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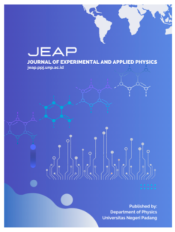

Design and Construction of A 3-Dimensional Vibration Measurment Tool Using Accelerometer Sensors Based On The IoT For Implementations of Building Structures

Totop Gabe[1], Yulkifli[1*], Yohandri[1], Suadi Ahadi[2]

[1] *Department of Physics, Universitas Negeri Padang, Padang 25131, Indonesia*
[2] *BMKG Padang Panjang, Jln. Meteorologi, Silaiang Bawah, Padang Panjang 27118, Indonesia*

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Corresponding Author
*Author Name: Second Author
Email: yulkifliamir@gmail.com

Abstract: A common form of building damage is cracking due to vibrations. These vibrations can originate from both inside and outside the building, often at low frequencies. To address this, a vibration measuring instrument needs to be designed. The research focuses on developing a tool to measure 3-dimensional vibrations in buildings using an Internet of Things (IoT)-based accelerometer sensor. This engineering research aims to design a 3-dimensional vibration measuring instrument. The system's performance specifications cover the electronic circuit of the tool and the design of the measurement value monitoring display. The system employs the MPU6050 sensor to measure vibrations, with Arduino Uno as the main microcontroller and NodeMCU ESP32 for transmitting measurement data from Arduino to the web server. Experimental tests were conducted to measure vibration frequency by repeatedly dropping a 100-gram load from a height of 70 cm onto a wooden table. The load was dropped 10 times, maintaining a 2 cm distance from the coordinates of the measuring device. The experiments provided real-time measurement results, showing varying frequencies each second. The device successfully detected very low vibrations, with a minimum recorded frequency of 11.26 mHz and a peak of 93.18 mHz in the sixth experiment. The varying results across experiments were influenced by factors such as measurement sensitivity, filtering, sampling frequency, calibration, data processing, and noise minimization. The analysis confirmed that the tool could detect vibrations every second with high sensitivity, making it suitable for real-time detection of various low-frequency vibrations under consistent load conditions.

Keywords: Building Structure; 3D Vibration; Accelometer Sensor; IoT

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1. Introduction

Building structure is part of a building system that works to distribute the loads caused by the presence of a building on the ground. The structural function of a building can be concluded to provide the strength needed to prevent a building from collapsing. However, building structures during their period of use can experience loads that were not anticipated in the design, which over time causes a decrease in structural quality and damage in unpredictable ways [1] . One form of damage that often occurs in buildings is cracks caused by vibration. In determining the level of damage to a building, the width of the crack is measured on the element that has the crack. The greater the width of the crack, the higher the level of damage that occurs [2].

The International Organization for Standardization or what we usually know as "ISO" creates standard criteria for building users and these standards are often used by various developed countries such as England, Australia, the United States, etc[3]. There are various things that can happen that cause the building to vibrate, including, originating from inside the building such as machine equipment (elevators, escalators, trolleys, generators, pump machines, etc.) as well as human activities inside the building (walking, jumping) . , running, etc.) . Originating from outside the building such as vehicle traffic on roads, trains , bomb explosions, construction activities around the building, strong winds and earthquakes. Problems between building damage and the intensity of vibrations often occur from both inside and outside the building[4]. In Siswanto's research results, it is stated that the damage that occurs can vary from simple ones such as plaster cracks, wall cracks to foundation cracks.

To detect vibration, various types of tools have been developed in the form of vibration sensors. There are many methods or techniques used to detect vibrations, for example by changing the electric charge of piezoelectric materials, changing capacitance, using lasers, changing position in a Linear Variable Displacement Transormer (LVDT) [6] . And also low vibration measuring instruments are currently needed to detect vibrations on bridges, earthquakes, dams and buildings. To detect vibrations, a sensor can be used. One of the sensors for detecting vibrations is the accelerometer sensor. An accelerometer is a tool that functions to measure acceleration. detect and measure vibrations, or to measure acceleration due to earth's gravity (inclination). Accelerometers are used to measure tilt angles or slopes along the X, Y and Z axes due to changes in speed, namely acceleration, detect and measure vibrations[7].

