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Development of a portable low-cost PC-independent accelerometer for multiple purposes

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Abstract
Modern seismographs are sensitive enough to record seismic waves with amplitudes as small as a few micrometers, but their manufacturing cost is also very high. This is a major difficulty when studying the dynamic response of buildings to earthquakes since usually large arrays of seismographs are needed to carry out such a study, making the affordability of this type of research in developing countries (regions where old or poorly-constructed buildings are more common) virtually impossible. In view of this problem, in this paper a prototype (named MiSismo) for an inexpensive PC-independent accelerometer is presented, along with its most outstanding features (such as backup power system, sample rate selection, automatic earthquake detection and email service), proposed applications and drawbacks. The sensitivity and noise density of the sensor of MiSismo (MMA8451Q, a micro-electromechanical accelerometer) are several orders of magnitude lower and higher respectively than those of commercially-available seismographs, but the manufacturing cost of MiSismo is also one order of magnitude lower. The performance of MiSismo was tested with real and simulated earthquakes. The results showed that MiSismo can detect local earthquakes with magnitude as small as 4.8Mw, and the data is clear enough to obtain the basic seismic parameters of moderate-to-large earthquakes. This characteristic of MiSismo could be useful for educational purposes. On the other hand, it was found that the measurements of MiSismo clearly detect the resonance effect on buildings, indicating that MiSismo could also be used for structural studies. Finally, the results of a simulated strong earthquake with subsequent blackout confirmed that the backup power system of MiSismo works perfectly since no loss of data was observed.

Keywords: Instrumentation in physics, low-cost accelerometer, education, structural studies.

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Desarrollo de un acelerómetro portátil, de bajo costo e independiente del PC para múltiples propósitos

Resumen

Los sismógrafos modernos son lo suficientemente sensibles para registrar ondas sísmicas con amplitudes tan pequeñas como unos cuantos micrómetros, pero su costo de fabricación también es bastante alto. Esta es una dificultad importante cuando se trata de estudiar la respuesta dinámica de edificios ante sismos, ya que usualmente redes enormes de sismógrafos son necesarias para llevar a cabo tal estudio, haciendo la asequibilidad de este tipo de investigación en países en vías de desarrollo (regiones donde edificios antiguos o mal construidos son más comunes) prácticamente imposible. Ante este inconveniente, en este artículo se presenta un prototipo (llamado MiSismo) de un acelerómetro de bajo costo que no requiere ordenador junto con sus características más resaltantes (tales como el sistema de respaldo de energía, la selección de la tasa de muestreo, la detección automática de sismos o el servicio por correo electrónico), aplicaciones propuestas y desventajas. La sensibilidad y la densidad del ruido del sensor de MiSismo (un acelerómetro micro-electromecánico MMA8451Q) son varios órdenes de magnitud más bajo y más alto, respectivamente, que los de sismógrafos disponibles comercialmente, pero el costo de fabricación de MiSismo también es un orden de magnitud menor. El rendimiento de MiSismo fue probado con sismos reales y simulados. Los resultados mostraron que MiSismo puede detectar sismos locales con magnitud tan baja como 4.8 Mw, y los datos son lo suficientemente claros para obtener los parámetros sísmicos básicos de sismos moderados a grandes. Esta característica de MiSismo podría ser útil para fines educativos. Por otro lado, se encontró que las mediciones de MiSismo claramente detectan el efecto de resonancia en edificios, indicando que MiSismo también podría ser usado para estudios estructurales. Finalmente, los resultados de un sismo simulado de alta intensidad con subsecuente corte de energía confirmaron que el sistema de soporte de energía funciona perfectamente, ya que no se observó ninguna pérdida de datos.

Palabras clave: Instrumentación física, acelerómetro de bajo costo, educación, estudios estructurales.

Introduction

Seismographs are instruments that measure and record the motion of the ground caused by natural and man-made sources. In general, there are three types of seismographs: accelerometers (to measure acceleration), seismographs (to measure velocity) and High Frequency Global Positioning Systems or HF GPS (to measure displacement). All these types share one thing in common: their extremely high sensitivity. This feature is necessary in all types of seismographs because the main function of most seismographs is to record seismic waves, whose amplitude can vary from a few micrometers to several centimeters. Unfortunately, this gain in sensitivity comes with a major drawback: the significant increase in the price of these instruments.

However, in recent years, there has been a major breakthrough in the development of seismographs: the implementation of micro-electro-mechanical-system (MEMS) accelerometers. The main advantage of MEMS accelerometers over the other types of seismic sensors is their very low price, but this also comes at the expense of a much higher noise density. The other main advantage of MEMS accelerometers is that they can record values of acceleration up to 16 times as high as Earth's gravity, reason for which they are mainly used in engineering [1].

