AN ANALYSIS OF VIBRATION SENSOR FOR CONVEYOR SYSTEM USING IOT TECHNOLOGY

AHMAD FAISAL BIN KAMARUDIN

UTeM
اونيۏرسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

AN ANALYSIS OF VIBRATION SENSOR FOR CONVEYOR SYSTEM USING IOT TECHNOLOGY

AHMAD FAISAL BIN KAMARUDIN

This report is submitted in partial fulfilment of the requirements for the degree of Bachelor Of Electronic Engineering with Honours

Faculty Of Electronics And Computer Technology and Engineering
Universiti Teknikal Malaysia Melaka

2025

UNIVERSITI TEKNIKAL MALAYSIA MELAKA
FAKULTI TEKNOLOGI DAN KEJURUTERAAN ELEKTRONIK DAN KOMPUTER

BORANG PENGESAHAN STATUS LAPORAN
PROJEK SARJANA MUDA II

Tajuk Projek : An Analysis Of Vibration Sensor For Conveyor System Using IoT Technology

Sesi Pengajian : 2024/2025

Saya AHMAD FAISAL BIN KAMARUDIN mengaku membenarkan laporan Projek Sarjana Muda ini disimpan di Perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Laporan adalah hakmilik Universiti Teknikal Malaysia Melaka.
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan laporan ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. Sila tandakan (✓):

☐	**SULIT***	(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)
✓	**TERHAD***	(Mengandungi maklumat terhad yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan.
☐	**TIDAK TERHAD**	

Disahkan oleh:

(TANDATANGAN PENULIS) (COP DAN TANDATANGAN PENYELIA)

Alamat Tetap: ,................................

DR. MUZALIFAH BINTI MOHD SAID
Pensyarah Kanan
Fakulti Teknologi Dan Kejuruteraan Elektronik Dan Komputer (FTKEK)
Universiti Teknikal Malaysia Melaka (UTeM)

Tarikh : 18 Januari 2025 Tarikh : 23 Januari 2025

*CATATAN: Jika laporan ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali tempoh laporan ini perlu dikelaskan sebagai SULIT atau TERHAD.

DECLARATION

I declare that this report entitled “An Analysis Of Vibration Sensor For Conveyor System Using IoT Technology” is the result of my own work except for quotes as cited in the references.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Signature : ……………………………………..

Author : AHMAD FAISAL BIN KAMARUDIN

Date : 18/1/2025

APPROVAL

I hereby declare that I have read this thesis and in my opinion, this thesis is sufficient in terms of scope and quality for the award of Bachelor of Electronic Engineering with Honours

Signature : ……………………………………..

Supervisor Name : TS. DR. MUZALIFAH BINTI MOHD SAID

Date : 18/1/2025

DEDICATION

Especially for: My parents & Mars who provided me with unconditional love, understanding, and support throughout my life.

ABSTRACT

Industrial operations depend heavily on a conveyor system because it makes material handling processes easier. Manufacturing facilities depend on different conveyor systems like belt and chain together with roller types. Taking care of these systems properly helps us prevent unplanned equipment failures. Many companies have poor maintenance tracking tools and only limited sensor testing work has been done across different vibration ranges. Our research creates a predictive maintenance conveyor system that stops operations right away when unusual vibrations are detected to avoid big system failures. The project studies how well MPU6050, ADXL335, and ADXL345 vibration sensors detect different vibration frequencies produced by a motor vibrator when measuring stability and reliability. Real-time control works through IoT technology which connects to phone applications to show system updates. The MPU6050 sensor shows superior results in measuring vibration accurately which makes it suitable for predictive maintenance in conveyor systems. Our research helps conveyor systems operate better and safer while making industrial maintenance more intelligent.

ABSTRAK

Sistem penghantar merupakan komponen penting dalam operasi industri yang memudahkan pengendalian bahan dengan efisien. Pelbagai jenis penghantar, termasuk penghantar tali sawat, penggelek, dan rantai, digunakan secara meluas dalam industri. Penyelenggaraan sistem ini adalah kritikal, dan penyelenggaraan ramalan menawarkan pendekatan proaktif untuk mencegah kerosakan yang tidak dijangka. Walau bagaimanapun, banyak industri kekurangan sistem pemantauan penyelenggaraan yang efektif, dan terdapat kekurangan kajian mengenai prestasi sensor getaran pada pelbagai frekuensi. Kajian ini bertujuan untuk menangani jurang ini dengan membangunkan sistem penghantar penyelenggaraan ramalan yang dilengkapi dengan penggera untuk mengesan getaran luar biasa dan menghentikan operasi serta-merta bagi mengelakkan kerosakan besar. Projek ini menilai prestasi sensor getaran MPU6050, ADXL335, dan ADXL345 dengan menganalisis kestabilan, kebolehpercayaan, dan kadar ralat mereka di bawah pelbagai frekuensi getaran yang dihasilkan oleh motor vibrator. Selain itu, sistem ini menggabungkan teknologi IoT untuk kawalan dan pemantauan masa nyata melalui aplikasi telefon. Hasil kajian menunjukkan bahawa sensor MPU6050 memberikan prestasi terbaik secara keseluruhan dari segi ketepatan dan kebolehpercayaan, menjadikannya pilihan yang sesuai untuk penyelenggaraan ramalan dalam sistem penghantar. Penyelidikan ini menyumbang kepada peningkatan kecekapan sistem penghantar dan keselamatan operasi sambil membolehkan amalan penyelenggaraan industri yang lebih pintar.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

ACKNOWLEDGEMENTS

To begin with, all credit goes to Allah S.W.T., the Most Beneficent and Merciful for their blessings I was able to endure and ultimately finish a Bachelor's Degree Project (PSM) or final year project. On the same note, I would like to express my heartfelt appreciation to my project supervisor, Dr. Muzalifah Binti Mohd Said for her support and encouragement throughout the completion of this project. This work was completed with a big help of her dedication, insightful ideas, and constant motivation. Of course, I would like to thank two project panels, firstly, Ir.Gs.Ts.Dr.Nik Mohd Zarifie Bin Hashim, whom I'd like to thank for useful comments, helpful advices and remarks that really assist me in the improving of chosen project and, secondly, Profesor Madya Dr. Lim Kim Chuan for the same useful and helpful advices and remarks. For these reasons and for many more, being a first-year student brings me a lot of joy in the Faculty of Electronic Engineering and Computer Engineering lecturers for sharing their knowledge and supporting the students even in their studies. Finally, I would wish to thank my parents and friends for standing by me and for this constant encouragement, without which I could not have been challenged to carry out this work to the end.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

TABLE OF CONTENTS

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

اونيۈرسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

LIST OF FIGURES

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

LIST OF TABLES

اونيورسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

LIST OF SYMBOLS AND ABBREVIATIONS

CC	:	Central canal
DAB	:	3,3'-diaminobenzidine
HRP	:	Horseradish peroxidase
MS222	:	Tricaine methanesulfonate

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

LIST OF APPENDICES

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

CHAPTER 1

INTRODUCTION

1.1 Background Project

In this kind of era, the reliability of conveyor systems are crucial to the operation of many manufacturing and processing units. Conveyor systems are basic components in industries such as automotive, foods and logistics. It is where making it easy for continuous movement of materials. But the performance of conveyor systems can become understood by issues like for example mechanical failures, misalignment and much more which causes increased maintenance. Thus, it poses a significant safety risk to personnel. A project titled, "An Analysis Of Vibration Sensors for Conveyor Systems Using IoT Technology," aims to assess the performance of vibration sensors in conveyor systems and analysis in improving system efficiency and safety. The problem lies in the lack of clarity regarding which sensor variant is most effective [1]. On the top of that, research for the conveyor system in most industries lacks on automated sensors for predictive maintenance that can inform to the technician

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

allowing them to make well organised and scheduled earlier, as highlighted by Giraud L in 2004 [2]. A vibration sensor as fault detection can be used to sense any abnormal vibration even the sightliest change in trend or unusual peak amplitude [3]. The main objective is to analyse three variants of vibration sensors to overcome existing issues and enhance their stability, reliability and error percentage. Furthermore, is to aims at improving by pursue in industry 4.0 through providing applicable statistical data and active measures using time domain [4] [5]. The methodology involves a comprehensive analysis of each sensor's performance under various conditions. Expected results anticipate identifying the most efficient and accurate sensor variant. This project will involve implementing an IoT feature to notify users via their smartphones when safety is compromised. In conclusion, this project aims to provide valuable insights into selecting the optimal vibration sensor for enhancing the performance and safety of conveyor systems in industrial settings.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

1.2 Problem Statement

In the current ever evolving industrial systems and structures system breakdowns because of failures constitute a major problem since it results to high costs of doing business and reduced output. Conveyor systems that are so vital in any industrial application are prone to mechanical damages. Faults are not easily noticed rather they manifest themselves when a system halts [6]. One common challenge has been the interaction of the physical asset with the environment leading to faults that would result in a decline in the physical asset's performance level predictive maintenance using IoT has been found to be part solution to such problems since it provides an opportunity to detect these defaults early enough for maintenance to be completed.

The existing literature does not provide detailed information about the specific threshold for vibration sensor according to its parameter such as efficiency and time response. Specifically, we will evaluate the effectiveness of different vibration sensors which are MPU6050 Accelerometer Module [7], ADXL345 Accelerometer [8], and ADXL335 Accelerometer [9], in detecting and monitoring vibrations in conveyor systems. By conducting a thorough analysis of these sensors performance, including stability and reliability. We aim to identify the most suitable sensor technology for effectively detecting and mitigating vibration related faulty in conveyor operations.

The current monitoring and alert systems for conveyor vibration incidents rely heavily on human action and response, leading to potential delays in detection and mitigation efforts [10]. Additionally, there is a lack of developed systems incorporating mobile applications for efficient warning alerts and real-time monitoring of vibration levels in conveyor systems [11]. Here is an urgent need to develop and deploy an IoT-based monitoring system to prevent conveyor vibration incidents.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

1.3 Objectives

The project uses IoT technology through smartphones providing personnel in monitoring and alerting for conveyor systems. Additionally, it aims to analyse and identify the most suitable vibration sensor. Thus, the objectives of the project are:

i. To develop a predictive maintenance conveyor system equipped with an alarm that prevents major faults by detecting unusual vibrations and stopping operations immediately.

ii. To evaluate the performance of various vibration sensors by analysing their response across different frequencies and identifying trends specific to each sensor.

iii. To control and monitoring the conveyor system using IoT technology via phone app.

1.4 Scope Of Work

The scope of work of this project is design a new conveyor with small size and low weight to apply for the experiments, designed to transport loads up to 100 g equipped with vibration sensors to analyze its performance with no load, 25 g, and 100 g load. Properly fix the sensors for dynamic stability then use a controlled vibrator to introduce incremental frequencies of vibration of between 23Hz and 144Hz continuously running the equipment for fifty days in order to capture the vibration regime of the equipment on a daily basis in order to monitor trends, degradation and variations in performance over time through mathematical analysis and graphical comparisons. Further, the IoT should be utilized to design the monitoring of important parameters in response to a control signal such as temperature, the status of the motors, and humidity using sensors like DS18B20 or DHT22.

CHAPTER 2

BACKGROUND STUDY

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2.1 Introduction

This section summaries the important knowledge and methodological approach that related to certain issue. The background study will discuss about the research that have been done by the previous research which from internet, article and others. Furthermore, it gives a full clarification regarding the titled project's components which are conveyor, IoT systems, and testing for 3 types of vibration sensor in purpose of choosing the suitable sensor for the project. Hence, such methods and analysis are utilized to seek the sensor's performance.

2.2 Conveyor System

The conveyor system is a mechanical device that used for transport items such as materials, goods and products from one location to another location. It is widely used in industries that involves manufacturing, mining, automotive and logistics. Purpose of this system is to improve the productivity processes and make it more efficient. As for the component, conveyor system include belts that made of rubber, plastic or metal depending on the work place. The object to support the belt is called rollers and pulleys.

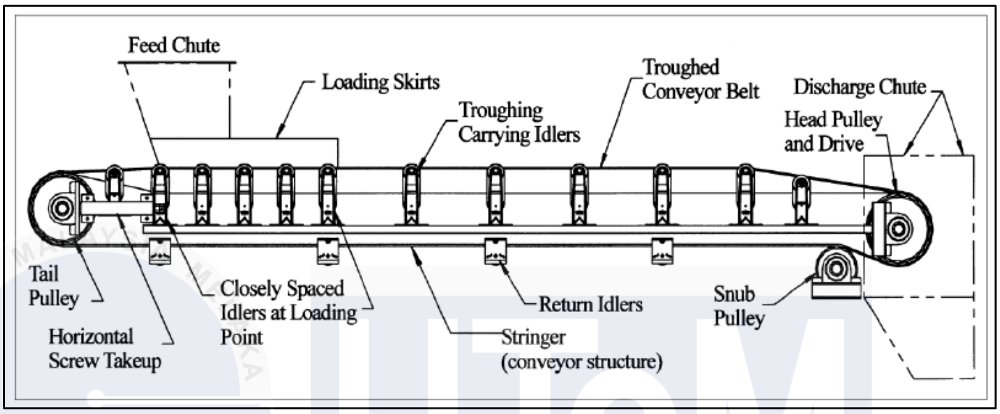


Figure 1: Common components of a troughed belt conveyor system

The belt is a key component of the conveyor system that can support the material while the system is operating for transport [12]. It describes in a closed loop around the conveyor system. Due to that, it is the largest component and most expensive. Selection of belts are crucial because of their connection to various conveyor components and also it depends on impact, tension, thermal, shear and wear.

Idlers on the other hand support the belt along the conveyor's length. They minimize the wear by allow it to free rotation supported by sealed bearings. Those assemblies consist of shell, axle, seals, bearings and bearing housings that support by transoms in purpose of efficient mounting on the conveyor.

Pulleys are for shaping, driving and assisting the belt. It is classified as drive and non drive pulleys. Usually, it make from steel drums with a rim and two end discs, mounted on the shafts with compression hubs.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Drive assemblies are mounted on a structural steel base and it is the part that power the system. It typically involve electric motors, speed reducers and power transmission devices.

2.2.1 Lightweight Conveyor

Lightweight conveyor designed for small items and lower load capacities. The system purposely for carry light materials such as aluminum or plastic and it is easy to install. Ideally for assembly lines, sorting, packaging operations and small scale distribution centers [13].

Figure 2: Lightweight Conveyor

2.2.2 Mediumweight Conveyor

Medium weight conveyor systems carry heavier compared to lightweight. Typically used in manufacturing, warehousing and logistics. By their appearance, the components include chain conveyors, gravity roller conveyors and powered roller conveyors. It is purposely to transport materials such as steel and have medium load capacities. Medium weight conveyor can use in automotive parts assembly, medium scale distribution and manufacturing facilities with medium load requirements.

Figure 3: Mediumweight Conveyor

2.2.3 Heavyweight Conveyor

Heavy weight conveyor systems designed to transport a very heavy materials, usually used in industries such as mining, construction, and bulk material handling. It include a heavy-duty belt conveyors, apron conveyors, and screw conveyors. The systems also made from reinforced steel and heavy-duty alloys so it capable to carry a high load capacities.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Figure 4: Heavyweight Conveyor

2.3 Enhancing Conveyor Efficiency Through Predictive Maintenance and Failure Analysis

Predictive maintenance is an offshoot of preventative maintenance whereby an organization analyses data in real time with the help of sensors and other devices and tries to prevent equipment failure from happening. Based on factors such as vibration, temperature, pressure or operational cycle, PM detects initial indicators of system deterioration or failure, offering opportunities for timely corrective measures to help avoid system failure or costly repairs. It optimizes time and frequency for performing maintenance work, increases equipment's life cycle, improves safety and slashes expenses by only fixing problems as the arise rather than having a standard time table like in preventive maintenance [14].

Conveyor stoppage means value loss because the chain transport means is designed for constant movement of material or products along a production line, thus any pause hinders the manufacturing process. Whenever a conveyor system ceases to run, everything comes to a stand still hence slows down productivity and employees wait. This disruption reduces revenue in a material way since production goals are not met and raw materials cannot be further processed. For instance, if a manufacturing plant produces 1000 units daily, and the conveyor stops for 2 hours, the company will lose 83 units, which is a lot of money lost. These interruptions reach every other stage or level of the supply chain and may in the process lead to inability to meet customers' delivery expectations and decreased profitability [6].

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

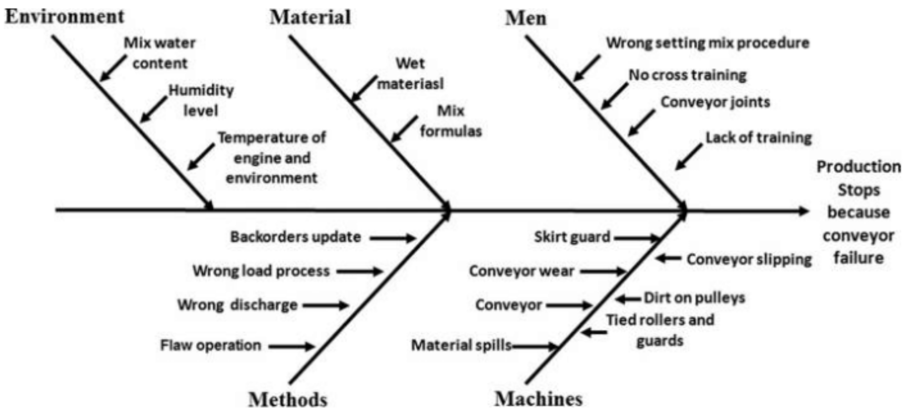


Figure 5: Cause effect diagram of conveyor failures

The figure above displays a tool that is used to determine the potentials of conveyors to fail in the process of manufacturing concrete blocks the Ishikawa or Fishbone diagram [15]. The diagram organizes potential causes into six categories as seen, parts of the cells are generally titled Environment, Man, Method, Machine, Material, and Measurement. The presented branches also show more particular details about the factors that cost time, including the conveyor alignment, wear at skirts and guards, loading errors, and other inefficiencies. This structure helps the project team focus and properly tackle the key concerns which may be hindering conveyor efficiency.

2.4 Vibration Sensor

Vibration is a mechanical phenomenon that involves a oscillation around equilibrium point. It can be deterministic if it can be precisely characterised or unsystematically. Studies stated that sound and vibration slightly identical because vibrating structures can produce sound, or pressure waves, which is also can cause vibration to structures [16]. There are many sensor that can use in vibration applications such as piezoelectric, accelerometer, and others. In this project, only 3 sensors has been chosen for the analysis which are MPU6050, ADXL335 and ADXL345.

2.4.1 Mpu6050 Accelerometer Module

The MPU6050 devices contain a 3-axis accelerometer and 3-axis gyroscope which are combined in one board. It is attached with Digital Motion Processor (DMP) able to processing complex 9-axis Motion Fusion algorithms. The sensor also provide temperature readings that can support for temperature variations that can effect the sensor accuracy Due to that, the MPU6050 is widely used microelectromechanical systems (MEMS) sensor. The sensor communicates with microcontroller via I2C, perfectly for integration into projects that relate with smartphones, gaming controller and much more [17].

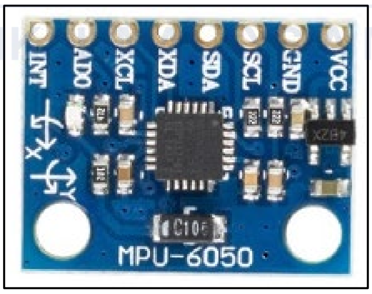


Figure 6: MPU6050 Breakout Board

According to the figure above [18], the MPU6050 sensor consist of 8 pins. VCC is Voltage supply pin which is normally 3.3 V or 5 V in this case it is 5 V. GND for grounding. SCL is for I2C communication, as is SDA. For additional sensors, there is Auxiliary Data Line known as XDA, and Auxiliary Clock Line that is abbreviated as XCL. SDA/OLED If this pin connected with GND, the least significant bit of I2C address is changed. And least but not the last is the Interrupt pin (INT) through which the host microcontroller is informed of an event [19].

Table 1: MPU6050 Absolute Maximum Ratings

Parameter	Rating
Supply Voltage, VDD	-0.5V to +6V
VLOGIC Input Voltage Level (MPU-6050)	-0.5V to VDD + 0.5V
REGOUT	-0.5V to 2V
Input Voltage Level (CLKIN, AUX_DA, AD0, FSYNC, INT, SCL, SDA)	-0.5V to VDD + 0.5V
CPOUT (2.5V ≤ VDD ≤ 3.6V)	-0.5V to 30V
Acceleration (Any Axis, unpowered)	10,000g for 0.2ms
Operating Temperature Range	-40°C to +105°C
Storage Temperature Range	-40°C to +125°C
Electrostatic Discharge (ESD) Protection	2kV (HBM); 200V (MM)
Latch-up	JEDEC Class II (2),125°C ±100mA

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

The table above shows the parameter ratings for MPU6050 [20], an integrated circuit used for motion tracking. The supply voltage (VDD) range from -0.5V to +6V, the VLOGIC input voltage level is between -0.5V and VDD + 0.5V. REGOUT voltage ranges from -0.5V to 2V. For CLKIN, AUX_DA, AD0, FSYNC, INT, SCL, and SDA input voltage levels, the range is -0.5V to VDD + 0.5V. The CPOUT voltage can go up to 30V. The device capable to withstand an acceleration of 10,000g for 0.2ms when it is unpowered. It operates within a temperature range of -40°C to +105°C and can stored between -40°C and +125°C. It also has electrostatic discharge (ESD) protection of 2kV (HBM) and 200V (MM), and complies with JEDEC Class II latch-up standards at 125°C with a tolerance of ±100mA [20].

2.4.2 Adxl335 Accelerometer Module

The ADXL335 is a small, thin, low power 3-axis accelerometer. It can provide signal conditioned voltage output. The purpose of this sensor is to measure acceleration with a small range of ±3 g and can detect both static acceleration of gravity in tilt sensing applications. Not only that, it is measure a dynamic acceleration resulting from motion, shock or vibration. Features of this sensor is it has analog voltage outputs proportional to acceleration along X, Y and Z. Due to the low power consumption, it makes it suitable for battery powered device. With that, it is an ideal for use in mobile phones, gaming controllers and other device that requiring accurate motion detection [21] [22].

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

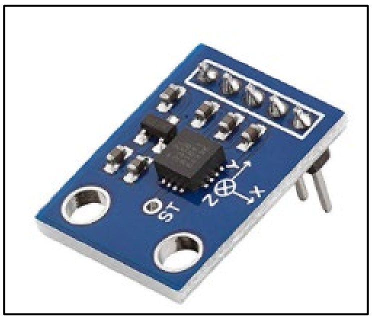


Figure 7: ADXL335 Breakout Board

The sensor needs two connections, the supply voltage known as VCC and the ground known as GND and three output leads. Output pins are user defined as XOUT, YOUT and ZOUT corresponding to measurements of X, Y and Z axis respectively. [21].

Table 2: ADXL335 Absolute Maximum Rating

Parameter	Rating
Supply Voltage, Vs	−0.3 V to +3.6 V
Acceleration (Any Axis, Unpowered)	10000g
Acceleration (Any Axis, Powered)	10000g
All Other Pins	(COM − 0.3 V) to (VS + 0.3 V)
Output Short-Circuit Duration (Any Pin to Common)	Indefinite
Temperature Range (Powered)	−55°C to +125°C
Temperature Range (Storage)	−65°C to +150°C

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

The table above shows the parameter ratings for ADXL335 [23]. It can endure the acceleration of 10000g on any axis for both unpowered and powered. The supply voltage (VS) range -0.3V to +3.6V. The other pins can handle voltages from (COM - 0.3 V) to (VS + 0.3 V). The sensor can operate an indefinite a short circuit duration forms any pin to common. The operating temperature range when powered is from -55°C to +125°C, and it can be stored at temperatures between -65°C and +150°C [23].

2.4.3 Adxl345 Accelerometer Module

The ADXL345 is a small compact with low power usage and has three axis accelerometer that provide high resolution measurements up to ±16g. It designed for various of application such as mobile devices, gaming systems and consumer electronics. One of the features is it provide a selectable measurement ranges of ±2g, ±4g, ±8g, and ±16g. Therefore, it is capable to detect a small changes in acceleration. This sensor has lower power consumption which is suitable for for battery powered devices. It includes an embedded functions such as tap detection, falling detection and motion detection. It operates over a wide voltage range around 2V to 3.6V [24].

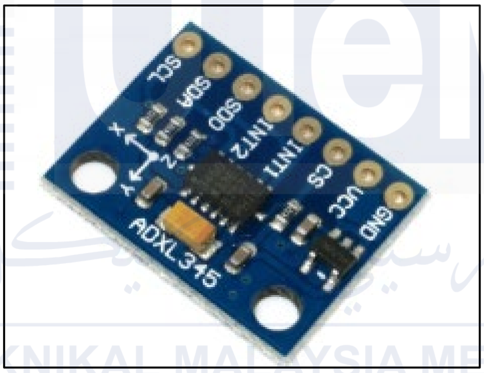


Figure 8: ADXL345 Breakout Board

It is used with 8 interface pins only. They are supply voltage (VS), ground (GND), chip select (CS), interrupt outputs (INT1, INT2), serial data (SDA), serial clock (SCL) & serial data output (SDO) [25].

Table 3: ADXL345 Absolute Maximum Ratings

Parameter	Rating
Supply Voltage, Vs	−0.3 V to +3.6 V

Supply Voltage, VDD I/O	−0.3 V to 3.6 V
Acceleration (Any Axis, Unpowered)	10000g
Acceleration (Any Axis, Powered)	10000g
All Other Pins	−0.3 V to 3.6 V
Output Short-Circuit Duration (Any Pin to Ground)	Indefinite
Temperature Range (Powered)	−40°C to +105°C
Temperature Range (Storage)	−40°C to +105°C

The table above shows a parameter ratings for ADXL345 [26]. The sensor can withstand acceleration of up to 10000g on any axis for both powered and unpowered. The supply voltage (VS) and VDD I/O voltage range from -0.3 V to 3.6 V, with all other pins only -0.3 V to 3.6 V. It can endure an indefinite short circuit duration from any pin to ground. The operational temperature range for the sensor when powered is -40°C to +105°C and also can be stored with the same temperature range [26].

