Open Access Research Journal of
Multidisciplinary Studies
Journals home page: https://oarjpublication/journals/oarjms/
ISSN: 2783-0268 (Online)

OARJ OPEN ACCESS RESEARCH JOURNALS

(REVIEW ARTICLE)

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Ground motion detection and risk mitigation system

Dexter M. Toyado [1, *], Donita Mae T. Teaño [2], Lyndon T. Buenconsejo [2], Isaac D. Arcilla [2] and John Paul C. Bagadiong [2]

[1] *Department of Civil Engineering, College of Engineering and Architecture, Catanduanes State University, Philippines, 4800.*
[2] *Department of Computer Engineering, College of Engineering and Architecture, Catanduanes State University, Philippines, 4800.*

Open Access Research Journal of Multidisciplinary Studies, 2024, 08(01), 075–084

Publication history: Received on 26 July 2024; revised on 04 September 2024; accepted on 07 September 2024

Article DOI: https://doi.org/10.53022/oarjms.2024.8.1.0049

Abstract

The importance of the study is that this detected major quake, informed citizens through automated continues beep sound, notified rescuers and automated shutdown of circuit breaker of the building during earthquake. This invention focusses on Catanduanes State University premise provided real-time warning scheme and alertness during and after strong quakes. The System Development Life Cycle (SDLC) model particularly the prototype method was used in the invention. Finally, prototype results are provided showing that the system support the expected performance of real seismic stimuli and a software monitoring data of detected ground-motion and its magnitude is also acquired by the system. As for future studies the researchers recommend to record the number of occurrences through a Database Management for possible tracking and monitoring purposes.

Keywords: Ground-motion detection; Real-time warning scheme; Arduino; Circuit breaker shutdown; Rescuer notification

1. Introduction

Earthquakes have always been one of the major problems in many countries due to the massive damages it brings particularly in infrastructures, houses and even affects natural resources. According to Philippine Institute of Volcanology and Seismology (PHIVOLCS), every day, there is an earthquake but some of it is so weak that people couldn't feel the ground shaking. We are so vulnerable when it comes to earthquake because we didn't know when and where will be the next occurrence of it.

Way back May 5, 2018. A magnitude 6.0 earthquake rattled Catanduanes. PHIVOLCS said that the quake, initially reported to be magnitude 5.9 struck about 2:19 p.m., with its epicenter located 46 kilometers northwest of Pandan, Catanduanes with a 21-km depth of focus. On Saturday morning of that same day, a magnitude 4.6 quake was also reported in Catanduanes. The trembling which hit at around 10:18 a.m. and has an epicenter 19 kilometers southeast of Baras, was felt at intensity 2 in Sorsogon City.

On July 21, 2010, the article "Geologist map two fault system in Virac" by Danny O. Calleja said that a study by local disaster experts have mapped two fault systems in this capital town. One of the fault systems begins from the northern end of barangay Buyo and proceeding eastward, passing through the northern end of Barangay Hicming before touching the northern periphery of Barangay Danicop. The other one crisscross the Dugui area leading to the San Vincente area barangays while majority of the poblacion barangays, particularly those along seashores and rivers, are susceptible to ground settlement as well as liquefaction during an earthquake, according to recent report of Catanduanes Tribune quoting local authorities. These fault systems are now incorporated in detailed maps provided by the Mines and

* Corresponding author: Dexter M. Toyado

Geosciences Bureau (MGB) of the Department of Environment and Natural Resources (DENR), and the planning and development offices of the capital town as well as the neighboring towns of Bato, San Andres and Caramoran.

It is very evident that earthquake causes much damage and may take many lives. This is the main problem that the researchers want to address in their study, "The Ground-motion Detection and Risk Mitigation System." The objective is to lessen the number of casualties during an earthquake and for the rescuer to easily determine the specific location of an individual trap in a building. The study will focus on the alarm system of Catanduanes State University during earthquake occurrence. Moreover, this system will allow the different rescue teams and respondents such as MDRRMO, Red Cross, etc. to be notified in order for them to respond immediately. This notification includes the specific location of an individual trap in a particular building. The system will also have the capability to shut down the circuit breaker of the building to avoid further disaster it may cause.

1.1. Objective of the Study

Earthquake is a devastating phenomenon that may cause severe injuries or even death. This is very possible if people do not have idea and has less knowledge on how to keep them safe and evacuate during an earthquake. In the event where buildings collapsed, the number of injured increases because of delay in search in rescue operation caused by lack of data such as the exact location wherein an individual is being trapped.