Until just very recently, MEMS accelerometers were exclusively used in the industry sector, but nowadays their use for seismological studies has increased as new research suggest that some models of MEMS accelerometers can detect nearby earthquakes with local magnitude as small as 2.0ML [2]. Similarly, some researchers are experimenting with MEMS accelerometers to evaluate the state of the infrastructure of old and new buildings [3]-[5] and bridges [6]- [7]. Their results indicate that the data produced by MEMS accelerometers is sufficiently reliable to make relevant conclusions about the state of these structures.

Real moderate earthquakes can also be used to evaluate the state of buildings with large arrays of MEMS accelerometers [4], but this is only possible in highly-earthquake prone regions. Even though Peru is located in one of the most seismically active regions of the world, the implementation of MEMS-based technologies is still mostly unknown, and many buildings and bridges in this country are over two centuries old. For this reason, in this article the prototype of a MEMS-based accelerometer is presented, along with its most outstanding features and suggested purposes. From now on, this project will be referred to as MiSismo.

1 Materials and Methods

Figure 1 shows the external appearance of MiSismo from different perspectives as well as the names of the additional items used to construct the device as a whole.

The case of MiSismo is entirely made of acrylic styrene acrylonitrile (layer height 0.2 mm and fill percentage 30%) and was designed using the free distribution software FreeCAD (https://www.freecad.org/). The dimensions of the housing for MiSismo are given in Table 1.

Parameter	Value (mm)
Width	140.00
Length	110.00
Height	60.00
Thickness	10.00

Table 1: Dimensions of the housing for MiSismo.

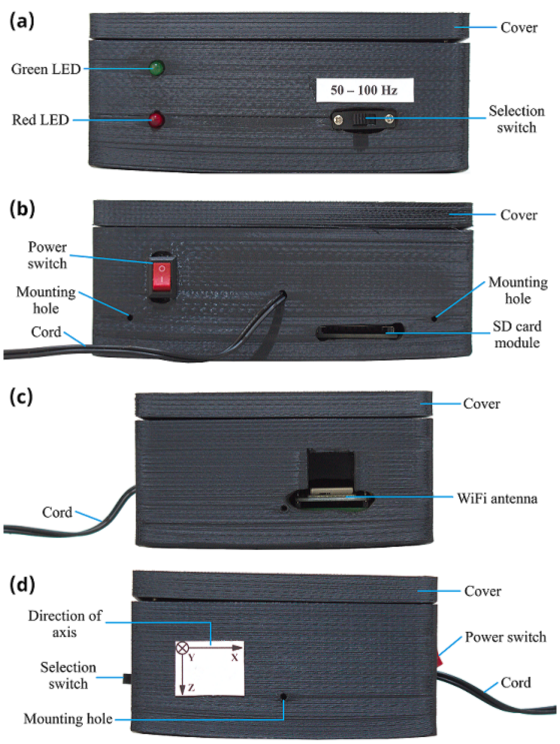

Figure 1: Photographs of MiSismo depicting (a) the front, (b) the rear, (c) the right side and (d) the left side of the housing. The locations and names of the external structures and devices of MiSismo are indicated with turquoise lines.

In order to avoid repetition, all the characteristics of MiSismo will be introduced while the overall functioning of this device is explained. Figure 2 illustrates the diagram block of MiSismo. First, even before MiSismo starts operating, the sample rate (50 or 100 Hz) must be selected. This is done with the selection switch (panels (a) and (d) in Figure 1). The state of the selection switch not only determines the sample rate, but also the maximum recording time of MiSismo (2 minutes at 100 Hz and 4 minutes at 100 Hz), for the reasons that will be explained later in this section.

After selecting the desired sample rate, the power switch must be set to position OFF (panels (b) and (d) in Figure 1). When the power switch is set to OFF, no flow of current is possible throughout the whole device. Following this, the user must plug in the accelerometer with a 12V AC/DC adapter using the black cord shown in panels (b), (c) and (d) in Figure 1, and set the power switch to position ON. The user can verify that MiSismo is using the external power supply by seeing the green and red LEDs (Figure 1 (a)) light up for 2 seconds immediately after the device has been switched on. This is warning for the user: MiSismo has now to stand completely still for the subsequent stages.

