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Characterization of the ADXL335 accelerometer for mechanical vibration analysis

Caracterización del acelerómetro ADXL335 para análisis de vibraciones mecánicas

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Abstract

This project focuses on the characterization of the ADXL335 accelerometer to conduct the analysis of mechanical vibrations, with special emphasis on its application for educational purposes in visualizing vibrational behavior in an educational environment. In a first phase, the creation of a module that helps the practical observation of vibrations is proposed. The implementation was conducted by using the ADXL335 accelerometer in conjunction with a mobile application and the Arduino-LabVIEW platform. Although the tests proved to be successful, the characterization of the ADXL335 revealed a zone of randomness in measurements, limiting its ability to supply correct results. In terms of scientific contribution, this project addresses the need to develop practical and didactic methods for the analysis of mechanical vibrations in educational settings. The integration of technologies such as Arduino, LabVIEW, and the ADXL335 accelerometer supplies an accessible and versatile platform for teaching concepts related to vibrational behavior. Despite the identified limitations in sensor characterization, the experience and results obtained supply valuable insights for future research aimed at improving measurement accuracy.

Characterization, accelerometer, mechanical vibration

Resumen

Este proyecto se centra en la caracterización del acelerómetro ADXL335 para llevar a cabo el análisis de vibraciones mecánicas, poniendo especial énfasis en su aplicación con fines didácticos para la visualización del comportamiento vibratorio en un entorno educativo. En una primera fase, se plantea la creación de un módulo que facilite la observación práctica de las vibraciones. La implementación se llevó a cabo mediante la utilización del acelerómetro ADXL335 en conjunto con una aplicación móvil y la plataforma Arduino-LabVIEW. Aunque las pruebas demostraron ser exitosas, la caracterización del ADXL335 reveló una zona de aleatoriedad en las mediciones, lo que limita su capacidad para ofrecer resultados precisos. En términos de contribución científica, este proyecto aborda la necesidad de desarrollar métodos prácticos y didácticos para el análisis de vibraciones mecánicas en entornos educativos. La integración de tecnologías como Arduino, LabVIEW y el acelerómetro ADXL335 ofrece una plataforma accesible y versátil para la enseñanza de conceptos relacionados con el comportamiento vibratorio. A pesar de las limitaciones identificadas en la caracterización del sensor, la experiencia y los resultados obtenidos proporcionan experiencias valiosas para futuras investigaciones en la mejora de la precisión de las mediciones.

Caracterización, acelerómetro, vibraciones mecánicas

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Introduction

Vibration monitoring and analysis are crucial elements in preventing machinery failures, becoming especially relevant in educational environments within engineering programs. Although the accelerometer, particularly the ADXL335 model, is widely used to measure parameters such as acceleration, velocity and displacement, its limitation in visualizing the vibration waveform has driven the need to improve its characterization. This article addresses the importance of overcoming this limitation, especially in educational contexts, and proposes a teaching approach that allows for a more complete understanding and practical visualization of vibrations.

Effective characterization of the ADXL335 accelerometer presents a challenge that impacts its ability to provide accurate measurements of acceleration amplitude. Given the crucial importance of vibration analysis in preventing machinery failures, it is imperative to overcome these limitations. This article seeks to develop a didactic approach that allows visualizing and understanding the behavior of vibrations in educational environments, thus contributing to the comprehensive training of engineering students.

The overall objective of the article is to model and characterize the ADXL335 accelerometer to overcome limitations in its application to mechanical vibration analysis. Specific objectives include performing a detailed diagnosis of critical variables for characterization, developing an integrated prototype, evaluating its performance, and performing comparative analysis with other tools, such as the Physics Toolbox Suite application.

The development process was divided into key stages. First, a diagnosis was performed using an Ishikawa diagram to identify critical variables. Then, a prototype was developed that integrates the ADXL335 accelerometer, a holding device, and a mobile phone. An electrical/electronic circuit was established for communication with an Arduino UNO board. In addition, a human-machine interface (HMI) was designed in LabVIEW for real-time observation of vibrations.