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

CHAPTER 3

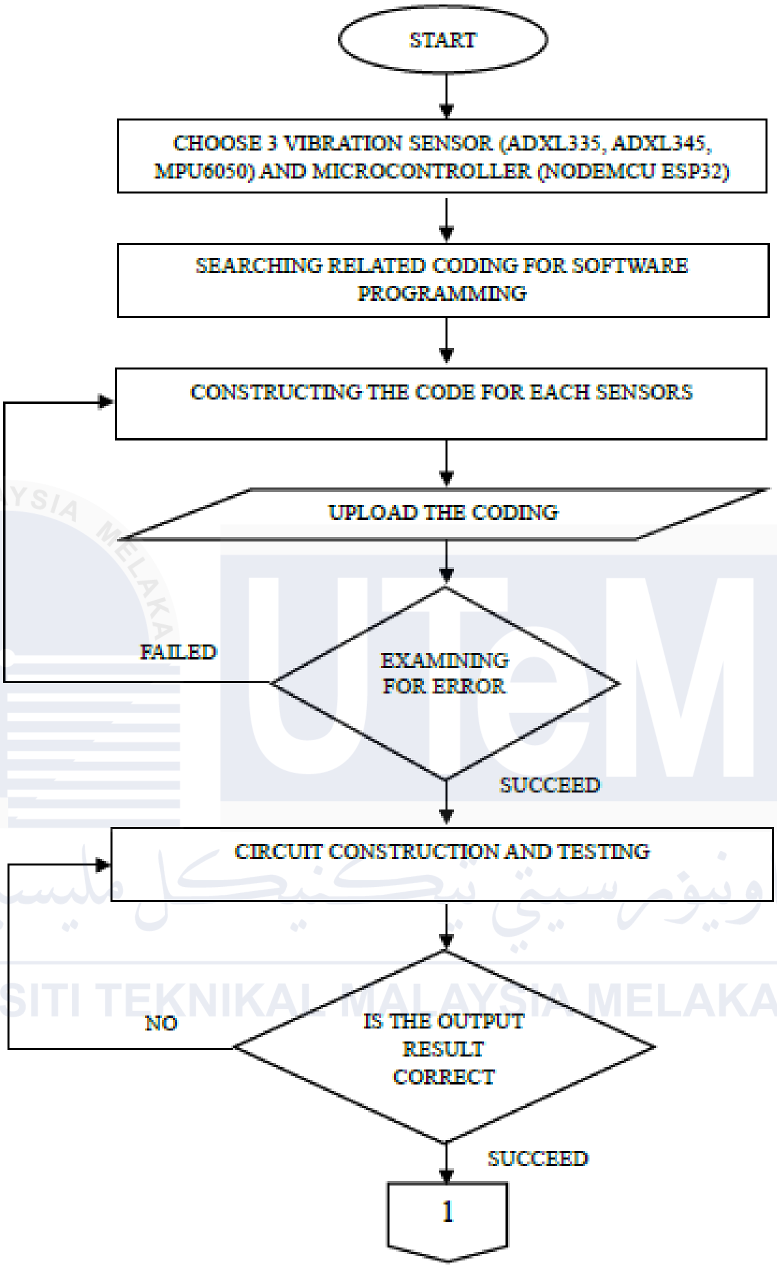
METHODOLOGY

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

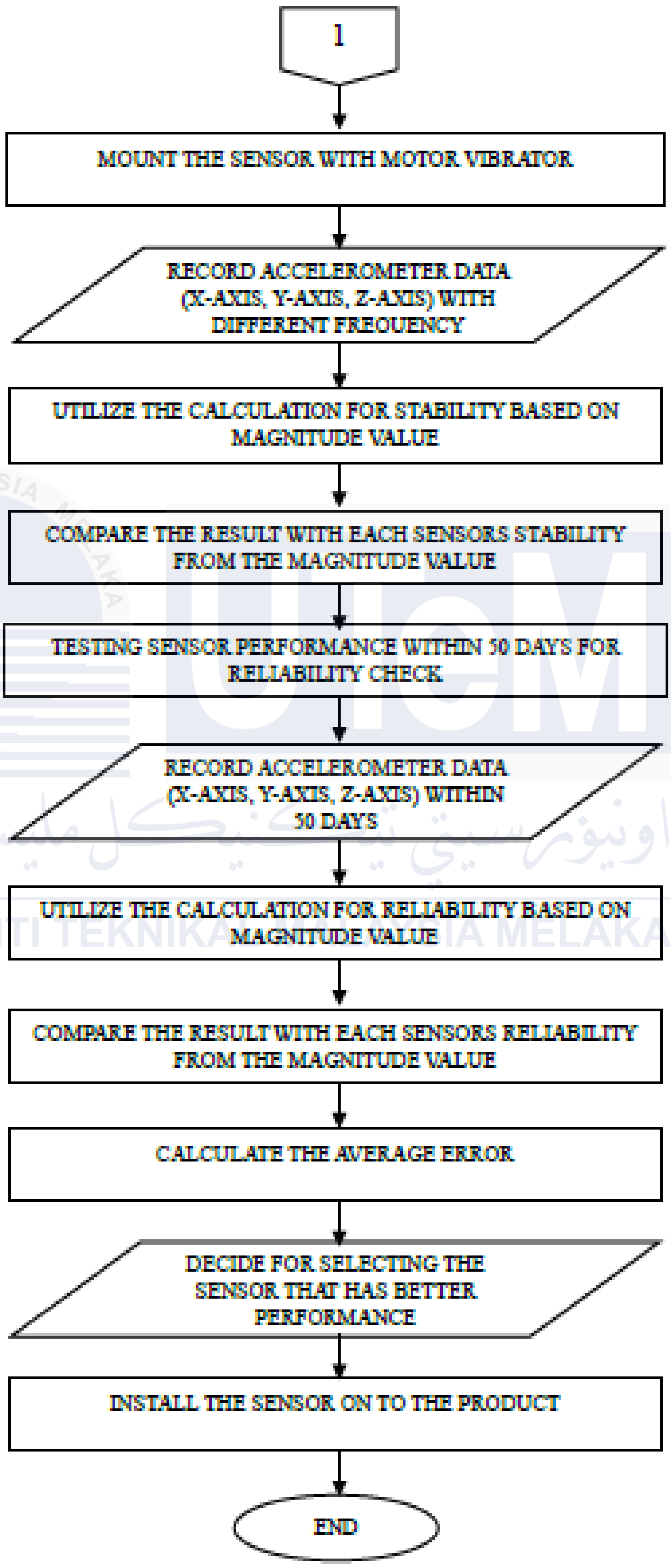
3.1 Introduction

The section of methodological analysis gives a rather comprehensible idea of the research methods in the study. Since the choice of the research design determines the whole research process from the start, it defines the type of research design selected and the reasons for selecting it. It also describe the data collection methods and the certain techniques used to do this project. In addition, for this project, it outlines the essential tools required to execute the project and expounds on the process of how the project is accomplished.

3.2 Analysis Flowchart



UNIVERSITI TEKNIKAL MALAYSIA MELAKA


1
MOUNT THE SENSOR WITH MOTOR VIBRATOR
RECORD ACCELEROMETER DATA (X-AXIS, Y-AXIS, Z-AXIS) WITH DIFFERENT FREQUENCY
UTILIZE THE CALCULATION FOR STABILITY BASED ON MAGNITUDE VALUE
COMPARE THE RESULT WITH EACH SENSORS STABILITY FROM THE MAGNITUDE VALUE
TESTING SENSOR PERFORMANCE WITHIN 30 DAYS FOR RELIABILITY CHECK
RECORD ACCELEROMETER DATA (X-AXIS, Y-AXIS, Z-AXIS) WITHIN 30 DAYS
UTILIZE THE CALCULATION FOR RELIABILITY BASED ON MAGNITUDE VALUE
COMPARE THE RESULT WITH EACH SENSORS RELIABILITY FROM THE MAGNITUDE VALUE
CALCULATE THE AVERAGE ERROR
DECIDE FOR SELECTING THE SENSOR THAT HAS BETTER PERFORMANCE
INSTALL THE SENSOR ON TO THE PRODUCT
END

3.2.1 Analysis Flowchart Explaination

The flowchart describes the strategy for the selection and validation of vibration sensor and microcontroller. The choosing of a microcontroller is done then three vibration sensors that are selected from a range of ADXL335, ADXL345, MPU6050. Then the relevant code for each sensor is developed with the support of the internet for other coding related resources. The circuit has been created and then tried out: The sensors are installed along with a motor vibrator to produce the vibration conditions, and mathematical conversions are made to determine the mean relative sensitivity RMS value to the individual sensors. These results are then cross checked with the reference sensor and the error values are then obtained.

The involve hardware sensors have been challenged to high vibration to check on the durability and reliability of the sensor, and know which sensor has a longer life span and which one is more reliable. During high speed motor vibration, acceleration data was obtained under different axes of the accelerometer. The objective was to check whether or not the sensors could withstand the stresses during operation and whether the time response detection capability remained as accurate as it was under the ideal conditions put into the experiment. This testing assists to determine the best sensor to this task that can last longer with high and consistent vibration input signals.

Once the correct output is obtained, then the mean value of the average error is computed, time data in second for each of the sensors. Finally, after having records of the various sensors, a decision is made on the development of the best performing sensor. Last but not least, the chosen sensor is assembled to the final product.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

3.3 Research Methodology

3.3.1 Accelerometer Comprehension

An accelerometer is a device that can measure acceleration forces in three directions being the X, Y, and Z directions. These axes work in three dimensional space in that the x axis measures horizonal acceleration, the y axis measures vertical acceleration while the z axis measures acceleration in the perpendicular direction of the other two axes. There are accelerometers that work on the basis of capacitive, piezoelectric or piezoresistive effects. In capacitive accelerometers, acceleration leads to capacitance change in view of displacement of a micro-mechanical structure [27].

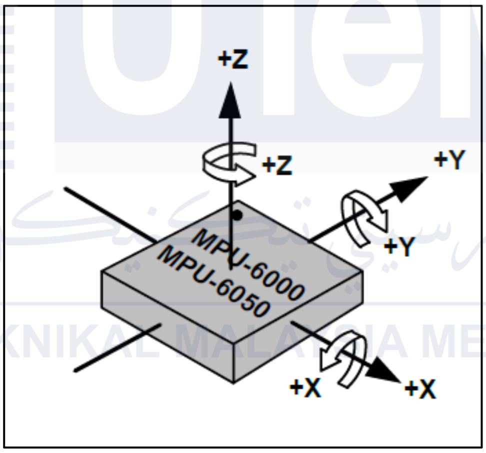


Figure 9: Accelerometer and Gyroscope Axes Orientation

Acceleration in each direction is denoted in g forces, which is just force created by gravity 1g, or roughly 9.81 m/s². Total acceleration that the accelerometer goes through is estimated as the components of axes acceleration by the x, y, and z formulas:

$$a_{total} = \sqrt{a_x^2 + a_y^2 + a_z^2} \tag{3.1}$$

Where a_{total} is the magnitude and a_x, a_y and a_z are the accelerations along the x, y, and z axes, respectively [28]. Additionally, the Root Mean Square (RMS) value of the acceleration data can be calculated to find an average measure of acceleration, which is suitable for analysing vibration data. The RMS value is given by:

$$a_{RMS} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} a_i^2} \tag{3.2}$$

Where a_{RMS} is the RMS acceleration, N is the number of samples and a_i is the acceleration value at the i-th sample [28].

The mean relative sensitivity of the accelerometer is also important for comparing different sensors and is calculated by taking the mean of the absolute values of the measured accelerations [29]. The accelerometer data x-axis, y-axis and z-axis is recorded at different frequencies to test sensor performance. The mean relative sensitivity RMS value is used to find the average performance of the sensor, which is then compared to reference sensors to determine error values and overall performance under varying conditions.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

3.4 Equipment Testing

3.4.1 Motor Vibrator

A motor vibrator is a mechanical device that generate the vibration. The vibration is often generated by an electric motor with an unbalanced mass on its driveshaft. There are many different types of vibrator. They are components of larger products such as smartphones, pagers, or video game controllers with a rumble feature [30].

Figure 10: Motor Vibrator

The purpose of motor vibrator is to use for generate the acceleration for the accelerometer sensor. The method to do this is by mount the motor vibrator on a steady object. Based on the previous research, to test the acceleration is by using a vibration shaker [7]. However, this project meant for the prototype and there is no such places that have the vibration shaker to sell nor to be afford by student. Vibration shaker activate using the frequency but motor vibrator could not. In that case, the vibrator will supplied by the power supply and frequency desired calculated based on the motor rotation (rpm). The formula to find the frequency based on rotation (rpm) shown as below [31]:

$$Frequency(Hz) = \frac{motor\ rotation(rpm)}{60} \quad (3.3)$$

This explained that 1Hz equals to 60rpm. Additionally, frequency to Revolutions per Minute conversion can be refer to table as below:

Table 4: Frequency to Revolutions per Minute conversion

Hertz (Hz)	Revolutions per Minute (rpm)
1	60

2	120
3	180
4	240

3.4.2 Digital Tachometer

A tachometer is an instrument measuring the rotation speed of a shaft or disk, as in a motor or other machine. he device usually displays the revolutions per minute (RPM) on a calibrated analogue dial, but digital displays are increasingly common [32].

Figure 11: Digital Tachometer

This method helps to detect the motor vibrator rotation to detect the revolutions per minute in order to convert it into frequency according to sets of testing frequency vibration.

3.5 Circuit

It will also ascertain how the schematic circuit is connected In this section. This will explicate the circuit in detail as to facilitate in its understanding. The project

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

requires three circuits for every sensor that interfaces with the microcontroller because it is a trinary system that requires three sensors to operate and analyze the acceleration information at any one time.

3.5.1 Esp32 With Adxl345

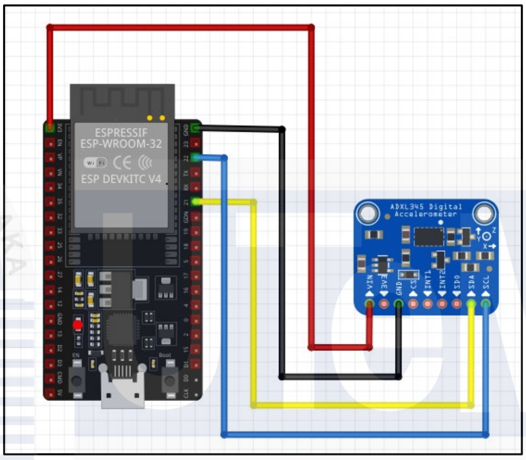


Figure 12: Schematic Circuit Esp32 with ADXL345

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

3.5.2 Esp32 With Adxl335

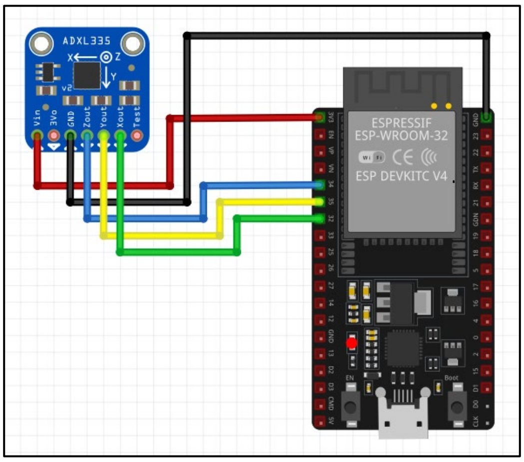


Figure 13: Schematic Circuit Esp32 with ADXL335

3.5.3 Esp32 With Mpu6050

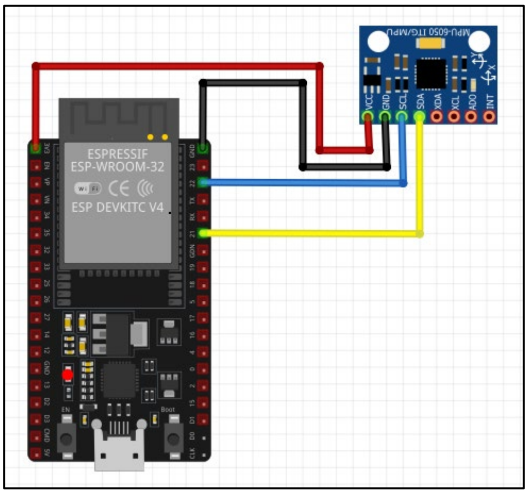


Figure 14: Schematic Circuit Esp32 with MPU6050

3.5.4 Circuit Hardware

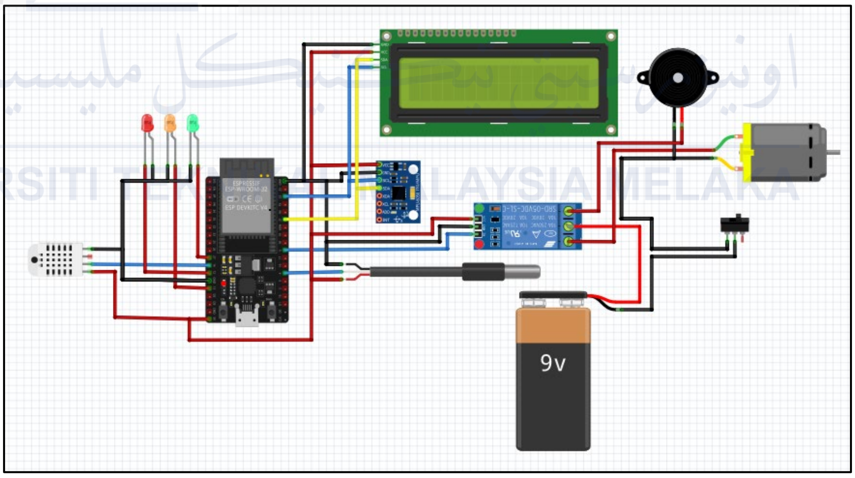


Figure 15: Circuit Hardware

This circuit is designed to monitor and control a motor system using an ESP32 microcontroller. It measures temperature with a DHT22 sensor and vibration with an MPU6050 sensor, displaying real-time data on an LCD. A relay manages motor operation, while LEDs and a buzzer provide alerts for system faults or abnormal

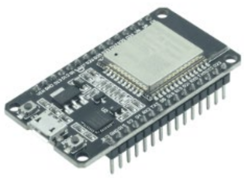
UTeM UNIVERSITI TEKNIKAL MALAYSIA MELAKA

conditions. If temperature or vibration exceeds predefined thresholds, the ESP32 can shut off the motor and trigger a warning. A push button allows manual reset, and the system is powered by a 9V battery or any supply within 9–12V, making it ideal for safety monitoring and fault diagnosis in motor conveyor applications.

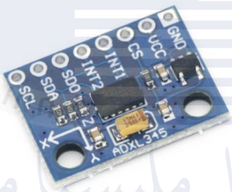
3.6 Components

Because all of the components required to construct the testing, analysis, and conveyor are well-known for creating electronic projects, they are readily available in the market. The function of each component used in the project is displayed in the table below. The NodeMCU ESP32, ESP32 Base, ADXL335, ADXL345, MPU6050, power supply, and motor conveyor are among the planned components.

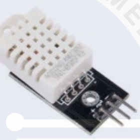
Table 5: List Of The Component For The Project

Component	Description
NodeMCU ESP32 	One of the components of this project is the ESP32 with which the sensor is tested and the results are displayed. The coding of each sensor will then upload the data into the microcontroller, allowing the microcontroller to create accelerometer data according to each of the frequencies stated. Besides, it helps to link an IoT system with an application for both, the control and the monitoring processes.
ESP32 Base	The simplest part to accommodate the microcontroller is the ESP32 base. Using a breadboard is different from what it is described here. Also, it provides the

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

	extension terminal to make easy connection with sensors in which many pins are included.
ADXL335 	The ADXL335 is a compact, thin, full 3-axis accelerometer with signal-conditioned voltage outputs that consumes little power. The sensor will be used as a testing to observe the performance of the acceleration data.
ADXL345 	The ADXL345 is a compact, thin, low-power, three-axis accelerometer that can measure up to ±16 g with excellent resolution. The sensor will be used as a testing to observe the performance of the acceleration data.
MPU6050 	A 3-axis accelerometer and a 3-axis gyroscope are combined onto one chip in the highly integrated motion processing device known as the MPU6050. The sensor will be employed in an experiment to monitor the acceleration data's performance.
12V Power Supply 	Power supply is used to supply electricity to motor conveyor so that it could operate for the period of the project would take. It is an electrical machine that generates a 12v supply to the system with no variations in the supply voltage.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

12V Worm Gear Motor (Motor Conveyor) 	A 12V worm gear motor is a kind of electric motor with a worm gear mechanism to produce high torque and low speed. It is also utilized in motor conveyor systems.
DHT22 Sensor 	This sensor used in the system is known as the DHT22 sensor is responsible for administering humidity surrounding the convener. When high humidity is sensed, the system is always beeping, signaling the technician in case of emergence of a problem or damage.
Temperature Sensor ds18b20 	This sensor used in the system is known as the DHT22 sensor is responsible for administering humidity surrounding the convener. When high humidity is sensed, the system is always beeping, signaling the technician in case of emergence of a problem or damage.
LCD 16x0 	The 16x2 LCD can be introduced to the conveyor system to show readings like a motor temperature, system condition, or any operating characters which are useful for monitoring or even maintenance goals as they are often straightforward and easy to read.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

3.7 Block Diagram

The block diagram starts with the smartphone through which the control and monitoring will be done as presented below. The use of the monitoring system is to provide the state on the acceleration, whether it is good or not depending with the state of the conveyor. The shut down action of the system will then take place immediately if the conveyors has abnormally or badly vibrating; because usually, the conveyor has a major component failure for instance. Our program is written and controlled by ESP32 microcontroller that is considered to be the brain of the developed system. It measures acceleration and may be wirelessly controlled by an application running on a smart phone. The accelerometer sensor is then utilized to measure vibrations of the conveyors. Last but not least, the conveyor system is one of the main projects carried out by the company.

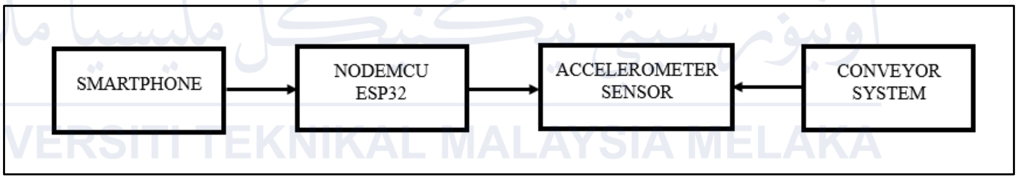


Figure 16: Block Diagram Of The Project Analysis

The figures above show the block diagram for a simplified conveyor condition monitoring system that is a prototype using ESP32 NodeMCU as the main controller, vibration sensor to check for mechanical problems, temperature sensor for overheating problems, and humidity sensor to check for appropriate conditions. For continuous display of local data, the system has a 16 by 4 LCD; it has a buzzer to notify when the limit levels are hit; and has a DC motor to symbolise the conveyor being monitored. Sensors acquired data transmitted to the ESP32 for further analysis and then sent to a smartphone via the Wi-Fi connection for remote monitoring decreasing the time for maintenance work and enhancing system dependability.

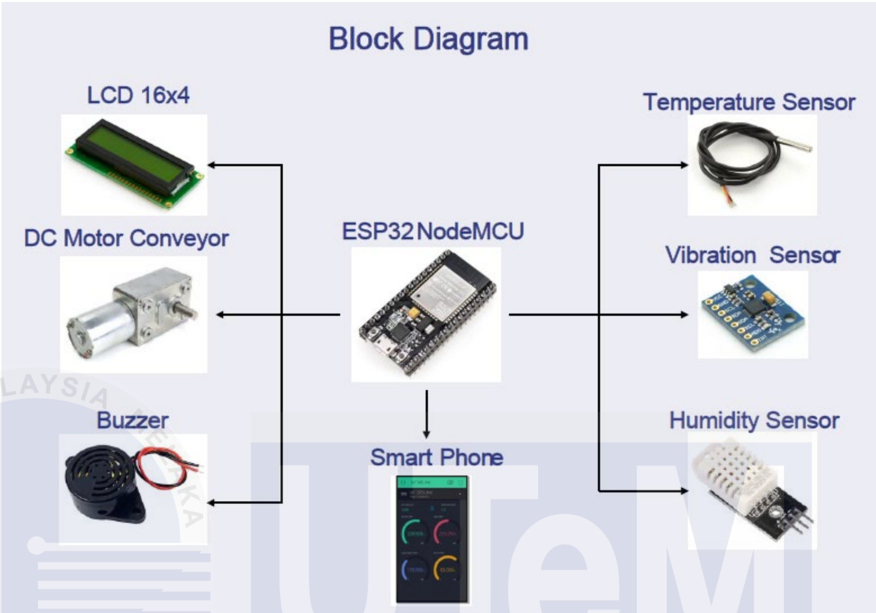


Figure 17: Block Diagram Of The Project Prototype

اونيورسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

3.8 Method Implemented

The functionality and analysis of the prototype must be validated using this technique approach that was developed for the product. Furthermore, the tactics are based in the significant study concerning vibration analysis and sensor performance. Both hardware and software techniques were used in the process.

3.8.1 Software Method

3.8.1.1 Arduino Ide

The main program employed in developing this project is the Arduino IDE. IDE is an abbreviation that is short for Integrated Development Environment. The primary function of Arduino Integrated Development Environment is to program the

Arduino Module. It makes code compilation again simple so that anyone who generates the files may begin understanding it without necessarily having prior knowledge about it. Stated authors pointed out that C and C++ languages are fully interoperable with this environment [33]. Each sensor needs to encode on its own as well. The sensor will not be the same for this reason because it has different specification and a different terminal, however it can be adjusted to make the default value equivalent. You may download the coding from the internet. As a way of making the device operate, one has to rely on the given source code, check for sems and then upload the code to the ESP32.

