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Microcontroller based Digital System for Monitoring and Analyzing Seismic Activity

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Abstract

An earthquake is a devastating natural disaster that can have a significant negative impact on our civilization. To decrease the damage from an earthquake and save several lives, we need to gather deep knowledge about seismicity and develop a seismic activity analyzer to record the ground motion caused by an earthquake. This article presents the development method of an Arduino-based low-cost electric device that can be constructed easily to detect and graphically present any seismic activity with a warning alarm. A microcontroller-based digital seismic activity analyzer uses Arduino microcontroller to process and analyze data from a seismic sensor to provide accurate and real-time information about seismic activity. The obtained result with the device is compared with an analogue seismogram which works on the principle of a simple pendulum. The comparison justifies that the digital seismic activity analyzer provides several advantages over traditional analogue systems including improved accuracy, real-time processing, display of three-dimensional data with storage facilities. So, the system can be proven as a useful tool for saving human lives and minimize the economic damage due to earthquake.

Keywords: Keywords: Earthquake; Microcontroller; ADXL335 sensor; Seismograph.

1. Introduction

An earthquake is a natural phenomenon characterized by the shaking of the Earth's surface caused by the sudden release of stored energy within the Earth's crust, resulting in the propagation of seismic waves [1]. which occurs due to the shifting of earth's plates, caused by the earth's core heat. That shifting results in a collision with another earth's plate and also raises a fault between the plates [2]. An earthquake occurs when seismic energy waves travel through the Earth's interior and reach the surface. The most destructive earthquakes often originate in two well-defined regions: the "circum-Pacific belt" and the "Mediterranean-Himalayan seismic belt." These zones are characterized by intense tectonic activity, where the movement and interaction of tectonic plates generate significant seismic energy, resulting in frequent and powerful earthquakes [3]. Earthquakes can be caused by several kinds of reasons, classified as either tectonic or non-tectonic causes. Tectonic causes result from the movement and interaction of tectonic plates along fault lines [4]. Faults, which are fractures between rock blocks, are commonly associated with tectonic activity. Non-tectonic causes include volcanic activity, landslides, and human-induced factors such as mining or reservoir- induced seismicity [5].

There is an earthquake when the motion happens quickly [6]. The earthquake has two centers: the hypocenter and the epicenter [7]. The hypocenter is the location where an earthquake first occurs. The depth of the hypocenter determines whether the earthquake is shallow or deep. The region on the surface that is most likely to experience shaking is the epicenter. It is located directly above the focus or hypocenter of the earthquake [8].

Seismic waves are waves of energy that travel inside the earth or along its surface. Different types of waves are produced by earthquakes, each with a different speed. One can broadly distinguish between body waves, which move through the earth, and surface waves, among the many different kinds of seismic waves [9].

The local geological conditions influencing the occurrences determine the shaking's intensity. Earthquakes can cause damage to man-made structures such as buildings, roads, dams, and bridges [10]. The earthquake's creation of bays, estuaries, and bays has improved navigation. A large number of geomorphological formations are created as a result of earthquakes. The average number of people killed by earthquakes each year is approximately 20,000. The majority of an earthquake's damage is brought on by ground vibrations. Flooding can be a result of earthquake tsunamis, earthquake dams, and other factors [11].

Bangladesh is situated between the Eurasian and Indian tectonic plates [12]. Therefore, earthquakes can happen when the Indian Plate shifts to the north and collides with the Euro-Asian Plate. In actuality, the Indian plate moves under the Euro-Asian plate by approximately 6 mm each year in the northeast [13]. The Myanmar fault extends through Bangladesh's northern and eastern regions. Along the boundary between Meghalaya and Bangladesh, there is a 300-km-long Dauki fault, a 150-km-long Madhupur fault, and a 300-km-long fault that extends along the Surma basin. The Chittagong-Myanmar Plate is the last one, and it is located close to the Bay of Bengal. Mild to moderate earthquakes frequently occur as a result of this group of faults in Bangladesh [14]. We already know that Bangladesh's tectonic structure makes it a seismically active region. As a result, the high-rise structures in Dhaka and Chittagong are under enormous threat. Due to the liquefaction effect, which could result in the abrupt sinking of vast regions close to huge rivers, it also poses a threat to the flood protection embankments. The failure of natural gas pipes during large earthquakes could result in enormous fires. Power outages on a large scale and problems with water connections are both possible. Geologists have identified three earthquake-prone zones in Bangladesh. When compared to the rest of Bangladesh, the Sylhet-Mymensingh region, as well as the areas near Chittagong, Dhaka, Comilla, and Tangail, are particularly susceptible to big earthquakes [15].