Finally, the prototype was evaluated, the accelerometer was characterized, and adjustments and improvements were proposed. Results include identification of critical variables, successful prototype development, accelerometer characterization, and data comparison with the Physics Toolbox Suite application. However, an area of randomness was observed when attempting to effectively characterize the accelerometer, suggesting the need for adjustments and improvements in future research.

Despite the achievements in prototype development, the zone of randomness in the characterization of the ADXL335 accelerometer poses challenges. The implementation of a control loop is proposed to vary the frequency and rotation speed of the motor in future research. Although the device may be useful for teaching purposes to visualize vibrations, the limitation in making accurate measurements with the accelerometer in its current state is recognized.

Generalities

Problem Statement

Vibration monitoring and analysis are crucial tools to prevent machine failures and these tasks become relevant in the inclusion of subjects in engineering programs, despite the accelerometer's ability to measure parameters such as acceleration, speed and displacement, the limitation stands out of not being able to visualize the waveform, which prevents a practical study of the characteristics of the vibrations. And although there are other devices to measure vibration values, such as frequency, amplitude and period, the need arises to measure the amplitude of the acceleration accurately, thus addressing the central difficulty of obtaining reliable data in vibration analysis, especially in an educational context.

Justification

The importance of the characterization of the ADXL335 accelerometer for mechanical vibration analysis. Although this sensor is widely used in educational settings and industrial applications, its effective characterization is problematic, limiting its ability to provide accurate measurements of acceleration amplitude.

Given the importance of vibration analysis in the prevention of machinery failures, it is crucial to overcome these limitations and develop a teaching approach that allows visualizing and understanding the behavior of vibrations in an educational environment.

General objective

Model and characterize the ADXL335 accelerometer to overcome the limitations in its application for the analysis of mechanical vibrations, facilitating the understanding and visualization of vibrations.

Specific objectives

– Perform a detailed diagnosis identifying the critical variables for the characterization of the ADXL335 accelerometer using an Ishikawa diagram.

– Develop a prototype that integrates the ADXL335 accelerometer, a holding device, and a mobile phone, guaranteeing the stability and reproducibility of the measurements.

– Evaluate the performance of the prototype through functional tests, verifying the ability to measure and visualize vibrations in the three axes.

– Perform a comparative analysis between the data obtained from the ADXL335 accelerometer and the Physics Toolbox Suite application, identifying possible discrepancies and adjusting the characterization accordingly.

Methodology

The project development process was divided into the following stages:

Diagnosis: A diagnosis was carried out to identify the critical variables involved in the characterization of the ADXL335 accelerometer. This process was carried out using an Ishikawa diagram, with the objective of comprehensively understanding and visualizing the factors that could affect the effectiveness of the characterization.

In that case, acceleration is measured, which is the variation of speed as a function of time and is defined as the second derivative of the displacement with respect to time, its unit of measurement is meters per second squared (m/s^2). “Vibration transducers […] are responsible for transforming vibrations into electrical signals” [1]

Prototype Development: We worked on the development of a comprehensive prototype that included the ADXL335 accelerometer, a holding device, and a mobile phone. The design had to guarantee the stability and reproducibility of the measurements, ensuring that the set of devices works in a coordinated and efficient manner.

In addition, an electrical/electronic circuit was established to establish communication between the ADXL335 accelerometer and the Arduino UNO board. Human-Machine Interface (HMI) Design in LabVIEW: A human-machine interface was designed in LabVIEW to observe vibrations in real time in the time and frequency domain.

Evaluation and functional tests of the prototype: Functional tests were carried out to evaluate the performance of the prototype. The system's ability to measure and display vibrations in all three axes (X, Y and Z) was verified to ensure that the results are consistent and reproducible.

