Analysis of Continuous Vibration Monitoring on Frequency Domain Using Various Sensors

Nagesparan Ainarappan
Faculty of Engineering, Technology & Built Environment
UCSI University
Kuala Lumpur, Malaysia
nagesparan@ucsiuniversity.edu.my

Tham Ming Sum
Faculty of Engineering, Technology & Built Environment
UCSI University
Kuala Lumpur, Malaysia
1001540344@ucsiuniversity.edu.my

Kanesan Muthusamy
Faculty of Engineering, Technology & Built Environment
UCSI University
Kuala Lumpur, Malaysia
kanesan@ucsiuniversity.edu.my

Abstract

Manufacturing Industries nowadays are looking for a possible competitive advantage to increase their production line output while lowering costs by adopting condition-based maintenance (CBM). One of the initiatives taken to address this issue is to study the condition monitoring solutions which, are becoming more popular for predicting machine problems through Predictive Intelligence systems in production machines such as motors and drives. This will prevent sudden equipment failures and unscheduled downtime. Tapping the vibration signals at the various section of the motor and drives and analyzing them is one of the most effective methods for preempting and early detection of equipment failures. Vibration analysis is a process that detects a machine's vibration level and frequency and then analyses the machine and its components' health conditions. The development of IoT-based machines and drive vibration sensor detection helps to increase production efficiency by minimizing unscheduled machine downtime. The captured vibration signals are analyzed by using Sliding Window Technique to study the variations with respect to the machine speed and running time. Based on the studies, the vibration of a machine increases as the speed of the machine increases but stabilizes over a period. Any continuous abnormal signals denote that the machines warrant further investigations and maintenance.

Keywords
Condition-Based Maintenance, Vibration Monitoring System, Vibration Analysis, IoT system

1. Introduction

Vibration analysis is a method of detecting and analysing a machine's vibration levels and frequency, as well as the conditions of the machines and their components. Vibrations are produced by the machine when it is in use, and it can affect the durability of the machine resulting in issues like damage or anomalous halting (Chaudbury et al. 2014). When a vibration sensor is attached to a machine, it will generate a signal that is proportional to the amount of vibration and the frequency of vibration produced. The vibration sensor data will send to the data collector, which converts the signal into a time waveform. Engineers or professional vibration analyzers will use software algorithms to analyse the data collected from the accelerometer to estimate the machine's health and detect potential issues. Misalignment, gearbox failures, imbalance, mechanical looseness, and other issues can all be detected using vibration analysis (Ganga and Ramachandran 2017).

The prototype designed in this research is expected to remote monitor vibration data by using a web-based application and analyze the changed behaviour of vibration signals. In this research paper, multiple SW-420 vibration sensors are used for vibration measuring. The research of Saputra et. al (2018) shows the SW-420 vibration sensor module is used as a vibration detector for earthquake vibration monitoring systems. The earthquake monitoring system necessitates a sensor system with a wide range of applications and ease of installation. This sensor module possesses the qualities listed above, and the sensor installation process is simple (Geitner and Bloch 2012).

The research of Saputra et al. (2018) also shows the advantages of using LoRa (Long Range) connections for wider distances. LOS and NLOS scenarios are used in LoRa-based data transmission testing, and data emergence is assessed using a web data centre. Because it used two microcontrollers, the Arduino Uno and Raspberry Pi, it has a higher cost and needs more advanced programming (Geitner and Bloch 2012). The research of Purnamasari (2017) shows the advantages of using multiple sensors to improve the accuracy of data as well as a way to monitor which sections of the vibration are detected. This system also includes a database for storing data and calculating processing time. The disadvantage is that the monitoring is done on a computer. Because the PC is not a mobile device, users will be forced to stay near it in order to keep an eye on the property. Because PCs consume a lot of power, they will incur additional charges for electrical power in the event of a power outage (difficult for users to monitor the system) (Olalere et al. 2018). Research from Chaudbury et al. (2014) has shown that vibration pattern analysis is one of the most effective and successful approaches for fault diagnosis and prognosis of rotating machines. Machine vibration has a well-defined analytical and practical knowledge in the literature. Machine vibration behavior in the time and frequency domain is the foundation for rotating machine monitoring. Machine vibration response is sensitive to any slight change in operating conditions or mechanical structural design. Induction motors are put to test with the sensor attached under various operating conditions. One of the main focuses of vibration signal analysis is to remove noise and attenuate undesired vibration signals which are noise from the sensor or other rotating machines and the target machine. A simulated signal is used to test the noise removal algorithm's efficacy. The noise signal, the original signal, and the damaged signals are all utilised to test the noise removal algorithm's performance (Khan et al. 2019). In this research, the vibration sensor and temperature sensor of the vibration monitoring IoT system will attach to the motor to capture the vibration and temperature.

1.1 Objectives

Vibration analysis is a process that detect the vibration levels and frequency of machine and then analyzing conditions of the machines and their components. By using vibration sensor to measure vibration, works get easier as the inner working and formula used to calculate different type of vibration is complicated. When the machine is in operation, it will produce vibrations. Voltage signal that correlates to the quantity of vibration and the frequency of vibration produce are generated by vibration sensor when attached to machine (Chaudbury et al. 2014).

The data from the sensor is sent to a data collector, which records the signal as a time waveform. Engineers or professional vibration analyzers will review the data gathered from the sensor using software algorithms to estimate the machine's health, detect potential issues so predictive maintenance can be performed. Predictive maintenance has a substantial impact on an organization's environmental sustainability by improving product quality and lowering raw material use. Vibration analysis can detect a variety of issues, including misalignment, gearbox failures, imbalance, mechanical looseness. Vibration Analysis can help the environment by preventing quality issues in the components that are being ground; this results in more efficient resource utilization because batches of defective parts are avoided. These faulty batches consumed energy and raw resources, which were ultimately thrown away.

Vibration analysis technique aid in the identification of three key parameters which is acceleration, velocity and displacement. Each of the parameters emphasizes different frequency ranges and they can be used to diagnose machine's problems. Acceleration is more important when measuring high frequency, the signal can be converted to velocity or displacement. Displacement is more important when measuring low frequency, by using it to find unbalance in a rotating part caused by a substantial quantity of displacement at the machine's shaft rotational frequencies. Velocity is the most important parameter as it related to vibration's destruction force. It plays an important role on both high and low frequencies (Ganga and Ramachandran 2017).

When analyzing machine vibrations, a number of key frequencies that are closely related to the movement of various machine parts are common. Vibration can affect the durability and reliability of industrial systems and structures, resulting in issues like damage, anomalous halting, and catastrophic failure. Vibration measurement is a key preventative measure to avoid these issues. Vibration measurements are used to capture these frequencies to analyze the performance of the machine (Geitner and Bloch 2012).

Collection of simple sinusoids with varying frequencies, amplitudes, and phases made up a waveform. Fourier series is a set of sine waves that split a signal into its individual sine wave components using Fourier analysis or spectrum analysis. The outcome is the amplitude of acceleration as a function of frequency, allowing to undertake frequency domain (or spectrum) analysis to better understand the vibration profile. The frequency domain will be used for the majority of vibration investigation.