Later, MiSismo reads the state of the selection switch and initializes the SD card module (Figure 1 (b)). If this procedure fails, then MiSismo turns on the red LED indefinitely. This is another warning for the user: if the SD card is not properly attached or has not been properly formatted (only FAT32 and exFAT are allowed), then MiSismo will not be able to record any earthquake, which is supposed to be its primary function. If the SD card module is successfully initialized, then MiSismo proceeds to connect to the WiFi network assigned by the user. Similarly, if during the following minute MiSismo fails to connect to the WiFi network, the red LED will blink for 30 seconds. In contrast to what happened in the case of the SD card module, in this case the warning is not permanent because the message conveyed to the user is that MiSismo can still record earthquakes and store the data into the SD card, but this data will neither be sent to the user's email nor contain the time at which the earthquake was recorded. To prevent this from happening, the user has to install MiSismo in an area with strong WiFi signal and make sure that there are no potential obstacles for the WiFi signal near the flat WiFi antenna of MiSismo (Figure 1 (c)).

In either case, later MiSismo proceeds to calibrate the MMA8451Q sensor (not shown in Figure 1), which is the three-axis MEMS accelerometer selected for MiSismo. The characteristics of the MMA8451Q sensor relevant for the objectives of MiSismo are listed in Table 2, such as the relative low noise (2.7468 cm/s^2 for the more popular MPU-6050 sensor [8]) and high sensitivity (3.8320 cm/s^2 for the ADXL345 sensor [9]). For further information, the reader may refer to the datasheet of the sensor [10]. In this stage, MiSismo computes the average acceleration for the three axis (X, Y and Z) to set these values as reference points. The difference between the measured and reference values will be used later by MiSismo to detect the occurrence of an earthquake. Finally, after this calibration process, MiSismo blinks the green LED for 30 seconds, indicating the user that the accelerometer is now awaiting for the occurrence of an earthquake.

Parameter	Value
Supply voltage	3.30 V
Power consumption	0.2851 Wh
Measurement range	± 1962.0000 cm/s^2
Sensitivity	0.4785 cm/s^2
Sensitivity accuracy	$\pm 2.64\%$
Low-pass filter	50, 100 Hz
Noise	0.6867, 0.9713 cm/s^2

Table 2: Main mechanical and electrical specifications of the MEMS accelerometer MMA8451Q as used in MiSismo.

After this stage, MiSismo merely measures the acceleration of the ground, but does not record any of the values because MiSismo has been programmed to record data only when an earthquake has been detected. This is done in order to prevent MiSismo from storing unwanted data which would otherwise make the SD card become full very quickly. In order to record earthquakes only, MiSismo uses a variation of the standard STA/LTA algorithm. In the original form of the algorithm, which is used by professional seismographs, an earthquake is recorded when the value of q, defined as shown in Equation (1), exceeds a pre-established value q_T [11].

