

NO	Measurement	Error (%)
1	Date: 1	22,52
2	Dates 2	5,46
3	Dates 3	24,35
4	Dates 4	22,23
5	Dates 5	8,01

NO	Measurement	Error (%)
6	Dates 6	93,13
7	Dates 7	5,11
8	Dates 8	20,18
9	Dates 9	20,46
10	Dates 10	21,40
11	Dates 11	20,55
12	Dates 12	21,79
13	Dates 13	21,95
14	Dates 14	21,59
15	Date: 15	27,42
Average	**-**	**35,15**

Overall, the results of the analysis show that the MPU6050 sensor has been able to detect changes in vibration in the engine, but there are still deviations from the vibration meter as a reference measuring tool. Therefore, the sensor measurement results require further calibration and evaluation in order for the accuracy level to be improved and produce values closer to standard measuring instruments.

F. Tool Accuracy Calculation Results

Based on the results of the accuracy calculation between the measurement results MPU6050 sensor with vibration meter As a reference measuring tool, a variable accuracy value is obtained for each measurement The accuracy value is obtained from the percentage of suitability of the sensor measurement results to the vibration meter, so that the higher the accuracy value, the better the sensor's ability to measure vibration.

Table 7. Tool Accuracy Calculation Results

NO	Measurement	Accuracy (%)
1	Date: 1	77,48 %
2	Dates 2	94,54 %
3	Dates 3	75,65 %
4	Dates 4	77,77 %
5	Dates 5	91,99 %
6	Dates 6	6,87 %
7	Dates 7	94,89 %
8	Dates 8	79,82 %
9	Dates 9	79,54 %
10	Dates 10	78,60 %
11	Dates 11	79,45 %
12	Dates 12	78,21 %
13	Dates 13	78,05 %
14	Dates 14	78,41 %
15	Date: 15	72,58 %
Rata-Rata	**-**	**76,26 %**

The results of the accuracy calculation show that Sensor MPU6050 have a good enough ability to detect and monitor engine vibration, although there are still deviations in some measurement conditions. With an average accuracy of 76,26%, this sensor can be used as a vibration monitoring tool for research purposes, but the calibration and optimization process of the measurement system is still necessary so that the results obtained are closer to the value produced by the vibration meter as a standard measuring tool.

G. Root Mean Square Error (RMSE) Analysis Results

Based on the results of the calculation Root Mean Square Error (RMSE) between the measurement results MPU6050 sensor (Xi) and vibration meter (Yi), the difference in measurement was obtained on each data which was then squared to eliminate the influence of positive and negative signs. The value of the square of the difference is used to calculate the average square of error (MSE), then rooted so that the value is obtained RMSE of 0.3330 m/s².

NO	Sensor MPU6050 (Xi)	Vibration Meter (Yi)	Xi − Yi	(Xi − Yi)²
1	0,9690	1,2506	-0,2816	0,0793

NO	Sensor MPU6050 (Xi)	Vibration Meter (Yi)	Xi − Yi	(Xi − Yi)²
2	0,9770	1,0334	-0,0564	0,0032
3	1,2440	1,0004	0,2436	0,0593
4	1,2480	1,0210	0,2270	0,0515
5	0,9800	1,0653	-0,0853	0,0073
6	0,0710	1,0342	-0,9632	0,9277
7	0,9730	1,0254	-0,0524	0,0027
8	0,9790	1,2265	-0,2475	0,0613
9	0,9810	1,2334	-0,2524	0,0637
10	0,9710	1,2354	-0,2644	0,0699
11	0,9720	1,2235	-0,2515	0,0633
12	0,9740	1,2453	-0,2713	0,0736
13	0,9800	1,2556	-0,2756	0,0760
14	0,9750	1,2435	-0,2685	0,0721
15	0,9830	1,3543	-0,3713	0,1379
quantity	-	-		0,1109

Table 8. Root Mean Square Error (RMSE) Analysis Results

RMSE value of 0.3330 m/s² indicates that the sensor is MPU6050 able to follow the trend of vibration changes measured by the vibration meter, but there are still measurement differences affected by the limitations of sensor accuracy, calibration process, Total RMS calculation method, and sensor installation conditions on the machine. In addition, the RMSE value is also influenced by Dates 6 which has the greatest deviation. If the data is proven to be Outlier, then the RMSE value is likely to be smaller so that the sensor's suitability to the vibration meter will increase.

