



Embedded System

Microcontroller Based Earthquake Detection and Magnitude Measuring (Richter Scale) System for Risk Mitigation

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A B S T R A C T

Earthquakes are unpredictable disasters that can cause immediate structural collapse, posing significant risks, especially when occurring at night or early morning when people are asleep and slower to react. To mitigate these risks, this research aims to design a microcontroller-based system for detecting earthquakes and measuring their magnitude using Richter scale. The system employs an SW420 sensor to detect tremors and an ADXL345 accelerometer to detect and measure acceleration of earthquakes, which is then converted into magnitude using formula, $Magnitude = \log(a) + (x + 3.3)$ SR. The system is equipped with an alarm that activates if magnitude exceeds 5.0 SR and PIR HC-SR501 sensor to detect the user's presence. Additionally, it can activate a 5-watt emergency light and use a GSM SIM800L module to send SMS notifications and make calls to the User's nearest contacts in the event of a significant earthquake. The research methodology involves Action Research, which includes reflection, action, and continuous adjustment. The findings indicate that system can detect vibrations up to 60 cm away and measure earthquake magnitudes starting from 1.0 SR. The alarm successfully activates for magnitudes greater than 5.0 SR, and system can detect the user's existence presence up to 250 cm in both dark and light conditions. Furthermore, system effectively activates the emergency light and send SMS notification and call if the magnitude exceeds 5.0 SR. This research confirms that the system performs as intended, helping to mitigate earthquake risks and providing crucial information to user and their contact.

INTRODUCTION

Indonesia is geographically located in the equatorial region and has diverse morphology. This diversity is primarily influenced by geological factors, particularly the active movement of tectonic plates around Indonesian waters, which causes fractures beneath the Earth's surface [1]. As a result, Indonesia is classified as prone to geological natural disasters, particularly earthquakes. An earthquake is the shaking of the Earth's surface due to the sudden release of energy caused by the slip or rupture of rock masses in the Earth's crust [2].

Based on data from the USGS (United States Geological Survey), more than 150 earthquakes with a magnitude of over 7.0 on the Richter scale have occurred in Indonesia from 1900 to 2022 [3]. According to records from the Indonesian Geological Agency, there have been between 5 and 26 destructive earthquakes (>7.0 magnitude) in Indonesia from 2000 to 2021 [4]. The most destructive earthquake in Indonesia in the last two decades occurred in 2021, resulting in significant risk. This was the Mamuju earthquake, which occurred on January 14, 2021, with a magnitude of 6.2 and a depth of 18.0 km [5].

From several recent earthquake events, such as the earthquake 34 km west of Gaziantep, Turkey, in February 2023 at 4:17 AM with a magnitude of 7.8 on the Richter scale, there were casualties of up to 12,000 people and massive building damage. In this earthquake in Turkey with a magnitude of 7.8, some people were late in evacuating to a safe place, and the occurrence of aftershocks, which might carry greater risks than the initial quake, could not be predicted. This risk is further heightened if the earthquake occurs at night or early morning when people are still asleep. It takes longer to realize the earthquake is happening and to evacuate quickly, while the quake occurs in a short span of time and can immediately cause significant risk [6].

Unlike in Japan, when an earthquake occurs, an earthquake warning is sent to residents' mobile phones. Every mobile phone in Japan is equipped with an earthquake warning system. This warning reaches residents' phones approximately 5 to 10 seconds after the earthquake occurs [7].

Based on a literature review of previous studies [8], an earthquake intensity and magnitude detection system using the MPU6050 accelerometer has been designed. However, this study had a limitation: the system was only capable of detecting and measuring earthquake magnitude intensity without providing further mitigation actions. In another study [9], an early warning system for landslides using the MPU6050 accelerometer was designed, and in studies [10-12], earthquake detection tools were developed using the H48C accelerometer [10], the ADXL335 accelerometer [11], and [12]. Another study designed an earthquake detection tool using the MPU6050 accelerometer and solar cells as an energy source [13], and an earthquake detection system using the ADXL345 accelerometer based on LoRa technology [14], which have not yet been fully optimized in their applications. Subsequent research has designed early warning systems for volcanic activity hazards [15] and earthquake measurement tools based on the Internet of Things [16], using the ESP8266 Wi-Fi module to send notifications. A drawback of using the Wi-Fi module in these studies is that if there is no internet connection, the system cannot send notifications.