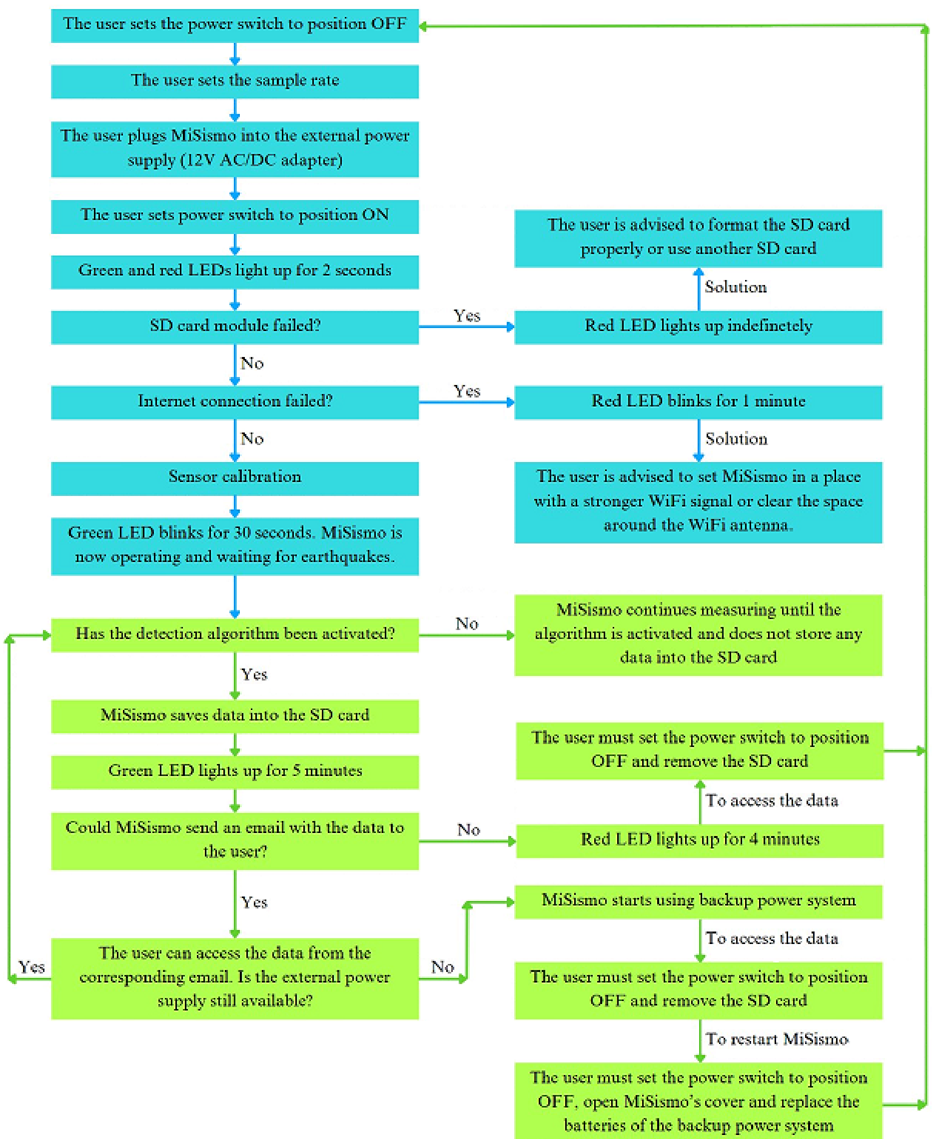

Figure 2: Block diagram of MiSismo. The turquoise and green rectangles differentiate the initialization and normal operation phases respectively.

$$q = \frac{\frac{1}{M}\sum_{i=N-M}^{N} a_i^2}{\frac{1}{N}\sum_{i=0}^{N} a_i^2}. \quad (1)$$

In Equation (1), a_i is the acceleration of the ground recorded along one particular axis, and N and M are the lengths of the datasets over which the sums must be taken. Usually $N \gg M$ because the aim of the STA/LTA algorithm is to increase the value of q as soon as any rapidly changing signal well over the background noise is detected. The STA/LTA algorithm could also have been applied to MiSismo, but the MMA8451Q sensor is not sensitive enough to measure non-earthquake-related signals over the background noise, making the latter fairly stable all the time. Therefore, the denominator in Equation (1) has no practical purposes for sensors not as sensitive as the ones used in professional seismographs, and as N is usually very large, the application of the STA/LTA algorithm in MiSismo would be computationally inefficient. To overcome this problem, an alternative form of the STA/LTA algorithm was applied to MiSismo:

$$q = \frac{1}{N}\sum_{i=0}^{N} |a_i|. \quad (2)$$

In contrast to Equation (1), in Equation (2) the squares in the numerator are no longer needed since these are mainly intended for professional seismographs, where slight changes in the average acceleration along the three axis can be expected.

When an earthquake has been detected by MiSismo, the measurements of the acceleration along the three perpendicular axis of the MEMS accelerometer are not directly stored into the SD card because the sample rate does not remain constant when the SD card module is used [3]. To overcome this problem, first the data is memorized in the form of arrays in an ESP32 microcontroller by progressively extending the value of N in Equation (2) until the earthquake is over or N reaches the maximum possible number of measurements (12600) that can fit in the 520 kB of RAM memory of the ESP32 [12]. This is why it was previously stated that the selection of the sample rate also determined the maximum recording time of the accelerometer. For example, for a sample rate of 50 Hz, the maximum recording time is 0.02 s $\times$ 12600 = 252 s, out of which 10 s correspond to data before q exceeded q_{T}. The same calculations can be performed to prove that for a sample rate of 100 Hz up to nearly 2 minutes of data can be stored. This inconvenience may seem to be a major limiting factor, but in fact it is not. Firstly, the longest rupture process in the central region of Peru in the 21st century was observed during the Pisco earthquake of August 15, 2007, and lasted for approximately 210 seconds [13], thus no earthquake recorded in the mentioned time frame has lasted more than 4 minutes. Secondly, only major earthquakes can last more than 2 minutes, and as their occurrence is much lower than that of weak-to-moderate earthquakes, most of the time a sample rate of 100 Hz will be sufficient to record the entirety of nearly all earthquakes. Therefore, in practice, the relatively short recording time of MiSismo is not a major drawback.

When the earthquake is over or N has reached the maximum possible number of measurements, then finally MiSismo proceeds to store the data into the SD card, along with the time (date and hours with decisecond precision, obtained using the networking protocol for clock synchronization called Network Time Protocol (NTP)) when q exceeded q_{T} for the first time (as long as internet connection is still available when the earthquake begins), and the sample rate. Once MiSismo is done storing all this information into the SD card, the green LED lights up for 5 minutes, indicating the user that the data has been successfully stored into the SD card as a text file under the name of "MiSismon.txt", where "n" is the number of earthquakes detected by MiSismo since it started operations.