3.8.1.1.1 Coding For Esp32 With Adxl335

```
#define X_PIN A0
#define Y_PIN A3
#define Z_PIN A4

// ADXL335 constants
const float VOLTAGE_REF = 3.3; // Voltage reference for the analog input (3.3V for ESP32)
const float ZERO_G_VOLTAGE = VOLTAGE_REF / 2; // Zero-g voltage (typically half of the reference voltage)
const float SENSITIVITY = VOLTAGE_REF / 10; // Sensitivity is 300mV/g, convert to V/g

void setup(void) {
  Serial.begin(115200);
  while (!Serial)
    delay(10); // will pause Zero, Leonardo, etc until serial console opens

  Serial.println("ADXL335 test!");

  Serial.println("");
  delay(100);
}

void loop() {
  /* Get new sensor readings */
  int rawX = analogRead(X_PIN);
  int rawY = analogRead(Y_PIN);
  int rawZ = analogRead(Z_PIN);

  // Convert raw values to voltages
  float voltageX = rawX * (VOLTAGE_REF / 4095.0); // For ESP32, 12-bit ADC
  float voltageY = rawY * (VOLTAGE_REF / 4095.0); // For ESP32, 12-bit ADC
  float voltageZ = rawZ * (VOLTAGE_REF / 4095.0); // For ESP32, 12-bit ADC
```

Figure 18: Coding For ESP32 With ADXL335

3.8.1.1.2 Coding For Esp32 With Adxl345

```
#include <Wire.h>
#include <Adafruit_Sensor.h>
#include <Adafruit_ADXL345_U.h>

// Create an ADXL345 accelerometer object
Adafruit_ADXL345_Unified accel = Adafruit_ADXL345_Unified(12345);

void setup(void) {
  Serial.begin(115200);
  while (!Serial)
    delay(10); // will pause Zero, Leonardo, etc until serial console opens

  Serial.println("Adafruit ADXL345 test!");

  // Try to initialize!
  if (!accel.begin()) {
    Serial.println("Failed to find ADXL345 chip");
    while (1) {
      delay(10);
    }
  }
  Serial.println("ADXL345 Found!");

  accel.setRange(ADXL345_RANGE_16_G);
  Serial.print("Accelerometer range set to: ");
  switch (accel.getRange()) {
  case ADXL345_RANGE_2_G:
    Serial.println("+-2G");
    break;
  case ADXL345_RANGE_4_G:
    Serial.println("+-4G");
```

Figure 19: Coding For ESP32 With ADXL345

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

3.8.1.1.3 Coding For Esp32 With Mpu6050

```
#include <Adafruit_MPU6050.h>
#include <Adafruit_Sensor.h>
#include <Wire.h>

Adafruit_MPU6050 mpu;

void setup(void) {
  Serial.begin(115200);
  while (!Serial)
    delay(10); // will pause Zero, Leonardo, etc until serial console opens

  Serial.println("Adafruit MPU6050 test!");

  // Try to initialize!
  if (!mpu.begin()) {
    Serial.println("Failed to find MPU6050 chip");
    while (1) {
      delay(10);
    }
  }
  Serial.println("MPU6050 Found!");

  mpu.setAccelerometerRange(MPU6050_RANGE_8_G);
  Serial.print("Accelerometer range set to: ");
  switch (mpu.getAccelerometerRange()) {
  case MPU6050_RANGE_2_G:
    Serial.println("+-2G");
    break;
  case MPU6050_RANGE_4_G:
    Serial.println("+-4G");
    break;
```

Figure 20: Coding For ESP32 With MPU6050

3.8.1.1.4 Coding For Project Prototype

```
mpu.getEvent(&a, &g, &temp);
sensors.requestTemperatures();
float temperatureC = sensors.getTempCByIndex(0);

// Calculate magnitude of acceleration vector
float magnitude = sqrt(pow(a.acceleration.x, 2) + pow(a.acceleration.y, 2) + pow(a.acceleration.z, 2));

// Critical and fault condition logic
bool criticalCondition =
    a.acceleration.x > 1.1 || a.acceleration.x < -0.1 ||
    a.acceleration.y > 0.73 || a.acceleration.y < -0.47 ||
    a.acceleration.z > 10.16 || a.acceleration.z < 8.96;

bool faultCondition =
    a.acceleration.x > 0.8 || a.acceleration.x < 0.2 ||
    a.acceleration.y > 0.43 || a.acceleration.y < -0.17 ||
    a.acceleration.z > 9.86 || a.acceleration.z < 9.26;

if (criticalCondition) {
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("Critical");
  Serial.println("Critical");
  digitalWrite(buzzerRelayPin, HIGH);
  digitalWrite(redLedPin, HIGH);
  digitalWrite(orangeLedPin, LOW);
  digitalWrite(greenLedPin, LOW);
  faultNotificationSent = false; // Reset fault notification flag
```

Figure 21: Coding For Project Prototype

3.8.1.2 Blynk App

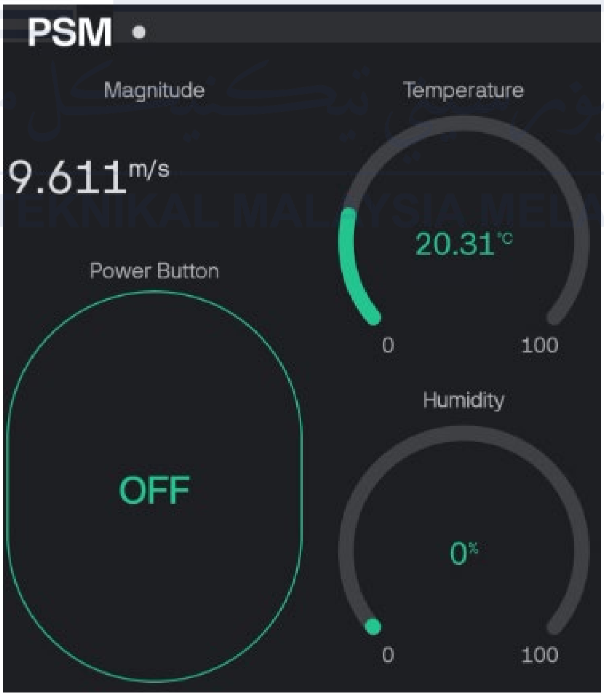


Figure 22: Blynk Interface

3.8.2 Hardware Method

3.8.2.1 Analysis Hardware

When engaging in the testing of the study and analysis, particular equipment needs to be prepared as follows. In order to have proper vibration data, there must be stability of the item that the sensor is placing. In addition to the motor vibrator there are additionally three accelerometer sensors placed on the item. If you do not want the sensor to move, one must secure the sensor and motor vibrator using double sided-scotch tape. The vibrator will be powered by the 12v variable power supply where by the voltage of the power supply can be changed to change the spin of the vibration. The rotation will be dependent on the frequency parameters to establish the rate of acceleration data acquired.

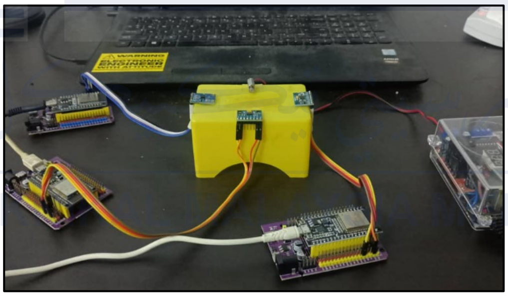


Figure 23: 3 Mounted Accelerometer Sensor On Object For Testing

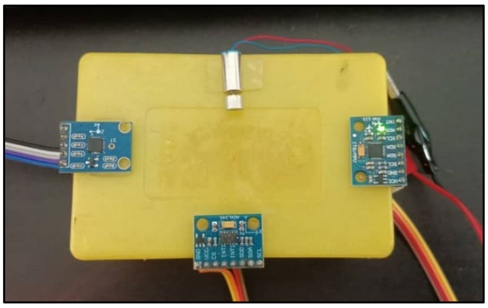


Figure 24: 3 Mounted Accelerometer Sensor On Object For Testing (Top View)

3.8.2.2 Prototype Hardware

Having chosen the most appropriate and functional vibration sensor for the project, the final touches to the project prototype were developed with the view to enhancing its performance and reliability as dictated by the conveyor system. The exact decision was made after cross checking and comparing the various test results to decide which sensor gave consistent high stability and low errors when exposed to high speed vibrations. After the final decision has been made regarding which type of sensor is the most suitable for the application, it forms part of a system together with temperature and humidity sensors as a means of continuously monitoring the performance of the conveyor. This approach enables an early detection of the weak areas they want addressed when conducting an analysis by ensuring that the prototype in question delivers accurate and reliable data.

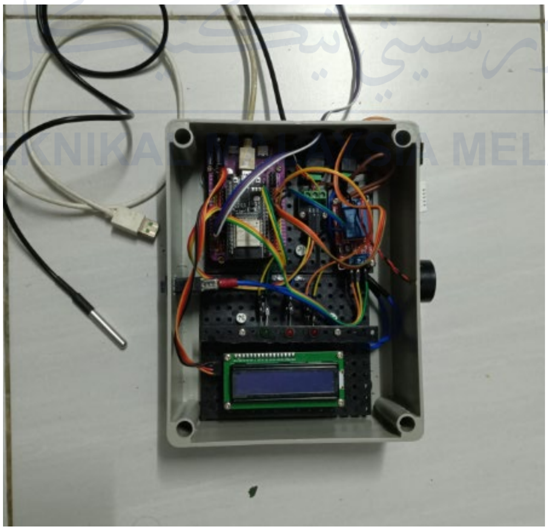


Figure 25: Project Device

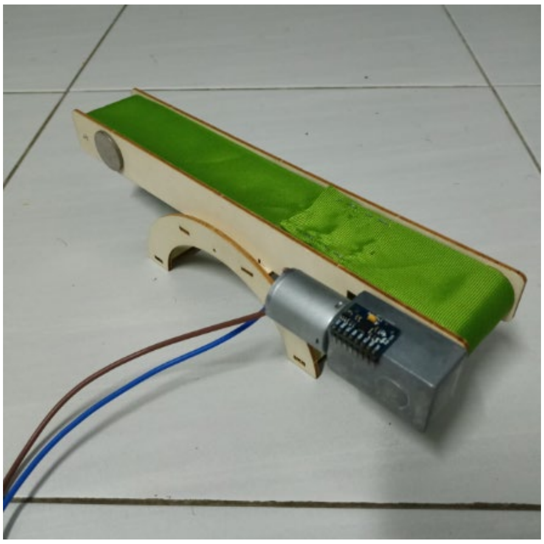


Figure 26: Conveyor Prototype

3.9 Project Costing

There are several hardware and component elements in this project. The parts involved are listed in the table below, along with tools for investigation and study including a motor vibrator and digital tachometer.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

3.9.1 Component Costing

Table 6: List Of Components Costing

No.	Item	Quantity	Price (RM)	Total (RM)
1.	NodeMCU ESP32 Development Board Type-C	3	17.17	51.51
2.	ESP32 Expansion Board 38 Pins	3	8.69	26.07
3.	GY-291 ADXL345 3-Axis Accelerometer	1	8.80	8.80

4.	GY-521 MPU6050 3-Axis Gyroscope & Accelerometer	1	10.50	10.50
5.	GY-61 ADXL335 3-Axis Accelerometer	1	17.16	17.16
6.	DHT22 Humidity Moisture and Temperature Sensor Module	1	16.00	16.00
7.	LCD (16x2) Yellow Backlight	1	10.50	10.50
8.	Temperature Sensor DS18B20 Module	1	2.99	2.99
9.	Buzzer 6-12V c/w Wire	1	3.00	3.00
10.	Jumper Wire	1	3.33	3.33
11.	LED light emitting diode 100pcs	1	5.19	5.19
Total (RM)				165.05

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

3.9.2 Testing And Analysis Equipment Costing

Table 7: List Of Testing And Analysis Equipment Costing

No.	Item	Quantity	Price (RM)	Total (RM)
1.	Digital Tachometer	1	28.99	28.99
2.	(3-4.5V)Vibration Motor 18000rpm	1	6.99	6.99
Total (RM)				35.98

3.9.3 Hardware Costing

Table 8: List Of Hardware Costing

No.	Item	Quantity	Price (RM)	Total (RM)
1.	DC Worm Geared Motor 4632	1	25.99	25.99
2.	12V 3.2A Power Supply	1	12.90	12.90
3.	863 Ip65 Weather Proof Pvc Enclosure Junction Box	1	10.50	10.50
4.	Conveyor Belt DIY 1 Set	1	15.99	15.99
Total (RM)				65.38

UTeM
اونيۏرسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

CHAPTER 4

RESULT AND ANALYSIS

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

4.1 Introduction

These are the three overall goals set out in Chapter 1 of this report and these are as follows; This report measures the response of the available vibration sensors to the frequency and provide a physical measurement of each of the three sensors, designing an automated conveyor with alarm that will shut the conveyor system down when unusual vibrations are detected to prevent risk of injury to personnel and to check on the vibration condition of the conveyor system using IoT technology. It also constructs a fake automated conveyor line to see if such a system is feasible and safe. The implications and actual findings of the current study for each of these areas will be discussed and assessed throughout this chapter.

4.2 Result And Analysis

The analysis and research segment mainly responds to the first two outcomes, which are the description of three kinds of vibration sensors. Further, it assesses the reliability and stability of these sensors in order to identify the option with a longer duration for use in a conveyor system.

4.2.1 Evaluation Performance Of Various Vibration Sensors By Analysing Their Response Across Different Frequencies And Identifying Trends Specific To Each Sensor.

4.2.1.1 Frequency Based Vibration Output

The below table shows the vibration output captured from three distinct sensor including ADXL335, MPU6050 and ADXL345 for the various frequencies corresponding to the motor speeds of 23Hz to 144Hz. These tests were planned to cover high vibration situations to check the viability of the sensors. The recorded data explain how stable, the sensors are as well as how efficient they are in detecting vibrations at different frequencies. This kind of comparison determines the best sensor to be incorporated in the conveyor system and one that equally works best at higher motor speeds.

Table 9: Frequency Based Vibration Output For Each Sensors

Motor Vibrator		Vibration Sensor								
		ADXL335			MPU6050			ADXL345		
Motor S	Frequency (I	X Axis	Y Axis	Z Axis	X Axis	Y Axis	Z Axis	X Axis	Y Axis	Z Axis
1380	23	-1.05	0.21	9.3	-1.45	0.27	9.32	0.24	-0.2	9.45
		-1.04	0.22	9.31	-1.47	0.27	9.31	0.24	-0.2	9.34
		-1.04	0.22	9.31	-1.46	0.26	9.33	0.24	-0.16	9.38
		-1.03	0.21	9.31	-1.47	0.25	9.32	0.31	-0.24	9.41
		-1.04	0.2	9.31	-1.46	0.26	9.32	0.31	-0.2	9.49
RMS Axis Data		1.04	0.2121	9.308	1.462	0.2621	9.32	0.2702	0.2016	9.4141
2220	37	-1.1	0.2	9.2	-1.45	0.27	9.33	0.24	-0.16	9.45
		-1.1	0.2	9.21	-1.44	0.27	9.34	0.24	-0.16	9.41
		-1.1	0.17	9.21	-1.44	0.25	9.33	0.27	-0.2	9.34
		-1.1	0.19	9.1	-1.44	0.26	9.33	0.24	-0.16	9.41
		-1.11	0.26	9.34	-1.44	0.28	9.34	0.24	-0.16	9.41
RMS Axis Data		1.102	0.2062	9.2123	1.442	0.2662	9.334	0.2463	0.1688	9.4041
2760	46	-1.01	0.23	9.11	-1.42	0.28	9.33	0.24	-0.2	9.41
		-1.04	0.25	9.11	-1.45	0.26	9.34	0.31	-0.2	9.41
		-0.99	0.26	9.19	-1.42	0.26	9.32	0.24	-0.12	9.34
		-0.98	0.22	9.1	-1.44	0.27	9.32	0.24	-0.12	9.38
		-1.09	0.29	9	-1.43	0.24	9.32	0.39	-0.2	9.41
RMS Axis Data		1.0228	0.2512	9.1022	1.432	0.2623	9.326	0.2902	0.1725	9.39
3600	60	-1.19	0.21	9.01	-1.58	0.27	9.31	1.02	0.08	9.34
		-1.22	0.25	9.05	-1.52	0.34	9.29	-1.26	-0.43	8.94
		-1.1	0.39	9.12	-1.47	0.4	9.32	1.14	0.27	9.34
		-1.24	0.21	9.09	-1.41	0.39	9.33	-0.78	-0.24	8.94
		-1.31	0.36	9.24	-1.21	0.34	9.35	1.33	0.35	9.77
RMS Axis Data		1.2139	0.2941	9.1023	1.4436	0.3511	9.32	1.1229	0.2981	9.2712
4380	73	-1.07	0.16	9.31	-1.47	0.42	9.36	2.43	-2	10.83
		-1.27	0.11	9.19	-1.32	0.28	9.37	-1.51	0.98	8.2
		-1.1	0.18	9.32	-1.17	0.27	9.39	2.21	-1.8	10.32
		-1.19	0.01	9.14	-1.2	0.24	9.38	-1.85	0.75	8.24
		-1.31	0.09	9.11	-1.17	0.22	9.38	1.01	-0.75	9.12
RMS Axis Data		1.1916	0.1251	9.2144	1.2713	0.2945	9.376	1.8715	1.3657	9.4032
5520	92	-1.02	0.24	9.23	-1.74	0.4	9.35	1.48	-1.06	9.06
		-1.34	0.21	9.01	-1.64	0.36	9.36	-0.12	-0.47	8.39
		-0.89	0.34	9.31	-1.59	0.29	9.36	1.01	-1.01	9.55
		-1.41	0.4	9.19	-1.41	0.21	9.41	0.2	-0.13	8.67
		-0.93	0.29	9	-1.27	0.19	9.4	0.01	-0.08	10.28
RMS Axis Data		1.1385	0.3038	9.1488	1.5392	0.3013	9.376	0.8081	0.6911	9.2144
6960	116	-1.25	0.02	9.11	-1.22	0.14	9.38	2.39	-1.57	9.96
		-0.89	0.09	9.19	-1.31	0.15	9.4	-0.9	-0.24	8.39
		-1.23	0.12	9.45	-1.39	0.24	9.38	2.08	-1.37	9.06
		-1.29	0.1	9.08	-1.44	0.25	9.4	-0.12	-0.47	8.39
		-1.32	0.19	9.22	-1.69	0.39	9.35	1.26	-1.22	10.08
RMS Axis Data		1.2062	0.1175	9.2109	1.4189	0.2507	9.382	1.578	1.1053	9.2052
8640	144	-0.94	0.26	9.41	-1.03	0.3	9.51	0.31	-0.55	6.24
		-1.54	0.19	9.17	-0.93	0.88	9.45	-1.77	0.55	11.85
		-1.49	0.09	9.06	-1.64	0.46	8.76	0.27	2.94	9.81
		-1.03	0.45	8.99	-1.58	-0.28	8.17	0.91	1.26	14.87
		-0.98	0.28	9.89	-0.66	-0.18	9.43	2.08	-2.66	5.84
RMS Axis Data		1.2245	0.2802	9.3097	1.2286	0.4872	9.0791	1.3005	1.8927	10.304