This project is aimed to fulfill the following objectives:

- To construct an IoT based machine's vibration monitoring system.
- To remote monitoring vibration data using web-based application.
- To analyze the continuation vibration signals in the frequency domain.
- To analyze the change behavior of vibration signals.

2. Literature Review

The vibration monitoring IoT system consists of five SW-420 vibration sensor that is used to detect vibration when attached to a machine, ESP32 microcontroller act as a data collector to capture and process all the data from the vibration sensor, and ESP32 consist of a built-in Wi-Fi module that used to transfer data to the cloud platform, DHT22 temperature sensor is used to capture the temperature of the machine and battery shield able to deliver support to this system for continuous operation for 4 hours. Figure 1 has showed the flow diagram of the system.

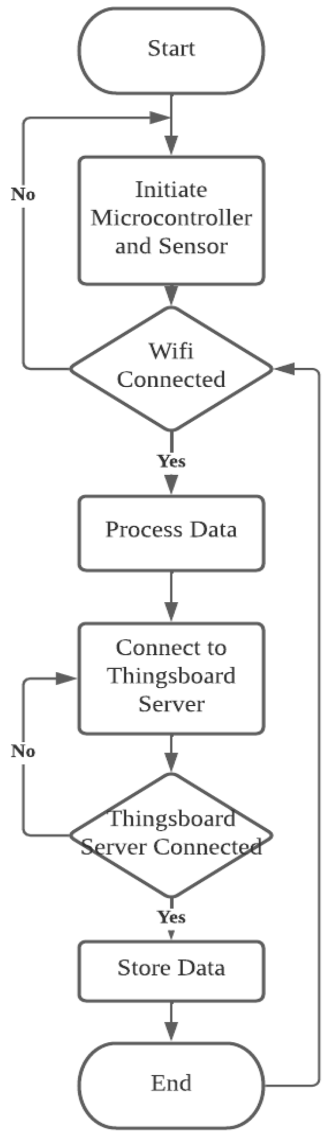


Figure 1: System Flow Diagram

As shown in figure 1, the vibration monitoring IoT system will initiate the ESP32 microcontroller, SW-420 vibration sensor, and DHT22 temperature sensor as soon as the ESP32 microcontroller is powered up by a battery shield. The vibration monitoring IoT system is running on C++ programming, it will be launched at the start-up of the ESP32 microcontroller. It will connect to the wireless network using the built-in Wi-Fi module of the ESP32 microcontroller after the start-up. If failed to connect to the wireless network set by the user, it will loop back to the initial state until it is connected to a network successfully. When the network is connected, it will process the data received from the ESP32 microcontroller and connect it to the Thingsboard cloud server. When the Thingsboard cloud server is connected, the captured data will send to the server and stored in the cloud server. The captured data will send to the server constantly and visualize in real time.

In this chapter, the introduction of vibration analysis will be reviewed. The type of MEMS sensor that can be used as a vibration sensor will be researched in order to get know which sensor is suitable for vibration measurement. Studies towards research paper on vibration monitoring on rotating machines, analysis of vibration signal, sliding window technique and data process on cloud platform will be carried out to identify the objective of this project.

2.1 MEMS Sensor

MEMS sensor is a highly integrated sensor system that integrates micro-mechanical and micro-electronic functions and is constructed of silicon-based materials and semiconductor integrated circuit fabrication method. The MEMS sensor size is small and lightweight with low power usage, most important it comes with great dependability, high resistance to shock and low cost. The feature sizes on the order of micrometres enable it to accomplish functions that conventional sensors are not able to accomplish (Khan et al. 2019). The advantages of the MEMS sensor are the size is small and comes with high measurement accuracy as the silicon micro gyroscope measures 7mm x 7mm x 3mm and with a mass of less than 1g. The source of error from the working mechanism able to reduce from the continuous innovation of technical solutions hence improves the accuracy of the sensor.

The high level of integration which makes MEMS sensor can be mass produced as the integration with other sensors that comes with different functions and sensitive directions can be done through the MEMS method to produce a micro-sensor array or micro-system.

2.2 MEMS Piezoresistive Sensor

The piezoresistive effect is the fundamental principle of the MEMS piezoresistive sensor. A varistor constructed on a sensitive film or a sensitive beam serves as the inductive component. The sensing method is as follows: as an item moves, the mass inside the accelerometer moves up and down due to the inertial force acting on it. Because the mass is supported by the cantilever beam, as the moving mass pulls on it, the varistor on the cantilever beam deforms and the resistance value changes, resulting in the Wheatstone power supply. The bridge circuit generates a small ripple voltage, and the Wheatstone bridge's output signal is amplified by the readout circuit. The magnitude of the corresponding acceleration can be calculated using the calibration rule, and the acceleration's change trend reflects the target's moving direction. Only the varistor is replaced by a piezoelectric component in the MEMS piezoelectric sensor, and the piezoelectric effect is employed to detect acceleration variation, and the working principle is identical to the piezoresistive type. Figure 2.1 are the physical diagram of MEMS piezoresistive sensor (TWI-Global).

Figure 2.1: Piezoresistive Sensor

2.3 Vibration Monitoring on Rotating Machines

Vibration pattern analysis is one of the most effective and successful approaches for fault diagnosis and prognosis of rotating machines. Machine vibration has a well-defined analytical and practical knowledge in the literature. Machine vibration behaviour in the time and frequency domain is the foundation for rotating machine monitoring. Machine vibration response is sensitive to any slight change in operating conditions or mechanical structural design (Shahzad and O'Nils 2018).

A 7.5KW induction motor is put on test with a sensor attached under various operating conditions. One of the main focuses of vibration signal analysis is to remove noise and attenuate undesired vibration signals which is noise from the sensor or other rotating machines and the target machine. A simulated signal is used to test the noise removal algorithm's efficacy. The noise signal, the original signal, and the damaged signals are all utilized to test the noise removal algorithm's performance. Figure 2.2 shows the mounting and orientation of the accelerometer to the induction motor. The orientation of the accelerometer is based on the direction that needs to be measured. Figure 2.3 shows a white gaussian noise signal, pure sinusoidal wave and combined signal (Shahzad and O'Nils 2018).