Experimental design and accelerometer characterization: A comparative analysis was carried out between the data obtained from the ADXL335 accelerometer and those generated by the Physics Toolbox Suite application. Possible discrepancies were identified, and the characterization of the accelerometer was adjusted accordingly, seeking greater agreement between both sources of information.

Proposals for Adjustments and Improvements: Based on the results obtained, adjustments and improvements to the prototype are proposed. These proposals were oriented towards optimizing the system for its implementation in educational environments and practical applications in engineering.

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Results

Diagnosis

Using an Ishikawa diagram, the variables to control were determined to design the system for the characterization of the sensor (Figure 1).

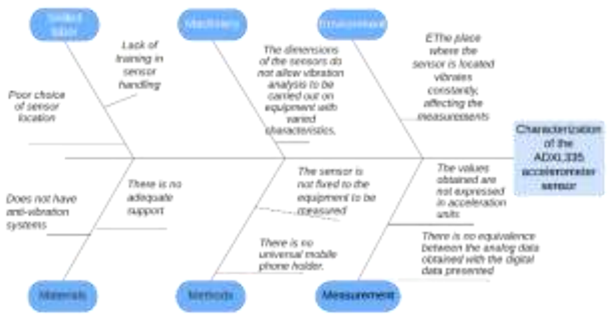

Figure 1 Ishikawa diagram to identify root cause (Original Creation)

The need to place the sensor together with the mobile phone was identified, so it was determined that a fixing system was required to be built. The previously selected sensor needed to be held together with the mobile phone to obtain acceleration values through the Physics Toolbox Suite application, for this a universal clamping was selected that allowed the equipment, the sensor, and the mobile phones to be unified, without affecting each other.

Prototype development:

The characterization device is built with commonly used materials. The materials that predominate in the structure of the device are wood, polymers, galvanized and low carbon steel.

The universal adapter designed for ANNA TOSANI brand cell phones is selected and used as a holding device, which has an integrated vertical support, is designed to be able to make 360 degree turns, has a backrest for the mobile phone with foam, It contains two spring tension arms and protective lips, so it expands from 2.3 inches to 4.1 inches to be able to retain any smartphone equipment, the ADXL335 accelerometer was attached to this device.

The entire clamping device is mounted on a wooden base, which rests on four springs with tension that serve as support, these are attached to two screws that are fixed to another larger wooden base, allowing the vibration of the base small (Figure 2).

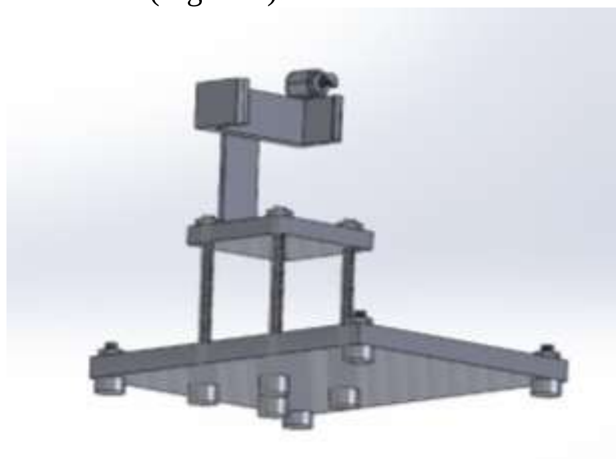

Figure 2 Clamping device
Original Creation

The ADXL335 triaxial accelerometer was used, characterized by its low energy consumption and the ability to measure both dynamic acceleration (motion, shock, or vibration) and static acceleration (inclination or gravity) in a range of ±3 g, with a nonlinearity of 0.3. % and a thermal stability of 0.01%/°C. This sensor, which has decoupling capacitors for optimal operation, allows the selection of the bandwidth using capacitors (C_X, C_Y y C_Z) on the X_{OUT}, Y_{OUT} and Z_{OUT}.