Specifically, this study seeks to answer for the following questions:

- To design a system that can detects the movement of the ground in the building structure;
- To integrate into the system that enable to shuts down the power supply source of the building during massive earthquake;
- To integrate a notification system that can send messages for the rescuers and the concern agencies if there is partial or possible collapse of a section or parts of the system or total collapse.

1.2. Conceptual Framework

The conceptual framework model is shown in figure 1, guide the researcher in achieving the required output of the project. The input includes literature review to identify existing studies similar to the design, materials was also gathered for the projects, and additional data gathering for the implementation of the prototype. The process includes designing, development following engineered project, testing to evaluate the system, data collection for evaluation and analyses of the performance of the design prototype. The final output is the Prototype of an Automated Building Seismic Sensor and Warning system.

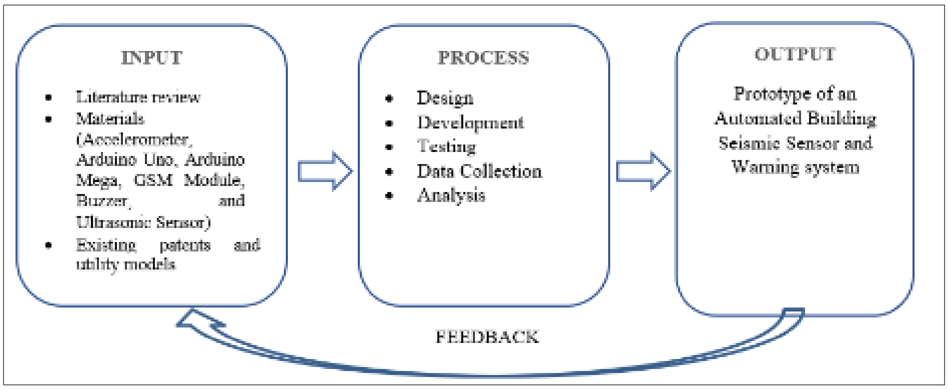

Figure 1 Conceptual Framework

In this system, the researchers used different microcontroller devices and sensors. This includes the Accelerometer, Arduino and the Ultrasonic Sensor. A sensor is a device that produces a measurable response to a change in a physical condition, such as temperature or thermal conductivity, or to a change in chemical concentration (www.engineershandbook.com, 2018). Sensors are particularly useful for making incite measurements such as in industrial process control. It is responsible for converting some type of physical phenomenon into a quantity measurable by a Data Acquisition (DAQ) system.

Based on "Accelerometer Theory and Design", 2008 an accelerometer is a sensor that measures the physical acceleration experienced by an object due to inertial forces or due to mechanical excitation. In aerospace applications accelerometers are used along with gyroscopes for navigation guidance and flight control. Conceptually, an accelerometer behaves as a damped mass on a spring. When the accelerometer experiences acceleration, the mass is displaced and the displacement is then measured to give the acceleration.

In these devices, piezoelectric, piezoresistive and capacitive techniques are commonly used to convert the mechanical motion into an electrical signal. They are unmatched in terms of their upper frequency range, low packaged weight and high temperature range. Piezoresistive accelerometers are preferred in high shock applications. Capacitive accelerometers performance is superior in low frequency range and they can be operated in servo mode to achieve high stability and linearity. Modern accelerometers are often small micro electromechanical systems (MEMS), consisting of little more than a cantilever beam with a proof-mass (also known as seismic-mass) realized in single crystal silicon using surface micromachining or bulk micromachining processes. Most accelerometers are MEMS. The basic principle of operation behind the MEMS accelerometer is the displacement of a small proof mass etched into the silicon surface of the integrated circuit and suspended by small beams (www.sensorwiki.org, 2018).

According to Inflibnet Site (2008), the principle of working of an accelerometer can be explained by a simple mass (m) attached to a spring of stiffness (k) that in turn is attached to a casing. The mass used in accelerometers is often called the seismic-mass or proof-mass. In most cases the system also includes a dashpot to provide a desirable damping effect. The dashpot with damping coefficient (c) is normally attached to the mass in parallel with the spring. When the spring mass system is subjected to linear acceleration, a force equal to mass times acceleration acts on the proof-mass, causing it to deflect. This deflection is sensed by a suitable means and converted into an equivalent electrical signal. Some form of damping is required, otherwise the system would not stabilize quickly under applied acceleration. To derive the motion equation of the system Newton's Second Law is used, where all real forces acting on the proof-mass are equal to the inertia force on the proof-mass. Accordingly, a dynamic problem can be treated as a problem of static equilibrium and the equation of motion can be obtained by direct formulation of the equations of equilibrium. This damped mass-spring system with applied force constitutes a classical second order mechanical system.