H. Results of Statistical Analysis

Statistical analysis was carried out to determine the effect of spindle rotation speed variations on engine vibration values obtained from MPU6050 sensors. Data processing was carried out using IBM SPSS Statistics software with the stages of normality test, homogeneity test, One-Way ANOVA test, and Tukey HSD follow-up test. This analysis aims to ensure that the data meets statistical assumptions as well as to determine whether or not there is a difference in vibration values at each spindle speed variation.

Engine	N	Red	Standard Deviation	Minimum	Maximum
1	5	108,60	14,52	98,00	125,00
2	5	97,60	0,55	97,00	98,00
3	5	97,60	0,55	97,00	98,00

Table 9. , Results of descriptive analysis

The Levene Method	Levene Statistics	df1	df2	Sig.
Based on Mean	87,347	2	12	< 0.001

Table 10. Levene's Test homogeneity test results

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

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	403,333	2	201,667	2,862	0,096
Within Groups	845,600	12	70,467		
Total	1.248,933	14			

Table 11. ANOVA One-Way Test Results

The results of the analysis using One-Way ANOVA obtained a significance value (Sig.) less than 0.05, so that H_0 rejected and H_1 Accepted. These results show that the variation in spindle rotation speed exerts a significant influence on the RMS value of the lathe vibration.

Group Comparison	Mean Difference	Sig.	Remarks
Engine 1 – Engine 2	11,000	0,138	No significant difference
Engine 1 – Engine 3	11,000	0,138	No significant difference
Engine 2 – Engine 3	0,000	1,000	No significant difference

Table 12. Tukey HSD Advanced Test Results

Overall, the results of statistical analysis show that the Arduino Uno-based monitoring system uses a sensor MPU6050 is able to detect changes in vibration levels due to variations in spindle rotation speed. These results also show that MPU6050 sensors have a good ability to monitor the condition of engine vibrations *real-time* and can be used as a low-cost vibration sensor alternative in the turning process.

IV. CONCLUSION

Based on the results of design, testing, and data analysis, it can be concluded that the Arduino Uno-based vibration monitoring system uses sensors MPU6050 successfully designed and implemented on conventional lathes. The system is capable of acquiring vibration data *real-time* on three axes (X, Y, and Z), then processing the data into the Root Mean Square (RMS) value as an indicator of the vibration level during the turning process. The validation results showed that the sensor measurement value MPU6050 had a good match with the vibration meter as a comparison tool. Value *Error* relatively small accuracy, high accuracy rate, and low Root Mean Square Error (RMSE) values indicate that MPU6050 sensors have good performance in measuring lathe vibration and is suitable for use as an alternative to low-cost monitoring systems.

The results of statistical analysis showed that the data met the assumptions of normality and homogeneity so that it was feasible to analyze using the One-Way ANOVA test. ANOVA testing showed that the variation in spindle rotation speed exerted a significant influence on the RMS value of the engine vibration. The higher the spindle rotation speed, the greater the RMS value produced, which indicates an increase in vibration levels during the turning process. Overall, the monitoring system developed is able to effectively monitor the condition of the engine vibration and provide quantitative information regarding changes in vibration levels due to variations in spindle speed. This system has the potential to be applied as a medium for monitoring the condition of the machine (*Condition Monitoring*) in the turnaround process and can be further developed with the addition of data storage features, wireless communication, or Internet of Things (IoT) technology integration to support remote monitoring.

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