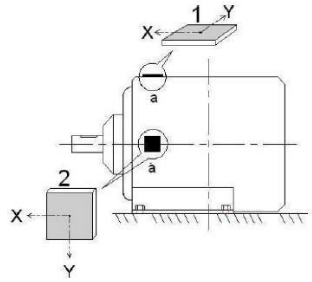


Figure 2.2: Location to fixed accelerometer on motor

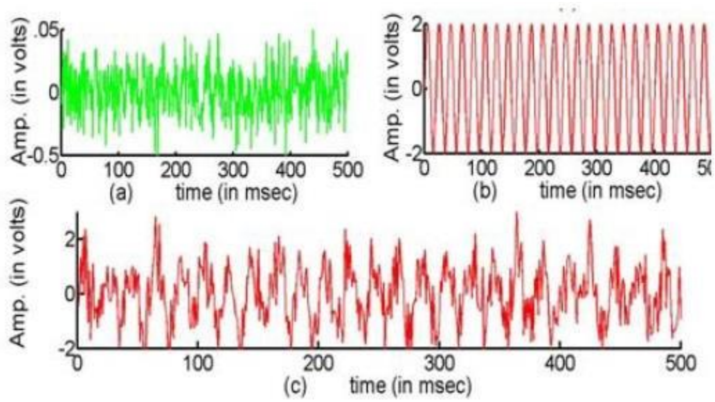


Figure 2.3 : (a) White gaussian noise (b) Pure Sinusoidal wave (c) Combined signal

The efficiency of the auto-correlation function was tested using various noise and signal ratio combinations. Other than the fundamental frequency peak, the frequency spectrum of a noisy signal comprises other peaks. The considerable suppression of noise after applying the ACR Filter are shown in Figure 2.4.

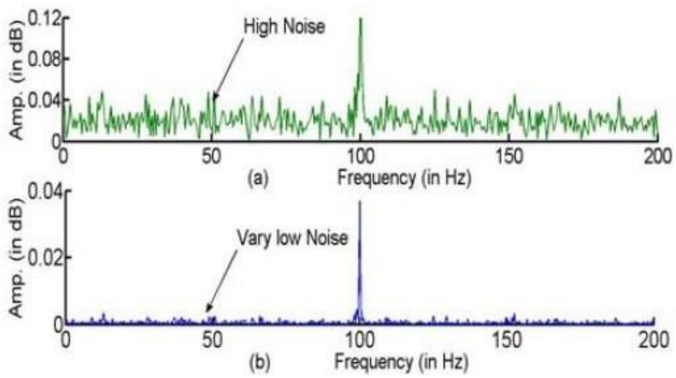


Figure 2.4: Result of noise removal after apply ACR filter

2.4 Analysis of Vibration Signal

The testing model for this research consists of a DC motor to generate the vibration and a potentiometer. The potentiometer is used to control the speed of the motor and increase the magnitude and frequency of the vibration. The motor is mounted on a metal plate that is connected to the unit's base by rubber supports which allow for the detection of large vibration magnitudes on the plate. Various sizes of bolts and weights were linked to the shaft of the motor, which created the force required to generate the required vibration level, to alter the strength of vibration at specified frequencies (Parida et al. 2019).

After acquiring the samples from the sensor, the signal will run through the band pass filter which includes a high pass and low pass filter. The filter cut-off frequencies are based on the measurement frequencies required in the research as shown in Equation 2.1. The frequency range in this research range from 10Hz to 100 Hz. Figure 2.5 is the samples in the time domain after running through the bandpass filter.

$$f_{min} \leq fc_{high-pass} < fc_{low-pass} \leq f_{max}$$

Equation 2.1: Filter cut off frequency equation

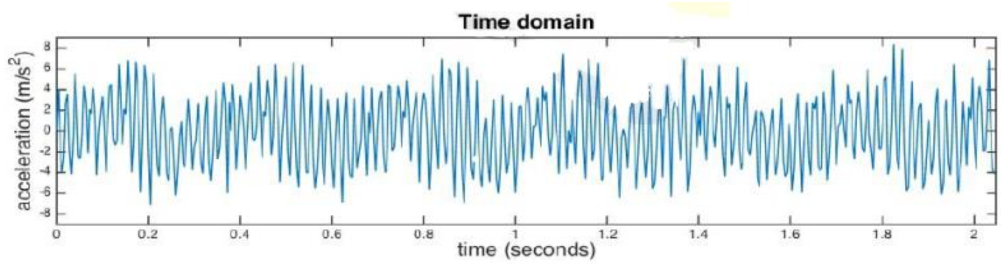


Figure 2.5: Samples in time domain

The sampling rate and the number of samples should be set before doing an FFT analysis on the time domain signal. This is based on the expected frequency range and time that want to be analyzed. The amounts of samples in the frequency domain will be defined by FFT and identified maximum frequencies are determined by the sampling rate. In this research, an FFT size of 512 and a sampling rate of 250 Hz is used to obtain the result. Figure 2.6 show the acceleration samples in the frequency domain after FFT (Wyld and Maurin 2009).

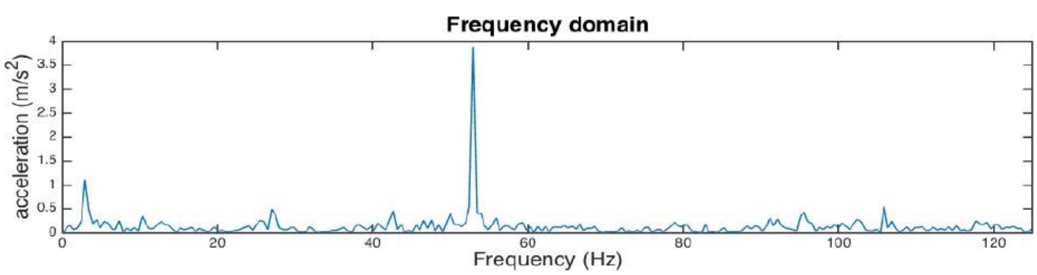


Figure 2.6: Samples in the frequency domain

After the calculation for the FFT of the samples is done, velocity in mm/s will be evaluated for each frequency bin. The samples obtained in acceleration are in metres per second square (m/s^2), to get the derived velocity, multiply 1000 to get the value in millimetres per second (mm/s) as shown in Equation 2.2.

$$v(n) = \frac{a(n)}{2 * \pi * \Delta f * n} * 1000$$

Equation 2.2: Equation of derived velocity

Due to the resolution of the FFT bins and the irregularity of the vibration signals, the magnitude of the vibration (after the FFT analysis) in some circumstances crosses across nearby frequencies after computing the corresponding velocity for each frequency. As seen in Figure 2.7, the results in a lower amplitude in the frequency domain. In Figure 2.8, using an RSS moving average on the samples corrects this issue, resulting in accurate and consistent results.