The accelerometer sensor measures acceleration due to the movement of an object attached to it. Accelerometers can be used to measure vibrations that occur in vehicles, buildings, machines, security installations, and can also be used to measure vibrations that occur on bridges, machine vibrations [8]. One technology that is often used in making systems based on the latest technology is the system. Internet of Things (IoT) based disaster warning information which has many advantages including being able to work automatically, working real time 24 hours, which means that the incoming data can then be used to anticipate disasters in other areas and can also be integrated with input output tools for Actions are taken automatically, so that disaster handling and mitigation can be anticipated as quickly as possible [9] . Physical devices in the Internet of Things infrastructure are hardware embedded with electronics, software, sensors and connectivity. Devices perform computations for processing data from sensor input and operate within the internet infrastructure [10].

IoT (Internet of Things) can be defined as the ability of various devices to be connected to each other and exchange data via the internet network. IoT is a technology that allows control, communication, collaboration with various hardware, data via the Internet network [11]. The data sending process is carried out in real time, where data from the voltage sensor and current sensor readings will be sent to the Android application. Sensors are devices that convert physical quantities into electrical quantities [12] . In its development, vibration level detectors can use various sensors and other tools to respond to vibrations. One of them is that vibrations are often encountered in everyday life, therefore vibration level detection systems have a very important role in various applications, such as tools for earthquake detection, machine work analysis, structural analysis of multi-story buildings, oil mine drilling, strength analysis. bridge vibrations, and so on, of course all applications related to vibration [13].

The existence of measurement and control instruments in an industry, the construction of flyovers such as Suramadu, dams and other developments is very important in order to provide early warning to users. One of them is sensors. The sensor must have good sensitivity and resolution, be easy to operate and be cheap and easy to obtain. A vibration sensor is a device that can read vibrations, where the vibrations will be converted into electrical voltage. The concept of a vibration sensor is to read vibration acceleration values which are read using an accelerometer. An accelerometer is a sensor used to measure the acceleration of an object. The resonance index in buildings can be determined by Low building resonance ($R > 25\%$) , Medium building resonance ($15\% < R > 25\%$) , High building resonance ($R > 15\%$) [14].

From the graph of previous research results related to research on resonance levels in buildings at the UNP economics faculty, data on the value of building conditions that are safe and in accordance with standards can be seen. Obtain the values of the natural frequency of the ground and the natural frequency of the building for each floor in the x, y and z directions[15]. The natural frequency of the soil measured outside the economics faculty building was 0.39 Hz for the first recording and 0.34 Hz for the second recording, so the average natural frequency of the soil was 0.36 Hz. Design and Construction of a 3-Dimensional Vibration Measuring Instrument Using an Accelerometer Sensor Based on the Internet of Things for Building Structure Implementation, a vibration measuring instrument from conventional to commercial with a 3-Dimensional Accelerometer sensor to make it easier to detect and acquire data and reduce data errors for low vibrations which can occur due to human activity movements which have an effect on the durability of building structures. Design is carried out from creating ideas and clarity of tasks, conceptual, design, arrangement, geometry, function, detailed design, creation of modeling tools, and testing. Carrying out research on designing a 3-Dimensional vibration measuring instrument using an Internet of Things- based accelerometer sensor for building structure implementation.

2. Materials and Method

Research is a study method carried out through careful and perfect investigation of a problem so that an appropriate solution to that problem is obtained[16]. This type of research is classified as engineering research. Engineering research is research that applies science into a design in order to obtain performance in accordance with specified requirements. The steps in carrying out engineering research include ideas and task clarity, conceptual, design, arrangement, geometry, function, detailed design, creation of modeling tools, and testing Low- frequency vibrations served as the research's primary source of data. The data measurement technique used is a direct measurement technique. Direct measurements are those that do not rely on other quantities, such as measurements of the lowest frequency values. Every part of the system that is being designed will be arranged geometrically according to its function at the arrangement, geometry, and function stage. Design block diagrams arranged geometrically for three-dimensional vibration measuring instruments Implementing Accelerometer Sensors in Building Structure.