What happens later depends on the external conditions. If internet connection is still available after all the data has been stored into the SD card, then MiSismo sends an email to the email address of the user with the file "MiSismon.txt" as an attachment. The aim of this procedure is to avoid as much as possible the cumbersomeness of removing the SD card from MiSismo, inserting it into a computer, downloading the text file into the computer, removing the SD card from the computer and inserting it back into MiSismo.

However, it can also happen that during or after very strong earthquakes there is a blackout. In this situation not only internet connection is impossible, but also MiSismo loses its external power supply, which may lead to the complete loss of the measurements of the earthquake. To overcome this issue, MiSismo includes inside the case a set of four non-rechargeable AA batteries that works as an internal backup power supply (minimum battery life: 20 hours) when the external power supply is no longer available. There is no risk of charging up the batteries since a specially designed circuit prevents MiSismo from drawing power from the batteries when the external power supply is available. This novel circuit was designed with the free distribution software EasyEDA (`https://easyeda.com/es`). The four batteries can be later replaced with the same type of batteries by opening the cover of the accelerometer (all panels in Figure 1) with a screwdriver.

Therefore, immediately after the beginning of a blackout, the continuation of the functioning of MiSismo is guaranteed, although nothing can be done about the internet connection. In this situation MiSismo will not be able to send the email with the measurements of the earthquake, thus after 1 minute it will turn on the red LED for 4 minutes as a warning. Summarizing, if only the green LED lights up after the end of an earthquake, the user is to understand that the data was successfully stored into the SD card and sent to the corresponding email, whereas if both LEDs light up one minute after the end of an earthquake, the user is to understand that the data was successfully stored into the SD card but not sent to the corresponding email. Later, MiSismo turns off both LEDs at the same time 5 minutes after the green LED lit up. In order to download the data into a computer, the user has to remove the SD card with MiSismo OFF, and as MiSismo at this point is running entirely on its internal batteries, the only way to do so is by setting the power switch to the position OFF.

Finally, at this point MiSismo simply resumes its normal operations, and continues to do so as long as the external power supply is available, or in the case of a lengthy blackout, until it runs out of the energy provided by the internal batteries. In the latter scenario, after replacing the batteries, the user will have to start the whole process all over again (both initialization and normal operations).

Model	Sample rate (Hz)	Sensitivity	Noise	BPS	Price ($)
MiSismo	50, 100	0.4785 cm/s^2	0.6867 cm/s^2	Yes	80.00
Raspberry Shake 3D	100	2.78 $\times 10^{-6}$ cm/s^2	-	No	799.99
Guowei GS201	250-32000	2.5/2^{32} V	1.2 μV	Yes	1000.00

Table 3: List of the main features of MiSismo and two three-axis seismographs available in the market without enquiries. BPS stands for backup power system. Further details are given in their corresponding websites [14]- [15].

It can be seen in Figure 1 that on three sides of the case (being the only exception the front) there are tiny wholes (called mounting holes) with no apparent application. The use of these wholes is completely optional since these were only designed to attach MiSismo to a solid surface if required by the user.

Table 3 compares the main features and price of MiSismo with those of two commercially-available high-level seismographs whose enquiries were not required. Even though it is very clear that the sensitivity and noise of the other two devices is far higher and lower respectively that those of MiSismo, the price of these devices is also one order of magnitude higher.

To test the performance of MiSismo, the data recorded by MiSismo had to be compared with the data produced by a standard professional seismograph. Due to issues that will not be addressed here, MiSismo could only be installed on the third floor of a four-storey building located near the intersection of the avenues Universitaria and Angélica Gamarra (latitude: −12.00733; longitude: −77.08004). According to the Instituto Geofísico del Perú (IGP) website (https://www.igp.gob.pe/servicios/aceldat-peru/red-acelerometrica), the closest seismic station to the location of MiSismo is station LOLI (Los Olivos district, Lima), located 1.60 km East of MiSismo's station. The type of soil on which station LOLI stands is the same as the type of soil on which the building where MiSismo is installed stands (Qp-C formation [16]), thus the observed seismic waves arriving at station LOLI should be nearly the same as the seismic waves arriving at MiSismo's station. Moreover, for very distant earthquakes, the arrival times of the seismic waves at both stations should also be nearly the same time.