The Arduino processor basically uses the Harvard architecture where the program code and program data have separate memory. The code is stored in the flash program memory, whereas the data is stored in the data memory. According to Louis (2016), the Arduino platform was designed to provide an inexpensive and easy way for hobbyists, students and professionals to create devices that interact with their environment using sensors and actuators. Based on simple microcontroller boards, it is an open source computing platform that is used for constructing and programming electronic devices.

Ultrasonic Sensor, the most commonly used in industrial applications to detect hidden tracks, discontinuities in metals, composites, plastics, ceramics, and for water level detection. For this purpose, the laws of physics which are indicating the propagation of sound waves through solid materials have been used since ultrasonic sensors using sound instead of light for detection.

According to Agarwal (2016), when an electrical pulse of high voltage is applied to the ultrasonic transducer it vibrates across a specific spectrum of frequencies and generates a burst of sound waves. Whenever any obstacle comes ahead of the ultrasonic sensor the sound waves will reflect back in the form of echo and generates an electric pulse. It calculates the time taken between sending sound waves and receiving echo. The echo patterns will be compared with the patterns of sound waves to determine detected signal's condition. The distance of obstacle or discontinuities in metals is related to velocity of sound waves in a medium through which waves are passed and the time taken for echo reception. Hence the ultrasonic detection can be used for finding the distances between particles, for detecting the discontinuities in metals and for indicating the liquid level.

The system shown in Figure 2 is comprised of highly sensitive gyro accelerometer, a microcontroller, GSM module and ultrasonic sensor. The purpose of the Accelerometer sensor is to read the vibrations from the earth surface which will depend in the mitigation system that will automatically shut down the circuit breaker. This sensor is connected with the Arduino MEGA and Arduino UNO respectively. Then the microcontroller is connected with GSM module, the purpose of those module is when the sensor package reads the vibration over the limit, it sends the signal to the module and makes the GSM to send text messages to the mobile phone and another signal is send to the PC for monitoring at it also sends real-time notification messages to rescuer when the Ultrasonic Sensor detects a collapse section, parts or entire building. It will be installed besides Fire detector system and Sprinkler system of a building placing it in every room of a building limited to a medium -rise structure.