Mathematically, the analog output of the sensor is formulated as:

$$V_{out} = (a * \mu)(V_O) \quad (1)$$

Where: Vout=sensor output (V), a=actual acceleration (g), µ=sensor sensitivity (v/g), V_0=Voltage at 0G (V) [2]

Connections were made through the ADXL335 sensor and the Arduino UNO board, between pin X with A0, pin Y with A1 and pin Z with A2, which are the pins where the movements of the axes to be used are determined. (Figure 3). The operating voltage of the accelerometer is 3.3V to 5V, its value detection range is 3G, in addition to its sensitivity ranging from 270mV/g to 330mV/g, and its weight is 2.0 gr.

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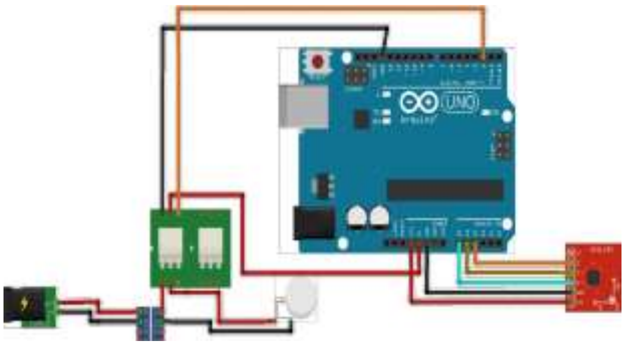

Figure 3 Electrical/Electronic Circuit
Original Creation

It was determined that the module could be used by different types of mobile phones. In addition, when applying a voltage of 5V alternating current to the motor, it vibrated constantly. The clamping devices allowed samples to be taken without significantly altering the behavior of the module. vibration, likewise, the Physics Toolbox Sensor Suite mobile application integrated into the Play Store platform in the Android mobile operating system was used, using measurement sensors integrated into the mobile device to obtain data to determine the characteristic equation of the sensor. The results are shown numerically or expressed in graphs where the activity is shown through straight lines, data files are generated in which the data obtained are stored, as a function of time [3] so Through the Physics Toolbox Suite application, vibration data was obtained in the three axes (Figure 4).

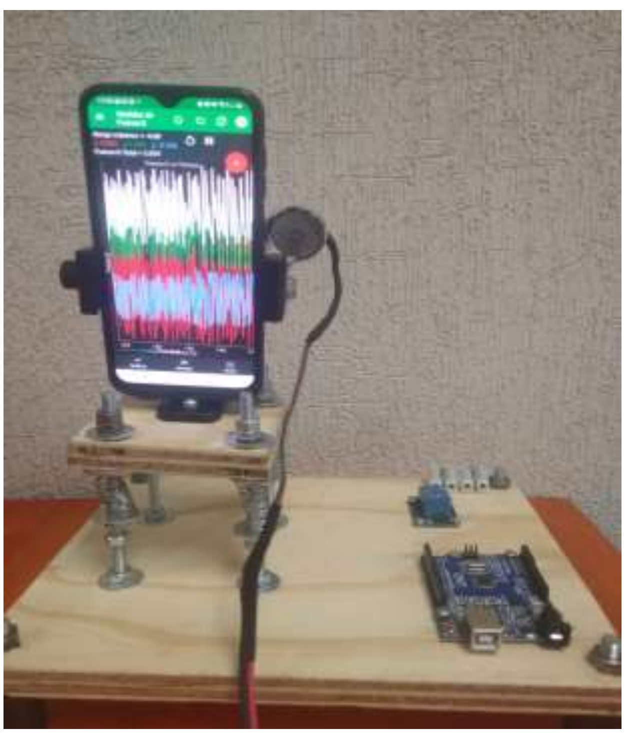

Figure 4 Test run

For data acquisition, LabVIEW, the standard software for measurement and control solutions, was combined with an Arduino UNO board to facilitate the integration of an even more complex system.