Given the significant potential for earthquakes in Indonesia and the issues discussed, the author designed a microcontroller-based system using Arduino Uno to detect and measure earthquake magnitudes and mitigate the associated risks. The system uses an SW420 vibration sensor to detect triggered vibrations, an ADXL345 accelerometer to detect and measure the earthquake's acceleration (which is then converted into magnitude on the Richter scale), a buzzer as an alarm to wake the user if the magnitude exceeds 5.0, a Passive Infrared sensor (HC-SR501) to detect the user's presence, LED lights as emergency lighting, and a GSM SIM800L module to send notifications, ensuring the system can function properly even without internet access.

Therefore, based on the provided description, the author has chosen the title for this final project: "Earthquake Detection and Magnitude Measurement System (Richter Scale) Based on Microcontroller for Risk Mitigation." It is hoped that this system will serve as an effective tool for detecting and measuring earthquake magnitudes, mitigating earthquake disaster risks, and being easy to apply and implement for all levels of society in Indonesia.

METHOD

Research Methodology

The method used in this final project research is the Action Research Method. Action Research is an approach aimed at improving or developing specific practices or actions in the field through a process of reflection, action, and continuous adjustment of the research [17].

Action Research is a highly effective research method for applied sciences, such as information systems disciplines, because it implements theory into practice. It is particularly suitable for research related to the interaction between technology, information, and people [18].

Earthquake

An earthquake is the shaking of the Earth's surface caused by the sudden release of energy due to the slip or rupture of rock masses in the Earth's crust, which then propagates to the surface. Earthquakes are sudden events or disasters whose timing, location, and magnitude on the Richter scale are currently unpredictable. They can occur during the day while we are working or at night while we are sleeping [19].

Earthquakes can be classified based on their causes into two types: tectonic and volcanic. Tectonic earthquakes are caused by the movement of tectonic plates beneath the Earth's surface, resulting from the release of energy due to the shifting of rocks along faults within these plates [20]. Volcanic earthquakes, on the other hand, occur in volcanic regions due to magma movement beneath the Earth's surface. These earthquakes are caused by magma rising towards the surface of a volcano, where friction among rocks produces seismic activity [21].

Seismic Waves

Seismic waves have two main variants that travel through the Earth's interior: P-waves (Primary waves) and S-waves (Secondary waves). P-waves consist of a series of compressions and expansions along the direction of their travel. In contrast, S-waves are transverse waves that propagate perpendicularly to their direction of travel [22].

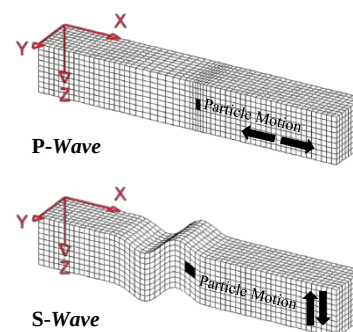


Figure 1. P Wave (P-Wave) and S Wave (S-Wave)

When there is a free surface, such as the interface between the air and the Earth's surface, both types of seismic waves can interact to form Surface Waves. These are known as Surface Waves and include Rayleigh Waves and Love Waves. Rayleigh Waves occur due to the interaction between P-waves and S-waves at the Earth's surface, while Love Waves result from the interference of shear waves. The effects of Surface Waves often cause greater vibrations compared to the waves that travel through the Earth's interior (Seismic Waves) [22].