Therefore, a low-cost, easily operable electronic device is needed for introducing scientific analysis into seismic activity occurrences. This research will give a brief idea about the earthquake and seismic activity and help the entrepreneur construct a low-cost microcontroller-based seismic activity analyzer and monitoring tool.

2. Methods and Materials

2.1 Analog Seismometer

The analogue seismometer is a device designed to detect earthquakes and create seismograms. It works on the principle of a pendulum, where a bob is connected to a base with a thin, inelastic wire. When an earthquake occurs, the bob moves freely, while the base and frame of the device vibrate with the ground's movements. However, the pendulum bob remains stationary due to its inertia and appears to move in relation to the shaking earth. This movement is recorded as a trace, or seismogram, which captures variations over time in the pendulum's displacement. Modern seismometers instead convert the base's motion with respect to the mass into an electrical voltage. The energy waves are captured as "wiggles" that record ground motion by the electrical voltage, which is then recorded on paper, magnetic tape, or another recording medium. We can only measure one axis deviation with this analog seismometer. The instrument's base and frame move when the ground trembles, but the pendulum bob remains stable due to inertia. In relation to the shaking earth, it will then appear to move. It tracks the displacements of the pendulum as it moves and how they fluctuate over time, providing a seismogram.

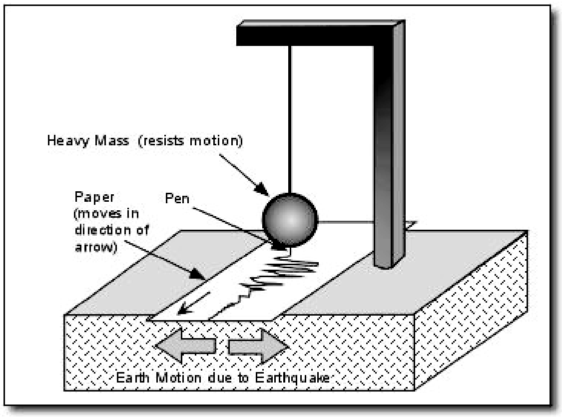

Fig. 1: Schematic diagram Analog seismometer

While the analog seismometer is a simple and effective tool for measuring ground movements, it has several limitations. One of the biggest limitations is that it can only measure one axis deviation, which means that it can only measure movement in one direction. This can make it difficult to accurately capture the full picture of ground movement during an earthquake or other event. Additionally, the analog seismometer is less precise than more modern digital seismometers and can be more prone to interference from other sources of vibration. It also requires manual interpretation of the seismogram, which can be time-consuming and subject to human error.

2.2 Digital Seismometer

The developed seismic monitoring system operates using a low voltage power supply sourced from a laptop, delivering a regulated 5-volt DC output. At the core of the system is the Arduino UNO, which serves as the central processing unit. It is seamlessly integrated with an ADXL335 sensor, allowing continuous collection of analog input signals. These signals are then processed by the microcontroller, which efficiently converts them into digital values. The measurement results are displayed on a laptop screen, providing a user-friendly interface for data visualization and analysis.

To simplify the understanding of the system, a block diagram is employed to illustrate the connections and information flow between the different components. Arrows within the block diagram represent the direction of data exchange, aiding in the design and comprehension of the electrical system. This simplified representation enhances the clarity of the system architecture and facilitates troubleshooting and maintenance.