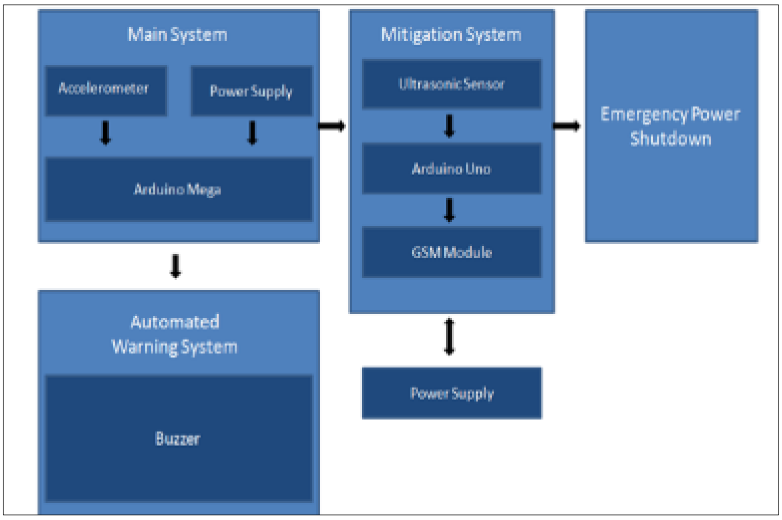

Figure 2 Diagram of Automated Ground-motion Detection and Warning System

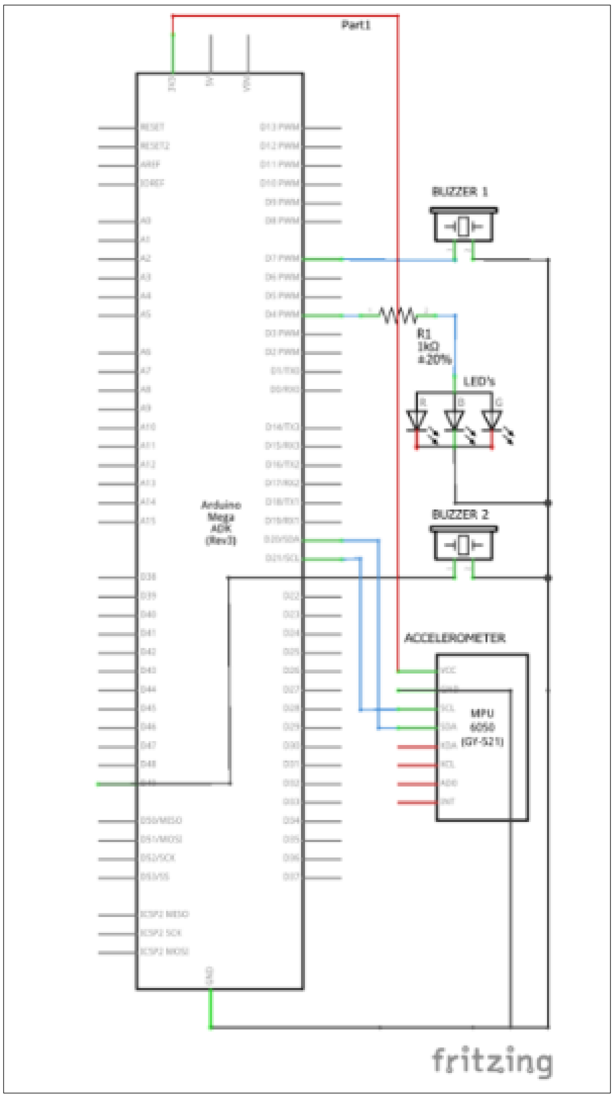

Figure 3 Detection System Schematic Diagram

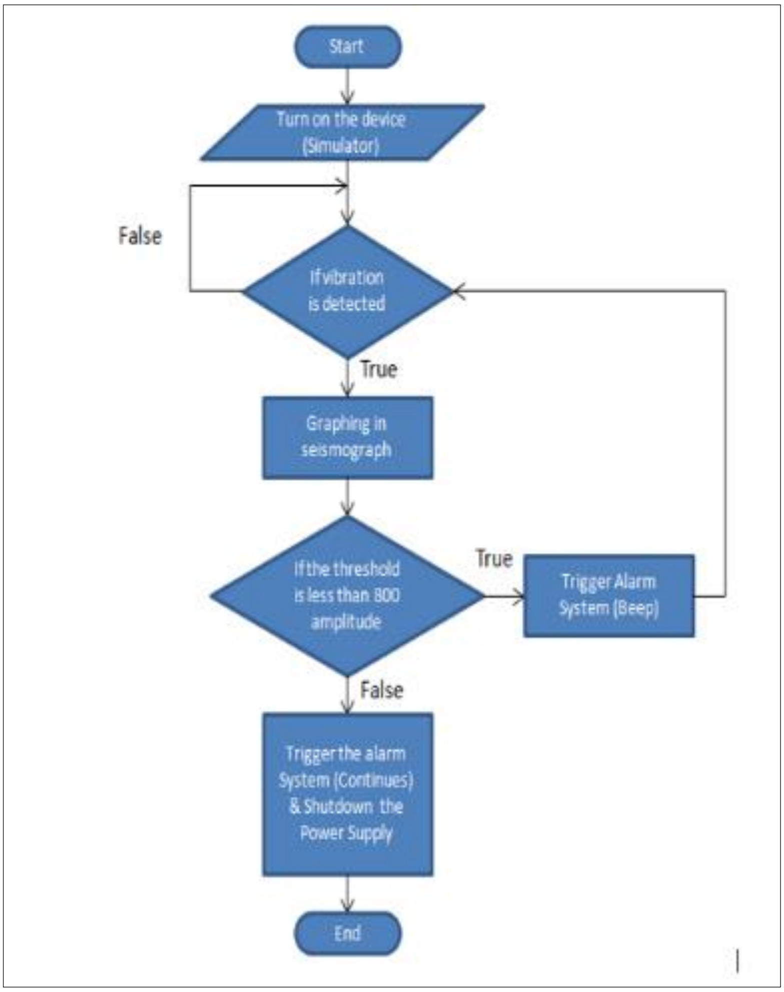

Figure 4 Detection System Flowchart

Figure 3 & 4 detection system schematic diagram and detection system flowchart use various sensors to detect the ground-motion, detect collapse section, parts or entire building and alert people. Warning systems play an important role in reducing the negative impact of these catastrophic events on densely populated areas and in mitigating the damage to strategic structures and lifelines. Emergency message delivery to the responders is the most important issue for earthquake warning system. Mitigation system for detecting building collapse for quick emergency response and the sub-system that will trigger the circuit breaker to forcefully shutdown depends upon the detected ground motion that exceed more than minor class earthquake.