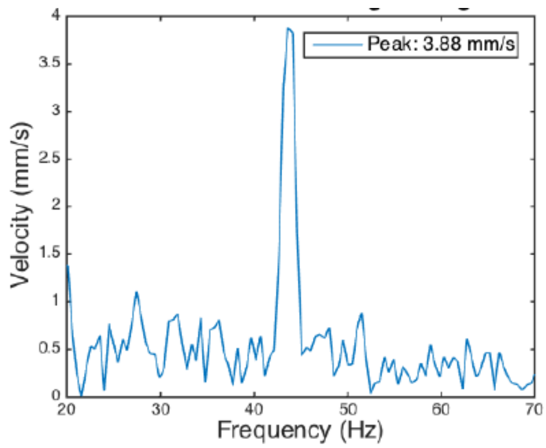


Figure 2.7 Before RSS moving average

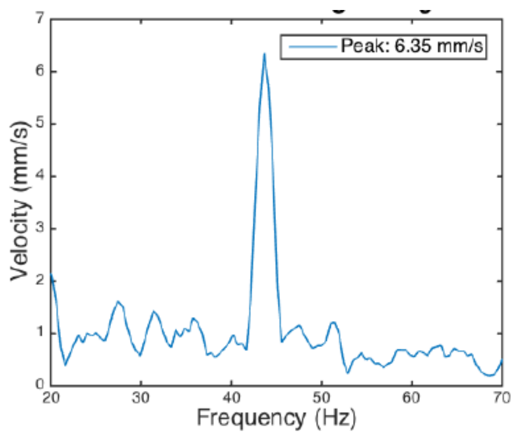


Figure 2.8: After RSS moving average

2.5 Sliding Window Technique on Data Stream

The sliding window technique is often used to analyse time series data. This technique's fundamental idea is to use a fixed-size window to capture more current data items. In many circumstances, people are only interested in finding hidden patterns in the most recent data items, rather than the full data history. To capture the most recent N objects, sliding window models are utilized. These windows only show data from the last t-time units or the last N data components.

All data items that are included within the size of a sliding window have a weight of 1 in this sliding window method, and all data elements that are not included within the size of a sliding window have a weight. This approach is simple to implement, but it will fail if the incorrect window size is chosen. Too small windows create very precise representations of the current state but are heavily influenced by noisy data, and too large windows produce more stable but equally erroneous findings due to the behavioral change of the streaming data (Purnamasari 2017).

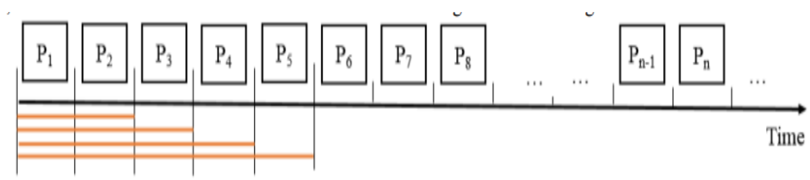


Figure 2.9: Sliding Window Technique on Data Stream

2.6 Time Series Data Classification Using Sliding Window Technique

Through efficient segmentation, the sliding window technique is used to offer a more compact representation. In the process of analyzing and researching time series data, time series segmentation is a critical step. Its significance should be considered in light of its consequences for the building of a valid time series model. Segmentation is a data mining research problem that focuses on separating time series into appropriate, internally homogeneous segments so that the structure of the time series can be exposed through pattern and/or rule discovery in the behavior of the observed variable (Bagheri 2018).

The Euclidean distance also minimizes the sum of squares of these distances, which is precisely defined as the square root of the sum of squared distances between empirical and approximated values. As a result, the essence of the segmentation problem is to determine the best estimate for which the error function, Ep, is the smallest. In reality, for the defined parameters, the optimal segmentation of the time series, T, is defined as the segmentation that produces the lowest segmentation error in comparison to other potential combinations of segmentation.

The sliding window computation operates in the division step by tying down the left purpose of a prospective fragment at the major information purpose of a period arrangement, then attempting to inexact the information to one side by expanding longer sections. Finally, the client indicated edge is more significant than the blunder for the possible fragments, thus the sub-sequence from the grapple to I-1 is altered into a section. The grapple is shifted to the area I, and the technique is repeated until the entire time arrangement has been transformed into a piecewise straight estimation (Bagheri 2018).

3. Methods

3.1 System Design

Figure 3 below are the vibration monitoring IoT system which consists of five SW-420 vibration sensors, an ESP32 microcontroller, a DHT22 temperature sensor, and a battery shield.

3.2 Data Sending to Thingsboard

When the vibration is captured by the SW-420 vibration sensor, the ESP32 microcontroller will transmit the captured data to Thingsboard using the wireless connection. The data will transmit using the MQTT API protocol and time series data will be visualized in the graph on the Thingsboard dashboard in real-time. Figure 3.1 below shows the data sent to the Thingsboard dashboard and data visualization in the graph.

3.3 Data Storing in Thingsboard

The captured data will send to the Thingsboard cloud platform and stored in SQL cloud storage. Captured data can be retrieved anytime from cloud storage. Each data comes with a timestamp, so it is easier to analyze. Figure 3.2 showed data stored in Thingsboard cloud storage.