By harnessing the power of the Arduino UNO and the precision of the ADXL335 sensor, the developed system demonstrates reliable and accurate monitoring of seismic activity. The utilization of a laptop as a power supply source and output display adds versatility and convenience to the system. This integrated design empowers users to effectively monitor and analyze seismic data, facilitating a deeper understanding of earthquake patterns and enabling prompt responses for disaster management. Because it shows the different parts of the system along with their interactions [16]. The block design seen in figure 1 was followed step by step as the main circuit was constructed.

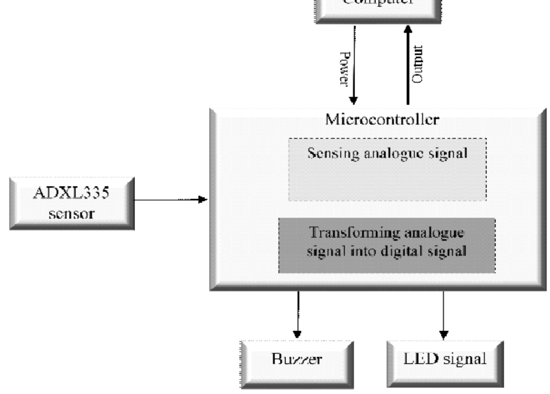

Fig. 2: Block diagram of the developed system interfacing its different parts

2.2.1 Arduino Microcontroller

Arduino is a low-cost and easy-to-use single-board microcontroller that allows users to quickly and easily create digital systems for a variety of applications. The Arduino UNO R3 board is equipped with AT328 and ATmega16U microcontrollers, making it a versatile and affordable option for hobbyists, students, and professionals alike [17]. These microcontrollers can take both digital and analog inputs and transform them into outputs such as controlling a motor, turning on an LED, or sending data online. The Arduino platform uses a simplified version of the C++ programming language, making it accessible for those with little to no programming experience. Overall, the Arduino microcontroller is a great tool for creating digital systems for monitoring and analyzing seismic activity, or any other project you have in mind [18].

2.2.1 Arduino Microcontroller

The ADXL335 is a small, low power accelerometer that measures acceleration on three axes (X, Y, and Z) with a range of ±3 g [19]. It works by detecting changes in capacitance caused by acceleration and converting that into voltage signals that can be read by a microcontroller or other device. The accelerometer can be used to measure static acceleration, such as gravity in tilt-sensing applications, as well as dynamic acceleration from motion, shock, or vibration [20].

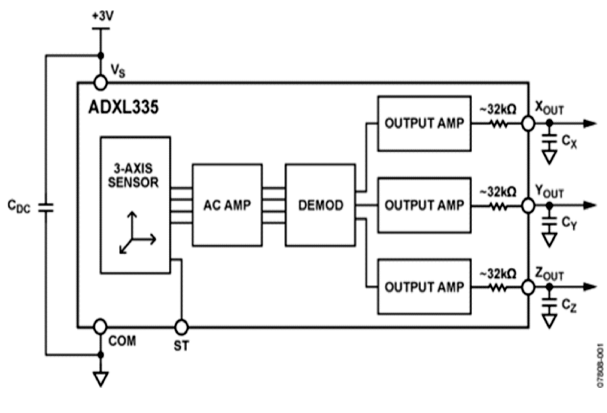

Fig. 3: Functional Block Diagram

2.2.3 Buzzer

A buzzer is a mechanical, electromechanical, or piezoelectric audio signaling device (piezo for short). Buzzers are frequently used as alarm clocks, timers, railway announcements, and confirmation of user action like a mouse click or keyboard press [21].

2.2.4 LED

A light-emitting diode (LED) is a semiconductor light source that produces light when current passes through it. Recombining electrons with electron holes in the semiconductor results in the release of energy in the form of photons (Energy packets). The energy needed for electrons to pass the semiconductor's band gap determines the hue of the light (equivalent to the energy of the photons) [22].

2.2.5 Power Supply and Monitoring System

A laptop was utilized as a power source for the microcontroller to ensure a stable and consistent supply of electricity. The laptop also served as an output monitor, displaying the results of the seismic activity analysis performed by the microcontroller. This setup allowed for easy and convenient monitoring of the system's performance and results, without the need for additional hardware or equipment. The use of a laptop in this manner not only added to the cost-effectiveness of the project, but also enhanced its flexibility and portability.