4.2.1.2 Adxl335 Vibration Output

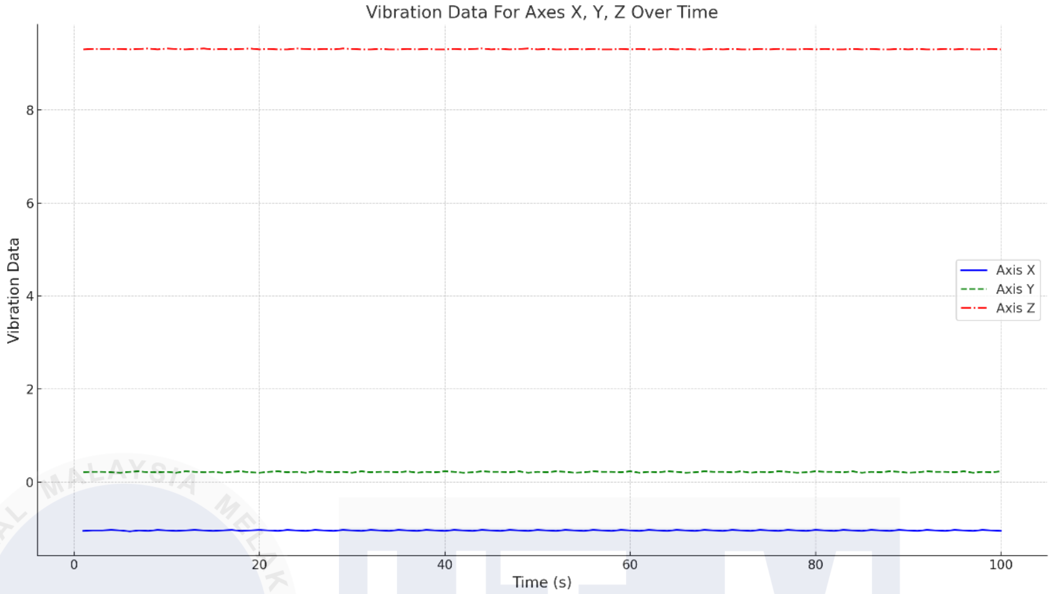


Figure 27: ADXL335 Output at 23Hz

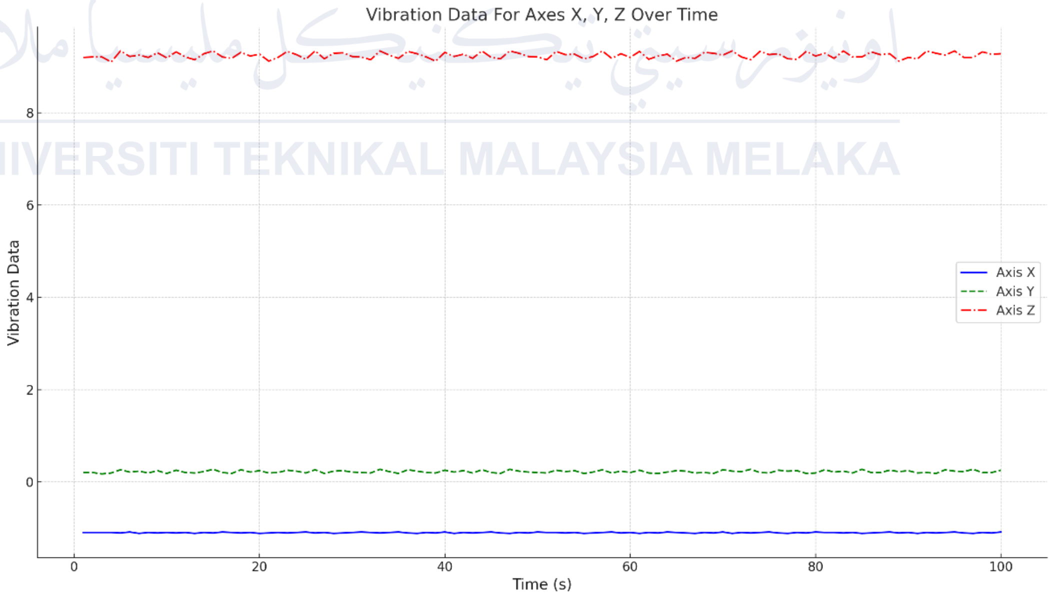


Figure 28: ADXL335 Output at 37Hz

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

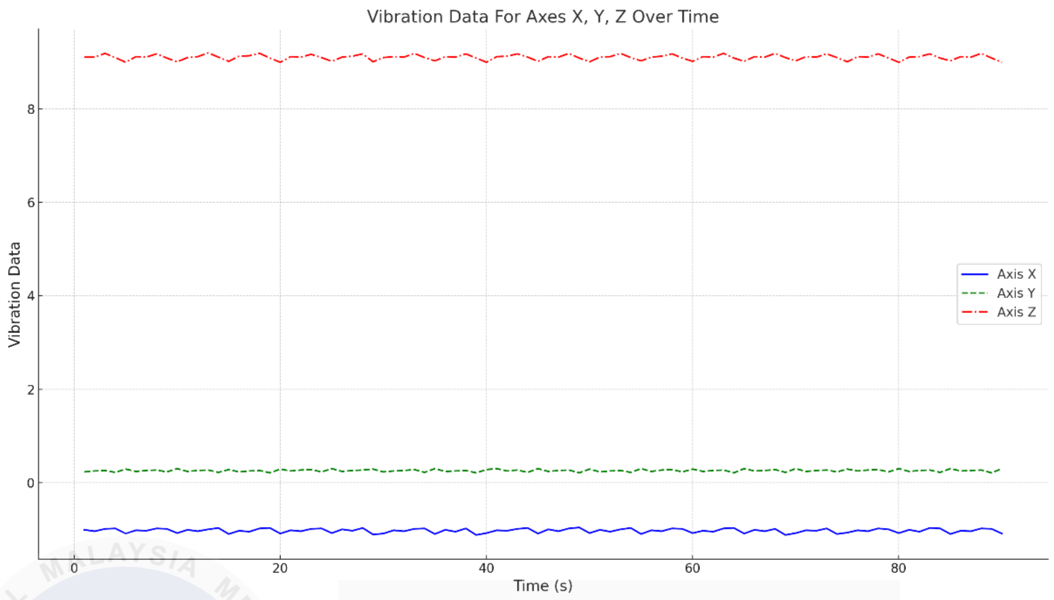


Figure 29: ADXL335 Output at 46Hz

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

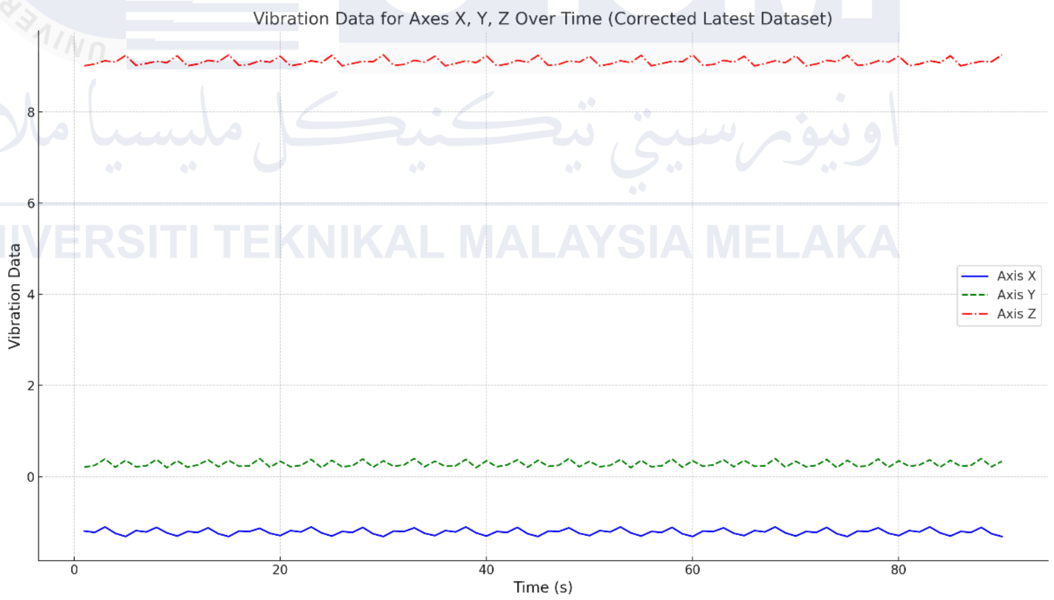


Figure 30: ADXL335 Output at 60Hz

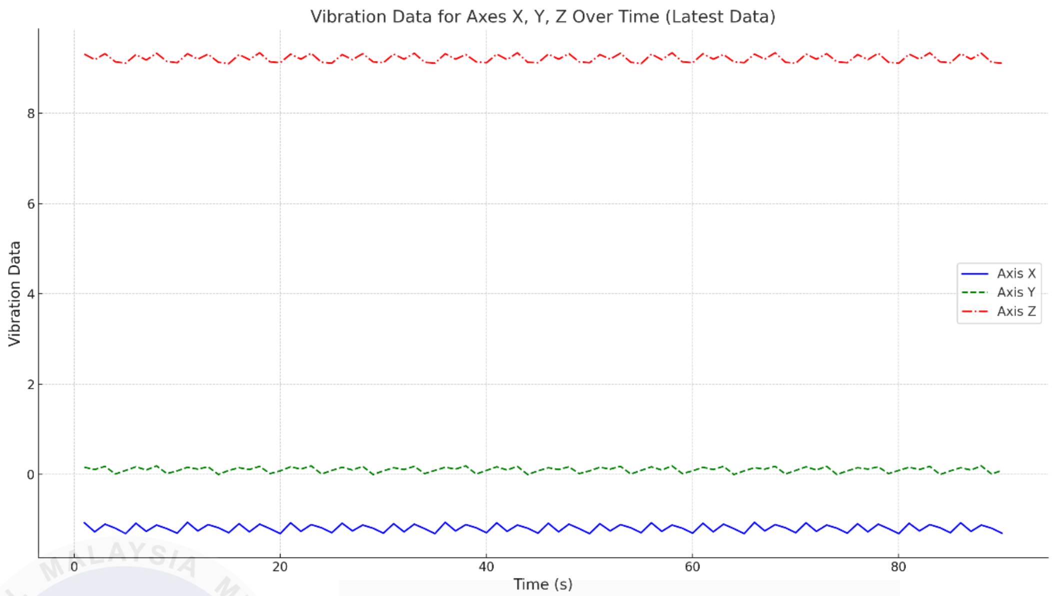


Figure 31: ADXL335 Output at 73Hz

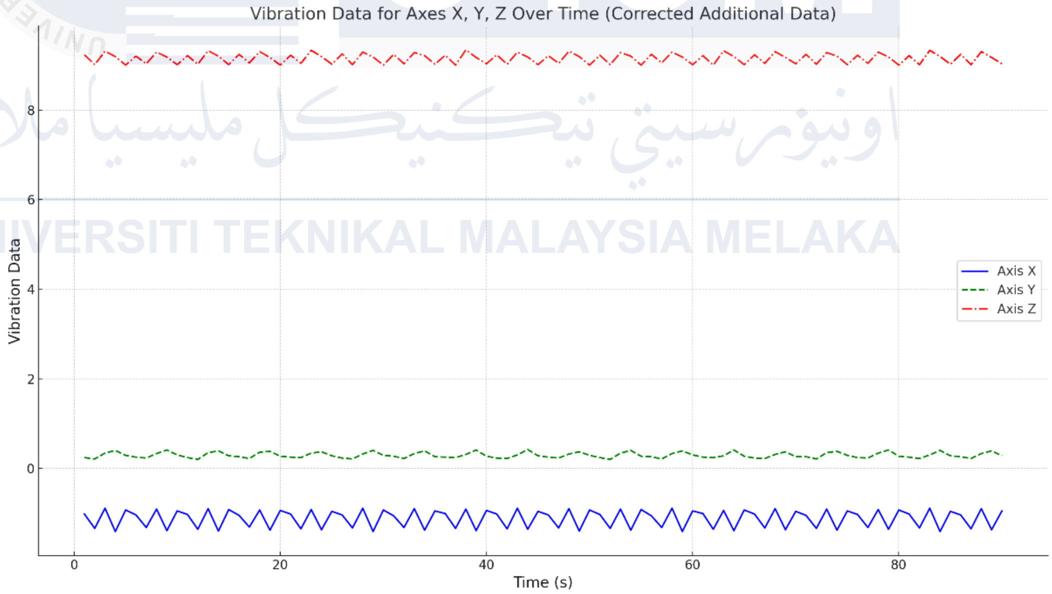


Figure 32: ADXL335 Output at 92Hz

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

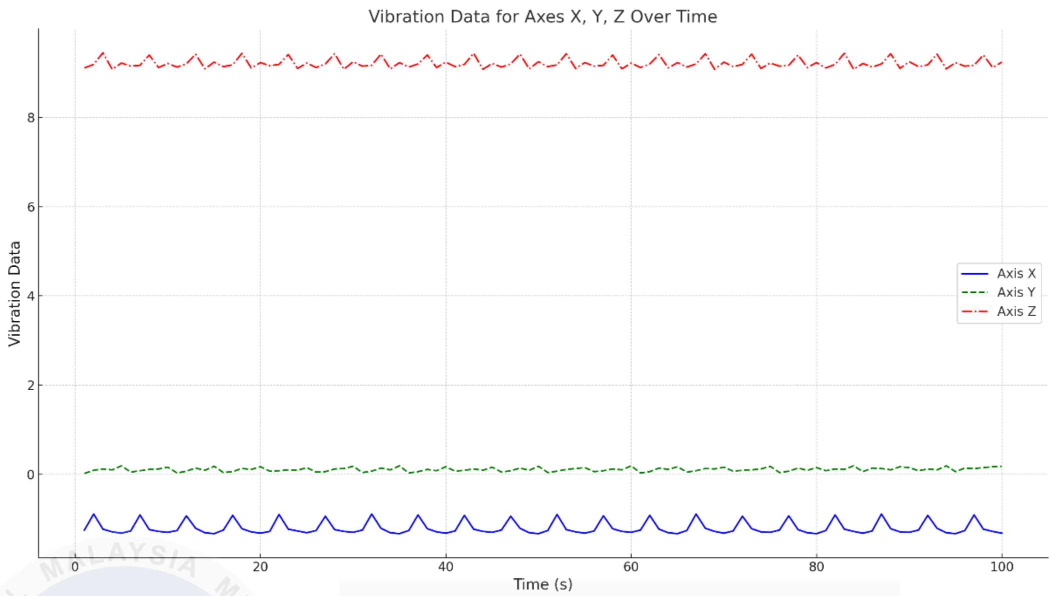


Figure 33: ADXL335 Output at 116Hz

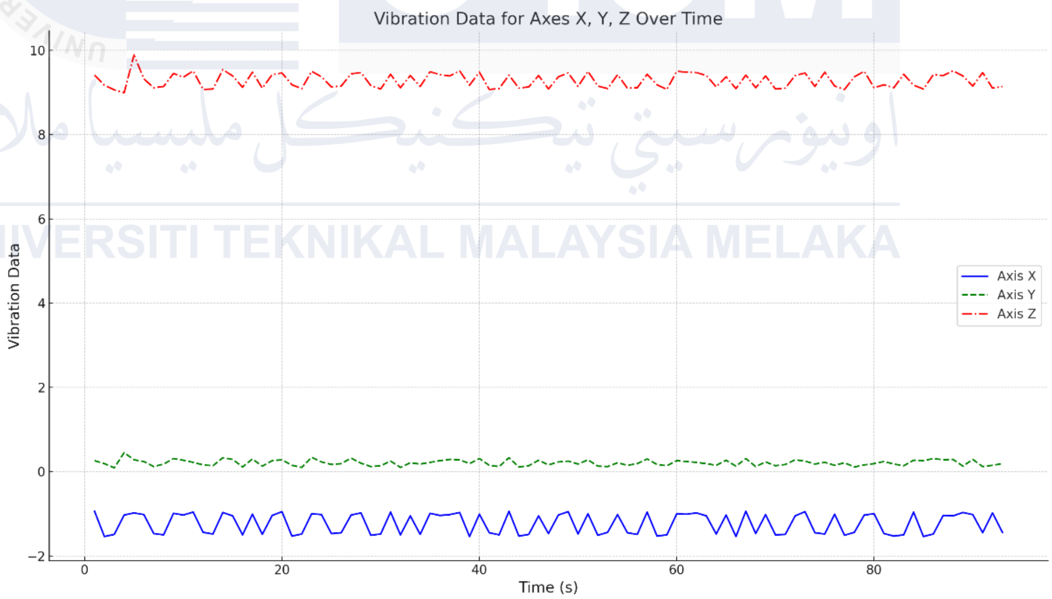


Figure 34: ADXL335 Output at 144Hz

4.2.1.3 Mpu6050 Vibration Output

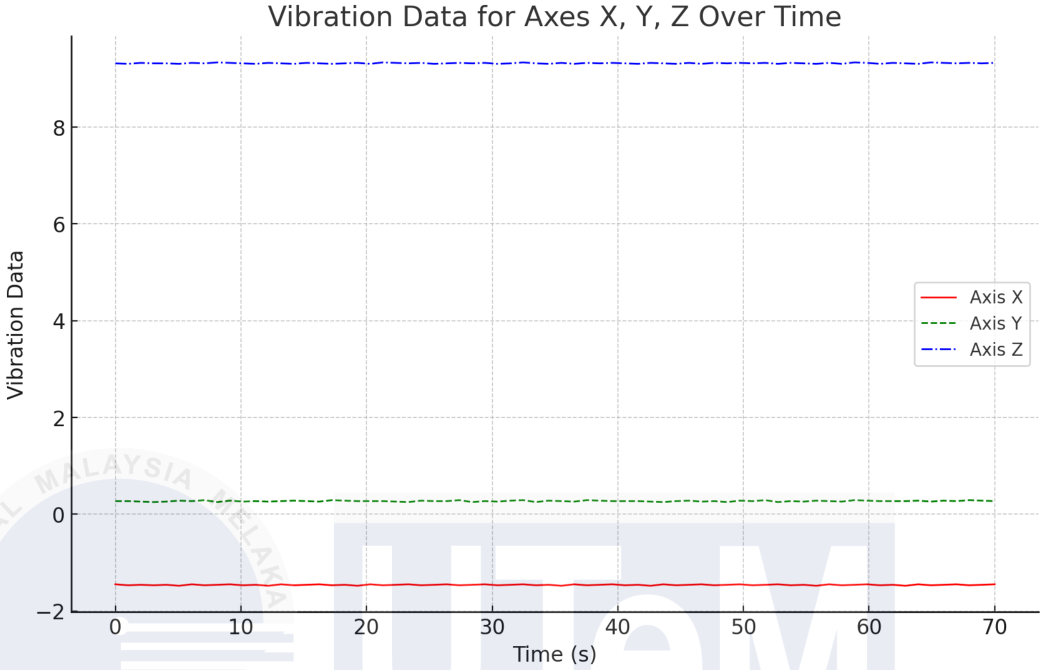


Figure 35: MPU6050 Output at 23Hz

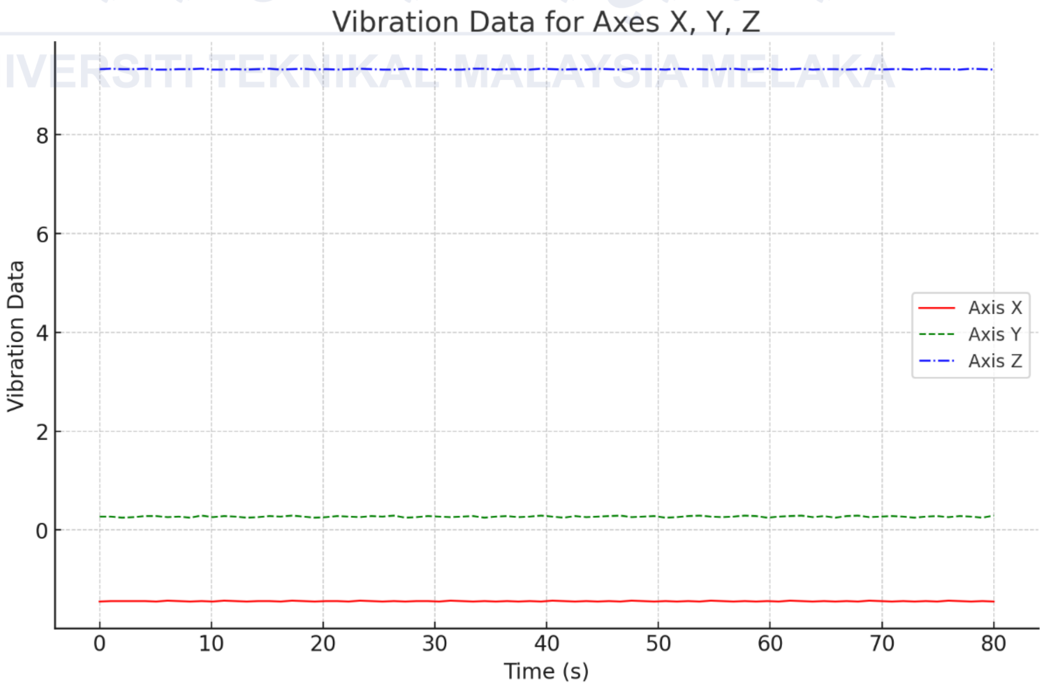


Figure 36: MPU6050 Output at 37Hz

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

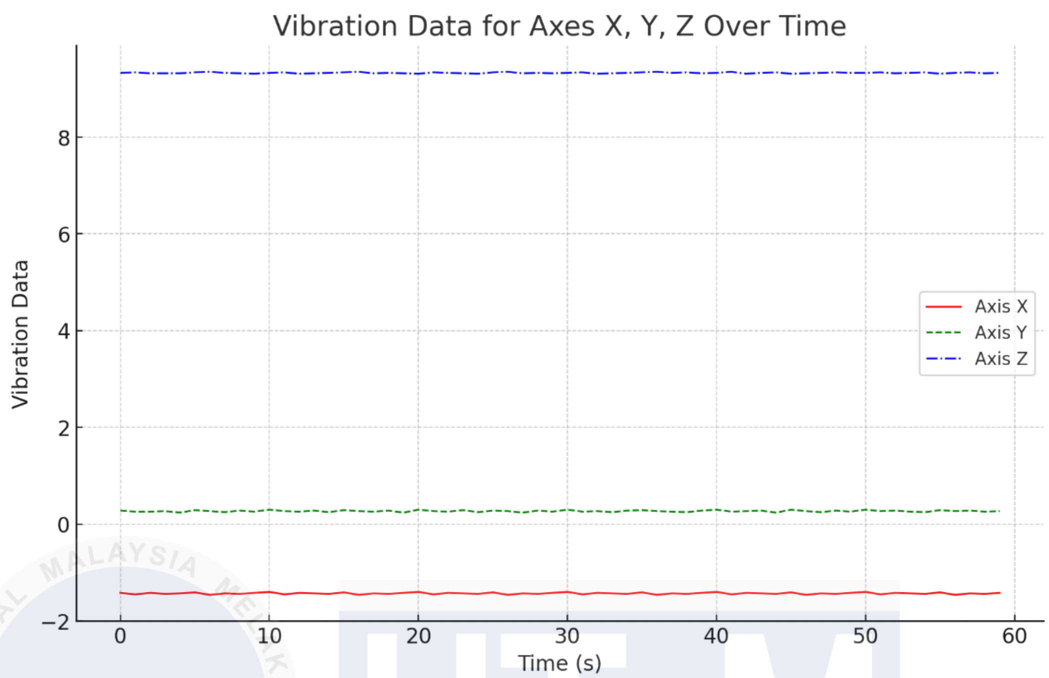


Figure 37: MPU6050 Output at 46Hz

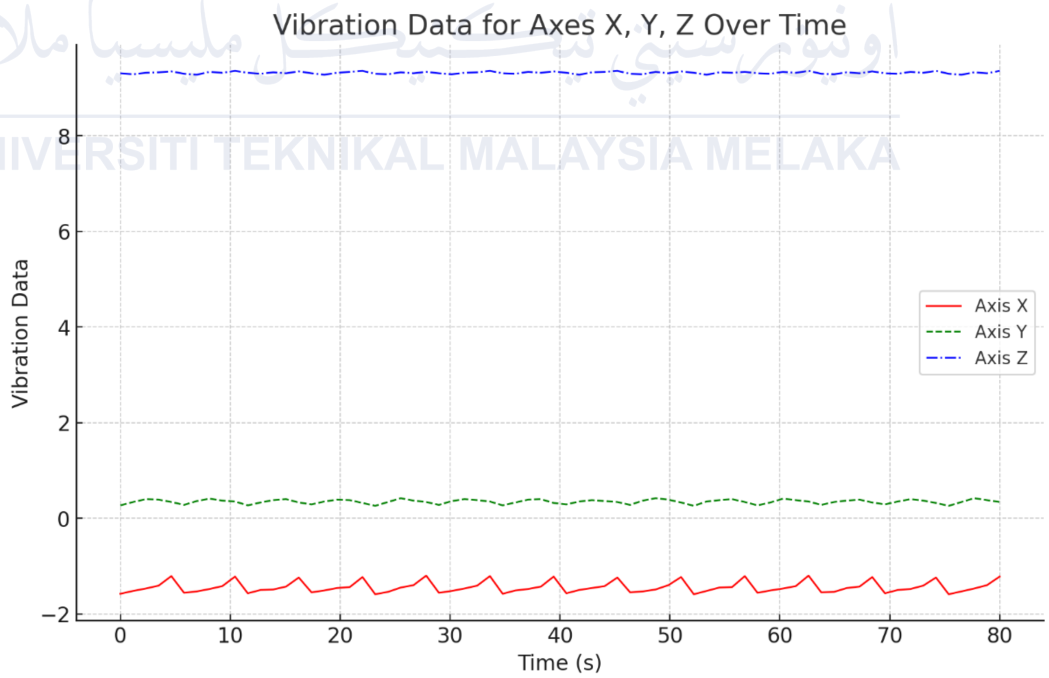


Figure 38: MPU6050 Output at 60Hz

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

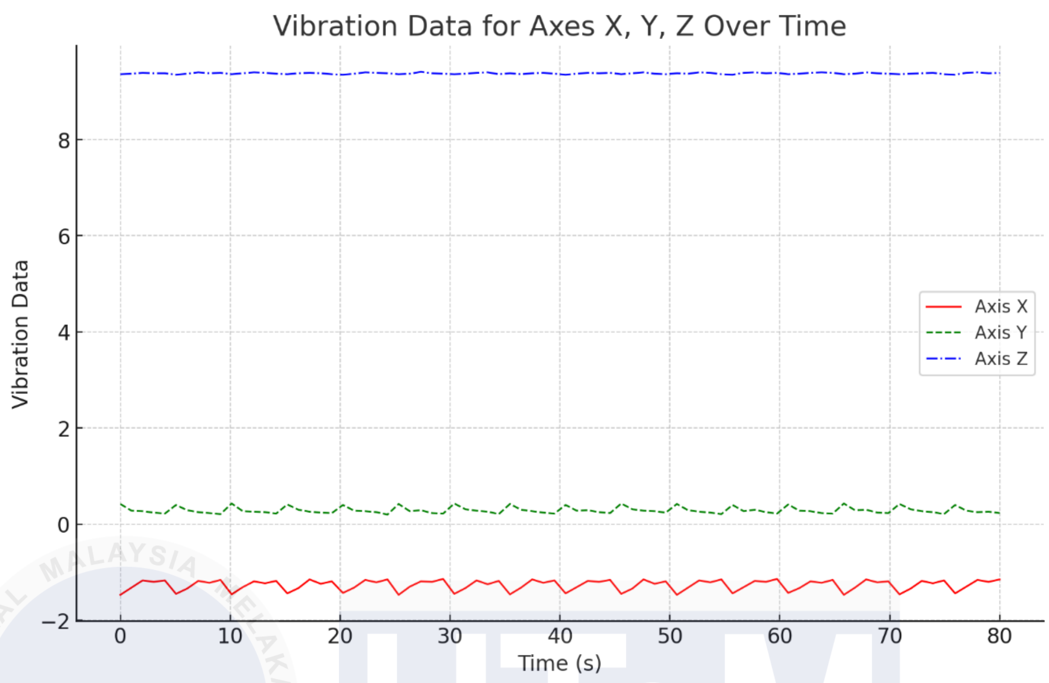


Figure 39: MPU6050 Output at 73Hz

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

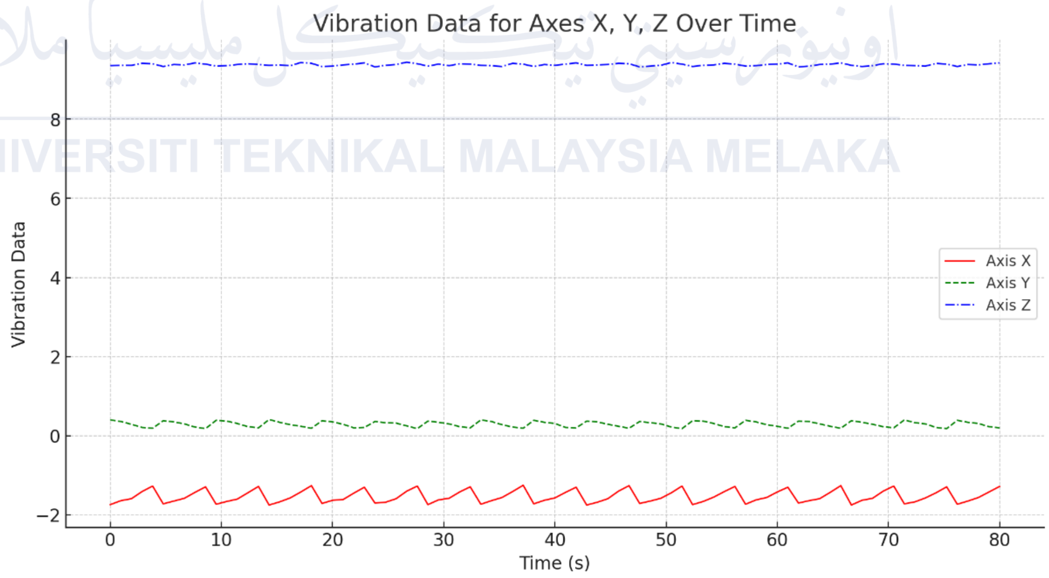


Figure 40: MPU6050 Output at 92Hz

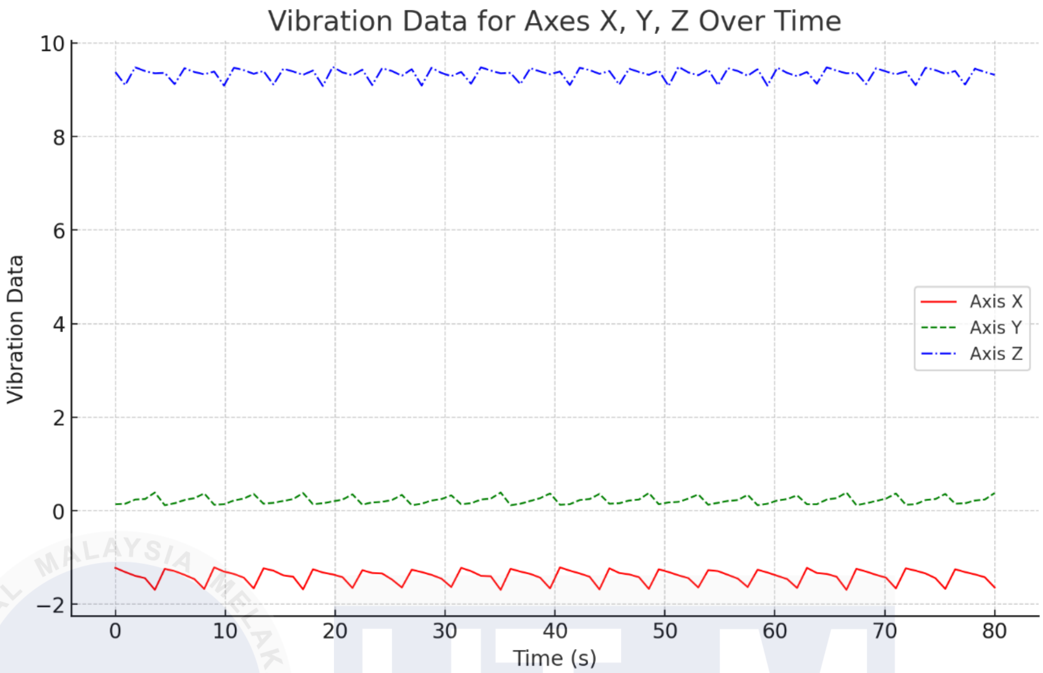


Figure 41: MPU6050 Output at 116Hz

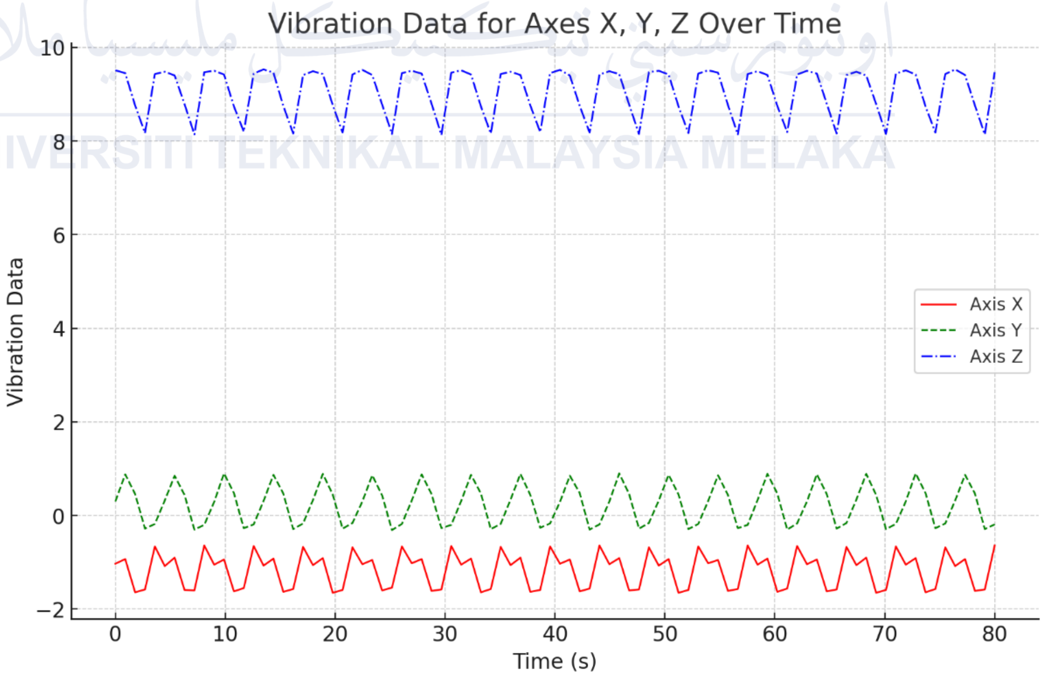


Figure 42: MPU6050 Output at 144Hz

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

4.2.1.4 Adxl345 Vibration Output

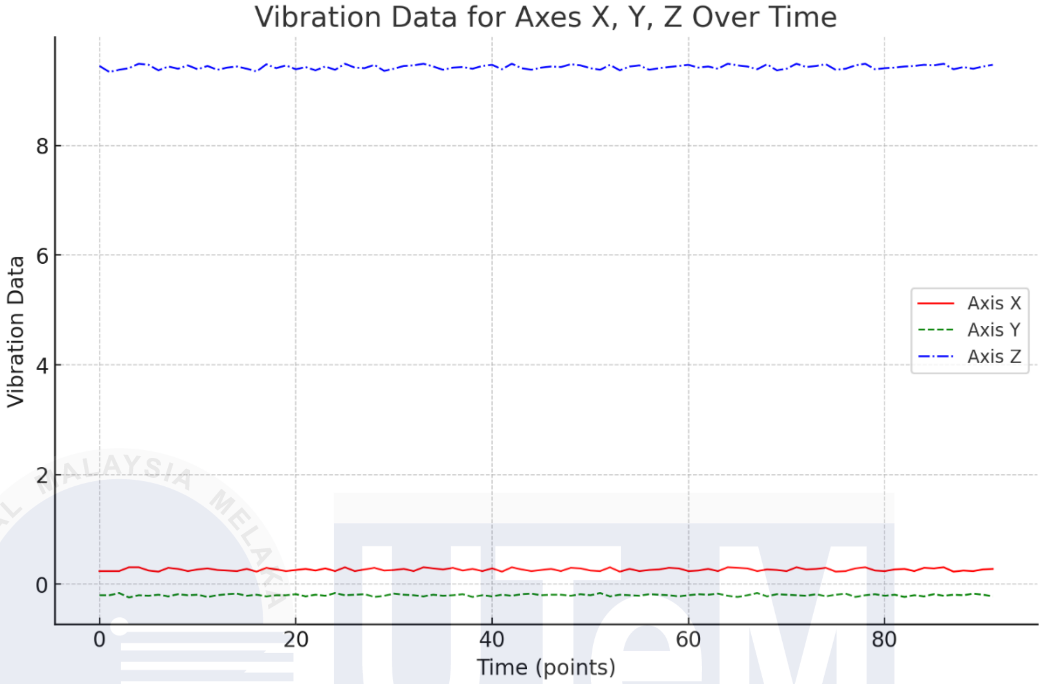


Figure 43: ADXL345 Output at 23Hz

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

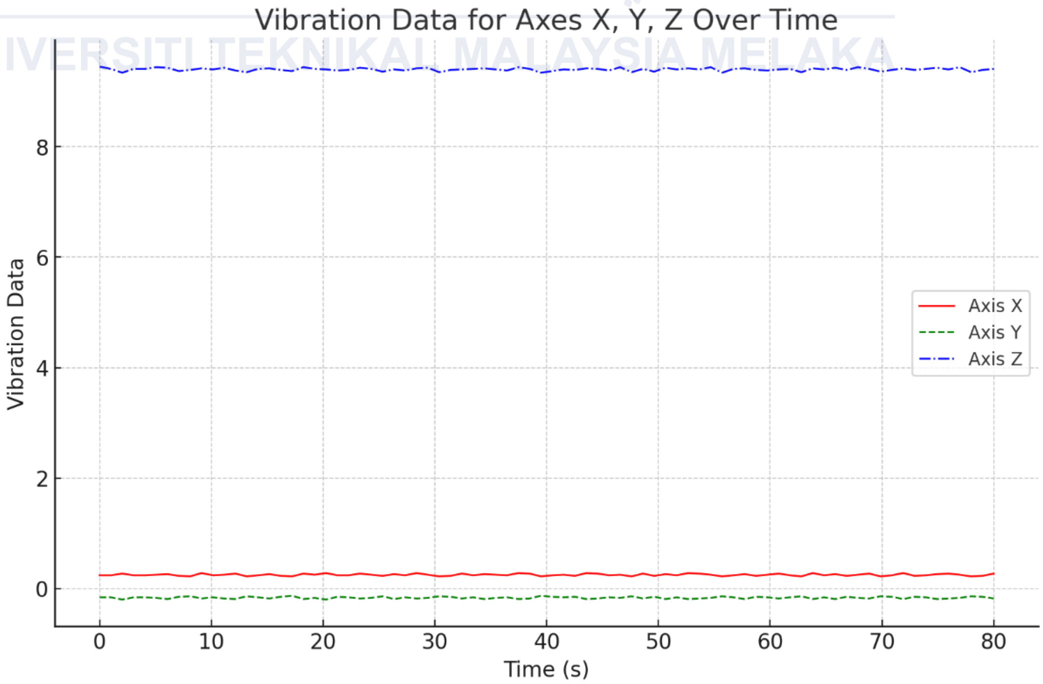


Figure 44: ADXL345 Output at 37Hz

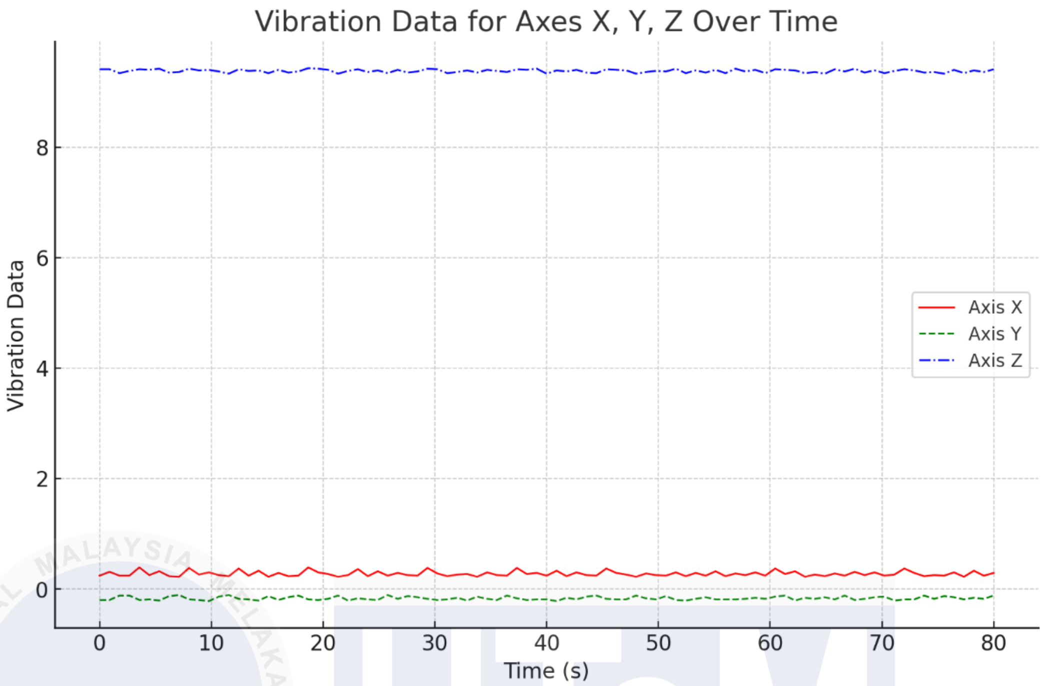


Figure 45: ADXL345 Output at 46Hz

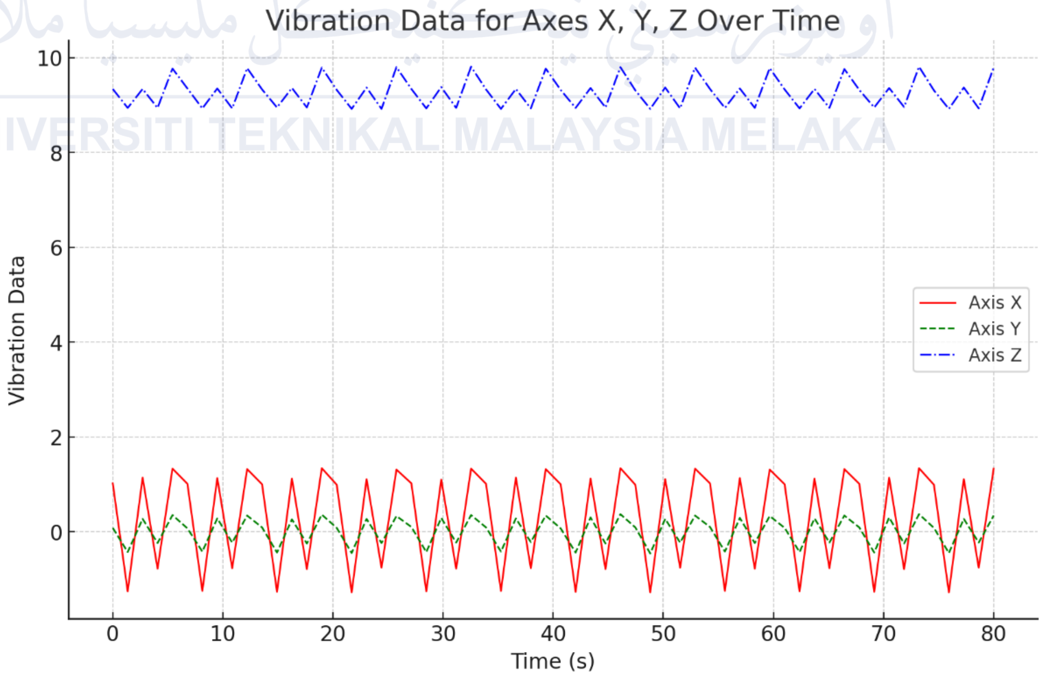


Figure 46: ADXL345 Output at 60Hz

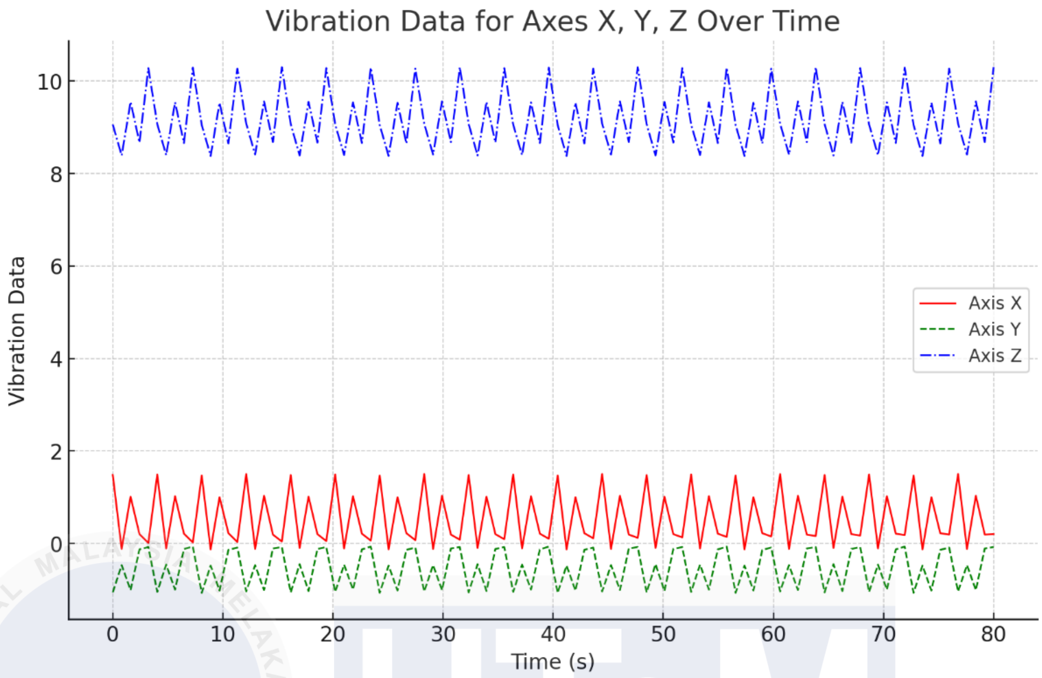


Figure 47: ADXL345 Output at 73Hz

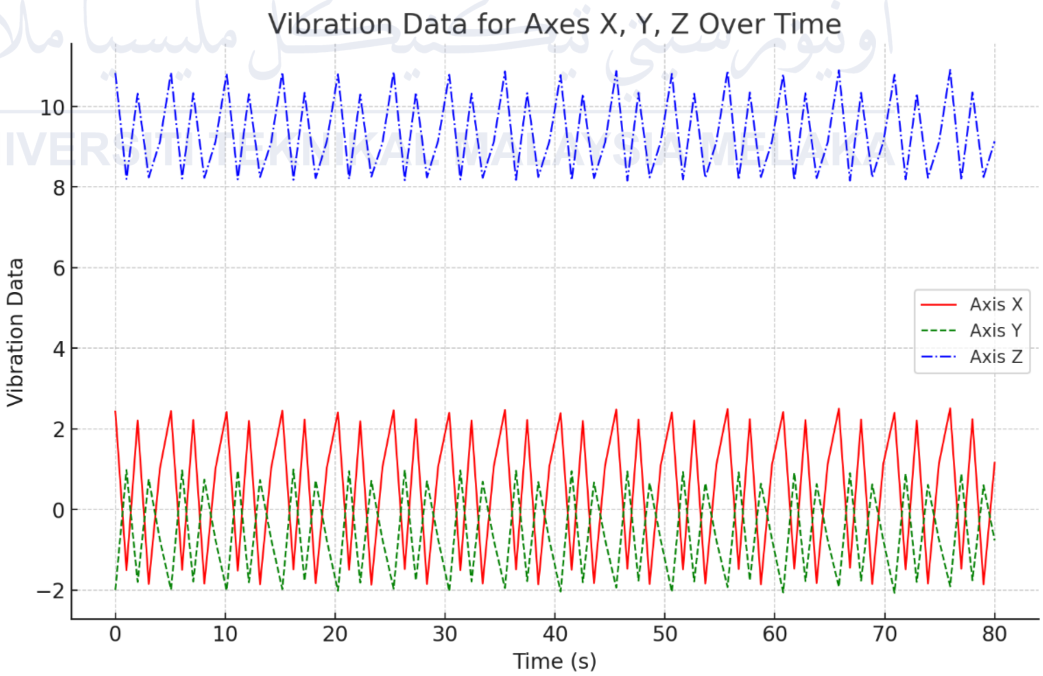


Figure 48: ADXL345 Output at 92Hz

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

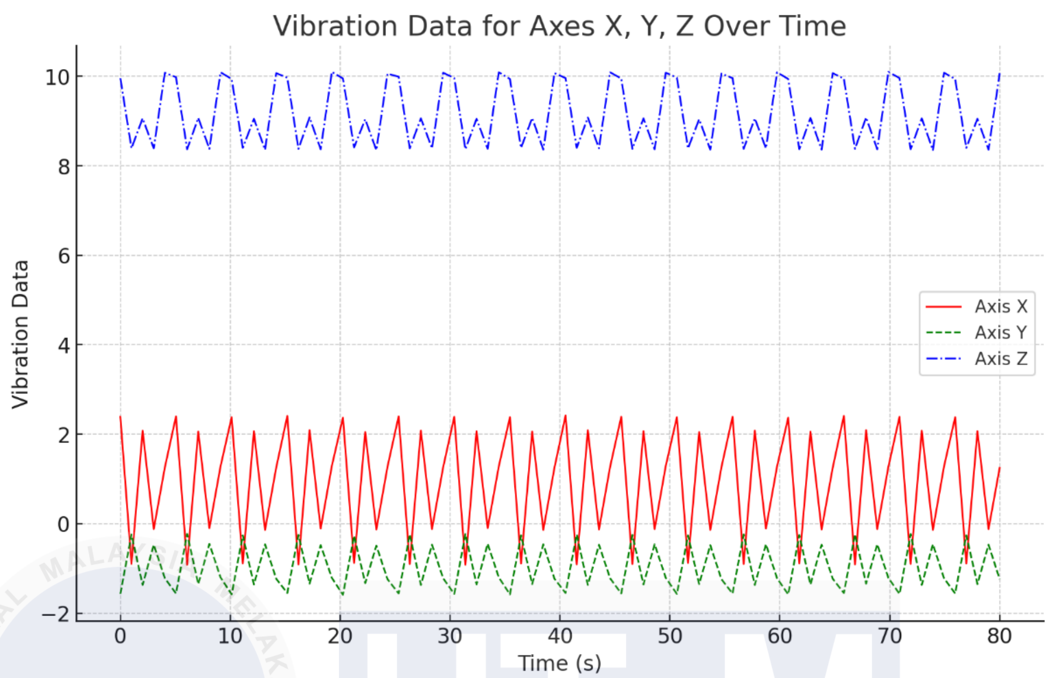


Figure 49: ADXL345 Output at 116Hz

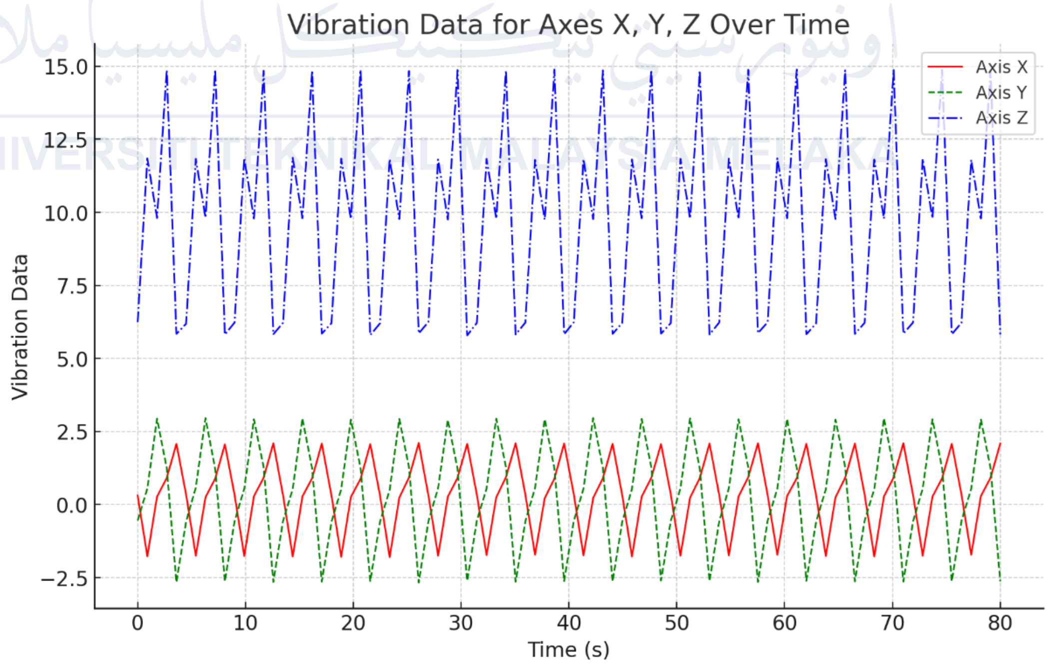


Figure 50: ADXL345 Output at 144Hz

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

4.2.1.5 Magnitude Value For Each Sensors

In table below, the values of each sensor ADXL335, MPU6050 and ADXL345 along x, y and z axis are given with the magnitude reading. These readings are used to monitor and evaluate the change in the sensors response and to analyse their stability in detail.

Table 10: Magnitude Value For ADXL335

Motor Vibrator		RMS ADXL335			
Motor S	Frequen	X ADXL	Y ADXL	Z ADXL	Combined RMS Accereleration
1380	23	1.04	0.21	9.3	9.360325849
2220	37	1.1	0.2	9.21	9.27761284
2760	46	1.02	0.25	9.1	9.160398463
3600	60	1.21	0.29	9.1	9.184672014
4380	73	1.19	0.12	9.21	9.287335463
5520	92	1.13	0.3	9.14	9.214472313
6960	116	1.2	0.11	9.21	9.288498264
8640	144	1.22	0.28	9.3	9.383858481

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Table 11: Magnitude Value For MPU6050

Motor Vibrator		RMS MPU6050			
Motor S	Frequen	X MPU6	Y MPU6	Z MPU6	Combined RMS Accereleration2
1380	23	1.46	0.26	9.32	9.437245361
2220	37	1.44	0.26	9.33	9.444051038
2760	46	1.43	0.26	9.32	9.432650741
3600	60	1.44	0.35	9.32	9.437081117
4380	73	1.27	0.29	9.37	9.460121564
5520	92	1.53	0.3	9.37	9.498831507
6960	116	1.41	0.25	9.38	9.488677463
8640	144	1.33	0.48	9.37	9.47608569

Table 12: Magnitude Value For ADXL345

Motor Vibrator		RMS ADXL345			
Motor S	Frequen	X ADXL	Y ADXL	Z ADXL	Combined RMS Accereleration3
1380	23	0.27	0.2	9.41	9.415997026
2220	37	0.24	0.16	9.4	9.404424491
2760	46	0.29	0.17	9.39	9.396015113
3600	60	1.12	0.29	9.27	9.341916292
4380	73	1.87	1.36	9.4	9.680211775
5520	92	0.8	0.69	9.21	9.270393735
6960	116	1.57	1.1	9.2	9.397600758
8640	144	1.3	1.89	10.3	10.55235045

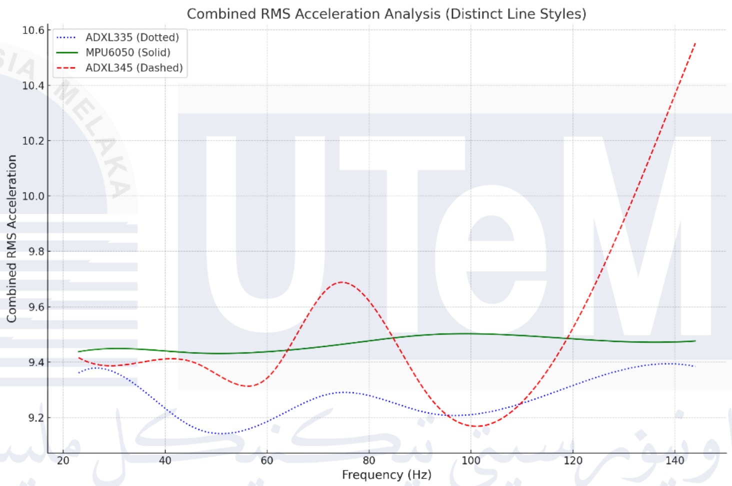


Figure 51: Combined Magnitude Value for Three Sensors

The graph relates the frequencies of the three sensors including ADXL335, MPU6050, as well as ADXL345 and the total RMS acceleration achieved from the three. The ADXL335 sensor demonstrates the decrease in the measured frequency response from 23 Hz to 46 Hz with moderate variations in the midpoint and increased frequency of up to 144 Hz. The RMS acceleration of the MPU6050 sensor shows stable output with only slight change up to 90 Hz. Of the represented RMS acceleration, the ADXL345 sensor has higher oscillations with a steep rise at 73 Hz, fall at 92 Hz and steep rise to record the highest value at 144 HZ. These trends reveal how the three sensors qualitatively respond to change in frequency as a result of differences in sensitivity and physical properties.

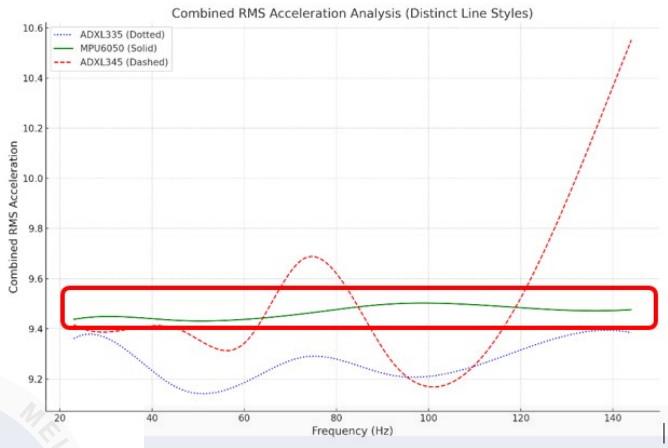


Figure 52: Performance shows MPU6050 has a better stability