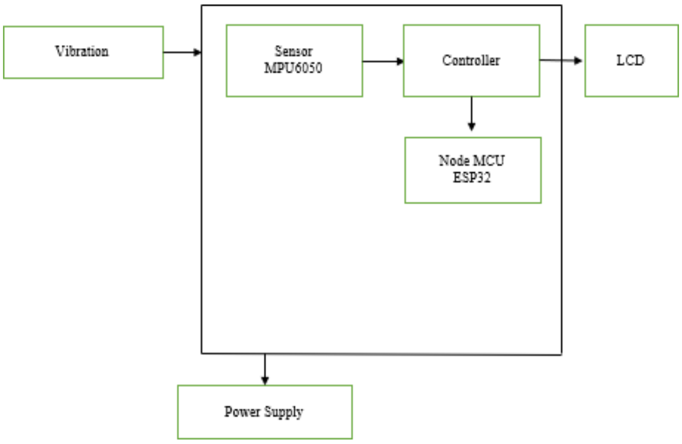


Figure 1. Block diagram

The MPU6050 sensor measures vibrations that will be received, as shown in Figure 1. The two measurement equipment, an accelerometer, and a gyroscope, are present on the MPU6050 sensor. The measured Gryscope data is then sent to the ESP32 node MCU. This PHP My Admin, serving as a web server, will display a graphic display that can be accessed in real-time and store the time (seconds, minutes, hours, dates, months, and years). NodeMCU ESP32 as a WiFi module to send data to the web server. Each of the system's parts is combined into one unit to form a network of links that produce the desired results. At this stage, a software program was also designed to measure low-frequency vibrations, which can be seen in Figure 2.

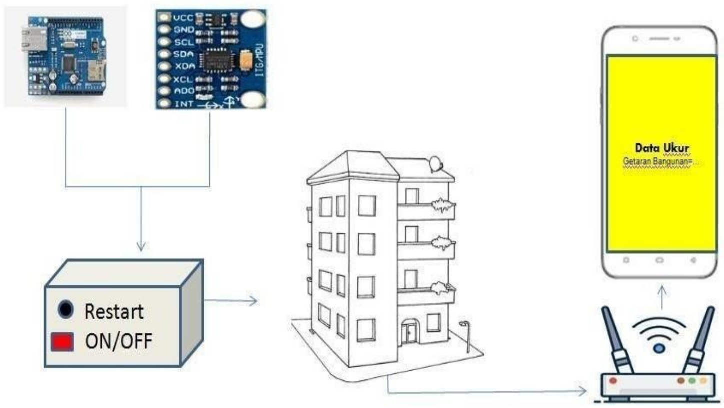


Figure 2. Instrument design plan

A circuit box containing a series of MPU6050 sensors, a NodeMCU ESP32, and an LCD as a data display comprise this system. WiFi, which is used to transmit information to the web server. r. The MPU-6050 itself is a chip with a 3-axis Accelerometer (acceleration sensor) and 3-axis Gyroscope (balance regulator), or in other words 6 degrees of freedom (DOF) IMU. Apart from that, the MPU-6050 itself has Digital Motion Processors (DMP), which will process raw data from each sensor. The DMP on the MPU6050 also functions to minimize the resulting errors [17]. The MPU6050 sensor module is a complete 6-axis motion tracking device [18]. The IoT system in this device uses WiFi as a data sender from the device to the webserver . The webserver is software that provides data services whose function is to receive HTTP or HTTPS requests from clients known as web browsers and send the results back in the form of website pages which are generally in the form of HTML documents. [19]. Buildings as objects whose vibrations will be measured. Next are the software design specifications, the devices used to operate the tool are Arduino and Ethernet Shield [20]. For programming, use the Arduino IDE. The programming language used by the Arduino IDE is C++. The display on the smartphone will use a web server using the HTML/IP address. The display in the software is in the form of graphs and tables of vibrations detected both from the x, y, and z axes, the results of these vibrations will be useful for testing the durability of a building, the flowchart design can be seen in figure 3, as follows:

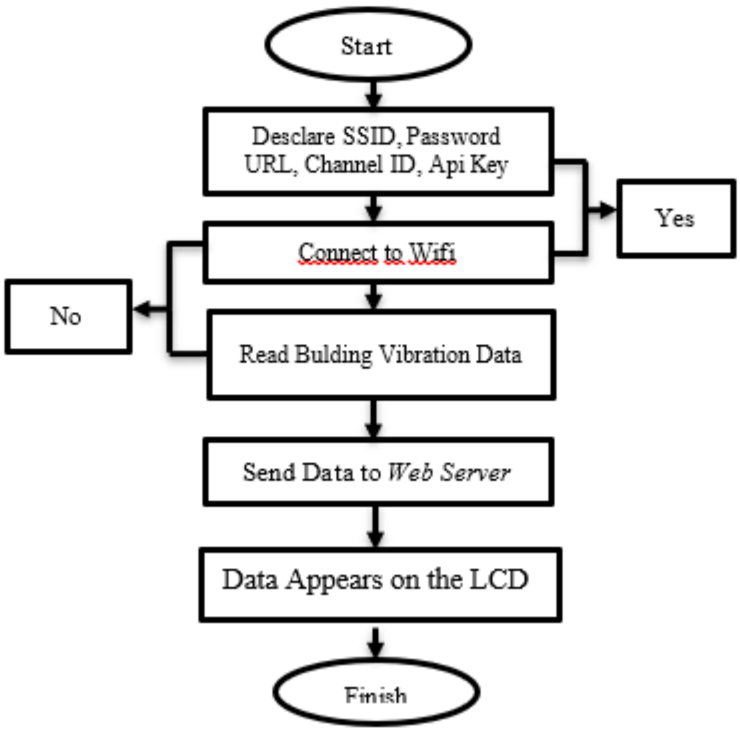


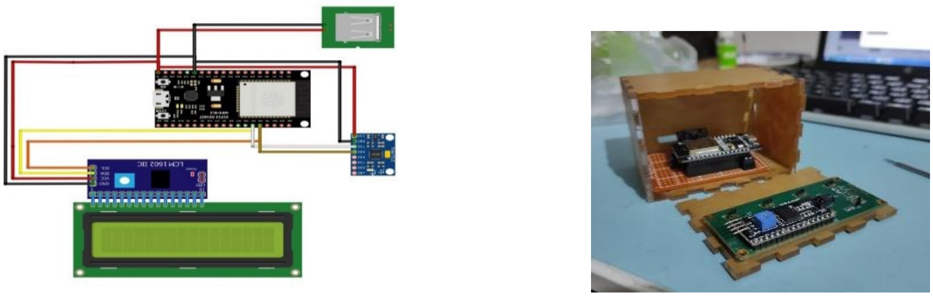
Figure 3. Diagram Block of Sending Data to Webserver

Figure 3 shows the Diagram Block of sending data to Thingspeak via the ESP8266 nodeMCU. The program starts by declaring the SSID, WiFi password, URL, and API Key that have been input into the program. Next, there is a looping program that functions to declare the

SSID and password if the ESP32 nodeMCU is still not connected to the WiFi network. After the ESP32 nodeMCU is connected to the appropriate WiFi network, the program will start sending sensor reading data to the Webserver. In designing software on the Arduino IDE, steps must be taken The step is to install the Arduino board on the Arduino IDE. The first step is to connect the nodeMCU ESP32. Board to the WiFi transmitter being used. The WiFi transmitter that will be used is declared SSID and password then continues to connect. If the board is not connected, the process will start again from the beginning until it is connected and if it is connected to the WiFi transmitter this board can access the internet then the data from the sensors can be read on the board and the data is sent to the web server with its HTML address.

3. Results and Discussion

The research results obtained from designing 3-dimensional vibration measuring instruments for building structure implementation are design specifications and performance specifications. The main objective of this research is to design a tool to measure 3-dimensional vibrations in a building using an Internet of Things-based accelerometer sensor. This tool is a vibration measuring tool from conventional to commercial with a 3- Dimensional Accelerometer sensor-based to make it easier to detect and acquire data and reduce data errors regarding low vibrations that can occur due to human activity movements which have an effect on the durability of building structures. Design is carried out from creating ideas and clarity of tasks, conceptual, design, arrangement, geometry, function, detailed design, creation of modeling tools, and testing. Design of a 3- dimensional vibration measuring instrument using an Internet of Things-based accelerometer sensor for building structure implementation. Based on system design block diagram in figure 1, a circuit schematic is obtained as shown in figure 4 below.