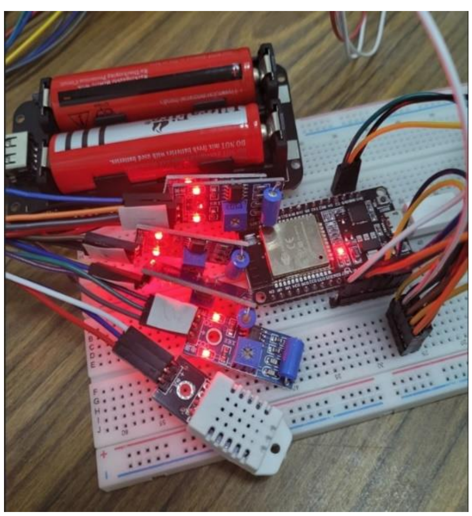


Figure 3: Vibration Monitoring IoT System

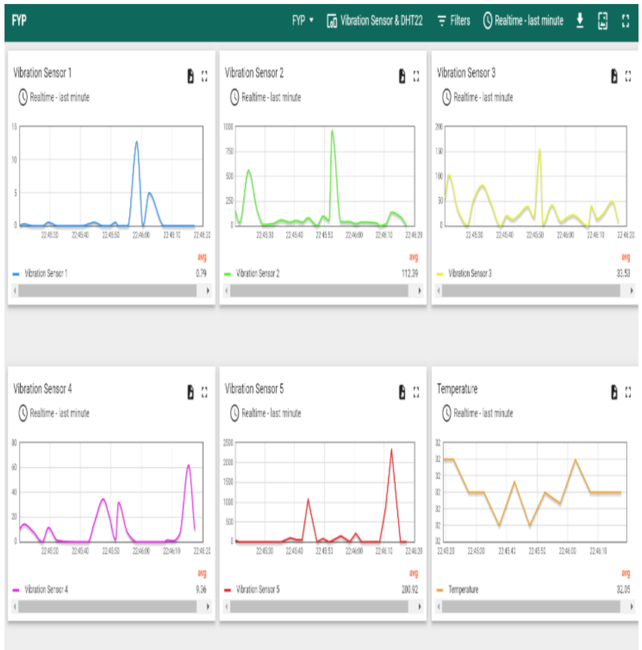


Figure 3.1: Thingsboard dashboard

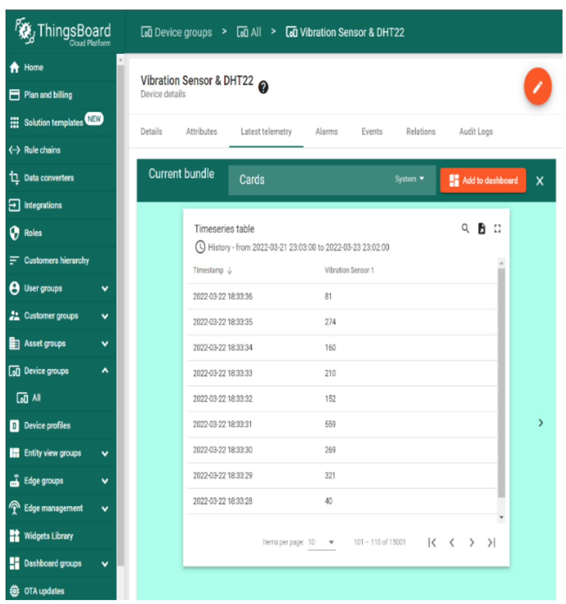


Figure 3.2: Thingsboard Cloud Storage

4. Results and Discussion

4.1 Sliding Window Technique using MATLAB

After the captured data is retrieved from Thingsboard cloud storage, the data will be analyzed using the Sliding Window technique in MATLAB. Sliding window techniques are used to avoid redundant iterations when working with a collection of data. It also provides an understandable lens through which data in subsections can be viewed. The buffer of the sliding window is set to 120 with an overlap of 5 data. Figure 4 below showed the raw data captured by the vibration sensor. Figure 4.1 are the data after applying Sliding Window Technique in MATLAB.

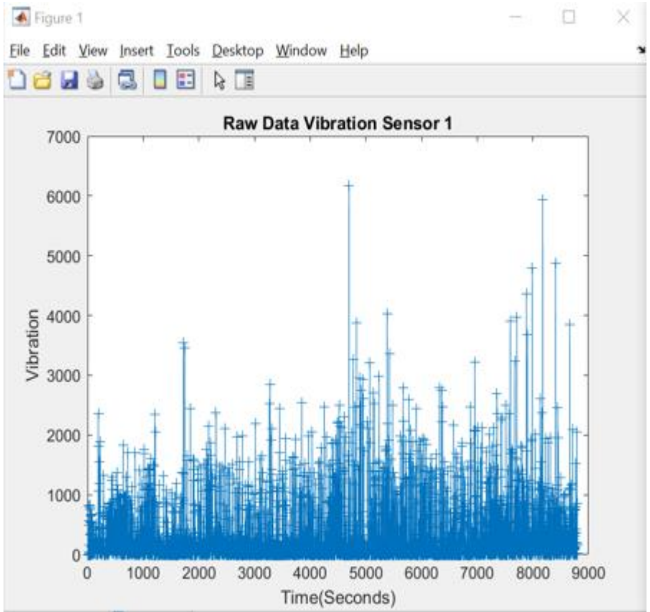


Figure 4: Raw data captured from the sensor

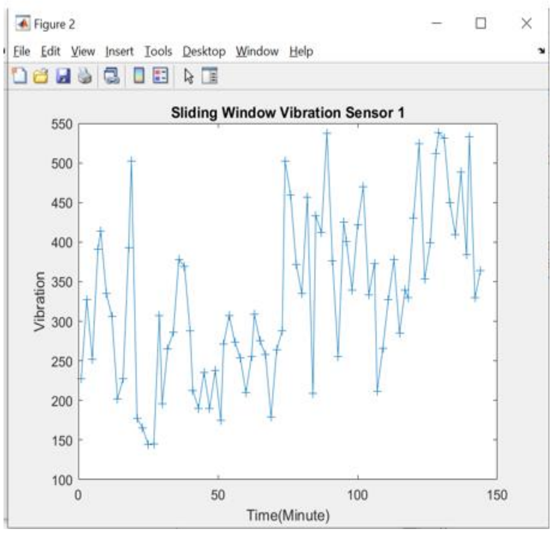


Figure 4.1: Data Applied With Sliding Window Technique

The vibration monitoring IoT system uses five SW-420 vibration sensors to capture the vibration, the output of the vibration sensor is an analog voltage signal based on the intensity of vibration. The vibration sensor was attached to the AC motor and attached to different places of the AC motor to vary the vibration produced by the AC motor. Data are captured at different speeds of the AC motor to see the changed behavior of the vibration signal in different duration. DHT22 temperature sensors are attached to the AC motor to monitor the surrounding temperature based on the speed of the AC motor. All the data will send to Thingsboard and stored in the cloud storage. Specification of the motor for data collection is using AC single phase induction motor, with 240V/50Hz power supply, speed 1 around 774-946 RPM and power consumption are 39-46W, speed 2 around 946-1103 RPM and power consumption are 47-54W, speed 3 around 1104-1349 RPM and power consumption are 55-61W. Figure 4.2 below are the sensor attached to different places of the AC motor.