The best sensor could be the one that will define the nature and performance of the sensors in the varying frequencies. Of all the sensors, the MPU6050 (green line) has the least variance in the reading it gives at different frequencies, which makes it the most suitable for stable and accurate measurements, for instance in aerospace. The same trend is observed in the ADXL335 sensor (blue line) which resonates with the characteristics of a systematic and gradual profile as data points but consistently illustrates lower RMS acceleration in its data range. It serves a purpose for applications which do not call for higher sensitivity or prominently observable vibrations. On the other hand, the ADXL345 sensor (red line) is very sensitive especially at high frequencies as clearly illustrated by the spike of the RMS acceleration at 144 Hz. However, frequent changes of this sensitivity provide a good chance of capturing high-frequency fluctuations, whereas the changes themselves are too large for more stable use.

4.2.1.6 Reliability Test Within 50 Days

The following table shows the reliability test result obtained after 50 days of trial. Similar to stability testing, the test involved the motor at its highest vibration speed. The procedure was the same with the use of RMS and magnitude formulas in arriving at the last result which was then graphed.

Table 13: Reliability Test For Each Sensor in 50 Days

DAY	VIBRATION SENSOR								
	ADXL335			MPU6050			ADXL345		
	X	Y	Z	X	Y	Z	X	Y	Z
1	-0.94	0.26	9.41	-1.03	0.3	9.51	0.31	-0.55	6.24
	-1.54	0.19	9.17	-0.93	0.88	9.45	-1.77	0.55	11.85
	-1.49	0.09	9.06	-1.64	0.46	8.76	0.27	2.94	9.81
	-1.03	0.45	8.99	-1.58	-0.28	8.17	0.91	1.26	14.87
	-0.98	0.28	9.89	-0.66	-0.18	9.43	2.08	-2.66	5.84
RMS AXIS DATA	1.22447	0.28025	9.3097	1.22861	0.4872	9.07914	1.30049	1.89271	10.3036
COMBINED DATA	9.39406			9.17484			10.5564		
2	-0.92	0.27	9.4	-1.02	0.31	9.5	0.3	-0.54	6.25
	-1.53	0.2	9.16	-0.94	0.87	9.44	-1.76	0.56	11.84
	-1.5	0.08	9.05	-1.63	0.47	8.75	0.28	2.93	9.82
	-1.04	0.46	8.98	-1.57	-0.27	8.16	0.92	1.27	14.86
	-0.97	0.29	9.88	-0.67	-0.17	9.42	2.09	-2.65	5.85
RMS AXIS DATA	1.22146	0.2881	9.29971	1.22431	0.48491	9.06916	1.30234	1.88815	10.3026
COMBINED DATA	9.384			9.16426			10.5549		
3	-0.89	0.26	9.42	-1.01	0.3	9.51	0.31	-0.53	6.24
	-1.55	0.22	9.15	-0.93	0.86	9.43	-1.75	0.55	11.83
	-1.48	0.1	9.07	-1.62	0.46	8.74	0.29	2.94	9.83
	-1.02	0.44	8.96	-1.56	-0.26	8.15	0.91	1.28	14.85
	-0.95	0.31	9.85	-0.66	-0.16	9.41	2.1	-2.64	5.84
RMS AXIS DATA	1.21061	0.28834	9.29546	1.21479	0.47632	9.06337	1.30237	1.88865	10.297
COMBINED DATA	9.3784			9.15681			10.5495		
4	-0.9	0.27	9.43	-1	0.31	9.52	0.3	-0.54	6.23
	-1.54	0.23	9.16	-0.92	0.85	9.42	-1.74	0.56	11.82
	-1.47	0.11	9.08	-1.61	0.47	8.73	0.3	2.93	9.84
	-1.01	0.45	8.97	-1.55	-0.25	8.14	0.9	1.29	14.84
	-0.94	0.32	9.86	-0.65	-0.15	9.4	2.11	-2.63	5.83
RMS AXIS DATA	1.20384	0.29759	9.30545	1.20528	0.47424	9.05759	1.30151	1.88526	10.2914
COMBINED DATA	9.38772			9.14972			10.5433		
5	-0.89	0.28	9.44	-1.01	0.32	9.53	0.3	-0.54	6.23
	-1.53	0.24	9.17	-0.91	0.84	9.43	-1.74	0.56	11.82
	-1.46	0.12	9.09	-1.6	0.46	8.74	0.3	2.93	9.84
	-1	0.46	8.98	-1.54	-0.24	8.15	0.9	1.29	14.84
	-0.93	0.33	9.87	-0.64	-0.14	9.41	2.11	-2.63	5.83
RMS AXIS DATA	1.19411	0.30689	9.31545	1.19912	0.46836	9.06757	1.30151	1.88526	10.2914
COMBINED DATA	9.39668			9.1585			10.5433		
6	-0.91	0.28	9.44	-1.01	0.32	9.53	0.31	-0.53	6.22
	-1.53	0.24	9.17	-0.91	0.84	9.41	-1.73	0.57	11.81
	-1.46	0.12	9.09	-1.6	0.48	8.72	0.31	2.94	9.85

	-1	0.46	8.98	-1.54	-0.24	8.13	0.91	1.3	14.83
	-0.93	0.33	9.87	-0.64	-0.14	9.39	2.12	-2.62	5.82
RMS AXIS DATA	**1.19712**	**0.30689**	**9.31545**	**1.19912**	**0.47236**	**9.05181**	**1.30442**	**1.887**	**10.2858**
COMBINED DATA	**9.39707**			**9.1431**			**10.5385**		
	-0.9	0.29	9.45	-1.02	0.31	9.52	0.32	-0.52	6.21
	-1.52	0.25	9.18	-0.92	0.87	9.46	-1.72	0.58	11.8
7	-1.45	0.13	9.1	-1.63	0.45	8.77	0.32	2.95	9.86
	-0.99	0.47	8.99	-1.57	-0.27	8.18	0.92	1.31	14.82
	-0.92	0.34	9.88	-0.65	-0.17	9.44	2.13	-2.61	5.81
RMS AXIS DATA	**1.18738**	**0.31623**	**9.32544**	**1.21911**	**0.4811**	**9.08912**	**1.3074**	**1.88878**	**10.2802**
COMBINED DATA	**9.40605**			**9.18313**			**10.5337**		
	-0.95	0.27	9.42	-1.04	0.32	9.5	0.32	-0.56	6.22
	-1.53	0.2	9.18	-0.94	0.89	9.47	-1.75	0.57	11.83
8	-1.48	0.1	9.07	-1.65	0.47	8.75	0.29	2.95	9.83
	-1.02	0.46	9	-1.59	-0.29	8.16	0.93	1.28	14.85
	-0.97	0.29	9.9	-0.67	-0.19	9.42	2.1	-2.64	5.82
RMS AXIS DATA	**1.21779**	**0.28934**	**9.3197**	**1.23812**	**0.49711**	**9.07541**	**1.30567**	**1.89468**	**10.2923**
COMBINED DATA	**9.40338**			**9.17296**			**10.5464**		
	-0.88	0.25	9.41	-1.02	0.33	9.54	0.3	-0.54	6.23
	-1.56	0.21	9.14	-0.93	0.83	9.44	-1.76	0.56	11.84
9	-1.49	0.09	9.06	-1.62	0.48	8.72	0.28	2.93	9.82
	-1.03	0.43	8.95	-1.56	-0.26	8.13	0.92	1.27	14.86
	-0.96	0.3	9.84	-0.66	-0.16	9.39	2.09	-2.65	5.83
RMS AXIS DATA	**1.21742**	**0.27914**	**9.28547**	**1.21646**	**0.47358**	**9.06016**	**1.30234**	**1.88815**	**10.298**
COMBINED DATA	**9.36909**			**9.15372**			**10.5503**		
	-0.87	0.24	9.42	-1.03	0.34	9.55	0.31	-0.53	6.22
	-1.55	0.22	9.15	-0.94	0.82	9.45	-1.75	0.57	11.83
10	-1.5	0.1	9.07	-1.63	0.49	8.71	0.29	2.94	9.81
	-1.02	0.44	8.96	-1.57	-0.27	8.12	0.93	1.28	14.87
	-0.95	0.31	9.85	-0.67	-0.17	9.38	2.1	-2.64	5.82
RMS AXIS DATA	**1.21263**	**0.28485**	**9.29546**	**1.22599**	**0.47537**	**9.05856**	**1.30519**	**1.88984**	**10.2943**
COMBINED DATA	**9.37855**			**9.1535**			**10.5474**		
	-0.86	0.23	9.43	-1.04	0.35	9.56	0.32	-0.52	6.21
	-1.54	0.21	9.16	-0.95	0.81	9.46	-1.74	0.58	11.82
11	-1.51	0.11	9.08	-1.64	0.47	8.7	0.3	2.95	9.8
	-1.01	0.45	8.97	-1.58	-0.28	8.11	0.94	1.29	14.88
	-0.94	0.32	9.86	-0.68	-0.18	9.37	2.11	-2.63	5.81
RMS AXIS DATA	**1.20789**	**0.28775**	**9.30545**	**1.23552**	**0.47123**	**9.05698**	**1.30811**	**1.89158**	**10.2906**
COMBINED DATA	**9.38793**			**9.153**			**10.5445**		
	-0.89	0.28	9.46	-1.01	0.32	9.53	0.33	-0.51	6.22
	-1.51	0.24	9.19	-0.91	0.88	9.47	-1.71	0.59	11.81
12	-1.44	0.12	9.11	-1.62	0.44	8.78	0.33	2.96	9.87
	-0.98	0.48	9	-1.56	-0.26	8.19	0.93	1.32	14.83