2.2.6 Arduino UNO software

The Arduino software (IDE), developed by arduino.cc, is an integrated development environment that is open source and used to program the Arduino boards. The Arduino software (IDE) was used to program the Arduino board [23].

The software facilitated the development of code to collect analog input signals from the ADXL335 sensor, convert them to digital values, and display the results on a laptop. The code was then uploaded to the Arduino board for real-time monitoring and control.

2.2.7 Processing software

Processing 2.0.1 is a free graphical library and integrated development environment (IDE) aimed at non-programmers in the electronic arts and visual design fields. It uses simplified Java language features and a user-friendly interface to facilitate visual programming and the creation of interactive and visually appealing elements in the project [24]. The Processing software can be utilized to generate seismic graphs based on the data obtained from the Arduino microcontroller and ADXL335 accelerometer. The seismic data collected by the microcontroller was processed and visualized using the graphical capabilities of Processing.

2.3 Experimental procedure

The experimental procedure commenced with the assembly and configuration of the seismic activity monitoring system. The system was carefully calibrated to establish a reliable baseline for measurements. Artificially generated seismic events were recorded using both the analog and digital systems and the result were compared.

The analog seismometer functions based on a simple pendulum mechanism. It is constructed with a wooden base and a bob connected by an inelastic wire with recording medium. The seismometer was carefully positioned to capture ground vibrations during seismic events.

Both the analog and digital seismogram were placed carefully on a 100 cm x 100 cm wooden seismic activity analyzing Platform. An artificial earthquake was generated by vibrating the platform manually in a controlled way. The vibration was started with a lower intensity then gradually increases to a certain limit and then got decreased. The displacement of the platform in all direction was calculated with a meter scale from a reference point. The graphical result was collected from both the devices for identically generated seismic event. This process is then repeated for several times and the obtained results were compared to calibrate the developed device and evaluate its accuracy.

The results were cross-referenced and discussed in the context of their respective limitations and capabilities. Safety protocols were strictly adhered to throughout the experimental process to ensure the well-being of the researchers and the proper functioning of the equipment. Detailed documentation was maintained to ensure the replicability and validity of the results.

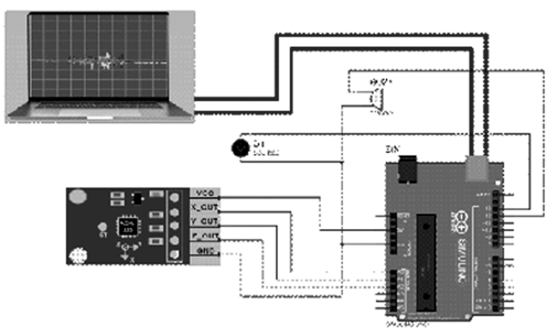

Fig. 4 : Circuit diagram of the developed system with microcontroller, sensors

3. Circuit Design

The design of the system is depicted in Figure 4 and was created using Proteus 7 software. The circuit diagram showcases the complete setup of the developed system.

4. Programming

The developed system utilized the Arduino UNO R3 microcontroller to sense analog inputs, convert them to digital values, and display the results on a laptop monitor. The microcontroller was programmed using the C programming language and the Arduino (Genuino) software [25]. The programming was transferred to the microcontroller through a data cable from a PC. A processing software program was also written to further enhance the functionality of the system. With the combination of the Arduino programming and the processing software program, the system was able to accurately monitor and analyze seismic activity. A flowchart that has been created to be simple to understand and develop the program is presented in figure 5.