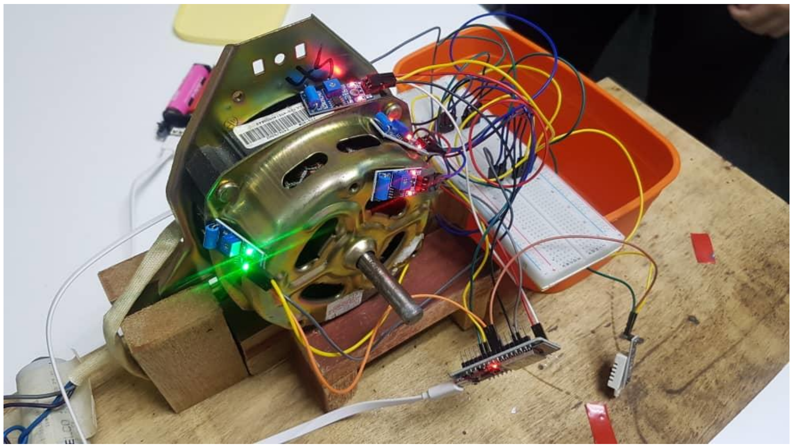


Figure 4.2a: Various Position of Sensors Attached to AC Motor

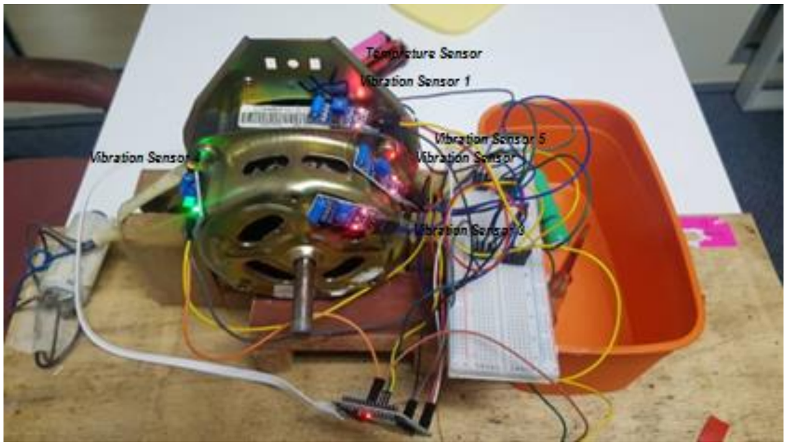


Figure 4.2b: Various Position of Sensors Attached to AC Motor

4.2 Motor Vibration vs its Speed vs Duration

The vibration and temperature data are captured from the AC motor at different speeds of a motor. Data are retrieved from the cloud storage of Thingsboard, sliding window technique is applied using MATLAB to analyze the captured data and provide the motor vibration behavior based on speed vs duration. A vibration threshold exists in every machine. The machine is defective if the threshold limit is exceeded by any means. However, without graph plotting, detecting the proper rate of vibration visualization is quite difficult. Figures 8-10 below are the graph of motor vibration in 60 minutes at different speeds captured by vibration sensor 1. Figure 8 shows a graph of vibration sensor 1 on motor speed 1 in 60 minutes, vibration sensor 1 has captured an average vibration value of 252mV. Figure 9 shows a graph of vibration sensor 1 on motor speed 2 in 60 minutes and has an average vibration value of 380mV. Figure 4.3 on load speed 3 in 60 minutes has an average vibration value of 450 mV.

Figure 4.3 shows a graph of vibration sensor 1 on motor speed 2 in 60 minutes, vibration in the beginning slowly decreased and fluctuates from the 5th minute to the 20th minute, it then reached a peak in the 25th minute and sharply decreased for 2 minutes. From the 31st minute to the 55th minute, the vibration is slowly decreasing. Vibration sensor 1 on motor speed 1 has captured an average vibration value of 252 mV.

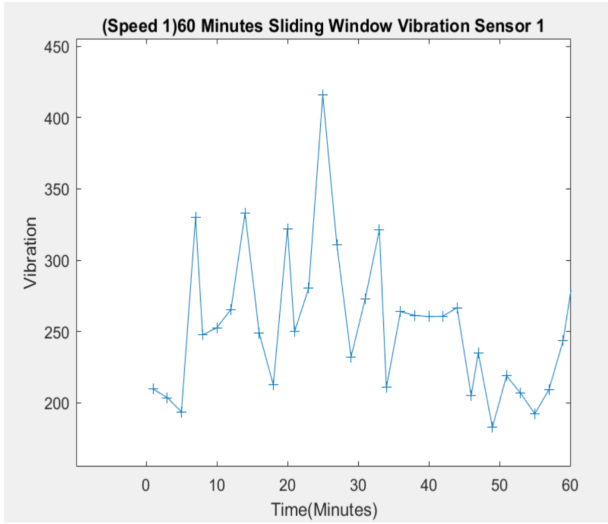


Figure 4.3: Vibration Data of Sensor 1 on motor Speed 1 in 60 Minutes

Figure 4.4 shows a graph of vibration sensor 1 on motor speed 2 in 60 minutes, vibration in the beginning slowly decreased and reach the bottom in the 5th minute, it then started to increase in the 10th minute and reach the peak in the 19th minute. The vibration then fluctuates from the 20th minute to the 60th minute. Vibration sensor 1 on motor speed 2 has captured an average vibration value of 380mV.

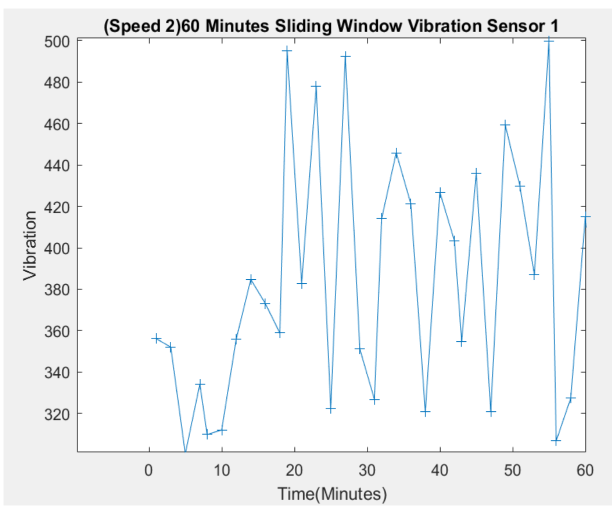


Figure 4.4: Vibration Data of Sensor 1 on motor Speed 2 in 60 Minutes

Figure 4.5 shows a graph of vibration sensor 1 on motor speed 3 in 60 minutes, vibration, in the beginning, is decreasing and sharply increase in the 3rd minute and reached its peak in the 7th minute, it then fluctuates from the 10th minute to the 60th minute. Vibration sensor 1 on motor speed 3 has captured an average vibration value of 450mV.

Table 1-3 have shown the average vibration value of the AC motor at various motor speeds running for 60 minutes. The result from table 4 has shown vibration sensor 1 and vibration sensor 2 have captured higher vibration compared to other vibration sensors. Vibration sensor 3 was attached to the middle of the AC motor, it captured lesser vibration than vibration sensor 1 and sensor 2. Vibration sensor 4 and sensor 5 are attached near to the motor shaft of the AC motor, it has the lowest vibration compared to other sensors. The result showed AC motor running on motor speed 3 produced higher vibration than running at motor speed 1 and motor speed 2, the vibration produced at motor speed 1 is the lowest. From the result, it can be observed that the vibration produced is different subject to the places attached to the sensor on the AC motor.

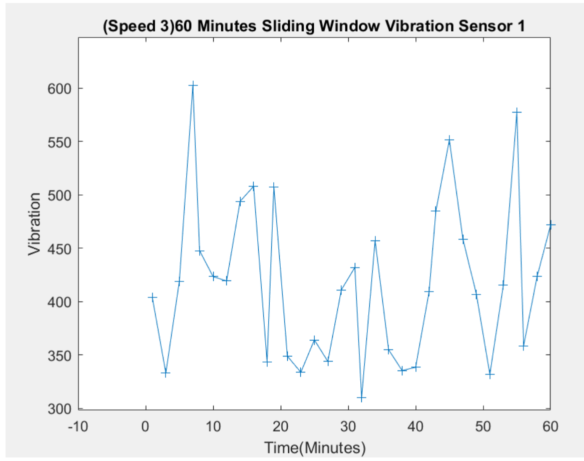


Figure 4.5: Vibration Data of Sensor 1 on motor Speed 3 in 60 Minutes

Table 1: Average Vibration Value of Vibration Sensors at Various Load Speed in 15 Minutes

15 Minutes	Motor Speed 1	Motor Speed 2	Motor Speed 3
Vibration Sensor 1	240 mV	345 mV	485 mV
Vibration Sensor 2	275 mV	320 mV	452 mV
Vibration Sensor 3	204 mV	245 mV	318 mV
Vibration Sensor 4	110 mV	155 mV	209 mV
Vibration Sensor 5	118 mV	162 mV	223 mV