To communicate the Arduino UNO board with LabVIEW, a toolkit was used (*Toolkit*) called LIFA, which is free to download, which uses the USB port of the computer and the Serial port of Arduino [UNO] for communication. [4]

Programming in the Arduino software (Figure 5) was carried out by declaring the values in integers, and then initiating serial communication. The input pin characteristics of A0 for the X axis, A1 for the Y axis and A2 for the Z axis were declared.

```
int valorA0;
int valorA1;
int valorA2;

void setup()
{
Serial.begin(9600);
pinMode(A0,INPUT);
pinMode(A1,INPUT);
pinMode(A2,INPUT);
}

void loop()
{
valorA0=10000+analogRead(A0);
valorA1=10000+analogRead(A1);
valorA2=10000+analogRead(A2);
Serial.print(valorA0);
Serial.print('\t');
Serial.print(valorA1);
Serial.print('\t');
Serial.println(valorA2);
delay(50);
}
```

Figure 5 Arduino programming
Original Creation

Afterwards, the values collected by the pins were taken to route them to the computer's serial bus. Programming in LabVIEW was more complex than in Arduino (Figure 6). The serial bus data from the Arduino UNO card was taken and grouped into a matrix and then transmitted to an Excel spreadsheet.

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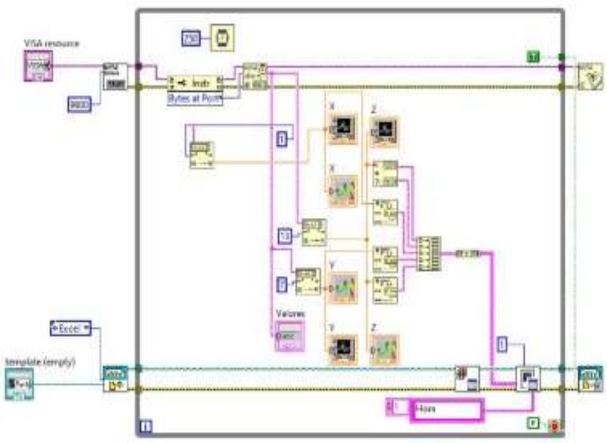


Figure 6 Programming in LabVIEW
Original Creation

On the LabVIEW front panel, acceleration graphs are displayed as well as numerical indicators to verify that the accelerometer is working with all its axes (Figure 7). Additionally, a section was designed to choose the COM port with which the Arduino UNO card communicates and the route where the spreadsheet will be located.

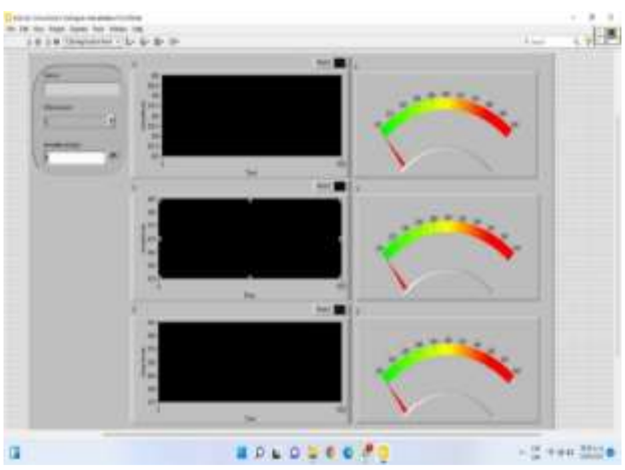


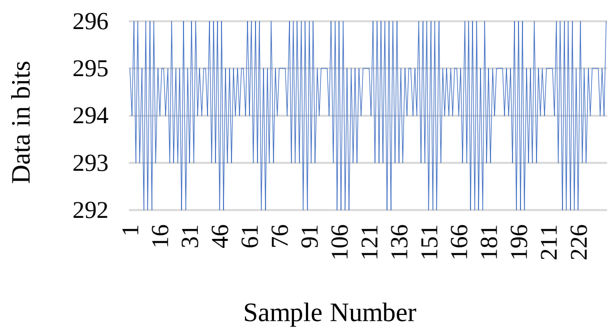
Figure 7 Panel Frontal
Original Creation