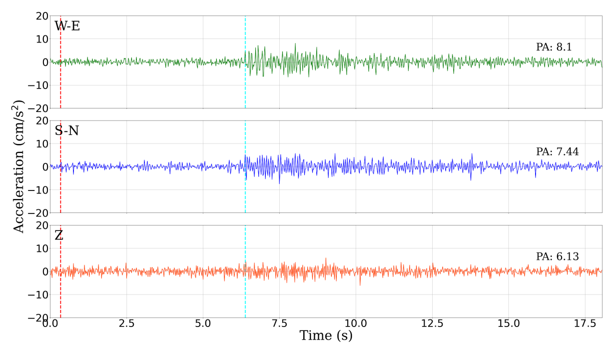

Figure 3: Seismograms of the West-East (W-E), South-North (S-N) and vertical (Z) axis for the 4.8Mw earthquake that struck the city of Lima on 2024-04-14 obtained using measurements of MiSismo. The red and turquoise vertical dashed lines denote the arrival times of the P (0.34s) and S (6.38 s) waves. PA stands for Peak Acceleration. Local time of first measurement: 08:56:57.2. Sample rate: 50 Hz.

The main disadvantage of the installation site of MiSismo is its location on a third floor. As buildings are not totally rigid, when seismic waves arrive at a building the base does not shake in the same way than the upper floors. In cases where the natural resonant frequency of the building closely matches the frequency of seismic waves with significant amplitudes, this leads to the amplification of the seismic waves in the corresponding frequency band in the upper floors [17]- [21]. Therefore, in contrast to station LOLI, MiSismo does not directly measure the seismic waves that arrive at the portion of soil where the four-storey building stands on. Instead, MiSismo only measures the perturbed seismic waves responsible of the oscillations of the third floor. However, this major drawback can also be used to study the response of the building to moderate-to-large earthquakes [5]. In order to do so, it must be assumed that the seismic waves arriving at station LOLI share exactly the same characteristics than the seismic waves arriving at the building where MiSismo is installed, which is quite reasonable since in both locations the composition of the soil is very similar [16].

To test the backup power system of MiSismo, a very strong earthquake was simulated by strongly shaking a regular wooden table. The subsequent blackout was simulated by simply switching off MiSismo during the development of the simulated earthquake.

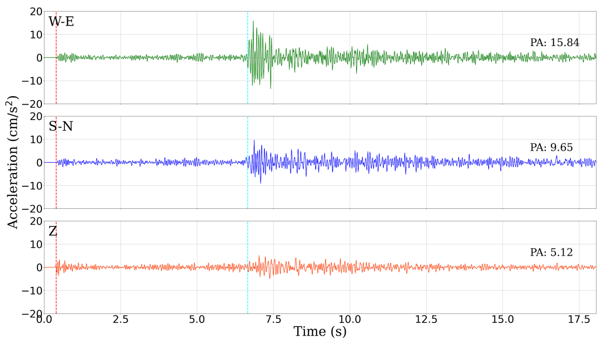

Figure 4: Same as Figure 3 but for station LOLI and with arrival times for the P and S waves of 0.39 s and 6.66 s respectively. Local time of first measurement: 08:56:57.

2 Results and Discussion

Figures 3 and 4 compare the quality of the data acquired by MiSismo and station LOLI during the 4.8Mw earthquake that struck the city of Lima on date 2024-04-14. The seismic report of this earthquake (as issued by IGP) is shown in Table 4.

Seismic parameter	Value
IGP/CENSIS/RS	2024-0235
Local time	2024-04-14 08:56:47
Magnitude	4.8Mw
Depth	34 km
Latitude	$-12.24°$
Longitude	$-77.37°$

Table 4: Seismic report issued by IGP (`https://ultimosismo.igp.gob.pe/evento/2024-0235`) of the earthquake depicted in Figures 3-6.

It is evident in Figures 3 and 4 that the evolution of the seismic waves in both stations was very similar, as expected from the explanation given by the end of Section 1. Even though the sensitivity of MiSismo is much lower than that of station LOLI, the arrivals of the P and S waves in the W-E and S-N seismograms of Figure 3 are discernible, which is remarkable since their arrival times can be used to compute the epicentral distance of the earthquake. Using the data shown in Figure 3, it was found that the P waves (~ 7 km/s) arrived 6.04 s earlier than the S waves (~ 4 km/s), which is equivalent to an epicentral distance of ~ 42.3 km. The exact location of the epicenter is given in Table 4, so this information was used to calculate the actual epicentral distance: 41.0 ± 0.8 km, which gives a relative error of 3.17%.

Once the epicentral distance is known, this parameter can be used along with the arrival time of the P waves to estimate the time the earthquake began since the P wave velocity is very well known. The estimated starting time of the earthquake was 2024-04-14 08:56:48.1, only 1.1 seconds after the official time (Table 4).