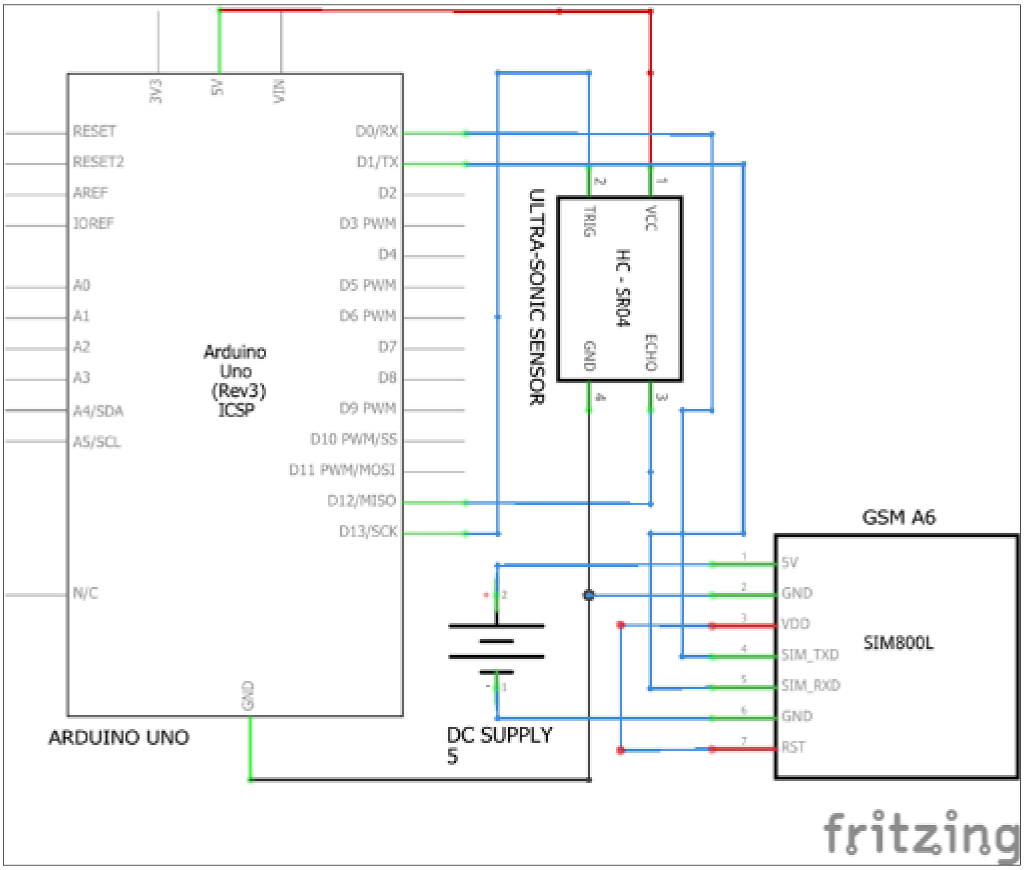

Figure 5 Mitigation System Schematic Diagram

The system has two other sub systems, namely the Automated Warning System and the Mitigation System. The main system is a standalone structure which means all power supply came from the battery. The main system's function is to detect ground-motion, which is connected to computer for monitoring, and transmit and receive data wirelessly to the mitigation system. Figure 5 & 6 above shows that if the detected threshold is greater than the peak threshold, the main system will send data to both systems to trigger the continuous warning system and will automatically shut down the power supply in facilities. If there is a collapse or a change in the foundation of the building, the sensor will automatically distinguish it and send data, such as time, status, and location, to the rescuers and immediately respond to the damaged facilities. Otherwise, if the measured threshold is lower than the peak threshold, the main system will send data to the system and will trigger the non-continuous or beeping sound. This means that the detected ground motion will serve as a precautionary measure for preparation.