Magnitude (Richter Scale)

The Richter Scale, also known as the Richter Magnitude Scale, is used to measure the energy or strength released by an earthquake. It was the first magnitude scale developed by Charles Richter in 1935 based on observations of earthquakes in Southern California. To this day, the scale is used by media worldwide. The following is a table of the intensity, effects, and impacts of earthquakes based on their magnitude on the Richter Scale [23].

Table 1. Intensity of Earthquake Effects and Impact Based on Magnitude

Magnitude (Richter Scale)	Description	Intensity of Earthquake Effects and Impact
1.0 – 2.0	Micro	Didn't feel the vibration, it was a small earthquake.
2.1 – 4.0	Minor	Not really felt, but detected by tools such as sensors.
4.1 – 5.0	Light	The vibrations are often felt, but rarely cause damage.
5.1 – 6.0	Curently	The vibrations were noticeable, but the damage was not significant.
6.1 – 7.0	Strong	The impact of the damage is limited to a small area and scale.
7.1 – 8.0	Major	Capable of causing damage with a radius of approximately 160 km.
8.1 – 10.0+	Great	Can cause and produce damage to a very, very wide area.

The Magnitude Scale is based on the measurement of seismic wave amplitudes recorded at a certain distance from the earthquake's epicenter. This magnitude scale is logarithmic with a base of 10, meaning that an increase of one magnitude unit corresponds to a tenfold increase in amplitude. Earthquakes on the Richter Scale are measured within a magnitude range from 1.0 to over 10.0. Intensity, on the other hand, is a qualitative measure of the strength of shaking caused by an earthquake, determined by observing its effects on people, objects, and buildings. For a given earthquake, the intensity typically decreases with increasing distance from the earthquake's epicenter. According to research by the British Geological Survey (BGS), for shallow earthquakes (Surface Waves Magnitude), which produce only surface waves, the magnitude can be calculated or estimated using the following formula:

$$\text{Magnitude} = \log(A/T) + 1,66 (\log \Delta) + (x + 3,3) \quad (1)$$

The magnitude is calculated in Richter Scale units (SR), where (A) is the maximum amplitude of Rayleigh Waves in micrometers (μm), (T) is the period in seconds, (Δ) is the distance in degrees, and (x) is the relationship between Magnitude and Linear Acceleration, which will be explained later [22]. In this final project research, the component used to calculate the earthquake magnitude (Richter Scale) is the accelerometer. Therefore, the maximum amplitude (A) and period (T) are derived from the Linear Acceleration (a) measurements in meters per second squared (m/s^2) provided by the accelerometer. The distance (Δ) in degrees can be neglected or assumed to be 0° , because the Linear

Acceleration (a) measured by the accelerometer for calculating the magnitude of shallow earthquakes (Surface Waves Magnitude) is along the horizontal axes of the accelerometer, namely the x-axis and y-axis, while the z-axis is ignored as it is affected by the constant gravitational force of the Earth (g). Therefore, for this final project, the formula from the British Geological Survey (BGS) for calculating the magnitude (Richter Scale) of shallow earthquakes (Surface Waves Magnitude) can be simplified to:

$$\text{Magnitude} = \log(a) + (x + 3,3) \quad (2)$$

Linier Acceleration (m/s^2)

Linear acceleration refers to the change in velocity experienced by an object at a given moment. The following Table 2.2 shows the relationship between Magnitude (Richter Scale) and Linear Acceleration (a) measured in m/s^2 [11].

Table 2. Relationship between Magnitude (Richter Scale) and Linear Acceleration (a)

Magnitude (Richter Scale)	Linier Acceleration (m/s^2)
1	< 0.017
2-3	0.017 – 0.14
4	0.14 – 0.39
5	0.39 – 0.92
6	0.92 – 1.8
7	1.8 – 3.4
8	3.4 – 6.5
9	6.5 – 12.4
10	> 12.4