	-0.91	0.35	9.87	-0.64	-0.16	9.45	2.14	-2.6	5.8
RMS AXIS DATA	**1.17765**	**0.31727**	**9.3312**	**1.20961**	**0.48241**	**9.09911**	**1.31045**	**1.89062**	**10.2874**
COMBINED DATA	**9.41057**			**9.19182**			**10.5414**		
13	-0.88	0.29	9.47	-1.02	0.33	9.54	0.33	-0.51	6.22
	-1.5	0.25	9.2	-0.92	0.89	9.48	-1.7	0.6	11.8
	-1.43	0.13	9.12	-1.63	0.45	8.79	0.34	2.97	9.88
	-0.97	0.49	9.01	-1.57	-0.27	8.2	0.94	1.33	14.84
	-0.9	0.36	9.88	-0.65	-0.17	9.46	2.15	-2.59	5.79
RMS AXIS DATA	**1.16792**	**0.32656**	**9.3412**	**1.21911**	**0.49098**	**9.10909**	**1.31306**	**1.89304**	**10.2888**
COMBINED DATA	**9.41959**			**9.20341**			**10.5435**		
14	-1.01	0.21	9.08	-0.98	0.33	9.53	-1.6	0.85	13.9
	-1.05	0.29	9.45	-0.95	0.9	9.48	0.45	2.8	6.5
	-1.57	0.18	9.91	-1.6	0.48	8.79	0.2	-2.5	6.1
	-0.92	0.46	9.2	-1.55	-0.25	8.2	0.6	1.4	9.9
	-1.52	0.11	8.98	-0.63	-0.15	9.46	2.15	-1.8	11.2
RMS AXIS DATA	**1.24453**	**0.27724**	**9.32992**	**1.20186**	**0.49685**	**9.107**	**1.2478**	**2.00062**	**9.96112**
COMBINED DATA	**9.41664**			**9.19939**			**10.2364**		
15	-0.95	0.24	9.12	-0.92	0.35	9.56	-1.55	0.9	13.7
	-1.1	0.32	9.5	-1	0.85	9.5	0.45	2.75	6.45
	-1.6	0.22	9.85	-1.55	0.5	8.8	0.25	-2.45	6
	-0.87	0.48	9.25	-1.6	-0.22	8.25	0.55	1.35	10
	-1.45	0.14	9	-0.58	-0.13	9.47	2.1	-1.75	11.1
RMS AXIS DATA	**1.22735**	**0.30279**	**9.3489**	**1.19543**	**0.48173**	**9.13047**	**1.21491**	**1.96265**	**9.88436**
COMBINED DATA	**9.43398**			**9.22098**			**10.1503**		
16	-0.88	0.5	9.1	-0.95	0.4	9.55	2.05	0.4	13.8
	-1.15	0.3	9.65	-1.05	0.9	9.45	0.3	1.4	6.5
	-1.55	0.25	9.8	-1.6	0.45	8.75	0.6	2.7	5.9
	-0.9	0.35	9.3	-1.65	-0.2	8.3	-1.5	-2.4	10.1
	-1.42	0.12	9.05	-0.6	-0.1	9.5	-1.7	0.3	11.2
RMS AXIS DATA	**1.21044**	**0.32845**	**9.38472**	**1.23673**	**0.49447**	**9.12368**	**1.39946**	**1.747**	**9.94937**
COMBINED DATA	**9.46816**			**9.22039**			**10.1981**		
17	-0.85	0.32	9.25	-1.23	-0.32	9.23	2.11	0.45	13.7
	-1.45	0.28	9.75	-1.3	1	8.58	0.51	1.42	6.31
	-1.38	0.15	9.12	-1.75	0.61	9	0.9	2.61	5.87
	-1.22	0.45	9.35	-1.81	0.52	8.29	-1.63	-2.5	10.69
	-0.95	0.47	9.55	-0.73	-0.22	9.7	-1.84	0.42	11
RMS AXIS DATA	**1.19334**	**0.35403**	**9.40664**	**1.41946**	**0.59888**	**8.97355**	**1.52084**	**1.75826**	**9.97235**
COMBINED DATA	**9.48864**			**9.10485**			**10.2397**		
18	-1.5	0.11	9.22	-1.12	-0.25	8.95	0.32	2.78	9.97
	-1.6	0.23	9.75	-1.4	1.2	8.75	0.95	1.33	15.02
	-1.2	0.32	9.55	-1.6	0.75	9.2	-1.85	0.67	11.52
	-0.85	0.47	9.1	-1.85	0.65	8.1	0.28	-0.53	5.98
	-0.9	0.27	9.35	-0.8	-0.15	9.5	2.12	-2.68	5.91
RMS AXIS DATA	**1.2476**	**0.30371**	**9.39687**	**1.40263**	**0.70852**	**8.91252**	**1.34166**	**1.86598**	**10.2801**
COMBINED DATA	**9.48419**			**9.04999**			**10.5338**		
19	-1.03	0.25	9.12	-1.06	0.34	9.53	2.11	-2.63	5.85
	-1.08	0.31	9.48	-0.96	0.92	9.49	0.3	2.95	9.84
	-1.6	0.21	9.88	-1.68	0.45	8.78	-1.74	0.58	11.87
	-0.94	0.49	9.24	-1.61	-0.27	8.18	0.32	-0.52	6.25
	-1.55	0.15	9.01	-0.69	-0.21	9.44	0.9	1.29	14.89
RMS AXIS DATA	**1.2707**	**0.30506**	**9.35112**	**1.25983**	**0.50626**	**9.0994**	**1.30247**	**1.89158**	**10.322**
COMBINED DATA	**9.44199**			**9.20014**			**10.5744**		
20	-1.05	0.27	9.15	-1.03	0.34	9.55	2.07	0.42	13.85
	-1.1	0.33	9.51	-0.93	0.9	9.49	0.28	1.42	6.48
	-1.62	0.23	9.9	-1.64	0.46	8.8	0.58	2.72	5.92
	-0.96	0.51	9.27	-1.58	-0.28	8.21	-1.52	-2.38	10.12
	-1.57	0.17	9.03	-0.66	-0.18	9.47	-1.68	0.28	11.18
RMS AXIS DATA	**1.29022**	**0.32364**	**9.37706**	**1.22861**	**0.4996**	**9.11907**	**1.40232**	**1.75123**	**9.96259**
COMBINED DATA	**9.47094**			**9.21502**			**10.2121**		

21	1.07	0.29	9.18	-1.05	0.32	9.54	0.33	-0.57	6.26
	-1.12	0.35	9.54	-0.95	0.87	9.47	-1.79	0.57	11.88
	-1.64	0.25	9.87	-1.66	0.44	8.78	0.29	2.96	9.83
	-0.98	0.53	9.29	-1.6	-0.3	8.15	0.93	1.28	14.89
	-1.59	0.19	9.06	-0.68	-0.2	9.41	2.1	-2.68	5.86
RMS AXIS DATA	**1.30976**	**0.34237**	**9.39243**	**1.24764**	**0.48639**	**9.08572**	**1.31697**	**1.90957**	**10.3248**
COMBINED DATA		**9.48949**			**9.18387**			**10.5821**	
22	1.09	0.31	9.2	-1.05	0.32	9.53	0.91	1.26	11.87
	-1.14	0.37	9.56	-0.94	0.9	9.47	2.08	-2.66	5.84
	-1.66	0.27	9.89	-1.66	0.48	8.78	-1.77	0.55	11.85
	-1	0.55	9.31	-1.6	-0.3	8.19	0.28	2.94	9.81
	-1.61	0.21	9.08	-0.67	-0.2	9.44	0.3	-0.55	6.24
RMS AXIS DATA	**1.32932**	**0.36125**	**9.41242**	**1.24504**	**0.50454**	**9.09703**	**1.30045**	**1.89271**	**9.49314**
COMBINED DATA		**9.51269**			**9.19569**			**9.76695**	
23	1.12	0.3	9.22	-1.05	0.33	9.5	2.15	0.45	14.05
	-1.1	0.39	9.58	-0.9	0.85	9.48	0.35	1.55	6.75
	-1.68	0.28	9.9	-1.6	0.47	8.79	0.63	2.85	6.1
	-0.98	0.56	9.33	-1.55	-0.25	8.2	-1.48	-2.25	10.25
	-1.6	0.2	9.1	-0.62	-0.16	9.42	-1.6	0.32	11.3
RMS AXIS DATA	**1.32719**	**0.36718**	**9.43031**	**1.20494**	**0.47758**	**9.09242**	**1.40658**	**1.78283**	**10.1285**
COMBINED DATA		**9.53032**			**9.18434**			**10.3799**	
24	-0.21	0.44	9.22	-1.6	-0.35	8.12	0.96	1.3	12.05
	-1.1	0.19	9.98	-0.72	-0.12	9.38	2.1	-2.6	5.9
	-1.68	0.11	10	-1.55	0.49	8.69	-1.75	0.58	12.05
	-1	0.7	9.33	-0.95	0.29	9.62	0.3	2.98	9.85
	-1.6	0.2	9.1	-1.02	0.82	9.41	0.32	-0.52	6.28
RMS AXIS DATA	**1.23584**	**0.39289**	**9.53381**	**1.21851**	**0.47613**	**9.06121**	**1.31046**	**1.89405**	**9.60912**
COMBINED DATA		**9.6216**			**9.15516**			**9.88129**	
25	-0.15	0.52	9.15	-1.5	-0.2	8.39	-1.12	1.45	13.32
	-1.05	0.24	9.8	-0.6	-0.18	9.51	0.72	-2.34	5.72
	-1.72	0.13	10.15	-1.45	0.52	8.75	-1.68	0.89	11.57
	-1.05	0.75	9.25	-0.9	0.31	9.62	0.23	2.41	9.92
	-1.55	0.18	9.05	-1	0.8	9.4	0.55	-0.41	6.15
RMS AXIS DATA	**1.23194**	**0.43354**	**9.48947**	**1.14215**	**0.46452**	**9.14657**	**0.99505**	**1.69389**	**9.80035**
COMBINED DATA		**9.57892**			**9.22931**			**9.99531**	
26	-1.75	0.16	10.18	-1.6	-0.26	8.2	2.18	0.48	14.1
	-1.08	0.78	9.28	-0.68	-0.16	9.47	0.38	1.58	6.8
	-1.58	0.21	9.08	-1.05	0.32	9.55	0.66	2.88	6.15
	-0.18	0.55	9.18	-0.95	0.9	9.5	-1.45	-2.22	10.3
	-1.08	0.27	9.83	-1.66	0.48	8.8	-1.57	0.35	11.35
RMS AXIS DATA	**1.2589**	**0.45902**	**9.51944**	**1.24764**	**0.49719**	**9.11936**	**1.40711**	**1.79288**	**10.1763**
COMBINED DATA		**9.61328**			**9.21773**			**10.4284**	
27	-1.17	0.4	9.6	-1.63	0.49	8.77	-1.43	-2.2	10.35
	-1.69	0.3	9.93	-1.57	-0.27	8.18	0.4	1.6	6.85
	-1.03	0.58	9.35	-1.04	0.35	9.56	0.68	2.9	6.2
	1.12	0.34	9.25	-0.94	0.87	9.46	-1.55	0.37	11.4
	-1.64	0.24	9.12	-0.67	-0.17	9.44	2.2	0.5	14.15
RMS AXIS DATA	**1.35867**	**0.38977**	**9.45436**	**1.22767**	**0.49423**	**9.09752**	**1.40782**	**1.79983**	**10.2242**
COMBINED DATA		**9.55943**			**9.19327**			**10.4764**	
28	-1.17	0.4	9.6	-1.63	0.49	8.77	-1.43	-2.2	10.35
	-1.69	0.3	9.93	-1.57	-0.27	8.18	0.4	1.6	6.85
	-1.03	0.58	9.35	-1.04	0.35	9.56	0.68	2.9	6.2
	1.12	0.34	9.25	-0.94	0.87	9.46	-1.55	0.37	11.4
	-1.64	0.24	9.12	-0.67	-0.17	9.44	2.2	0.5	14.15
RMS AXIS DATA	**1.35867**	**0.38977**	**9.45436**	**1.22767**	**0.49423**	**9.09752**	**1.40782**	**1.79983**	**10.2242**
COMBINED DATA		**9.55943**			**9.19327**			**10.4764**	

	-1.12	0.62	9.45	-1.1	0.35	9.62	0.3	1.5	6.8
	1.05	0.33	9.15	-0.98	0.88	9.31	0.58	2.8	6.2
29	-1.58	0.28	9.05	-1.58	0.52	8.69	-1.52	-2.3	10.3
	-1.25	0.45	9.85	-1.47	-0.22	8.26	-1.65	0.35	11.4
	-1.55	0.35	9.75	-0.72	-0.12	9.52	2.05	0.42	13.9
RMS AXIS DATA	**1.32803**	**0.42349**	**9.45529**	**1.21211**	**0.496**	**9.09499**	**1.39009**	**1.77081**	**10.1384**
COMBINED DATA	**9.55748**			**9.18881**			**10.3854**		
	-1.1	0.6	9.5	-1.1	0.33	9.6	2.2	0.45	14.1
	1.1	0.35	9.2	-1	0.9	9.3	0.4	1.6	6.8
30	-1.55	0.3	9.1	-1.6	0.5	8.7	0.65	2.9	6.2
	-1.2	0.47	9.9	-1.45	-0.2	8.3	-1.4	-2.2	10.3
	-1.6	0.38	9.8	-0.7	-0.1	9.5	-1.55	0.33	11.4
RMS AXIS DATA	**1.32834**	**0.43308**	**9.50526**	**1.21347**	**0.49374**	**9.09373**	**1.39893**	**1.79563**	**10.1935**
COMBINED DATA	**9.6074**			**9.18762**			**10.4446**		
	1.14	0.31	9.24	-1.05	0.32	9.41	0.58	2.72	6.32
	-1.09	0.4	9.6	-0.95	0.88	9.23	-1.38	-2.18	10.18
31	-1.67	0.29	9.92	-1.5	0.55	9.6	-1.58	0.28	10.95
	-0.97	0.57	9.35	-1.4	-0.15	8.51	1.92	0.42	13.75
	-1.59	0.21	9.12	-0.6	-0.08	8.89	0.42	1.45	6.88
RMS AXIS DATA	**1.32254**	**0.37662**	**9.4503**	**1.14673**	**0.49157**	**9.13623**	**1.31149**	**1.70341**	**9.99874**
COMBINED DATA	**9.54982**			**9.22102**			**10.2272**		
	-1.72	0.18	10.15	-1.2	-0.3	9.25	2.18	0.43	12.12
	-1.05	0.75	9.25	-1.28	0.97	8.6	0.38	1.58	6.82
32	-1.55	0.23	9.1	-1.72	0.58	9.02	0.63	2.88	6.22
	-0.2	0.57	9.2	-1.78	0.55	8.32	-1.38	-2.18	10.32
	-1.1	0.3	9.8	-0.7	-0.2	9.72	-1.53	0.31	13.42
RMS AXIS DATA	**1.24205**	**0.46102**	**9.50868**	**1.39249**	**0.58477**	**8.99537**	**1.38123**	**1.779**	**10.1852**
COMBINED DATA	**9.60053**			**9.12128**			**10.4313**		
	-1.15	0.38	9.62	-1.58	-0.24	8.22	0.34	2.8	9.99
	-1.67	0.28	9.95	-0.66	-0.14	9.49	0.97	1.35	15.04
33	-1.01	0.56	9.37	-1.03	0.34	9.57	-1.83	0.69	11.54
	1.14	0.32	9.27	-0.93	0.92	9.52	0.3	-0.51	6
	-1.62	0.22	9.14	-1.64	0.46	8.82	2.14	-2.66	5.93
RMS AXIS DATA	**1.34577**	**0.37073**	**9.47435**	**1.22861**	**0.50016**	**9.13932**	**1.34722**	**1.86945**	**10.2989**
COMBINED DATA	**9.57663**			**9.23509**			**10.5536**		
	1.16	0.33	9.26	-1.61	0.51	8.79	0.48	2.02	7.32
	-1.07	0.42	9.62	-1.55	-0.25	8.2	-1.35	-2.28	8.28
34	-1.65	0.31	9.94	-1.02	0.37	9.58	-1.61	0.3	11
	-0.95	0.59	9.37	-0.92	0.89	9.48	1.79	0.49	13.75
	-1.57	0.23	9.14	-0.65	-0.15	9.46	0.51	1.39	7.01
RMS AXIS DATA	**1.30999**	**0.39558**	**9.47029**	**1.20863**	**0.5048**	**9.11748**	**1.27351**	**1.51928**	**9.81166**
COMBINED DATA	**9.56865**			**9.21109**			**10.0099**		
	-1.57	0.23	9.14	-1.63	0.5	8.81	1.37	-2.16	10.21
	-1.65	0.31	9.94	-1.56	-0.26	8.22	-1.56	0.26	10.98
35	-0.95	0.59	9.37	-1.03	0.38	9.57	1.91	0.41	13.7
	1.16	0.33	9.26	-0.93	0.88	9.47	0.44	1.47	6.9
	-1.07	0.42	9.62	-0.66	-0.16	9.45	0.61	2.75	6.35
RMS AXIS DATA	**1.30999**	**0.39558**	**9.47029**	**1.22081**	**0.50239**	**9.11869**	**1.3057**	**1.71025**	**10.0043**
COMBINED DATA	**9.56865**			**9.21376**			**10.233**		
	-1.55	0.25	9.16	-0.91	0.9	9.49	-1.36	-2.17	10.2
	1.18	0.35	9.28	-0.64	-0.14	9.47	0.6	2.73	6.34
36	-1.05	0.44	9.64	-1.54	-0.28	8.19	-1.57	0.29	10.94
	-1.63	0.33	9.96	-1.04	0.36	9.59	1.9	0.43	13.72
	-0.93	0.61	9.39	-1.62	0.48	8.78	0.43	1.46	6.89
RMS AXIS DATA	**1.29763**	**0.41463**	**9.49028**	**1.20957**	**0.50359**	**9.12002**	**1.30149**	**1.7066**	**9.9963**
COMBINED DATA	**9.58756**			**9.21365**			**10.2241**		
	1.2	0.37	9.3	-1.6	0.52	8.8	-1.59	0.3	10.97

37	-1.03	0.46	9.66	-1.57	-0.24	8.21	1.93	0.44	13.76
	-1.61	0.35	9.98	-0.63	-0.13	9.48	0.45	1.48	6.92
	-0.91	0.63	9.41	-1.01	0.39	9.6	0.62	2.74	6.36
	-1.53	0.27	9.18	-0.9	0.91	9.5	-1.39	-2.19	10.19
RMS AXIS DATA	**1.28546**	**0.43377**	**9.51027**	**1.20432**	**0.5148**	**9.13372**	**1.32454**	**1.71917**	**10.0185**
COMBINED DATA	**9.60655**			**9.22715**			**10.2509**		
38	-1.09	0.4	9.6	-1.58	-0.29	8.18	1.92	0.42	13.74
	-1.67	0.29	9.92	-1.05	0.34	9.55	0.41	1.44	6.86
	-0.97	0.57	9.35	-0.95	0.86	9.45	0.59	2.71	6.33
	-1.59	0.21	9.12	-1.64	0.47	8.76	-1.37	-2.2	10.17
	1.14	0.31	9.24	-0.68	-0.18	9.43	-1.55	0.27	10.96
RMS AXIS DATA	**1.32254**	**0.37662**	**9.4503**	**1.23721**	**0.48839**	**9.08933**	**1.30246**	**1.70335**	**9.99466**
COMBINED DATA	**9.54982**			**9.18614**			**10.2221**		
39	-1.01	0.48	9.68	-1.03	0.35	9.56	0.6	2.73	6.34
	-1.59	0.37	10	-0.94	0.87	9.46	-1.38	-2.18	10.18
	-0.89	0.65	9.43	-1.65	0.46	8.75	-1.56	0.28	10.95
	-1.51	0.29	9.2	-1.56	-0.27	8.17	1.91	0.43	13.73
	1.22	0.39	9.32	-0.67	-0.16	9.44	0.42	1.45	6.87
RMS AXIS DATA	**1.27348**	**0.45299**	**9.53026**	**1.22878**	**0.48775**	**9.09187**	**1.30557**	**1.70711**	**9.9944**
COMBINED DATA	**9.62564**			**9.18748**			**10.2229**		
40	1.24	0.41	9.34	-1.66	0.45	8.74	0.61	2.75	6.35
	-0.99	0.5	9.7	-1.59	-0.28	8.16	-1.4	-2.21	10.2
	-1.57	0.39	10.02	-1.04	0.33	9.54	-1.58	0.29	10.98
	-0.87	0.67	9.45	-0.96	0.85	9.44	1.94	0.45	13.78
	-1.49	0.31	9.22	-0.69	-0.19	9.42	0.46	1.49	6.93
RMS AXIS DATA	**1.26171**	**0.47227**	**9.55026**	**1.24603**	**0.47925**	**9.07562**	**1.32693**	**1.72935**	**10.0283**
COMBINED DATA	**9.64481**			**9.17329**			**10.2625**		
41	-0.24	0.44	9.13	1.59	-0.6	8.92	0.39	3.02	9.32
	-1.11	0.19	10	-1.43	0.12	9.02	-1.29	-2.3	8.58
	-1.52	0.11	9.79	-0.99	0.53	9.6	-1.66	0.32	11
	-1.02	0.71	9.24	-0.93	0.66	8.39	1.8	0.99	12.23
	-1.67	0.01	9.1	-0.71	-0.12	9.49	0.47	1.89	9.01
RMS AXIS DATA	**1.21897**	**0.38626**	**9.45927**	**1.17661**	**0.47017**	**9.09438**	**1.26749**	**1.95269**	**10.1216**
COMBINED DATA	**9.5453**			**9.18223**			**10.3859**		
42	-0.22	0.45	9.23	-0.98	0.84	9.45	0.49	2.03	7.33
	-1.12	0.2	9.99	-1.05	0.32	9.55	-1.36	-2.29	8.29
	-1.7	0.12	10.01	-0.7	-0.18	9.43	-1.62	0.31	11.01
	-1.01	0.71	9.34	1.68	0.47	8.75	1.8	0.5	13.76
	-1.61	0.21	9.12	-1.6	-0.26	8.18	0.52	1.4	7.02
RMS AXIS DATA	**1.2494**	**0.40127**	**9.54571**	**1.25979**	**0.47516**	**9.08741**	**1.28254**	**1.52782**	**9.82131**
COMBINED DATA	**9.63549**			**9.18661**			**10.0218**		
	-0.23	0.46	9.24	1.58	-0.27	8.15	0.5	2.04	7.34
	-1.13	0.21	10	-1.03	0.34	9.53	-1.37	-2.3	8.3