1.3. Scope and Limitation

This study will focus on the design and development of prototype of Ground-motion Detection System and Warning System to provide real-time warning scheme, during and after strong earthquake. Feature includes shutting does the circuit breaker if the magnitude exceeds to its danger alert level to prevent explosion or any danger that cause of electricity during a strong earthquake. And if there is a detected collapse in a section, parts or entire building, a message notification will automatically be sent to the rescuers for immediately respond to that specific location for rescue operation if ever there are injured person inside that building. However, it will only focus on getting the magnitude to alarm, shutdown the circuit breaker during a strong earthquake and send notification to the rescuers for immediately response but it will not cover of getting the exact location of the earthquake or the epicenter and the time when the strong earthquake will strike and It will not determine if there someone's inside of the building or facilities.

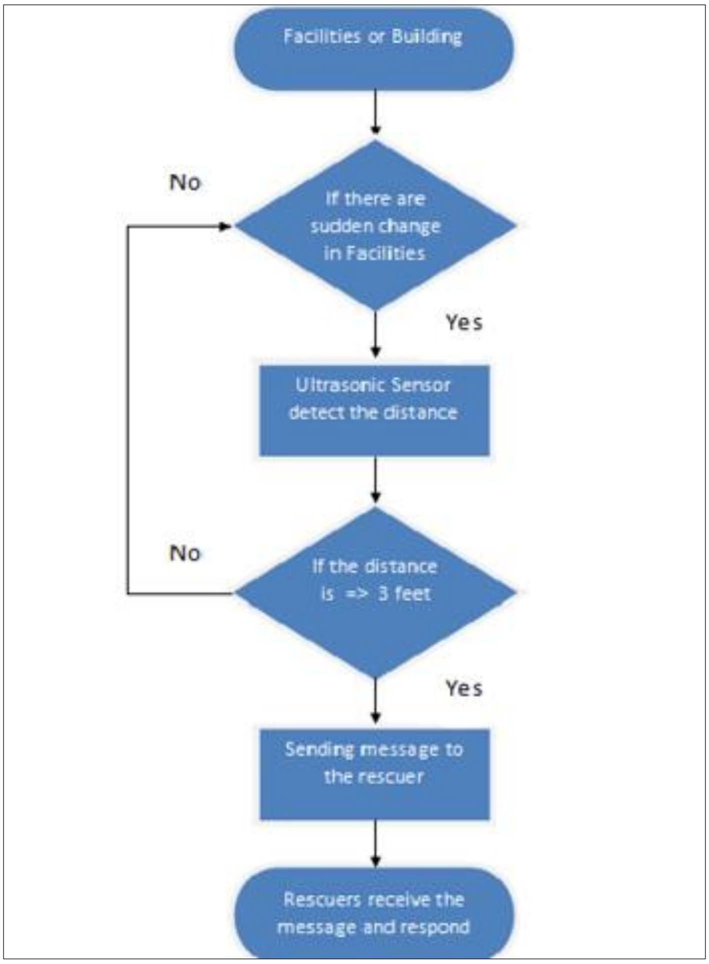

Figure 6 Mitigation System

2. Research Methodology

The System Development Life Cycle (SDLC) model particularly the prototyping method was used in this study. A prototype is an early sample, model, or release of product built to test the concept or process or to act as a thing to be replicated or learn from. It is a term used in a variety of context, including semantics, design, electronics, and software programming. This Prototype system will test the ground movements or shaking within in small area, it can help the researcher to gather some reliable data and to test out the capacity of the prototype system, if it is good enough or it has still plenty of room for improvements. In prototype system the researcher will manage to check the data of mitigation system if it is accurate enough from the actual minor event.

The research will develop and observe in CatSU to offer the system that will benefits such as disaster risk reduction. We will conduct some data inside the CSU to know the vulnerability level of the place when it comes in earthquake.

2.1. Data Gathering Methods and Procedures

In making the system's prototype, the following components are considered as active components; the microcontroller, accelerometer, buzzer and the ultrasonic sensor while, the GSM module is considered as the passive component.

The idea of making this prototype was done on the reason that earthquake, as an unpredictable phenomenon, takes a long time to gather information if we only depend on the long-term data gathering. Before we work on this, we have study all about the different types of earthquakes, its impact on the structures of the buildings, and the safety measures done when the earthquake strikes for information purposes and basis on our prototype. By doing this, we are able to create a prototype that will have the same result.