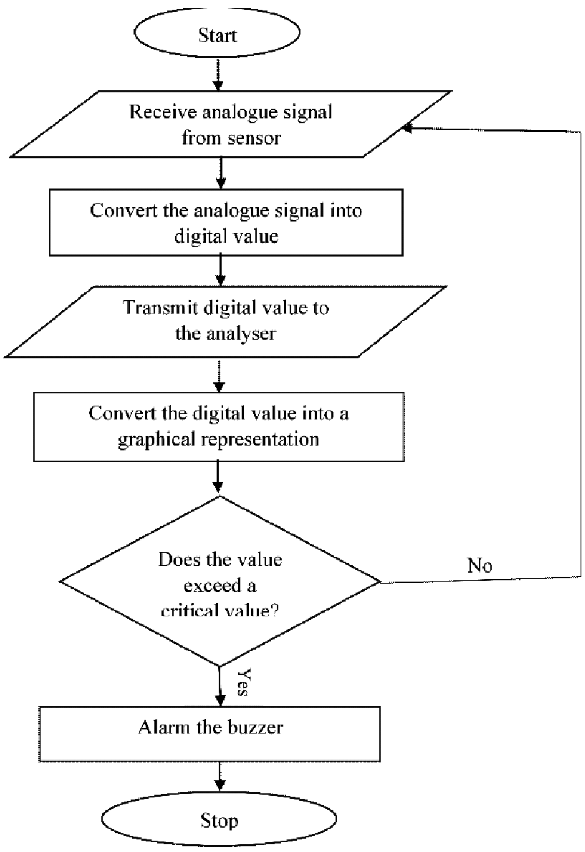

Fig. 5 : Flowchart for building the program of the microcontroller

5. Result and Discussion

The analog system detects seismic activity but produces a single-dimensional graph which measures only the horizontal ground motion. On the other hand, the digital system provides a three-dimensional graph of seismic activity for any kind of ground motion. In this section a detailed analysis of the obtained results is discussed. In the seismogram showed in Figure 6, red line represents the ground motion in X axis, blue is for Y axis and green is for Z axis.

Table 1 represent data for axes deviation of seismic activity from the theory and developed system.

Table 1. Data for displacement of the platform.

No. of observation	Z axis in mm	Y axis in mm	X axis in mm
01	-2	10	17
02	-3	6	11
03	-6	-1	-4
04	2	3	-11
05	5	11	14
06	-9	8	16
07	-5	12	18
08	2	9	-17
09	1	21	31
10	10	-12	-40
11	-2	-7	-19
12	-3	12	13
13	7	12	21
14	13	-26	-71
15	1	12	26

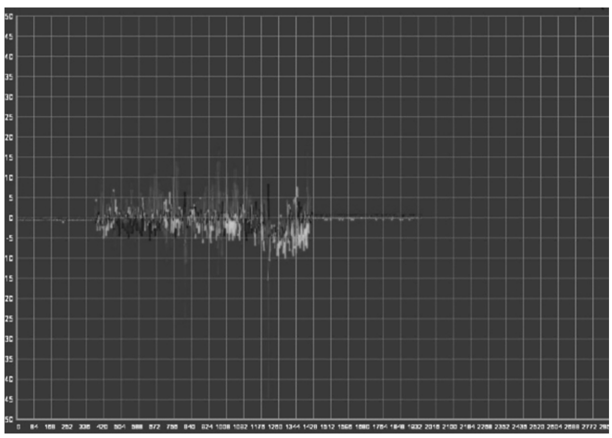

Fig. 6 : Digital seismic graph for earthquake vibration

Some evaluation of analog seismic graph and digital seismic graph for the identical vibration are shown in Figure 7 where (a) represent the analog seismic graph, and (b) represent the digital graph. In analog graph, it represents X axis while in digital system red line represents X axis, the blue line represents Y axis, and the green line represents Z axis.