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

43	-1.62	0.22	9.13	-0.97	0.86	9.46	-1.63	0.32	11.02
	-1.02	0.72	9.35	-0.68	-0.2	9.41	1.81	0.51	13.77
	-1.72	0.13	10.02	-1.67	0.46	8.73	0.53	1.41	7.03
RMS AXIS DATA	**1.26119**	**0.40973**	**9.5557**	**1.24495**	**0.48574**	**9.07189**	**1.29157**	**1.53637**	**9.83097**
COMBINED DATA		**9.64728**			**9.16979**			**10.0338**	
	-0.24	0.47	9.25	-1.69	0.48	8.76	0.54	1.42	7.04
	-1.14	0.22	10.01	-1.61	-0.25	8.17	-1.64	0.33	11.03
44	-1.63	0.23	9.14	-1.06	0.35	9.56	0.51	2.05	7.35
	-1.74	0.14	10.03	-0.99	0.87	9.47	1.82	0.52	13.78
	-1.03	0.73	9.36	-0.71	-0.21	9.44	-1.38	-2.31	8.31
RMS AXIS DATA	**1.273**	**0.41826**	**9.5657**	**1.26933**	**0.49323**	**9.09587**	**1.30062**	**1.54495**	**9.84062**
COMBINED DATA		**9.65909**			**9.19725**			**10.0457**	
	-0.25	0.48	9.26	-1.62	-0.24	8.18	0.52	2.06	7.36
	-1.15	0.23	10.02	-1.07	0.36	9.57	-1.39	-2.32	8.32
45	-1.75	0.15	10.04	-1.7	0.49	8.99	-1.65	0.34	11.04
	-1.04	0.74	9.37	-1	1.88	8.48	0.55	1.43	7.05
	-1.64	0.24	9.15	-0.72	-0.22	9.45	1.83	0.53	13.79
RMS AXIS DATA	**1.28208**	**0.42685**	**9.57569**	**1.27888**	**0.89556**	**8.9502**	**1.30969**	**1.55354**	**9.85028**
COMBINED DATA		**9.67056**			**9.08535**			**10.0577**	
	-1.16	0.24	10.03	-0.73	-0.23	9.46	0.53	2.07	7.37
	-1.76	0.16	10.05	-1.01	0.89	9.49	-1.4	-2.33	8.33
46	-1.05	0.75	9.38	-1.08	0.37	9.58	-1.66	0.35	11.05
	-1.65	0.25	9.16	-0.63	-0.23	8.19	1.84	0.54	13.8
	-0.26	0.49	9.27	-1.71	0.5	8.78	0.56	1.44	7.06
RMS AXIS DATA	**1.29119**	**0.4355**	**9.58568**	**1.09913**	**0.50691**	**9.11584**	**1.31876**	**1.56215**	**9.85994**
COMBINED DATA		**9.68205**			**9.19584**			**10.0696**	
	1.16	0.73	9.89	-1.72	0.51	8.79	-1.41	-2.34	8.34
	-1.56	0.27	9.01	-1.64	-0.22	8.2	-1.67	0.36	11.06
47	-0.29	0.59	9.28	-1.09	0.38	9.59	0.54	2.08	7.38
	-1.15	0.15	9.89	-1.02	0.9	9.5	1.85	0.55	13.81
	-1.77	0.17	10.06	-0.74	-0.24	9.47	0.57	1.45	7.07
RMS AXIS DATA	**1.28986**	**0.4484**	**9.63459**	**1.29801**	**0.51391**	**9.12582**	**1.32786**	**1.57077**	**9.8696**
COMBINED DATA		**9.73088**			**9.23198**			**10.0816**	
	-0.28	0.51	9.29	-1.73	0.52	8.8	-1.68	0.37	11.07
	-1.18	0.26	10.05	-1.65	-0.21	8.21	1.86	0.56	13.82
48	-1.78	0.18	10.07	-1.1	0.39	9.6	0.58	1.46	7.08
	-1.07	0.77	9.4	-1.03	0.91	9.51	0.55	2.09	7.39
	-1.67	0.27	9.18	-0.75	-0.25	9.48	-1.42	-2.35	8.35
RMS AXIS DATA	**1.30943**	**0.45297**	**9.60566**	**1.30758**	**0.521**	**9.1358**	**1.33696**	**1.57941**	**9.87925**
COMBINED DATA		**9.70508**			**9.2436**			**10.0936**	
	-1.19	0.27	10.06	-1.66	-0.2	8.22	0.56	2.1	7.4
	-0.29	0.52	9.3	-1.11	0.4	9.61	-1.43	-2.36	8.36
49	-1.79	0.19	10.08	-1.04	0.92	9.52	-1.69	0.38	11.08
	-1.08	0.78	9.41	-0.76	-0.26	9.49	1.87	0.57	13.83
	-1.68	0.28	9.19	-1.74	0.53	8.81	0.59	1.47	7.09
RMS AXIS DATA	**1.31857**	**0.46178**	**9.61566**	**1.31716**	**0.52819**	**9.14579**	**1.34608**	**1.58807**	**9.88891**
COMBINED DATA		**9.71662**			**9.25523**			**10.1057**	
	-0.3	0.53	9.31	-1.75	0.54	8.82	0.57	2.11	7.41
	-1.2	0.28	10.07	-1.67	-0.19	8.23	-1.44	-2.37	8.37
50	-1.8	0.2	10.09	-1.12	0.41	9.62	-1.7	0.39	11.09
	-1.09	0.79	9.42	-1.05	0.93	9.53	1.88	0.58	13.84
	-1.69	0.29	9.2	-0.77	-0.27	9.5	0.6	1.48	7.1
RMS AXIS DATA	**1.32772**	**0.47064**	**9.62565**	**1.32674**	**0.53546**	**9.15577**	**1.3552**	**1.59674**	**9.89857**
COMBINED DATA		**9.72818**			**9.26688**			**10.1177**	

Table 14: Reference Value For Comparison

REFERENCE			
DAY	VIBRATION SENSOR		
	ADXL335	MPU6050	ADXL345
1	9.39406	9.17484	10.5564

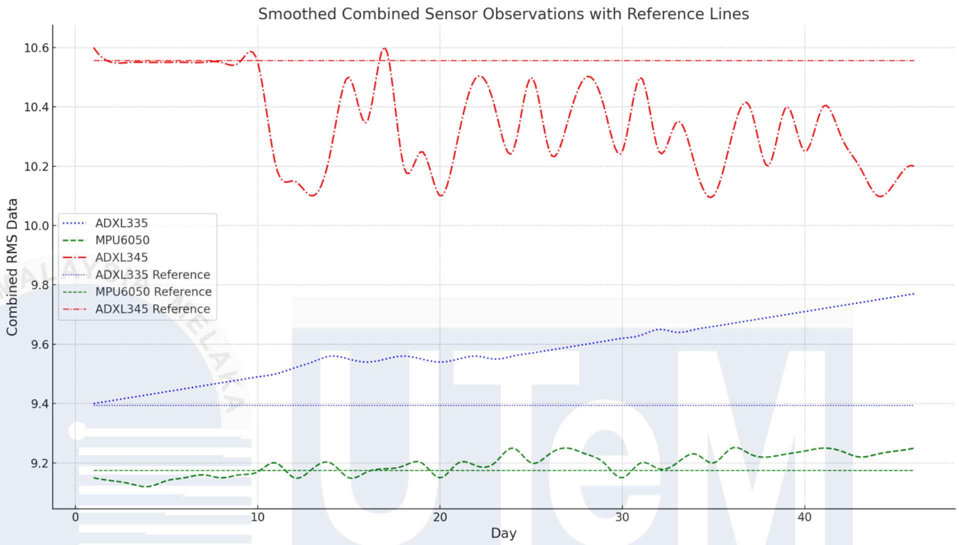


Figure 53: Reliability Magnitude Performance

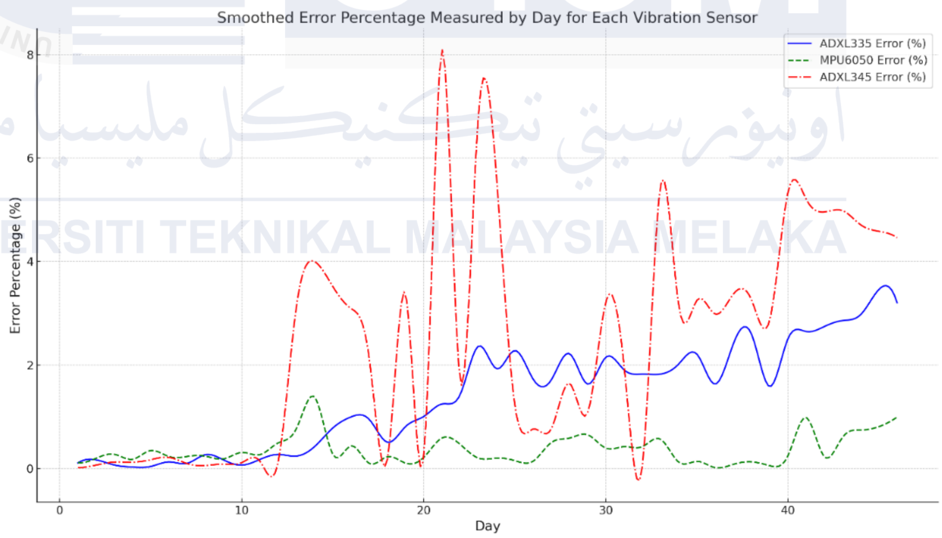
This graph represents the data of three sensors namely ADXL335, MPU6050 and ADXL345 together with their calibrated curves at different days. The performance of the ADXL335 sensor labeled by blue dotted line increases steadily, and the fluctuations are small as compared to the reference line. The MPU6050 sensor indicated with a green dotted line describe a fairly stable performance and only exhibit small amplitudes of oscillations with reference to its reference line, which indicates a high degree of accuracy is being achieved. On the other hand, the ADXL345 sensor shown in the figure below with red dash-dotted line is characterized with various fluctuations, which includes more peaks and troughs and is quite apart from the reference line. This means that the ADXL345 sensor is likely to have higher errors rates or sensitive to external interferences than other sensors.

Table 15: Error Percentage Compared to 1st Day

DAY	VIBRATION SENSOR		
	ADXL335	MPU6050	ADXL345
2	0.10719	0.1154	0.01421
3	0.16706	0.19683	0.06536
4	0.06757	0.27446	0.12413
5	0.02789	0.17843	0.12413
6	0.03196	0.34712	0.16978
7	0.12743	0.09029	0.21523
8	0.09904	0.0205	0.09462
9	0.26651	0.2307	0.05762
10	0.16542	0.23308	0.08529
11	0.0653	0.23859	0.11271
12	0.17543	0.18481	0.14191
13	0.27098	0.3105	0.12189
14	0.23981	0.26686	3.1262
15	0.4231	0.50044	4.00082
16	0.78258	0.49399	3.51368
17	0.99673	0.76873	3.09239
18	0.95032	1.37949	0.21399
19	0.50756	0.275	0.17052
20	0.81171	0.43606	3.37163
21	1.00561	0.09836	0.24318
22	1.24701	0.22673	8.0828
23	1.42972	0.10349	1.70026
24	2.36486	0.21494	6.83209
25	1.92979	0.59018	5.61339
26	2.28039	0.46529	1.22739
27	1.72991	0.20053	0.76358
28	1.72991	0.20053	0.76358
29	1.70987	0.15202	1.64664
30	2.22051	0.13908	1.0705
31	1.63104	0.50088	3.21836

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

32	2.1506	0.58717	1.19945
33	1.90636	0.65243	0.02688
34	1.82453	0.39353	5.45917
35	1.82453	0.42242	3.15982
36	2.01816	0.42127	3.25003
37	2.21193	0.56694	2.98057
38	1.63104	0.12305	3.27038
39	2.40581	0.13764	3.26264
40	2.5998	0.01687	2.86386
41	1.58444	0.08047	1.64204
42	2.50559	0.12815	5.33382
43	2.62472	0.05505	5.20861
44	2.7438	0.24368	5.08352
45	2.85917	0.98494	4.95857
46	2.97444	0.22844	4.83375
47	3.46134	0.61901	4.70907
48	3.20467	0.74388	4.58453
49	3.31964	0.86863	4.46012
50	3.4345	0.99325	4.33585



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Figure 54: Error Percentage For Each Sensors

This graph illustrates the error percentages measured daily for three vibration sensors which are ADXL335, MPU6050, and ADXL345. The ADXL335 sensor (blue curve) initially has low error percentage and as the time progresses gradually spikes up showing minor instability. Among the three sensors, the error percentage of

MPU6050 is lowest and its fluctuation level is also minimum and steady which confirms that it is powerful and reliable sensor. On the other hand, the ADXL345 sensor (the red curve) oscillates in error percentage highly, in this test, it has some sharp peaks and valleys during the observation time. This has brought about inconsistency in the sensors' performance and higher error rates than the other two sensors. All in all, the MPU6050 can be summarized as being the most stable sensor amongst all tested, to lesser extent the ADXL335 and finally the ADXL345.

Table 16: Average Error Percentage

AVERAGE ERROR			
DAY	VIBRATION SENSOR		
	ADXL335	MPU6050	ADXL345
1	1.48668	0.36123	2.46124

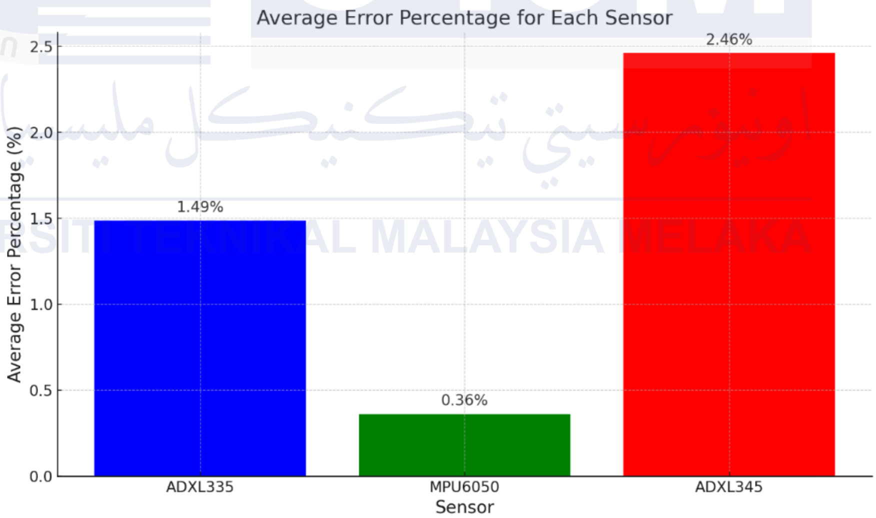


Figure 55: Average Error Percentage For Each Sensors

This chart compares the average error percentages of three vibration sensors. The ones worth mentioning here are ADXL335, MPU6050, ADXL345. The MPU6050 sensor has proven to yield the least level of error, approximately 0.36% on average which shows high levels of accuracy compared to the other sensors. The average error percentage of the ADXL335 of 1.49% can also be said to fall in a moderate relationship to the expected output of the sensor with some variation. The specific data reveals that the ADXL345 sensor is the least accurate test, with an average error percentage of 2.46%, and the one that varies the most. The above comparison shows that the MPU6050 is more reliable than the other sensors while the ADXL345 should be modified to reduce the amount of error.

4.2.2 Development Predictive Maintenance Conveyor System Equipped With An Alarm That Prevents Major Faults By Detecting Unusual Vibrations And Stopping Operations Immediately.

The sensors were then assessed and from these evaluations the MPU6050 was chosen as the main sensor due to better performances in the area of; vibration. For the purpose of covering all aspects needed for conveyor condition monitoring, more sensors were added to the hardware system including DHT22 that was used for measuring the humidity and a temperature sensor. We have incorporated a working conveyor system that has been designed to mimic the prototype in this project during its operation so as to assess the functionality of the monitoring solution. Outputs to be monitored are shown on an LCD screen hence offering real time information of the vibration and other information. Another key component of the system is a buzzer which is safety feature of the system to alert the operator of abnormal or unusual vibration signal patterns, that are indicative of possible problems with the equipment. Such a selection of sensors and the alerting systems will make sure the project fulfils the requirements for monitoring in addition to improving the reliability as well as the safety of the conveyor systems.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

4.2.2.1 Model Design Of The Predictive Maintenance Conveyor System Device

The following set of pictures represents the full design of the project model the pictures depict the fully closed casings of the model and also the fully opened casings of the model. The design is connected to the conveyor prototype and all the necessary sensors, MPU6050, DHT22, the temperature sensor, which is used for the conveyor state control. The closed casing version is focused on emphasizing the structure and space, which is inside the system while the open casing version shows the detailed connections of the wires and image of the internal components of the hardware of the system.

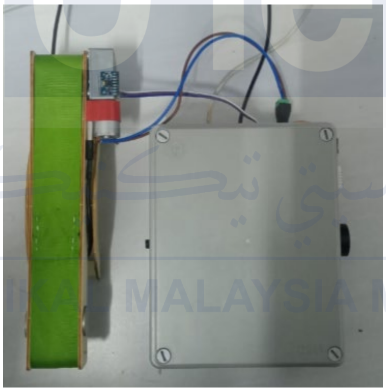


Figure 56: View Of The Project

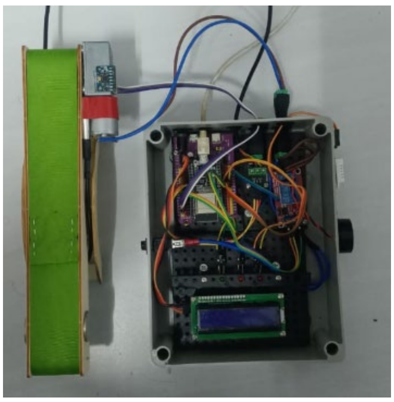


Figure 57: View Of The Project (Opened)

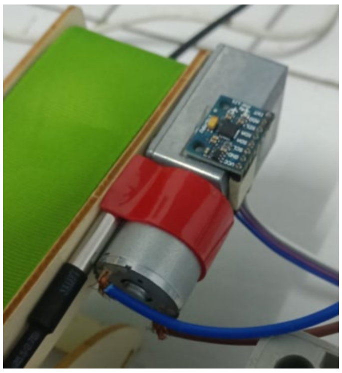


Figure 58: DS18B20 Temperature Sensor and MPU6050 Vibration Sensor Connected To The DC Motor

Figure 59: Buzzer and DHT22 Humidity Sensor Placed At The Side Of The Casing

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

4.2.2.2 Output Of The Predictive Maintenance Conveyor System Device

This section concentrates on the output capability of the device. The device used is a 16 x 2 LCD which presents the monitoring data such as temperature, humidity, and the condition of the conveyor as it is at the time of monitoring. The system identifies and displays three distinct conditions normal, fault, and critical. As for these conditions, LED indicator also change color, green is normal, orange is for fault, and red for critical condition visually giving the operator an easy to understand signal.

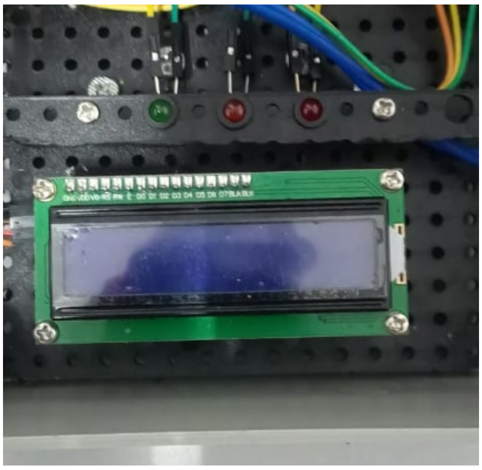


Figure 60: LCD 16x2 And 3 LEDs

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Figure 61: Conveyor In Normal Condition

Figure 62: Conveyor In Normal Condition (Plotter)

Figure 63: Conveyor In Faulty Condition

Figure 64: Conveyor In Faulty Condition (Plotter)

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Figure 65: Conveyor In Critical Condition

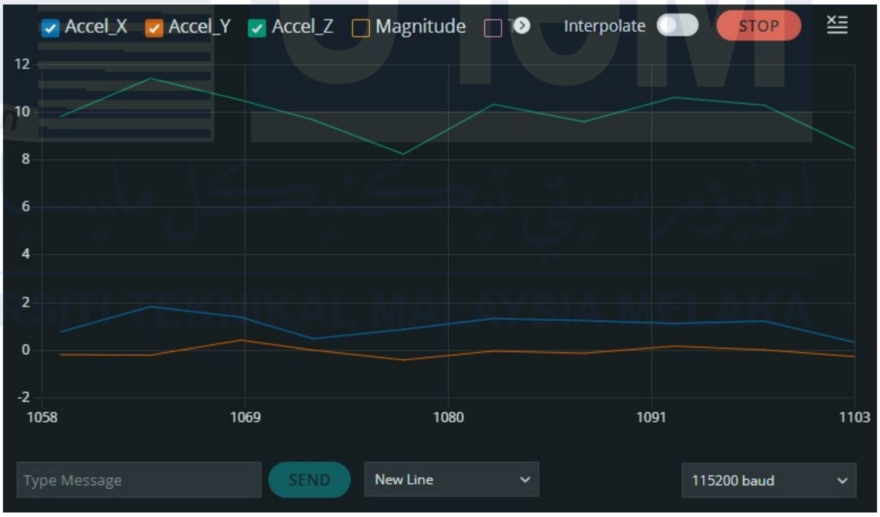


Figure 66: Conveyor In Critical Condition (Plotter)

4.2.3 Control and monitoring the conveyor system using IoT technology via phone app

This segment explains the Blynk mode of operation where essential data such as the magnitude of vibration or the temperature and humidity of the area as provided to the users in a friendly format. The interface also has the control buttons to enable starting or stopping of the conveyor from a distance in order to ease the operations management.

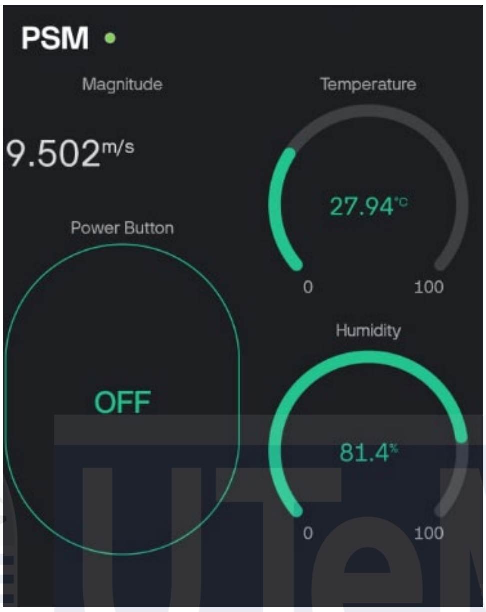


Figure 67: Blynk Interface (OFF Buzzer/ON Conveyor)

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

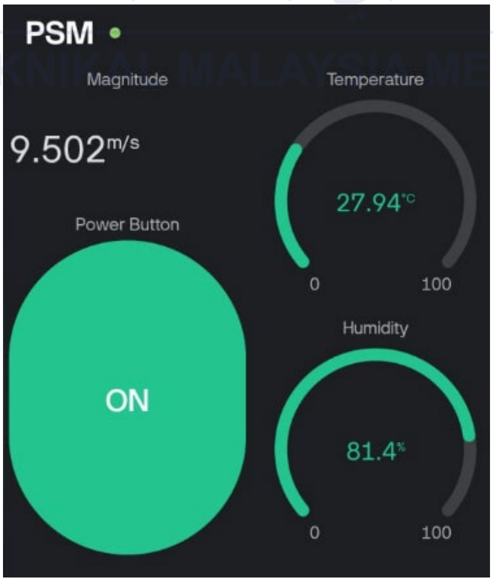


Figure 68: Blynk Interface (ON Buzzer/OFF Conveyor)

The following figure shows the Blynk interface where notifications can be set for if the system ever recognises a fault condition.

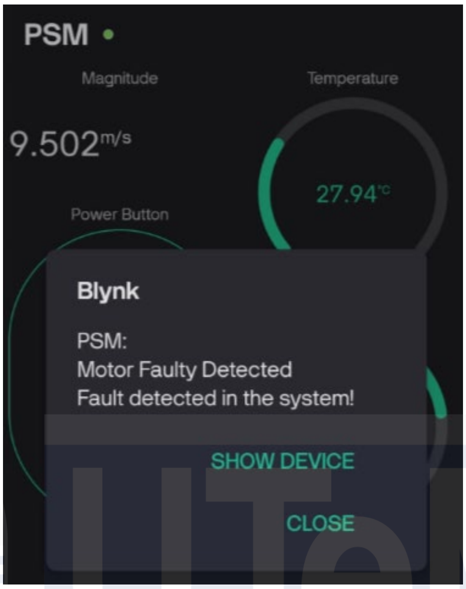


Figure 69: Blynk Interface Notification Received (Faulty Condition)

4.2.4 Sustainability of Design Product/Technology and Research Analysis

This material aligns SDG 8 (Decent Work and Economic Growth) and SDG 9 (Industry, Innovation, and Infrastructure) with the sustainability of the designed conveyor monitoring system in improving the reliability and productivity in the conveyor systems, thus, cutting time wastage. High quality sensors including MPU6050 and DHT22 temperature along with temperature sensors are incorporated in the system to facilitate early detection of faults which in turn reduces costs of production while maintaining production rate. Through efficiency of conveyor movement, the system conserves energy and minimizes the use of materials, creating environmental benefits. Further, applying IoT technology, including the Blynk platform also encourages innovation and allows for the development of robust industrial infrastructure to be implemented remotely. The project also helps to make workplaces safer by providing timely notification and thus creating decent workplace for the employees. Furthermore, its compact and flexible structure ensures the company's orientation toward different spheres of the economy, promoting stable development and the use of innovative high-performance technologies in various fields.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

CHAPTER 5

CONCLUSION AND FUTURE WORK

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

5.1 Conclusion

This project exemplarily built a predictive maintenance system for conveyor operations by incorporating sophisticated sensors and IoT into a single solution. It was also established that the MPU6050 sensor was the most reliable and stable out of the available sensor types providing enhanced performance in vibration measurement during different operation. Due to its reliability and ability to offer consistent results for longer, it is perfect in the management of the conveyors and overall reduction of all risks associated with mechanical breakdowns. Other sensors such as the DHT22 temperature sensor were incorporated to complement MPU6050 to give the complete status of the performance of the conveyor system by monitoring features such as humidity and temperature. They include LCD 16x2 display module for displaying the continuously real-time monitoring data and an LED indicator and buzzer for alarming when the data is beyond normal/abnormal or critical value. Further, as a part of the IoT element, the model incorporates Blynk Technology, this gives users a chance to monitor and control the conveyor's vibration magnitude, temperature, and humidity levels through a smartphone application. The project specifically runs diagnostics tools to detect faults that would otherwise take a longer period to identify, fix and prevent; thus, the project minimizes or eradicates any downtime and disruption of operations that could translate to increased safety risks and lower productivity. From the perspective of Industry 4.0 which is primarily based on automation and data exchange this project can become the example of how different industrial processes could be modernized for perceiving new challenges and promoting further sustainable development. Concisely, the theoretical and practical analysis of this kind of predictive maintenance system demonstrates the efficiency of this solution for increasing the reliability and safety of conveyor equipment and operations in industrial settings.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

5.2 Future Work

For the future enhancement of the system, the enhancements could be made by adding more sensors to the system that can indicate some other important parameters such as, load distribution, tension of the belt and health of the motor, thus giving a more sophisticated solution to the problem. Having a cloud-based IoT could add to the system by providing means of real-time storage, analytics, and even predictive modeling, all of which work as a foundation for improved decision making and long-term maintenance planning. Use of more advanced artificial intelligence techniques such as Machine Learning could be incorporated to enhance the capability of fault detection through evaluating elaborate sign patterns in vibration and environmental information as well as the capability to improve with different operation conditions over time. Furthermore the integration of the prototype would be possible for larger industrial systems or could be in adapted for other industries requirements. Additional testing to environments that are not favorable for the generation of power could be carried out whereby the system could be tested at very high and very low temperatures and under high humidity conditions. The improvement of the functionality and insertion of energy-saving components and renewable energy sources, such as the solar panels, to increase the sustainability of the system may increase the relation between the Objectives and SDG 8 (Decent Work and Economic Growth) and SDG 9 (Industry, Innovation, and Infrastructure). Finally, while extending the system, investigating how AR can be used for maintenance instructions or for support when remote could provide new ideas on how to assist the technician in identifying and responding to a fault in the most advantageous and proficient manner to support the totality of the system.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

REFERENCE

[1] Alharbi F, Luo S, "A Review of Fault Detecting Devices for Belt Conveyor Idlers," *Article in Journal of Mechanical Engineering Science and Technology,* vol. 8, no. 1, pp. 39-53, 2024.

[2] Giraud L, Masse S, Schreiber L, "Machine Safety Machine Safety Belt Conveyor Safety Understanding the hazards," *Professional Safety,* vol. 11, pp. 20-27, 2004.

[3] Martínez Parrales R, Del Carmen Téllez Anguiano A, "Vibration-based Fault Detection System with IoT Capabilities for a Conveyor Machine," *Acta Polytechnica Hungarica,* vol. 19, no. 9, pp. 2022-2029, 2022.

[4] Jo B, Lee Y, Khan R, Kim J, Kim D, "Robust Construction Safety System (RCSS) for collision accidents prevention on construction sites," *Sensors,* vol. 19, no. 4, 2019.

[5] Nascimento R, Carvalho R, Delabrida S, Bianchi A, Oliveira R, Garcia L, "An integrated inspection system for belt conveyor rollers advancing in an

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

enterprise architecture," *International Conference on Enterprise Information Systems (ICEIS),* pp. 190-200, 2017.

[6] Joloda Hydraroll, "The Economic Impact of Downtime of Your Conveyor System," Joloda Hydraroll, 2023. [Online]. Available: https://www.joloda.com. [Accessed 30 November 2024].

[7] Mohd Sultan J, Zani N, Azuani M, Ibrahim S, Md Yusop A, "Analysis of Inertial Measurement Accuracy using Complementary Filter for MPU6050 Sensor," *Jurnal Kejuruteraan,* vol. 34, no. 5, pp. 959-964, 2022.