The first thing we do is to test the accuracy of our prototype (the shake table) for calibration. Using the sensors, we will know the compatibility of each device attached to our prototype such as the real time ground shaking, data gathering, sending message and the buzzers. For data accuracy, to make our prototype almost similar to the ground motion or the real time ground shaking, we first study the maximum and minimum magnitude of the common earthquake but we realize that knowing the magnitude is not enough to make our prototype similar to ground motion that’s why we came up the idea of converting the magnitude to amplitude to know the certain level of the ground shaking because we discovered that knowing the magnitude alone is not accurate when it comes observing the capacity of the earthquake. After that, we learned not only the magnitude and amplitude is the key of knowing the ground motion, we discovered that acceleration, velocity and displacement is the foundation of the magnitude that’s why we created a software that will combine the elements and to make some tests through our prototype to make a data similar to a ground motion and to make sure to know some measurements on how the system identify the stabilize or strong ground shaking. The last function of our prototype is the buzzer, it is the key of knowing if the ground shaking is reaching to its minimum or maximum amplitude, if the ground shaking is stabilized then the buzzer will make a non - continues sound but once the system detected the strong earthquake the buzzer will make a continues beeping.

In warning system, the prototype send an alert message to a certain cell phone that will act as a rescuer through GSM Module, the prototype in mitigation is a model building, it is responsible on activating one of our sensors to send a message if the condition is met by the help of the Ultrasonic Sensor. The second capability of our prototype is to shut down its own original power if the amplitude will reach to the maximum level and will immediately change to the backup power to maintain the power of the mitigation. In shutting down the main power supply we first came up on using a relay but we discovered that we must use a high capacity voltage to activate the relay that we couldn't afford to use because of the size of our prototype that’s why we got an idea to just manipulate the program to make our own relay function that will automatically shut down the main power supply in exchange to our backup power.

3. Analysis, Presentation and Interpretations of Data

This section of the paper presents the interpretations and analysis of the data gathered during the testing of the accelerometer sensor, ultrasonic sensor, relay module, and GSM module used in the system.

Table 1 Accelerometer Sensor Output during testing

Level	**Displacement X**	**Velocity Y**	**Acceleration Z**	**Ground Movement**	**Buzzer Alert**
1	4.32	21.84	-31.45	Normal	Non-continues beep sound
2	283.70	-442.67	162.78	Moderate	Non-continues beep sound
3	912.65	-484.47	470.75	High	Continues beep sound

Table shown that the level 1 which have a Displacement (X) with the value of 4.32 amplitude (amp), Velocity (Y) with the value of 21.84 amp and Acceleration with the value of -31.45 amp are equivalent to normal ground movement and also buzzer alert is activated which contained non-continues beep sound. Level 2 with the value of X equal to 283.70-amp, Y equal to -442.67amp and Z value is equal to 162.78 amp is equivalent to ground movement. While the level 3 contained with the value of X equal to 912.65-amp, value of Y equal to -484.47amp and the value of Z equal to 470.75 amp. Those data detected by Accelerometer Sensor. Figure below is the detected ground motion during the testing of the device.