(a) (b)

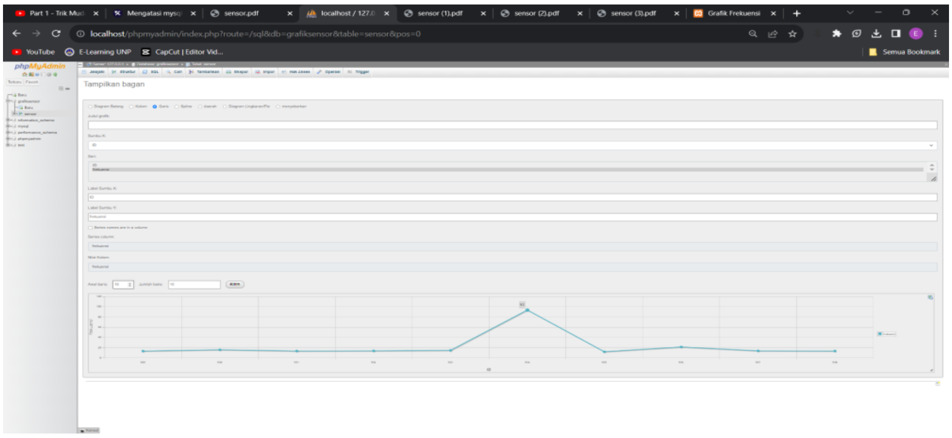
Figure 4. System Image (a) Creation of a 3-dimensional vibration measuring system using an internet of things (b) System results

At this stage, all components of the system being designed will be arranged geometrically based on their function. From the image above it can be seen that vibrations will be detected by the MPU6050 sensor. Programmed using the Arduino IDE to regulate and convert the output from the sensor into decibel units and display the vibration conditions in a building. The notification display will be displayed via the LCD installed on the tool. Programmed using an Arduino board and Ethernet Shield, the Ethernet Shield is also useful as an experimental connection to the internet, so that data detected on the device can be monitored using an Android application. The power supply functions as a supply of electric current to the components. Next, the device design consists of hardware design and software design. At the hardware design stage, it explains the physical part of the system, while software design provides instructions for the hardware to complete its tasks. MPU-6050 itself is a chip with a 3-axis Accelerometer (acceleration sensor) and 3-axis Gyroscope (balance regulator), or in other words a 6 degrees of freedom (DOF) IMU. Apart from that, the MPU-6050 itself has Digital Motion Processors (DMP), which will process raw data from each sensor. The DMP on the MPU6050 also functions to minimize the resultingerrors [17] . The MPU6050 sensor module is a complete 6-axis motion tracking device [18].

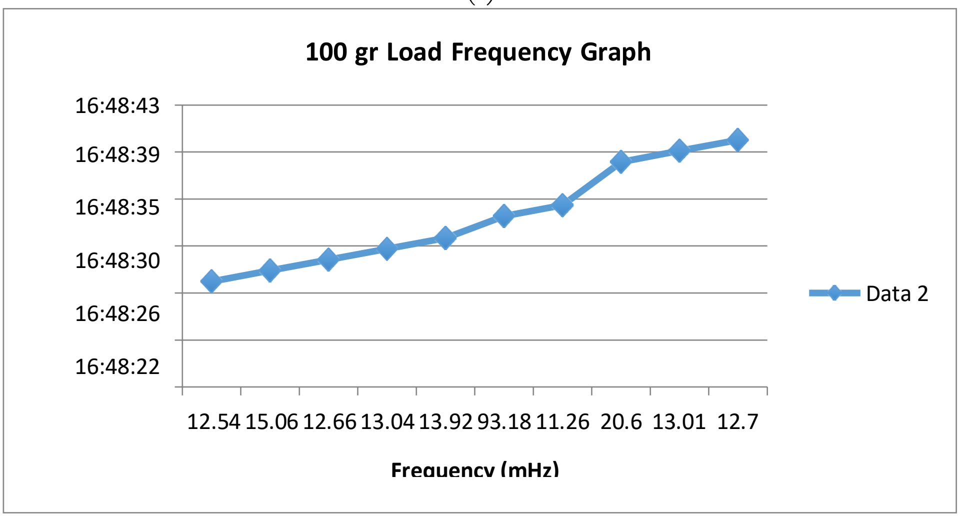
The IoT system in this device uses WiFi as a data sender from the device to the webserver. The webserver is software that provides data services whose function is to receive HTTP or HTTPS requests from clients known as web browsers and send the results back in the form of website pages which are generally in the form of HTML documents. [19]. That is why, webserver is used to display data and store data in the form of graphics in realtime[20]. Next, the software design specifications, the devices used to operate the tool are Arduino and nodeMCU ESP32. For programming, use the Arduino IDE. The programming language used by the Arduino IDE is C++. The display on the smartphone will use a web server using the html/IP address. The display in the software is in the form of graphs and tables of vibrations detected both from the x, y and z axes, the results of these vibrations will be useful for testing the durability of a building. Before designing software on the Arduino IDE, steps must be taken The step is to install the Arduino board on the Arduino IDE. The first step is to connect the nodeMCU ESP32 board to the WiFi transmitter being used. The WiFi transmitter that will be used is declared SSID and password then continues to connect. If the board is not connected, the process will start again from the beginning until it is connected and if it is connected to the WiFi transmitter this board can access the internet then the data from the sensors can be read on the board and the data is sent to the webserver with its html address.