Experimental design and characterization of the accelerometer

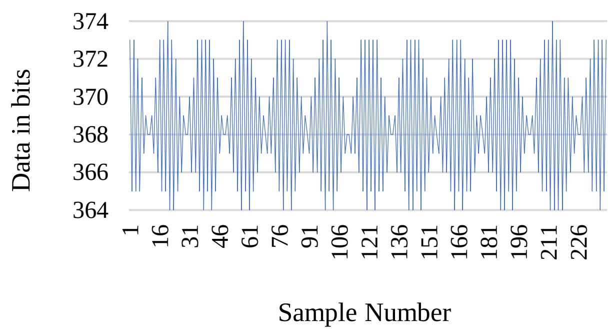
The experimental design consisted of data collection from the accelerometer in three axes (X, Y and Z), whose values range from 0 to 1023, which corresponds to a BIT, which were compared with the data obtained with the Physics App. Toolbox Suite whose values range from -3G to +3G, with $G=9.81m/s^2$.

The interactions in data collection from both the Arduino platform and the LabVIEW program were every 250 ms, over one minute, giving a total of 240 data acquired. In the case of the Physics Toolbox Suite App, since it has a frequency of 4Hz, it corresponds to taking 4 data per second, which over the course of a minute corresponds to the 240 data acquired.

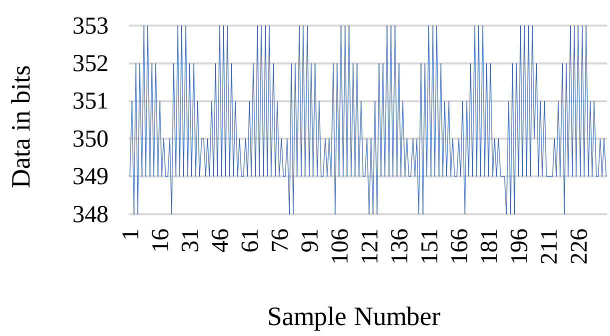
The acquired data were graphed with the help of a spreadsheet to obtain the characteristic function that governs the behavior of the ADXL335 accelerometer in the Fx, Fy and Fz axes. (Graphs 1, 2 and 3)



Graphic 1 Data Acquired ADXL335 On the Fx axis
Own Elaboration



Graphic 2 Data Acquired ADXL335 on the Fy axis
Own Elaboration



Graphic 3 Data Acquired ADXL335 on the Fz axis
Own Elaboration

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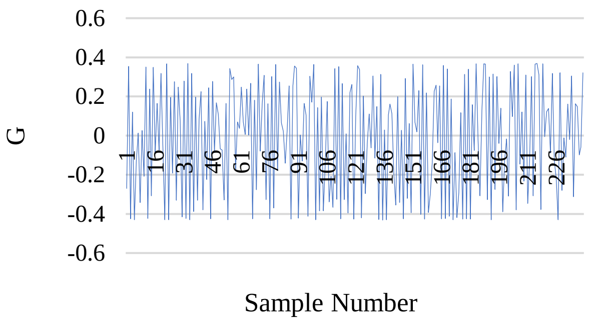
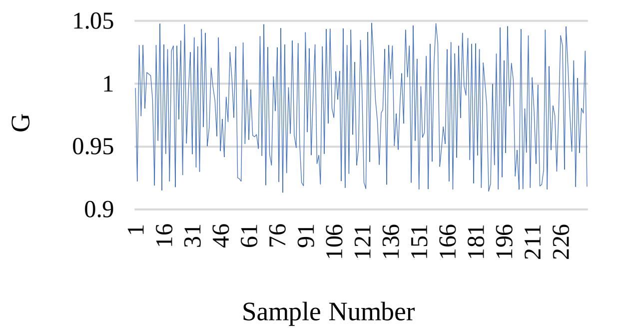
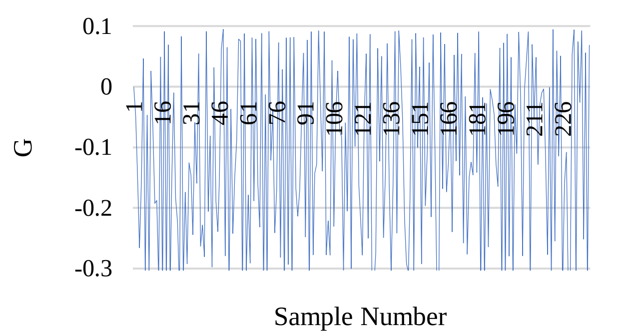
Thus, the data acquired by the Physics Toolbox Suite application in the X, Y, Z axes were analyzed in the same way. (Graph 4, 5 and 6)