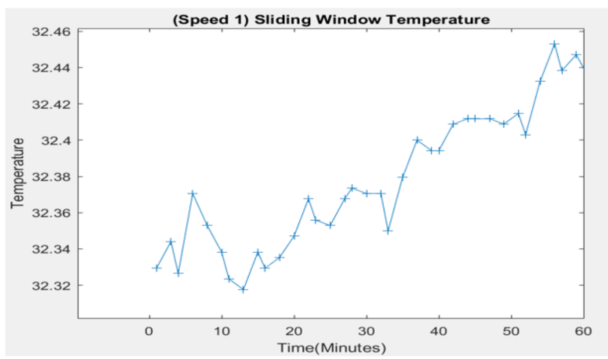
Table 2: Average Vibration Value of Vibration Sensors at Various Load Speed in 30 Minutes

30 Minutes	Motor Speed 1	Motor Speed 2	Motor Speed 3
Vibration Sensor 1	258 mV	364 mV	434 mV
Vibration Sensor 2	256 mV	335 mV	453 mV
Vibration Sensor 3	175 mV	252 mV	312 mV
Vibration Sensor 4	120 mV	153 mV	206 mV
Vibration Sensor 5	121 mV	159 mV	223 mV

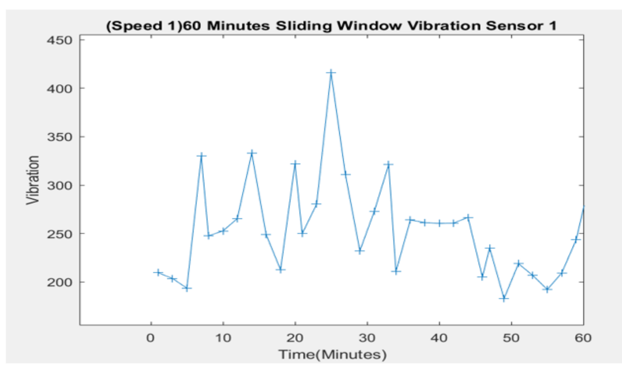
Table 3: Average Vibration Value of Vibration Sensors at Various Load Speed in 60 Minutes

60 Minutes	Motor Speed 1	Motor Speed 2	Motor Speed 3
Vibration Sensor 1	252 mV	380 mV	450 mV
Vibration Sensor 2	248 mV	365 mV	438 mV
Vibration Sensor 3	155 mV	271 mV	313 mV
Vibration Sensor 4	117 mV	150 mV	207 mV
Vibration Sensor 5	115 mV	154 mV	226 mV

4.3 Temperature vs Motor Speed vs Vibration Data of Sensor 1 vs Duration



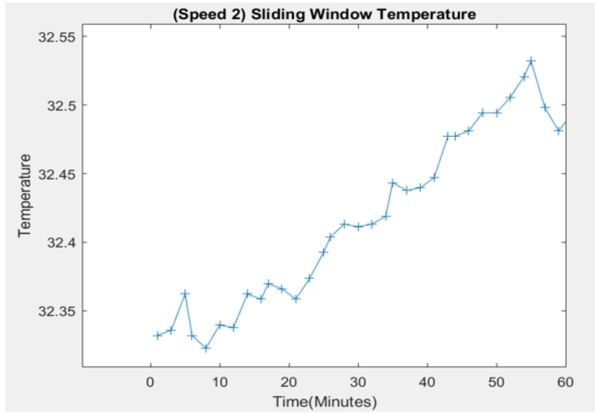
(a) Temperature Data



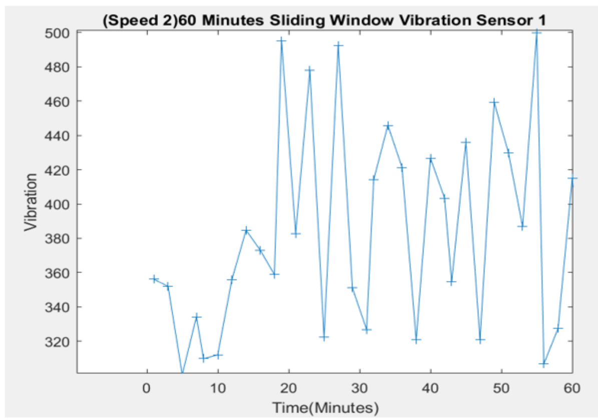
(b) Vibration Data of Sensor 1

Figure 5: Temperature Data and Vibration Data of Sensor 1 on Motor Speed 1 in 60 Minutes

Figure 5 shows a graph of temperature data and vibration data of sensor 1 on motor speed 1 in 60 minutes. From the graph, it can be observed the temperature decreased from the 5th minute to the 11th minute but the vibration fluctuates up and down from the 5th minute to the 20th minute along with changes in load torque. Although the vibration is decreasing from the 25th minute to the 60th minute, the temperature is rising as the motor operates continuously at full load and reached the peak temperature of 32.45 °C in the 55th minute and has an average temperature of 32.37 °C.



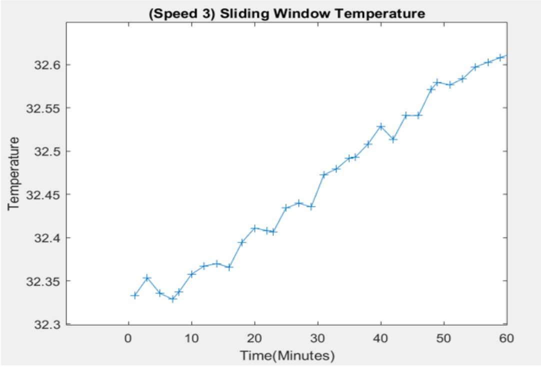
(a) Temperature Data



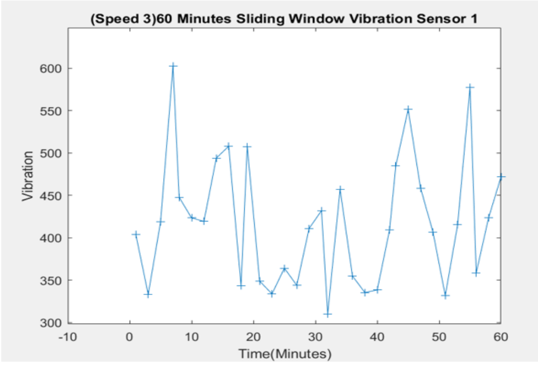
(b) Vibration Data of Sensor 1

Figure 5.1: Temperature Data and Vibration Data of Sensor 1 on motor Speed 2 in 60 Minutes

Figure 5.2 shows a graph of temperature data and vibration data of sensor 1 on motor speed 2 in 60 minutes. From the graph, it can be observed that temperature and vibration are decreasing in the 5th minute, and the temperature slowly increases in the 10th minute to the 55th minute, the motor operates continuously at full load. The vibration started to increase on the 10th minute and vibration fluctuates up and down from the 20th minute to the 55th minute along with changes in load torque. When temperature and vibration reached the peak on the 55th minute, vibration sharply decreased as the output torque increased, the output speed decreases proportionately, and temperature decreased after reaching peak temperature at 32.53 °C due to winding temperature decreased when not operating at full load. The temperature on motor speed 2 has an average temperature of 32.42 °C.