After hardware and software, the next step is creating a modeling tool by integrating or unifying all the components that make up the system. All components are combined, both hardware and software components of the system. All components for creating an earthquake-based early warning system The IoT-assisted MPU6050 sensor with LCD is integrated to form a design according to the initial idea. At this stage the finished product has been formed according to the initial idea chosen. At the testing stage there are data collection techniques and data analysis techniques. Testing of the tool was carried out by implementing the product on a microtremor which can record small movements on the ground under certain conditions. This test was carried out to determine the functionality of the tool in detecting vibrations that occur in the building. Equipment testing carried out included testing the accuracy of the MPU6050 sensor, testing the accuracy of the MPU6050 sensor and simulating the occurrence of vibrations. Accuracy testing is carried out by comparing the sensors used with previous research. Accuracy testing is carried out by giving the sensor the same treatment and carry out repeated data collection during this situation.

Data from 3-dimensional vibration measurements with the IoT-based MPU6050 sensor with mass frequency measurements of 100 grams in 10 experiments via the webserver in graphic form can be seen in Figure 5.



(a)



(b)

Figure 5. Frequensi (a) Frequency measurement web Server graph with a load mass of 100 gr , (b) Frequency measurement graph with mass load 100 gram

From images (a) and (b) it can be concluded how the frequency graph in the webserver and the measurement graph for each experiment carried out, the first graph in image a, is a frequency graph with a load mass of 100 grams produced by the webserver in real time with a data transmission time span of 1 second. . is a graphic result from the Webserver in an experiment with a load mass of 100 grams where the experiment was carried out 10 times with the same conditions and time. Where the highest peak frequency obtained is 93.18 mHz, or around 0.093 Hz, where the graph is taken from a webserver database where measurements are carried out in real time. Figure b shows the measurement value in the experiment with a load of 100 gr. The graph shows that the lowest frequency is 11.26 mHz or 0.011 Hz. The highest frequency peak that can occur is in the 6th experiment. Where this can occur can be caused by other vibration disturbances, whether caused naturally or artificially, apart from the experiment of dropping the load, so this greatly affects the ongoing measurements.

Next, accuracy testing, accuracy testing is carried out by giving the sensor the same treatment and carry out repeated data collection 10 times under the same conditions when the load is dropped with the tool. The accuracy of the system in measuring vibrations can be seen in table 1. The general equation used to calculate angular velocity from changes in yaw, itch and roll positions is as follows:

$$\omega = \sqrt{(\omega x^2 + \omega y^2 + \omega z^2)} \quad (1)$$

where x, y, and z are the angular velocity components obtained from the gyroscope, which give the rotation rate around the axes. Meanwhile, to calculate the frequency of movement if the changes in yaw, itch and roll positions are known, you need to know the relationship between frequency and angular velocity as follows:

$$f = \omega / 2\pi s \quad (2)$$

Table 1. Experimental results data

Experiment to	Load Mass (gr)	Date	Frequency (mHz)	Frequency (Hz)
1	100	2023-10-23 16:48:27	12.54	0.01254
2	100	2023-10-23 16: 48:28	15.06	0.01506
3	100	2023-10-23 16: 48:29	12.66	0.01266
4	100	2023-10-23 16: 48:30	13.04	0.01304
5	100	2023-10-23 16: 48:31	13.92	0.01392
6	100	2023-10-23 16: 48:33	93.18	0.09318
7	100	2023-10-23 16: 48:34	11.26	0.01126
8	100	2023-10-23 16: 48:38	20.6	0.0206
9	100	2023-10-23 16: 48:39	13.6	0.0136
10	100	2023-10-23 16: 48:40	12.7	0.0127

From the results of the experiment in table 1 which was carried out 10 times with the same load mass of 100 grams, dropped to the same height of 70 cm and landed at the same coordinate point on a wooden table. The load was dropped 10 times using wire media as a slide for the load to fall, the distance from the coordinates of the load falling with the tool made was 2 cm. From 10 experiments, it was able to provide real-time measurement results by showing varying frequency results every second. And this experiment measures how much the device measures the frequency caused by a dropped load.