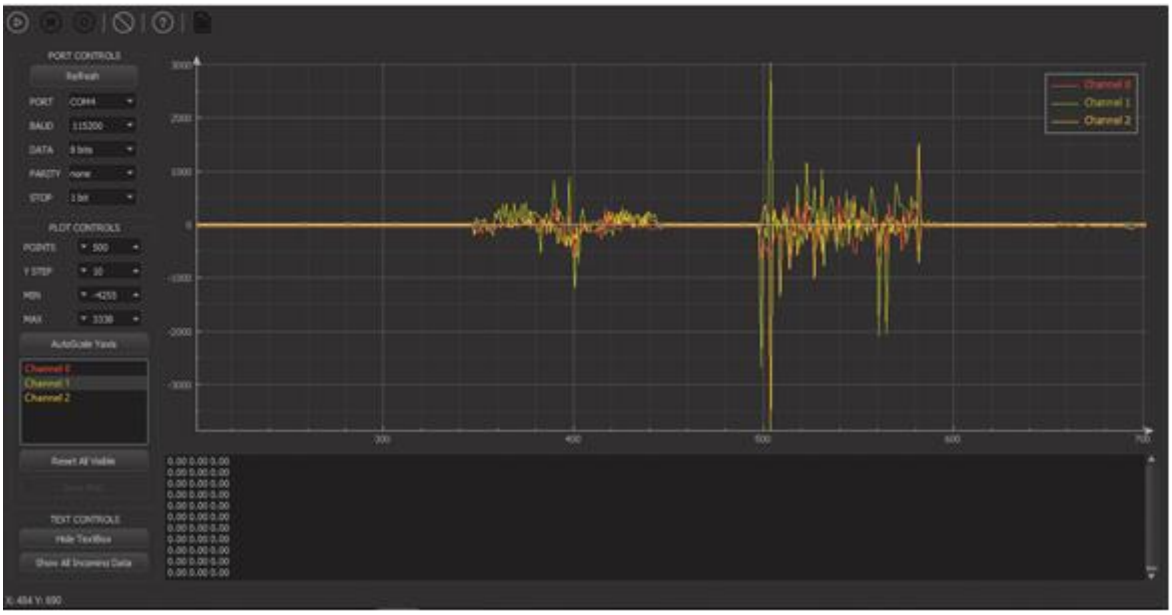

Figure 7 Combinations of Normal, Moderate and High Ground Movement Detected by Accelerometer Sensor

Table 2 The Arduino control to shut down the main power supply of the whole building where the device is installed

Table 2 Arduino Uno

Level	Amplitude Level	Circuit Breaker Control	Back-up Battery Supply	Buzzer Alert
1	500>x<912	None	None	Non-continues Beep Sound
2	x>912	Shutdown the power supply of the building	Switch On the back-up battery for emergency power supply of the system.	Continues Beep Sound

Legend: X = Accelerometer Condition

Table 2 shown the output of the RM of the system. Two (2) level was set for Relay Module. Level (1) means no earthquake was detected by the accelerometer sensor which is connected to relay, thus there is no notification and non-continues beep sound. Level 2 is reached when there is detection from Accelerometer, the Relay Module will be activated then the circuit breaker will be automatically shut down the power supply of the building. And the back-up battery for emergency power supply of the system will be activated or switch on and also continues beep sound.

The system notifies the rescuers such as Red Cross, MDRRMO, and another rescue group. The system will send notification if there where partial or possible collapse of a section, parts or entire building for them to decide on what respond they will provide based on the level of damage and emergency situation.

Table 3 Output of GSM Module using different Network Provider

Network	Number of trials	Average Time
GLOBE	10	1-2 mins
TNT	10	2-3 mins

The study tested two network providers to determine which network is more efficient to use in the GSM module. Table 3 shown the output of the GSM module using 2 different network providers. To test the time, it took for each provider to deliver an SMS, the time sent and the time received was recorded and from there, the researchers calculated the average time. The researchers conducted 10 trials, and it was found that Globe averaged 1-2 minutes, while TNT averaged 2-3 minutes. Globe was faster than TNT.

Based upon the presented data above, the researcher came up with the procedures, first steps the Researchers, gathered information through the use of internet. Second steps, an interview conducted with our adviser, about the building structures and where to installed our mitigation system for its efficiency and effectiveness. Third step, Conceptualization through the use of flow chart, framework, and schematic diagram. Fourth steps, the conceptualized ideas promulgated using Prototype. And last steps, we conducted testing of completed prototype.

4. Conclusion

The study was conducted to develop a Ground-motion Detection and Risk Mitigation System. The system is able to detect the ground movement. Through the use of accelerometer sensor, normal movement of the ground is equivalent to the vibration caused by footsteps of the people while the ground motion caused by vehicles are called moderate ground movement so there is no danger detected. But if the detected ground motion equal or exceed to High ground movement then that’s the time the system will send the warning signal to the people through a continues beep sound in order for them to prepare for incoming earthquake.

The system is able to shut down the power supply of a building. Using relay which is connected to circuit breaker, if there’s a detected earthquake and the condition reached then it will automatically activate the relay module. The system notifies the rescuers such as Red Cross, MDRRMO, etc. to determine where the casualties are in order for them to quickly respond through the use of GSM Module with TNT sim card the said message notification is rapidly receive by our rescuers with in a second.

Recommendations

The researchers recommend the inclusion of the following features to the system for future studies. Integrate Rapid Earthquake Disaster Analysis Software develop by the DOST. Evaluate and monitored damages or changed in a building caused by an earthquake. Analysis using software the number of occurrence ground-motion through a Database Management System for tracking and monitoring purposes. Furthermore, this study will be the basis of further improvement of the device to integrate other functionality for motivating and adaptation of measure to lessen the effect of earthquake.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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