Linear acceleration, denoted as a , is expressed as a vector quantity with units of meters per second squared (m/s^2). In practice, linear acceleration can be measured using an accelerometer. In this case, the linear acceleration (a) on the accelerometer is obtained based on the concept of finding the length of a vector or the distance between two specific points, such as from (x, y) to (x', y') in a two-dimensional coordinate system, using the Pythagorean Theorem, which is given by:

$$p = \sqrt{(x' - x)^2 + (y' - y)^2} \quad (3)$$

whereas if applied to an accelerometer the equation would become:

$$a = \sqrt{(\text{value}(sb.x))^2 + (\text{value}(sb.y))^2} \quad (4)$$

The Linear Acceleration (a) measured is relative to the horizontal axes (x-axis and y-axis). In this case, the z-axis can be disregarded because it is influenced by the Earth's constant gravitational force, which has a value of $\pm 1g$ (Gravitational Acceleration of 9.8 m/s^2).

The linear acceleration (a) measured is with respect to the horizontal axes (x-axis and y-axis). In this case, the z-axis can be ignored because it is affected by the constant gravitational force of the Earth, which is approximately $\pm 1g$ (gravitational acceleration of 9.8 m/s^2).

Risk Mitigation

Risk mitigation involves taking steps to reduce or minimize the negative impacts that may arise from existing risks. Given that risks often come with a degree of uncertainty, it is crucial to manage risks effectively and accurately to anticipate potential adverse effects. The goal of risk mitigation is to decrease the likelihood of harmful events occurring or to lessen the negative impacts that a disaster, such as an earthquake, may cause [24].

Arduino Uno Rev3 ATmega328P

The Arduino Uno is a development board based on the ATmega328P microcontroller, featuring 32 kB of Flash memory, 0.5 kB of bootloader, 2 kB of SRAM (Static Random Access Memory), and 1 kB of EEPROM (Electrically Erasable Programmable Read-Only Memory). The Arduino Uno operates at a clock speed of 16 MHz and includes a USB connection, a DC power supply, ICSP (In-Circuit Serial Programming) pins, VIN and GND pins, and a reset button.

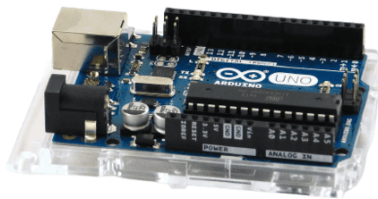


Figure 2. Arduino Uno Rev3 ATmega328P

The Arduino Uno features 14 digital I/O pins (6 of which are PWM/Pulse Width Modulation), 6 analog pins, operates at a voltage of 5 volts, and is recommended to have an input voltage of 7 to 12 volts. Other functions supported by the Arduino Uno Rev3 ATmega328P and allowed by the Arduino software include serial communication (RS), I2C protocol, and external interrupts. Due to its popularity, the Arduino Uno is widely used in a variety of projects, ranging from simple to more complex applications such as robotics [25].

SW420 Sensors

The SW420 sensor is a vibration detection sensor that operates on the principle of a ball bearing moving across a spring inside the sensor. When vibrations occur, the ball bearing makes contact with the spring, resulting in an electrical contact that produces a HIGH output signal.

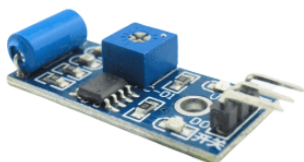


Figure 3. SW420 Vibration Sensor

The SW420 sensor has three pins: VCC (3.3V/5V), GND (Ground), and D0 (Digital Output), which is the digital output pin. When the sensor detects vibrations, the output signal will switch from 'LOW' (0) to 'HIGH' (1) [26].

Accelerometer ADXL345

The ADXL345 accelerometer is a high-resolution sensor capable of measuring acceleration along three axes (x-axis, y-axis, z-axis). It offers a high resolution of up to 13 bits at its highest sensitivity. The ADXL345 provides measurement ranges from $\pm 2g$ to $\pm 16g$, where $1g$ represents the average gravitational acceleration of the Earth, approximately 9.8 m/s^2 . At the $\pm 2g$ range, the sensitivity of the ADXL345 accelerometer is approximately 256 LSB/g (Least Significant Bit), according to the ADXL345 datasheet.