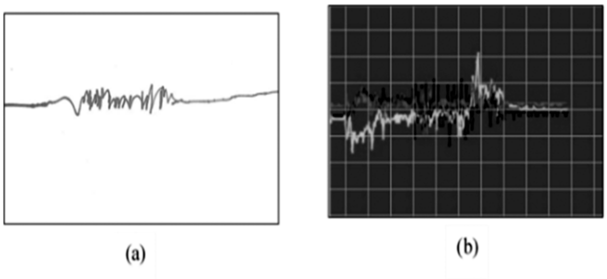

Fig. 7.1 : Observation no. 1

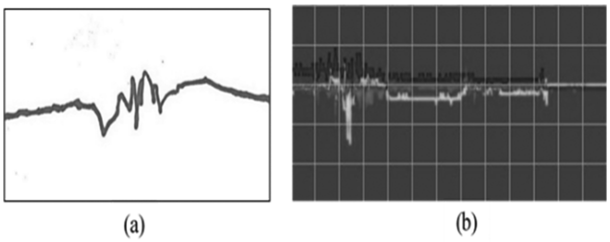

Fig. 7.2 : Observation no. 2

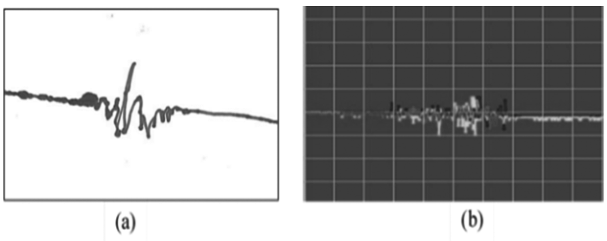

Fig. 7.3 : Observation no. 3

The graphical analysis shows that the pattern of vibration recorded by both the system are almost similar for X direction. In other two dimension the seismogram data agrees with the manual displacement data shown in Table 1. The comparison graph with the analog seismogram verifies the reliability of the developed system.

6. Cost Analysis of the Developed System

To develop the system, all the equipment and materials were obtained from the local market located in Tangail, Bangladesh. The cost of constructing the system is detailed in the following table 2:

Table 2. Total Cost of the developed system.

No.	Parameter	Specification	Unit price in BDT	Quantity	Total price in BDT	Total cost in BDT
01	Microcontroller	Arduino uno R3	1200	1	1200	
02	Sensor	ADXL335	450	1	450	
03	Buzzer	KXG1203C	20	1	20	1725
04	LED	Red LED	5	2	10	
05	Connecting wires	Jumper wires	3	15	45	

7. Conclusion

In this project, we studied seismic activity and designed a monitoring system using a microcontroller. Earthquakes, which have caused immense destruction in recent years, occur when the energy stored within the Earth's crust is suddenly released, resulting in the propagation of powerful seismic waves.

The seismic activity monitoring system has been designed, developed, and performed with an Arduino, LED, buzzer, laptop, and ADXL 335 accelerometer. For this purpose, we first studied and designed different parts of the system separately and represented the total system with the help of a block diagram. A laptop was used as a regulated low-voltage power supply source to power up the Arduino microcontroller. When any seismic activity occurs, the ADXL 335 sensor sends a signal to the microcontroller. Arduino senses the input signal, converts the analog signal into a digital signal, and displays the value on a laptop. We use software, specifically Arduino IDE and Processing, to detect earthquakes and generate the corresponding graphs. The results and graph analysis show that the device is reliable. At first, we used Proteus software for the simulation of the system. Besides, we constructed an analog seismometer, which works on the principle of a pendulum. An analog seismometer also gives a graph when it is subject to seismic activity. We compare both graphs for artificially generated seismic activity, the result were nearly similar. With this developed system, it can detect when an earthquake starts and send an alarm by beeping a buzzer and lighting an LED if the activity exceeds a certain threshold value. So that we can be alerted during an earthquake and go to a safe location to protect our lives and property. It can be used in multipurpose buildings, offices, and institutions to detect the earthquake and alert everyone. I think it must be used in high-risk areas for earthquakes. In short, earthquake detectors help warn people of approaching earthquakes so that we can take appropriate precautions to save lives and prevent significant property damage.

The developed seismic activity monitoring system is highly user-friendly and dependable in its operation. It has been meticulously designed using easily accessible components from the local market, ensuring convenience and affordability. The system is cost-effective, offering a significantly lower price compared to similar instruments available internationally. Its affordability makes it accessible to a wider range of users, allowing for wider adoption and utilization in various settings without compromising on performance and reliability.

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