Then the tool was able to detect very low vibrations with a result of 11.26 mHz and in the 6th experiment the highest frequency peak was obtained at 93.18 mHz. From experiments 1-10, the graphic results obtained varied. This is influenced by the configuration of measurement sensitivity, filtering, sampling frequency, calibration, data processing , minimizing noise, empirical tests and other things, causing the data taken to experience differences from the first to the tenth experiment. The next results are based on the results of the test analysis carried out, the tool is able to detect vibrations every second and this tool is able to detect low frequency vibrations with a high level of sensitivity and can be used to detect various vibrations. This is supported by several previous studies in 2020 by Shahdan where the IoT-based MPU6050 sensor had quite high sensitivity and read vibrations well [20]. This research provides empirical evidence that the sensor has good accuracy and is able to detect low vibrations

Performance specifications are known through identifying the function of each component that makes up the system. Meanwhile, the system design specifications are known based on the results of the measurement data analysis that has been carried out. The results of the design of the first 3-Dimensional Vibration Measuring Instrument system are performance specifications. The system has 1 type of sensor which is used to measure 1 type of physical parameter, namely the MPU6050 sensor for measuring vibration parameters. The microcontroller used is the Arduino Uno as the main microcontroller that controls all system work and the NodeMCU ESP32 as the sender of measurement data from the Arduino to the Webserver.

The results of the design specifications for a 3-dimensional vibration measuring system for the implementation of building structures which consist of system accuracy and accuracy. The accuracy and accuracy values are obtained from comparing the analysis results using system instrument readings with 3-dimensional measuring instrument readings and formula calculations. The accuracy value for each load was obtained with the highest frequency value of 93.18 mHz. As well as detecting the lowest frequency vibrations with a frequency value of 11.26 mHz. To get an even lower frequency, it can be done by paying attention to measurement sensitivity, filtering, sampling frequency, calibration, data processing, minimizing noise, empirical tests or other things that can reduce the level of measurement accuracy.

So, based on data analysis, physical parameter results were obtained with high precision and precision values. The data obtained from measurements using standard tools is close to the values read on the system. The measurement values obtained on each floor are different, this is because natural and artificial vibrations that occur in each configuration of measurement sensitivity, filtering, sampling frequency, calibration, data processing, minimizing noise, empirical testing and other things are different. The smaller the natural or artificial vibrations that occur, the better the measurement value obtained and vice versa. The smaller the disturbance that occurs during measurement, the higher the level of data accuracy. Through the results of the accuracy and accuracy of the 3-dimensional vibration measuring system for implementing building structures, it can be concluded that when measuring vibrations for each load, data is obtained that is close to accurate.

4. Conclusion

So, based on data analysis, physical parameter results were obtained with high precision and precision values. The data obtained from measurements using standard tools is close to the values read on the system. The measurement values obtained on each floor are different, this is because natural and artificial vibrations that occur in each configuration of measurement sensitivity, filtering, sampling frequency, calibration, data processing, minimizing noise, empirical testing and other things are different. The smaller the natural or artificial vibrations that occur, the better the measurement value obtained and vice versa. The smaller the disturbance that occurs during measurement, the higher the level of data accuracy. Through the results of the accuracy and accuracy of the 3-dimensional vibration measuring system for implementing building structures, it can be concluded that when carrying out vibration measurements on each floor, data is obtained that is close to accurate. Based on the research that has been carried out, it can be concluded that this tool is capable of detecting vibration frequencies in real time with varying frequency results over different time periods and the same load mass, with the highest frequency value of 93.18 mHz. As well as detecting the lowest frequency vibrations with a frequency value of 11.26 mHz. To get an even lower frequency, it can be done by paying attention to measurement sensitivity, filtering, sampling frequency, calibration, data processing, minimizing noise, empirical tests or other things that can reduce the level of measurement accuracy..

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