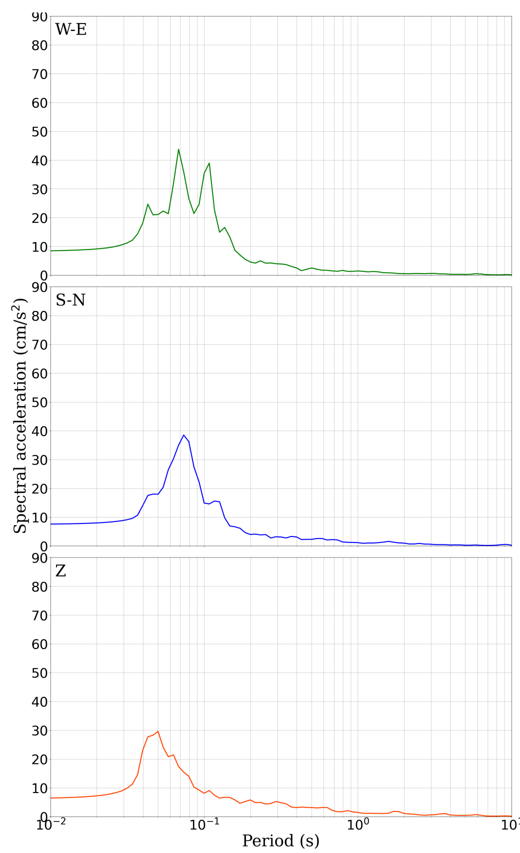

Figure 5: Spectral accelerations for the 4.8Mw earthquake that struck the city of Lima on 2024-04-14 obtained using measurements of MiSismo. Damping: 5%.

The results introduced above clearly demonstrate that MiSismo can be used to calculate basic seismic parameters of local earthquakes with magnitude as small as 4.8Mw, which is remarkable considering the limiting factors under which MiSismo operates. Therefore, a potential use of MiSismo could be for educational purposes. For example, MiSismo could be installed in schools to teach their students how seismographs work (although it should be emphasized all the time that MiSismo is only an accelerometer and not a professional seismograph) and how data directly acquired from their MiSismo can be used to compute basic seismic parameters. In fact, with the data of at least three accelerometers, the approximate location of the epicenter of an earthquake can also be calculated. Later, they could compare their measurements and calculations with those of the official report issued by the corresponding geophysical agency.

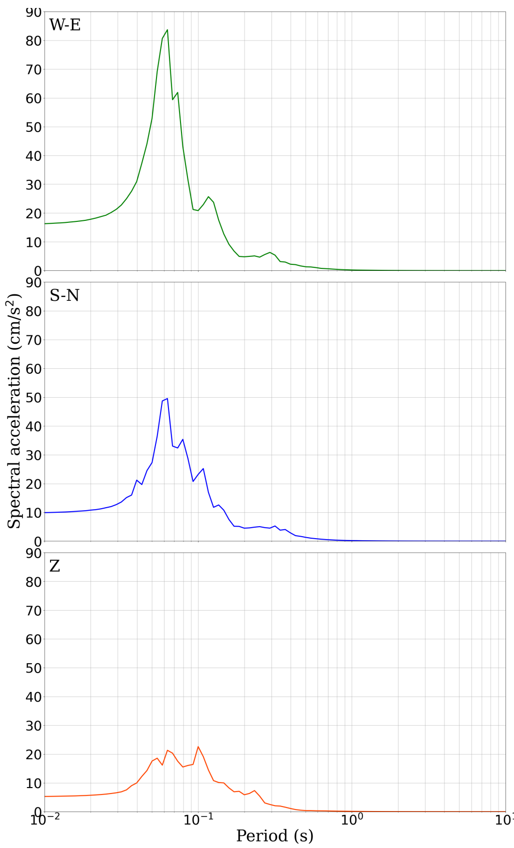

Figure 6: Same as Figure 5 but for LOLI station.

Figures 5 and 6 compare the spectral accelerations in the period domain of the oscillations recorded by both MiSismo and station LOLI using the data shown in Figures 3 and 4 respectively. It is evident that the highest acceleration values along the two horizontal axis were recorded by station LOLI, indicating that the resonant frequency of the four-storey building where MiSismo is installed does not match the wave frequency of earthquakes with epicentral distances of around 40 km and less. Additionally, Figure 6 reveals that at station LOLI high amplitude waves in the W-E axis were mainly recorded in the band 0.020-0.100 s (with a peak at 0.063 s), whereas at MiSismo (Figure 5) the spectral acceleration values peaked at 0.068 s (in agreement with the peak observed at station LOLI) and 0.108 s. The latter peak is also observed at station LOLI, but it is barely discernible because of the much higher first peak. This result indicates that the four-storey building where MiSismo is installed is more sensitive to vibrations with periods of 0.8-1.2 s, but not below, which is a clear manifestation of the resonance effect. This result demonstrates that MiSismo can also be used to study the basics of a building's response to real earthquakes. This type of application could be of particular interest for college students and civil engineers. In the market there are already devices destined to the study of the dynamic response of buildings to earthquakes, but these are at least one order of magnitude more expensive than MiSismo (Table 3). This detail is particularly important for regions where this type of technology is not affordable, but that at the same time need these devices more because people in these places mostly live in poorly-constructed or old residences.