(a) Temperature Data



(b) Vibration Data of Sensor 1

Figure 5.3: Temperature Data and Vibration Data of Sensor 1 on motor Speed 3 in 60 Minutes

Figure 5.3 shows a graph of temperature data and vibration data of sensor 1 on motor speed 3 in 60 minutes. From the graph, it can be observed the vibration fluctuates up and down from the beginning to the end along with changes in load torque. The temperature is rising constantly on the 7th minute to the end as the motor operates continuously and reached the peak temperature at 32.61 °C and has an average temperature of 32.51 °C.

Table 4: Peak Temperature and Average Temperature on Different Motor Speed in 60 Minutes

60 Minutes	Motor Speed 1	Motor Speed 2	Motor Speed 3
Peak Temperature	32.45°C	32.53°C	32.61°C
Average Temperature	32.37°C	32.42°C	32.51°C

Figures 11-13 show the temperature rise when the AC motor operates continuously for 60 minutes. The AC motor running on load speed 3 has the highest temperature which has a peak temperature of 32.61 °C and an average temperature of 32.51 °C. AC motor running on load speed 1 has the lowest temperature compared to load speed 3 and load speed 2. The result from table 5 has shown that the AC motor running on load speed 3 dissipated more heat than running on load speed 1 and load speed 2, the temperature of the AC motor will rise when the motor operates continuously.

4.4 Proposed Improvements

Two improvements can be made to improve the vibration monitoring IoT system. The first improvement is using the MLX90640 infrared thermal sensor instead of the DHT22 temperature sensor. The purpose of using this sensor is to monitor the motor's exterior surface temperature, which is a good indicator of the interior temperature. As the inside of the motor gets hotter, the exterior surface also gets hotter. The second improvement is using a 4G GPRS modem instead of using a Wi-Fi connection. The vibration monitoring IoT systems are highly dependent on the Wi-Fi connection, the system can't function without a Wi-Fi connection. Hence, the 4G GPRS modem is to replace the Wi-Fi connection as it uses a SIM card to provide an internet connection. Vibration monitoring IoT systems can be used indoors or outdoors without restrictions by using an internet connection provided by a SIM card.

5. Conclusion

The development of an IoT-based machine vibration monitoring system is said to be successful despite some improvements that can be made. The IoT-based machine's vibration monitoring system is capable of remote monitoring vibration data by using a wireless connection and web-based application to remote monitoring anywhere using smart devices. Hence, the objective is achieved. The system is beneficial for its proper measurement to analyse the continuation of vibration signals and temperature. The sliding window technique used in this system has resulting more accurate data to analyse the changed behaviour of vibration signals and temperature. Finally, the IoT-based machine's vibration monitoring system is yet to be improved to provide more precise data for analysis. MLX90640 infrared thermal sensor was considered to replace DHT22 temperature, it is also to observe the effect and impact it could bring to the vibration IoT monitoring IoT system.

References

Bagheri, M., Nurmanova, V., Zollanvari, A., Nezhivenko, S. and Phung, B. T., IoT Application in Transformer Fault Prognosis Using Vibration Signal, *2018 IEEE International Conference on High Voltage Engineering and Application (ICHVE)*, Athens, Greece, September 10-13, 2018

Chaudbury, S. B., Sengupta, N. and Murkherjee. K., Vibration Monitoring of Rotating Machines Using MEMS Accelerometer, *International Journal of Scientific Engineering and Research (IJSER)*, vol. 2, no. 9, 2014.

Ganga, D. and Ramachandran, V., IoT based Vibration Analytics of Electrical Machines, *IEEE Internet of Things Journal*, vol.5, no.6, 2017.

Geitner, F. K., and Bloch H. P., *Machinery Failure Analysis and Troubleshooting*, 4th Edition, Elsevier, 2012. Khan, N., Rafiq, F., Abedin, F. and Khan, F., IoT Based Health Monitoring System for Electrical Motors, *2019 15th International Conference on Emerging Technologies (ICET)*, Peshawar, Pakistan, December 2-3, 2019.

Olalere, I. O., Dewa, M. and Nleya B., "Remote Condition Monitoring of Elevator's Vibration and Acoustics Parameters for Optimised Maintenance Using IoT Technology", *2018 IEEE Canadian Conference on Electrical & Computer Engineering (CCECE)*, Quebec, Canada, May 13-16, 2018.

Parida, D., Behera, A., Naik, J. K., Pattanaik, S. and Nanda, R. S., Real-time Environment Monitoring System using ESP8266 and ThingSpeak on Internet of Things Platform, *2019 International Conference on Intelligent Computing and Control Systems (ICCS)*, Madurai, India, May 15-17, 2019.

Purnamasari, W., Home Security Systems Using Vibration Sensors With Pc-Based Sound Output, *Pelita Nusantara Journal*, vol. 21, no. 1, p. 59, 2017.

Saputra, J. F., Rosmiati, M. And Sari. M. I., Pembangunan Prototype Sistem Monitoring Getaran Gempa Menggunakan Sensor Module SW-420, *e-Proceeding of Applied Science,* vol. 4, no. 3, pp. 2055–2068, 2018.

Shahzad, K. and O'Nils, M., Condition Monitoring in Industry 4.0-Design Challenges and Possibilities: A Case Study, *2018 Workshop on Metrology for Industry 4.0 and IoT*, Brescia, Italy, April 16-18, 2018.

What is Vibration Analysis and What is it Used For?, *TWI-Global*, Available: https://www.twi-global.com/technical-knowledge/faqs/vibration-analysis.

Wyld, D. C. and Maurin, R., *Moving to the Cloud: An Introduction to Cloud Computing in Government*, IBM Center for The Business of Government, 2009.

Biography

Nagesparan Ainarappan received an undergraduate BEng (Hons) degree from The Manchester Metropolitan University, Manchester (UK) and Master's in Project Management from The George Washington University (US). He held various engineering and management positions with Maxis Communication Bhd. Currently, he is an Asst. Professor with the Faculty of Engineering and Technology, UCSI University, Kuala Lumpur, Malaysia. His research

interest includes IoT Based Automation, IoT Based Smart Cities/Interfaces and Project Management, HIRARC/OSH. He is a Chartered Engineer with the Engineering Council United Kingdom, a Professional Engineer registered with the Board of Engineers Malaysia, and a European Engineer of Federation of European Union (FEANI).

Kanesan Muthusamy received the Ph.D. degree in Information Engineering (Operations Research) from the Osaka University, Japan. In the past, he has held various engineering and management positions with Robert Bosch, Motorola, and Panasonic. Currently, he is an Asst. Professor with the Faculty of Engineering and Technology, UCSI University, Kuala Lumpur, Malaysia. His research interest includes OR/OM, TQM, Project Management and OSH. Dr. Muthusamy is a Professional Engineer registered with the Board of Engineers, Malaysia.