Graphic 4 Data Acquired *Physics Toolbox* Suite on the Fx axis
Own Elaboration



Graphic 5 Data Acquired *Physics Toolbox* Suite on the Fy axis
Own Elaboration



Graphic 6 Data Acquired *Physics Toolbox* Suite on the Fz axis
Own Elaboration

The maximum and minimum values between the interval from 0 to 1023 were obtained, measured by the ADXL335 accelerometer (Table 1).

	X axis	Axis y	Hey Z
Higs	296	374	353
Lows	292	364	348

Table 1 Values obtained by the ADXL335 accelerometer
Original Creations

	X axis	Axis y	Hey Z
Highs	0.3687	1.0483	0.0946
Lows	-0.4317	0.9135	-0.3449

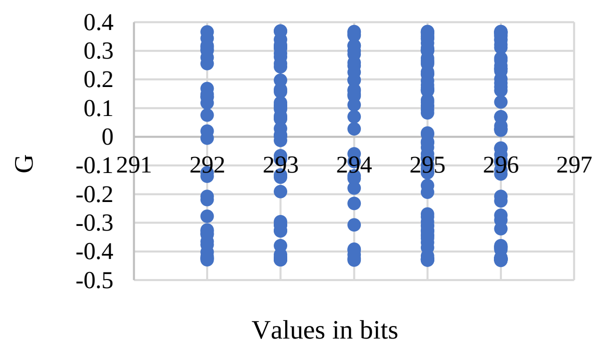
Table 2 Values taken from the Physics Toolbox Suite application
Original Creations

Considering the maximum and minimum values from the ADXL335 Accelerometer and making the comparison with those obtained by the Physics Toolbox Suite application, the characteristic functions for each of the axes were obtained (Table 3).

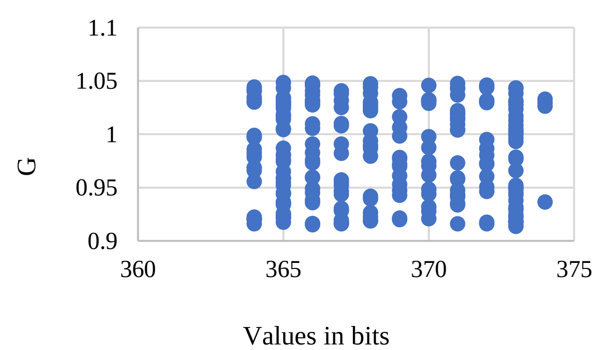
Axis	Characteristic Function
X	gFx = 0.2001bits – 58.861
Y	gFy = 0.0054bits - 0.9683
Z	gFz = 0.0879bits - 30.934