Figure 7 shows the measurements obtained by MiSismo during the simulated strong earthquake with subsequent blackout. The lack of missing data confirms that the backup power system of MiSismo worked accordingly.

There are still some improvements to be made to MiSismo:

- It is very clear from Figure 3 that the noise density of MiSismo is much higher than that of station LOLI. This can be partly solved by using many MEMS accelerometers simultaneously [22], but this would also increase the manufacturing cost of MiSismo. Besides, the noise density does not decrease linearly with the number of sensors used. For example, eight MEMS accelerometers are need to reduce the noise density to nearly one third of its original value [22]. However, the implementation of many MMA8451Q sensors in MiSismo cannot de discarded in the future.

- Figure 3 shows that the first P wave was detected only 0.34 s after the first measurement when this value was supposed to be around 10 s for a sample rate of 50 Hz, suggesting that the threshold q_T may be too high for MiSismo to detect the first (and usually less intense) seismic waves of an earthquake. This issue can be solved by lowering the threshold value in the program for future versions of MiSismo.

- A overheating problem was detected in the AMS1117 voltage regulator of the ESP32 microcontroller. Even though this issue neither affected the overall functioning of MiSismo nor represented any problem, it is always preferable to keep all electronic components as cool as possible. Electronic fans or heat sinks could be used to overcome this problem.

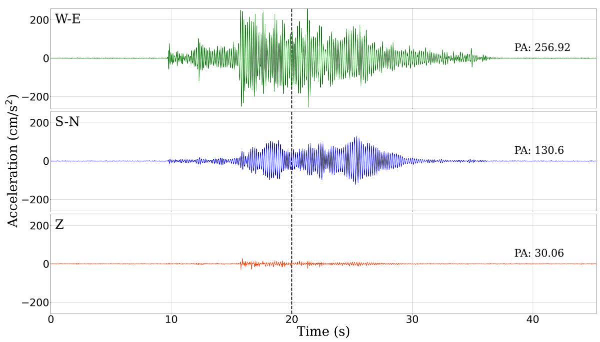

Figure 7: Seismograms of the simulated strong earthquake. The vertical dashed line denotes the time MiSismo was switched off (20 s). Sample rate: 50 Hz.

3 Conclusions

A low-cost accelerometer (named MiSismo) was developed with the aim of substituting the more expensive professional seismographs in tasks where not all their capabilities are needed. The main characteristics of MiSismo can be summarized as follows:

- The final price of MiSismo is one order of magnitude lower than that of professional seismographs.
- Only earthquakes are recorded to prevent the device from storing unnecessary data.
- All the data is stored into an SD card. No computer is needed except to read and process the data.
- The sample rate can be set at 50 Hz (maximum recording time: 4 minutes) or 100 Hz (maximum recording time: 2 minutes).
- The noise density and sensitivity of the accelerometer of MiSismo (MMA8451Q) is far lower than those of other more commercialized MEMS accelerometers.
- If internet connection is available during and after the occurrence of an earthquake, MiSismo sends the measurements to the email address of the user along with the time (with millisecond precision) when the earthquake was detected.
- It has a 20-hour backup power system consisting of four non-rechargeable AA batteries that can be easily replaced after running out of energy.
- If any problems are encountered, then a couple of LEDs light up in specific ways to communicate the user what the problem is.

The performance of MiSismo was tested with a real earthquake and a simulated strong earthquake with a subsequent blackout. The results can be summarized as follows:

1. The quality of the data recorded by MiSismo during the real earthquake was high enough to calculate the basic seismic parameters of a local earthquake (epicentral distance of 41 km) with 4.8Mw. This remarkable feature makes MiSismo suitable for educational purposes.
2. Graphs of the spectral acceleration elaborated using data collected by MiSismo during the real earthquake clearly showed the resonance effect on the installation site of MiSismo, indicating that MiSismo could also be used for studies on the dynamic response of buildings to moderate and large earthquakes.
3. MiSismo continued recording data after the simulated blackout began, which objectively proves the correct functioning of the backup power system.

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