[8] Pakpahan, I. E. A., Sihombing, P., & Nasution, M. K., "Analysis of the Sw-420 vibration sensor performance on vibration tools by using a fuzzy logic method," *International Conference on Culture Heritage, Education, Sustainable Tourism, and Innovation Technologies (CESIT 2020),* no. 1, pp. 543-550, 2020.

[9] Varanis, M., Silva, A., Mereles, A., & Pederiva, R., "MEMS accelerometers for mechanical vibrations analysis: a comprehensive review with applications," *Journal of the Brazilian Society of Mechanical Sciences and Engineering,* vol. 40, no. 11, pp. 1-18, 2018.

[10] Wijaya H, Pathmanathan P, Prof R, Gad E, "Application of Distributed Acoustic Sensor for Condition Monitoring of Mining Conveyor," *Swinburne University of Technology,* pp. 1-6, 2022.

[11] D. Mendes, P. D. Gaspar, F. Charrua-Santos, and H. Navas, "Enhanced Real-Time Maintenance Management Model—A Step toward Industry 4.0 through

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Lean: Conveyor Belt Operation Case Study," *Electronics,* vol. 12, no. 18, p. 3872, 2023.

[12] Conveyor Equipment Manufacturers Association, Belt conveyors for bulk materials, 6 ed., Florida: USA: Conveyor Equipment Manufacturers Association, 2007.

[13] M. Zhang, Y. Zhang, M. Zhou et al., "Application of Lightweight Convolutional Neural Network for," *Applied Sciences,* vol. 11, no. 16, pp. 1-15, 2021.

[14] C3.ai, Inc., "Predictive Maintenance and AI-Powered Reliability Solutions," [Online]. Available: https://www.c3.ai.com. [Accessed 22 November 2024].

[15] S. A. N. Morales, A. V. Ch., V. T. Argüelles, E. M. G., and A. H. G, "Six Sigma improvement project in a concrete block plant," *Construction Innovation,* vol. 16, no. 4, pp. 526-544, 2016.

[16] Tustin, Wayne, "Where to place the control accelerometer: one of the most critical decisions in developing random vibration tests also is the most neglected," *EE-Evaluation Engineering,* 2006.

[17] A. F. Albaghdadi, A. Ali, "An Optimized Complementary Filter For An Inertial Measurement Unit Contain MPU6050 Sensor," *Iraqi Journal of Electrical and Electronic Engineering,* vol. 15, no. 2, pp. 71-77, 2019.

[18] Hompage arduino.cc, "Arduino," [Online]. Available: https://playground.arduino.cc/Main/MPU-6050. [Accessed 26 May 2024].

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

[19] InvenSense, "MPU-6000 and MPU-6050 Product Specification Revision 3.4.," *InvenSense official website,* pp. 7-28, 2013.

[20] InvenSense, "MPU6000 and MPU6050 Product Specification Revision 3.3," InvenSense, Inc., 2011.

[21] Analog Devices, "ADXL335: Small, Low Power, 3-Axis ±3 g Analog Output Accelerometer," 2019. [Online]. Available: https://www.analog.com/en/products/adxl335.html. [Accessed 26 May 2024].

[22] Electronic Wings, "Complete Guide ADXL335 Accelerometer with Arduino Interfacing," 2024. [Online]. Available: https://www.electronicwings.com/sensors-modules/adxl335-accelerometer-module. [Accessed 26 May 2024].

[23] Analog Devices, "ADXL335: Small, Low Power, 3-Axis ±3 g Accelerometer," Analog Devices, Inc, 2008.

[24] A Najmurrokhman, Kusnandar, U. Komarudin, A. M. Annas, R. Rahim, "Design and Realization of A Low Cost Clinometer based on ADXL345 Sensor, Ultrasonic Sensor, and Android based Smartphone," *Journal of Physics: Conference Series,* vol. 1424, pp. 1-8, 2019.

[25] H. Ferdinando, H. Khoswanto, D. Purwanto, "Performance Evaluation of MMA7260QT and ADXL345 on Self Balancing Robot," *TELKOMNIKA,* vol. 11, no. 1, pp. 1-10, 2012.

[26] Analog Devices, "ADXL345: Three-Axis, ±2/4/8/16g Digital Accelerometer," Analog Devices, Inc., 2008.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

[27] D. Xia, M. Yao, J. Li, "Digital Tri-Axis Accelerometer with X/Y-Axial Resonators and Z-Axial Capacitive Seesaw," *Micromachines,* vol. 13, no. 8, pp. 11-74, 2022.

[28] Visser, P.N.A., IJssel, J.A.A.v.d, "Calibration and validation of individual GOCE accelerometers by precise orbit determination," *Journal Of Geodesy,* vol. 90, no. 1, pp. 1-13, 2016.

[29] Sankar, A.R., Jency, J.G., "Design, fabrication and testing of a high performance silicon piezoresistive Z-axis accelerometer with proof mass-edge-aligned-flexures," *Microsystem Technologies,* vol. 18, no. 1, pp. 9-23, 2012.

[30] S. Gao, S. Yan, A. Nathan, Touch-Based Human-Machine Interaction: Principles and Applications, Springer, 2021.

[31] D. Makarov, "Hertz to Revolutions per Minute Conversion," ASUTPP, June 2023. [Online]. Available: https://www.asutpp.com/hz-to-rpm.html.

[32] J. Erjavec, Automotive Technology: A Systems Approach, illustrated ed., Thomson/Delmar Learning, 2005, p. 1401.

[33] M. Fezari, A. al Dahoud, "Integrated Development Environment 'IDE' For Arduino Speech Processing View project A comparative Analysis of Data Fragmentation in Distributed Database View project Integrated Development Environment 'IDE' For Arduino Introduction to Arduino IDE," *Research Gate,* 2018.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

APPENDICES

Appendix A – ADXL335 Datasheet

SPECIFICATIONS

$T_A = 25°C$, $V_S = 3$ V, $C_X = C_Y = C_Z = 0.1$ µF, acceleration = 0 *g*, unless otherwise noted. All minimum and maximum specifications are guaranteed. Typical specifications are not guaranteed.

Table 1.

Parameter	Conditions	Min	Typ	Max	Unit
SENSOR INPUT	Each axis				
Measurement Range		±3	±3.6		*g*
Nonlinearity	% of full scale		±0.3		%
Package Alignment Error			±1		Degrees
Interaxis Alignment Error			±0.1		Degrees
Cross Axis Sensitivity[1]			±1		%
SENSITIVITY (RATIOMETRIC)[2]	Each axis				
Sensitivity at X_{OUT}, Y_{OUT}, Z_{OUT}	$V_S = 3$ V	270	300	330	mV/*g*
Sensitivity Change Due to Temperature[3]	$V_S = 3$ V		±0.01		%/°C
ZERO *g* BIAS LEVEL (RATIOMETRIC)					
0 *g* Voltage at X_{OUT}, Y_{OUT}	$V_S = 3$ V	1.35	1.5	1.65	V
0 *g* Voltage at Z_{OUT}	$V_S = 3$ V	1.2	1.5	1.8	V
0 *g* Offset vs. Temperature			±1		m*g*/°C
NOISE PERFORMANCE					
Noise Density X_{OUT}, Y_{OUT}			150		µ*g*/√Hz rms
Noise Density Z_{OUT}			300		µ*g*/√Hz rms
FREQUENCY RESPONSE[4]					
Bandwidth X_{OUT}, Y_{OUT}[5]	No external filter		1600		Hz
Bandwidth Z_{OUT}[5]	No external filter		550		Hz
R_{FILT} Tolerance			32 ± 15%		kΩ
Sensor Resonant Frequency			5.5		kHz
SELF TEST[6]					
Logic Input Low			+0.6		V
Logic Input High			+2.4		V
ST Actuation Current			+60		µA
Output Change at X_{OUT}	Self test 0 to 1		−300		mV
Output Change at Y_{OUT}	Self test 0 to 1		+300		mV
Output Change at Z_{OUT}	Self test 0 to 1		+550		mV
OUTPUT AMPLIFIER					
Output Swing Low	No load		0.1		V
Output Swing High	No load		2.8		V
POWER SUPPLY					
Operating Voltage Range		1.8		3.6	V
Supply Current	$V_S = 3$ V		350		µA
Turn-On Time[7]	No external filter		1		ms
TEMPERATURE					
Operating Temperature Range		−40		+85	°C

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Appendix B – ADXL345 Datasheet

SPECIFICATIONS

T_A = 25°C, V_S = 2.5 V, $V_{DD\ I/O}$ = 1.8 V, Acceleration = 0 *g*, unless otherwise noted.

Table 1. Specifications[1]

Parameter	Conditions	Min	Typ	Max	Unit
SENSOR INPUT	Each axis				
Measurement Range	User Selectable		±2, 4, 8, 16		*g*
Nonlinearity	Percentage of full scale		±0.5		%
Inter-Axis Alignment Error			±0.1		Degrees
Cross-Axis Sensitivity[2]			±1		%
OUTPUT RESOLUTION	Each axis				
All g-ranges	10-bit mode		10		Bits
±2 *g* range	Full-Resolution		10		Bits
±4 *g* range	Full-Resolution		11		Bits
±8 *g* range	Full-Resolution		12		Bits
±16 *g* range	Full-Resolution		13		Bits
SENSITIVITY	Each axis				
Sensitivity at X_{OUT}, Y_{OUT}, Z_{OUT}	V_S = 2.5 V, ±2 *g* 10-bit or Full-Resolution	232	256	286	LSB/*g*
Scale Factor at X_{OUT}, Y_{OUT}, Z_{OUT}	V_S = 2.5 V, ±2 *g* 10-bit or Full-Resolution	3.5	3.9	4.3	m*g*/LSB
Sensitivity at X_{OUT}, Y_{OUT}, Z_{OUT}	V_S = 2.5 V, ±4 *g* 10-bit mode	116	128	143	LSB/*g*
Scale Factor at X_{OUT}, Y_{OUT}, Z_{OUT}	V_S = 2.5 V, ±4 *g* 10-bit mode	7.0	7.8	8.6	m*g*/LSB
Sensitivity at X_{OUT}, Y_{OUT}, Z_{OUT}	V_S = 2.5 V, ±8 *g* 10-bit mode	58	64	71	LSB/*g*
Scale Factor at X_{OUT}, Y_{OUT}, Z_{OUT}	V_S = 2.5 V, ±8 *g* 10-bit mode	14.0	15.6	17.2	m*g*/LSB
Sensitivity at X_{OUT}, Y_{OUT}, Z_{OUT}	V_S = 2.5 V, ±16 *g* 10-bit mode	29	32	36	LSB/*g*
Scale Factor at X_{OUT}, Y_{OUT}, Z_{OUT}	V_S = 2.5 V, ±16 *g* 10-bit mode	28.1	31.2	34.3	m*g*/LSB
Sensitivity Change due to Temperature			±0.02		%/°C
0 *g* BIAS LEVEL	Each axis				
0 *g* Output (X_{OUT}, Y_{OUT}, Z_{OUT})	V_S = 2.5 V, T_A = 25°C	-150	0	+150	m*g*
0 *g* Offset vs. Temperature			<±1		m*g*/°C
NOISE PERFORMANCE					
Noise (x-, y-axes)	Data Rate = 100 Hz, ±2 *g* 10-bit or Full-Res.		<1		LSB RMS
Noise (z-axis)	Data Rate = 100 Hz, ±2 *g* 10-bit or Full-Res.		<1.5		LSB RMS
OUTPUT DATA RATE / BANDWIDTH	User Selectable				
Measurement Rate[3]		0.1		3200	Hz
SELF TEST					
Output Change X		+0.31		+1.02	*g*
Output Change Y		-0.31		-1.02	*g*
Output Change Z		+0.46		+1.64	*g*
POWER SUPPLY					
Operating Voltage Range (V_S)		2.0	2.5	3.6	V
Interface Voltage Range ($V_{DD\ I/O}$)		1.7	1.8	V_S	V
Supply Current	Data Rate > 100 Hz		130	150	μA
Supply Current	Data Rate < 10 Hz		25		μA
Standby Mode Leakage Current			0.1	2	μA
Turn-On Time[4]	Data Rate = 3200 Hz		1.4		ms
TEMPERATURE					
Operating Temperature Range		−40		85	°C

Appendix C – MPU6050 Datasheet

6.2 Accelerometer Specifications

VDD = 2.375V-3.46V, VLOGIC (MPU-6050 only) = 1.8V±5% or VDD, T_A = 25°C

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS	NOTES
ACCELEROMETER SENSITIVITY						
Full-Scale Range	AFS_SEL=0		±2		*g*	
	AFS_SEL=1		±4		*g*	
	AFS_SEL=2		±8		*g*	
	AFS_SEL=3		±16		*g*	
ADC Word Length	Output in two's complement format		16		bits	
Sensitivity Scale Factor	AFS_SEL=0		16,384		LSB/*g*	
	AFS_SEL=1		8,192		LSB/*g*	
	AFS_SEL=2		4,096		LSB/*g*	
	AFS_SEL=3		2,048		LSB/*g*	
Initial Calibration Tolerance			±3		%	
Sensitivity Change vs. Temperature	AFS_SEL=0, -40°C to +85°C		±0.02		%/°C	
Nonlinearity	Best Fit Straight Line		0.5		%	
Cross-Axis Sensitivity			±2		%	
ZERO-G OUTPUT						
Initial Calibration Tolerance	X and Y axes		±50		m*g*	1
	Z axis		±80		m*g*	
Zero-G Level Change vs. Temperature	X and Y axes, 0°C to +70°C		±35			
	Z axis, 0°C to +70°C		±60		m*g*	
SELF TEST RESPONSE						
Relative	Change from factory trim	-14		14	%	2
NOISE PERFORMANCE						
Power Spectral Density	@10Hz, AFS_SEL=0 & ODR=1kHz		400		μ*g*/ √Hz	
LOW PASS FILTER RESPONSE	Programmable Range	5		260	Hz	
OUTPUT DATA RATE	Programmable Range	4		1,000	Hz	
INTELLIGENCE FUNCTION INCREMENT			32		m*g*/LSB	

1. Typical zero-g initial calibration tolerance value after MSL3 preconditioning
2. Please refer to the following document for further information on Self-Test: *MPU-6000/MPU-6050 Register Map and Descriptions*

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Appendix D – ESP32 Pin Configuration

UTeM
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Appendix E – ADXL335 Code

```
#define X_PIN A0
#define Y_PIN A3
#define Z_PIN A4

// ADXL335 constants
const float VOLTAGE_REF = 3.3; // Voltage reference for the analog input (3.3V for ESP32)
const float ZERO_G_VOLTAGE = VOLTAGE_REF / 2; // Zero-g voltage (typically half of the reference voltage)
const float SENSITIVITY = VOLTAGE_REF / 10; // Sensitivity is 300mV/g, convert to V/g

void setup(void) {
  Serial.begin(115200);
  while (!Serial)
    delay(10); // will pause Zero, Leonardo, etc until serial console opens

  Serial.println("ADXL335 test!");

  Serial.println("");
  delay(100);
}

void loop() {
  /* Get new sensor readings */
  int rawX = analogRead(X_PIN);
  int rawY = analogRead(Y_PIN);
  int rawZ = analogRead(Z_PIN);

  // Convert raw values to voltages
  float voltageX = rawX * (VOLTAGE_REF / 4095.0); // For ESP32, 12-bit ADC
  float voltageY = rawY * (VOLTAGE_REF / 4095.0); // For ESP32, 12-bit ADC
```

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

```
float voltageZ = rawZ * (VOLTAGE_REF / 4095.0); // For ESP32, 12-bit ADC

// Convert voltages to accelerations in g's
float accelerationX = (voltageX - ZERO_G_VOLTAGE) / SENSITIVITY;
float accelerationY = (voltageY - ZERO_G_VOLTAGE) / SENSITIVITY;
float accelerationZ = (voltageZ - ZERO_G_VOLTAGE) / SENSITIVITY;

/* Print out the values in a format suitable for Serial Plotter */
Serial.print(accelerationX);
Serial.print(",");
Serial.print(accelerationY);
Serial.print(",");
Serial.print(accelerationZ);
Serial.println();

delay(500);
}
```

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Appendix F – ADXL345

```
#include <Wire.h>
#include <Adafruit_Sensor.h>
#include <Adafruit_ADXL345_U.h>

// Create an ADXL345 accelerometer object
Adafruit_ADXL345_Unified accel = Adafruit_ADXL345_Unified(12345);

void setup(void) {
 Serial.begin(115200);
 while (!Serial)
  delay(10); // will pause Zero, Leonardo, etc until serial console opens

 Serial.println("Adafruit ADXL345 test!");

 // Try to initialize!
 if (!accel.begin()) {
  Serial.println("Failed to find ADXL345 chip");
  while (1) {
   delay(10);
  }
 }
 Serial.println("ADXL345 Found!");

 accel.setRange(ADXL345_RANGE_16_G);
 Serial.print("Accelerometer range set to: ");
 switch (accel.getRange()) {
 case ADXL345_RANGE_2_G:
  Serial.println("+-2G");
  break;
 case ADXL345_RANGE_4_G:
  Serial.println("+-4G");
```

```
    break;
  case ADXL345_RANGE_8_G:
    Serial.println("+-8G");
    break;
  case ADXL345_RANGE_16_G:
    Serial.println("+-16G");
    break;
  }

  Serial.println("");
  delay(100);
}

void loop() {
  /* Get new sensor events with the readings */
  sensors_event_t event;
  accel.getEvent(&event);

  /* Print out the values in a format suitable for Serial Plotter */
  Serial.print(event.acceleration.x);
  Serial.print(",");
  Serial.print(event.acceleration.y);
  Serial.print(",");
  Serial.print(event.acceleration.z);
  Serial.println();

  delay(500);
}
```

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Appendix G – MPU6050

```
#include <Adafruit_MPU6050.h>
#include <Adafruit_Sensor.h>
#include <Wire.h>

Adafruit_MPU6050 mpu;

void setup(void) {
  Serial.begin(115200);
  while (!Serial)
    delay(10); // will pause Zero, Leonardo, etc until serial console opens

  Serial.println("Adafruit MPU6050 test!");

  // Try to initialize!
  if (!mpu.begin()) {
    Serial.println("Failed to find MPU6050 chip");
    while (1) {
      delay(10);
    }
  }
  Serial.println("MPU6050 Found!");

  mpu.setAccelerometerRange(MPU6050_RANGE_8_G);
  Serial.print("Accelerometer range set to: ");
  switch (mpu.getAccelerometerRange()) {
  case MPU6050_RANGE_2_G:
    Serial.println("+-2G");
    break;
  case MPU6050_RANGE_4_G:
    Serial.println("+-4G");
    break;
```

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

```
case MPU6050_RANGE_8_G:
  Serial.println("+-8G");
  break;
case MPU6050_RANGE_16_G:
  Serial.println("+-16G");
  break;
}
mpu.setGyroRange(MPU6050_RANGE_500_DEG);
Serial.print("Gyro range set to: ");
switch (mpu.getGyroRange()) {
case MPU6050_RANGE_250_DEG:
  Serial.println("+- 250 deg/s");
  break;
case MPU6050_RANGE_500_DEG:
  Serial.println("+- 500 deg/s");
  break;
case MPU6050_RANGE_1000_DEG:
  Serial.println("+- 1000 deg/s");
  break;
case MPU6050_RANGE_2000_DEG:
  Serial.println("+- 2000 deg/s");
  break;
}

mpu.setFilterBandwidth(MPU6050_BAND_5_HZ);
Serial.print("Filter bandwidth set to: ");
switch (mpu.getFilterBandwidth()) {
case MPU6050_BAND_260_HZ:
  Serial.println("260 Hz");
  break;
case MPU6050_BAND_184_HZ:
  Serial.println("184 Hz");
```

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

```
    break;
  case MPU6050_BAND_94_HZ:
    Serial.println("94 Hz");
    break;
  case MPU6050_BAND_44_HZ:
    Serial.println("44 Hz");
    break;
  case MPU6050_BAND_21_HZ:
    Serial.println("21 Hz");
    break;
  case MPU6050_BAND_10_HZ:
    Serial.println("10 Hz");
    break;
  case MPU6050_BAND_5_HZ:
    Serial.println("5 Hz");
    break;
  }

  Serial.println("");
  delay(100);
}

void loop() {
  sensors_event_t a, g, temp;
  mpu.getEvent(&a, &g, &temp);
  Serial.print(a.acceleration.x);
  Serial.print(",");
  Serial.print(a.acceleration.y);
  Serial.print(",");
  Serial.println(a.acceleration.z);
  delay(500);
}
```

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Appendix H – Project Device Code

```
#define BLYNK_TEMPLATE_ID "TMPL6ld-rnZBZ"
#define BLYNK_TEMPLATE_NAME "PSM"
#define BLYNK_AUTH_TOKEN "z-vz8sV4Bp7OZUCrlgN62kzCtYXBhPb6"

#include "DHT.h"
#include <Adafruit_MPU6050.h>
#include <Adafruit_Sensor.h>
#include <Wire.h>
#include <WiFi.h>
#include <BlynkSimpleEsp32.h>
#include <OneWire.h>
#include <DallasTemperature.h>
#include <LiquidCrystal_I2C.h>

// DHT Sensor setup
#define DHTPIN 14 // Digital pin connected to the DHT sensor
#define DHTTYPE DHT22 // DHT 22 (AM2302), AM2321
DHT dht(DHTPIN, DHTTYPE);

// Blynk and WiFi credentials
char auth[] = BLYNK_AUTH_TOKEN;
char ssid[] = "IfUrNotInMyBlacklistUMayConnect";
char pass[] = "001010011";

// Pin Definitions
#define BUZZER_TOGGLE_PIN V4
const int oneWireBus = 4;
const int buzzerRelayPin = 5;
const int redLedPin = 12;
const int orangeLedPin = 13;
const int greenLedPin = 27;
```

```
Adafruit_MPU6050 mpu;
OneWire oneWire(oneWireBus);
DallasTemperature sensors(&oneWire);
LiquidCrystal_I2C lcd(0x27, 16, 2);

bool buzzerToggleState = false; // Buzzer toggle state
bool faultNotificationSent = false; // Track if notification was sent

// Blynk Virtual Pin for Buzzer Toggle
BLYNK_WRITE(BUZZER_TOGGLE_PIN) {
  buzzerToggleState = param.asInt(); // Read toggle switch state (0 or 1)
  digitalWrite(buzzerRelayPin, buzzerToggleState ? HIGH : LOW); // Control buzzer
}

void setup() {
  Serial.begin(115200);

  // WiFi and Blynk setup
  WiFi.begin(ssid, pass);
  Blynk.begin(auth, ssid, pass);

  // DHT22 setup
  dht.begin();

  // MPU6050 setup
  if (!mpu.begin()) {
    Serial.println("Failed to find MPU6050 chip");
    while (1) delay(10);
  }
  mpu.setAccelerometerRange(MPU6050_RANGE_8_G);
  mpu.setGyroRange(MPU6050_RANGE_500_DEG);
```

```
  mpu.setFilterBandwidth(MPU6050_BAND_5_HZ);

  // DS18B20 and LCD setup
  sensors.begin();
  lcd.begin();
  lcd.backlight();
  lcd.setCursor(0, 0);
  lcd.print("Initializing...");
  delay(2000);
  lcd.clear();

  // Pin Modes
  pinMode(buzzerRelayPin, OUTPUT);
  pinMode(redLedPin, OUTPUT);
  pinMode(orangeLedPin, OUTPUT);
  pinMode(greenLedPin, OUTPUT);
  digitalWrite(buzzerRelayPin, LOW); // Ensure buzzer is off
}

void loop() {
  Blynk.run();

  // Read DHT22 sensor data
  float humidity = dht.readHumidity();
  float temperatureDHT = dht.readTemperature();

  // Handle DHT22 read errors
  if (isnan(humidity) || isnan(temperatureDHT)) {
    Serial.println(F("Failed to read from DHT sensor!"));
    humidity = -1; // Use -1 as an error flag
    temperatureDHT = -1;
  }
```

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

```
  // Sensor readings
  sensors_event_t a, g, temp;
  mpu.getEvent(&a, &g, &temp);
  sensors.requestTemperatures();
  float temperatureC = sensors.getTempCByIndex(0);

  // Calculate magnitude of acceleration vector
  float magnitude = sqrt(pow(a.acceleration.x, 2) + pow(a.acceleration.y, 2) +
pow(a.acceleration.z, 2));

  // Critical and fault condition logic
  bool criticalCondition =
    a.acceleration.x > 1.1 || a.acceleration.x < -0.1 ||
    a.acceleration.y > 0.73 || a.acceleration.y < -0.47 ||
    a.acceleration.z > 10.16 || a.acceleration.z < 8.96;

  bool faultCondition =
    a.acceleration.x > 0.8 || a.acceleration.x < 0.2 ||
    a.acceleration.y > 0.43 || a.acceleration.y < -0.17 ||
    a.acceleration.z > 9.86 || a.acceleration.z < 9.26;

  if (criticalCondition) {
   lcd.clear();
   lcd.setCursor(0, 0);
   lcd.print("Critical");
   Serial.println("Critical");
   digitalWrite(buzzerRelayPin, HIGH);
   digitalWrite(redLedPin, HIGH);
   digitalWrite(orangeLedPin, LOW);
   digitalWrite(greenLedPin, LOW);
   faultNotificationSent = false; // Reset fault notification flag
```

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

```
} else if (faultCondition) {
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("Fault Detected");
  Serial.println("Fault Detected");
  digitalWrite(buzzerRelayPin, buzzerToggleState ? HIGH : LOW);
  digitalWrite(redLedPin, LOW);
  digitalWrite(orangeLedPin, HIGH);
  digitalWrite(greenLedPin, LOW);

  // Send notification if not already sent
  if (!faultNotificationSent) {
    Blynk.logEvent("faultNotificationSent", "Fault detected in the system!");
    faultNotificationSent = true; // Prevent duplicate notifications
  }
} else {
  lcd.setCursor(0, 0);
  lcd.print("Temp:");
  lcd.print(temperatureC);
  lcd.print("C ");
  lcd.setCursor(0, 1);
  lcd.print("Hum:");
  lcd.print(humidity);
  lcd.print("%");
  digitalWrite(buzzerRelayPin, buzzerToggleState ? HIGH : LOW);
  digitalWrite(redLedPin, LOW);
  digitalWrite(orangeLedPin, LOW);
  digitalWrite(greenLedPin, HIGH);
  faultNotificationSent = false; // Reset fault notification flag
}

// Serial output
```

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

```
  Serial.print("Accel_X:");
  Serial.print(a.acceleration.x);
  Serial.print(", Accel_Y:");
  Serial.print(a.acceleration.y);
  Serial.print(", Accel_Z:");
  Serial.println(a.acceleration.z);
  Serial.print("Magnitude:");
  Serial.println(magnitude);
  Serial.print("Temp_C:");
  Serial.println(temperatureC);
  Serial.print("Humidity:");
  Serial.println(humidity);

  // Blynk virtual write
  Blynk.virtualWrite(V0, a.acceleration.x);
  Blynk.virtualWrite(V1, a.acceleration.y);
  Blynk.virtualWrite(V2, a.acceleration.z);
  Blynk.virtualWrite(V3, temperatureC);
  Blynk.virtualWrite(V5, humidity); // Send humidity to Blynk
  Blynk.virtualWrite(V7, magnitude); // Send magnitude to Blynk

  delay(500);
}
```

UNIVERSITI TEKNIKAL MALAYSIA MELAKA