Table 3 Characteristic functions
Original Creations

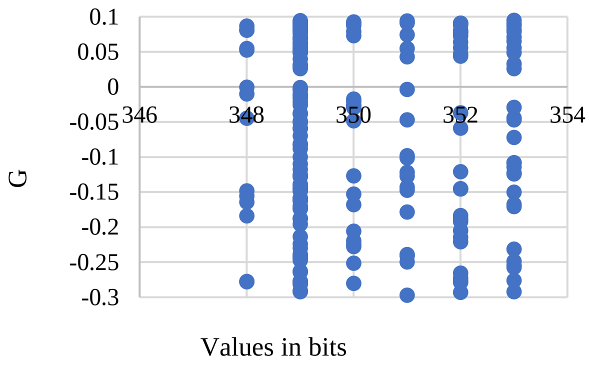
These data facilitate the incorporation of the characteristic functions in the LabVIEW program and thus obtain values in fractions of G or even in m/s^2, instead of getting the data in bits. As part of the characterization, all the data were now compared (not just maximums and minimums), but the graphs turn out not to have a one-to-one correspondence (Graph 7, 8 and 9)



Graphic 7 Bits Scatter Plot x-axis VS gFx
Own Elaboration

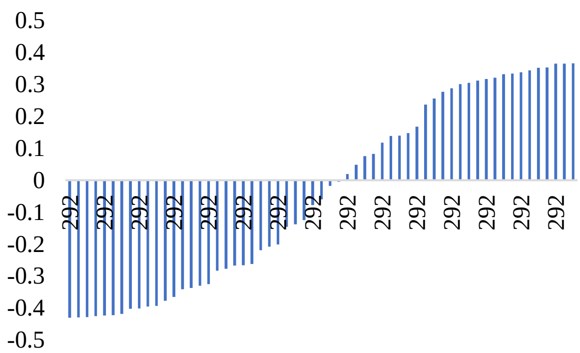


Graphic 8 Bits Scatter Plot y-axis VS gFy
Own Elaboration



Graphic 9 Bits Scatter Plot z-axis VS gFz
Own Elaboration

When observing the graphs, there is no functional correspondence of any value in bits with the fractions of G obtained by the application, so a detailed observation is made of several bits chosen at random from the X axis, resulting in which is shown in figure 10.



Graphic 10 Bits Scatter Plot 292 z-axis VS gFz
Own Elaboration

The graph shows that there is no functionality between the values of bit 292 with the values obtained from the gFx, resulting in a zone of randomness that prevents the correct characterization of the ADXL335 accelerometer, even though applying only the maximum and minimum values there is such a thing characteristic function. Once this analysis has been carried out, other bits are evaluated, having the same random result in all the correspondences between bits obtained from the ADXL335 accelerometer and fractions of G measured by the Physics Toolbox Suite application.

Conclusions

The module can fix the ADXL335 sensor and the mobile device to obtain measurements, like the one reported by Luiso, and Muñoz (2018), with a substantial difference, these authors mount the devices "…to carry out the measurements. mounted the computer together with the IMU on a correctly leveled goniometer" [5] however, the device could be affected by metallic objects as it is a sensor that includes a magnetometer, and in addition, human error could be included when calibrating the goniometer; The module of this project by not having to be adjusted manually could eliminate that error.

On the other hand, according to Alzate's degree thesis, characterizing acceleration sensors use a "*protoboard*" to fix 4 sensors and manually tilting them from 0° to 90° with 10° increments which can also include a reading error and parallax, however, this author mentions that he takes 400 data for the characterization and also "the data taken in the different positions, were processed in the MATLAB software and a histogram and a Gaussian approximation were made for each one, for each axis of each sensor"[6], it would be possible to analyze the data in the MATLAB software even when analysis with LabVIEW is planned.

After analyzing the data, it is concluded that there is an area of randomness when carrying out the measurements, which is why the ADXL335 accelerometer cannot be characterized effectively. On the other hand, at the end of the experiments, it was observed that, by not having control over the vibrations provided by the motor, a randomness is generated that affects the results, so in subsequent investigations it is intended to provide a control loop to be able to vary the frequency and speed of rotation of the motor, or even use other methods of movement such as a pneumatic piston that will have an alternative movement.

And although the device can be used for educational purposes to visualize vibrations, measurements cannot be made with the accelerometer since the characterization with this method was not successful.

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