Figure 4. ADXL345 Accelerometer

The ADXL345 accelerometer features an ADC (Analog-to-Digital Converter), a digital filter to reduce noise during conversion, and serial I/O. It uses digital interfaces for communication, specifically I2C or SPI. For I2C, ADXL345 has SDA (Serial Data) and SCL (Serial Clock) pins. The SDA pin is used for transferring data between the microcontroller and the accelerometer, while the SCL pin controls the data transfer rate between them. SCL indicates when data on the SDA pin is to be changed or read. Additionally, ADXL345 includes features for tap detection, gravity direction detection, and the ability to measure both static and dynamic acceleration [26].

PIR HC-SR501 Sensors

The HC-SR501 PIR (Passive Infrared Receiver) sensor is an infrared-based sensor. It consists of several components, including a Fresnel lens, an IR filter, a pyroelectric sensor, an amplifier, and a comparator. The HC-SR501 PIR sensor operates by detecting infrared radiation emitted by humans and objects with temperatures above absolute zero (0°C) [27].

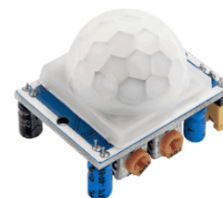


Figure 5. PIR HC-SR501 Sensors

The HC-SR501 sensor outputs binary signals, where 0 indicates no detection of infrared radiation and 1 indicates the detection of infrared. The sensor operates with a voltage range of 4.7 - 5 volts, a standby current of $300 \mu\text{A}$, and a working temperature range of -20°C to 50°C . It has a detection range of approximately 5 to 7 meters and a detection speed of 0.5 seconds [28].

Buzzer

A buzzer is an electronic component designed to convert electrical vibrations into sound vibrations. Its operating principle involves mechanical movement within the buzzer when an electric current flows through it, producing sound.



Figure 6. Buzzer

Generally, the type of buzzer commonly used as an alarm is the piezoelectric buzzer, which operates within a voltage range of 3 volts to 24 volts DC. The specifications of a piezoelectric buzzer include a negative pin, which is the shorter pin connected to the negative current or GND, and a positive pin, which is the longer pin connected to the positive current or VCC (5 volts).

LED DC Lights

According to the KBBI (Kamus Besar Bahasa Indonesia), the term "lamp" refers to a device used for illumination. The type of lamp used in this research is a DC LED. DC LED, or Light Emitting Diode with direct current, is a type of LED designed to operate with direct current (DC) electricity.



Figure 7. LED DC 5-Watt Lights

A DC LED uses a semiconductor diode as the light source and emits light when current flows in a specific direction. DC LEDs have important polarity: the anode (+) must be connected to the positive terminal of the direct current source, while the cathode (-) must be connected to the negative terminal.

GSM (Global System for Mobile Communication)

GSM (Global System for Mobile Communication) is a wireless communication technology, but the wireless aspect only applies between the Mobile Station (MS) and the Base Transceiver Station (BTS). GSM is a second-generation telecommunication network that uses TDMA (Time Division Multiple Access) technology to handle both voice and data (SMS). GSM operates using a cellular network structure, where the network is divided into cells interconnected with each other. Each cell has a base station (BTS) that handles the reception and transmission of radio signals between user devices and the cellular network. GSM also employs encryption technology to protect user privacy and prevent network abuse [29].

SIM800L GSM Module

The SIM800L module is a GSM/GPRS module designed to provide affordable and easy-to-use wireless communication. It can be used for sending and receiving SMS messages, making phone calls, and other communication tasks.

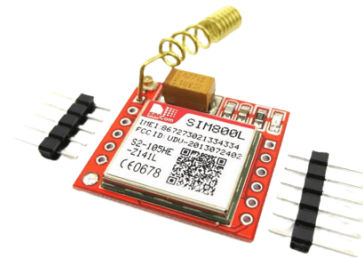


Figure 8. SIM800L GSM Module

The SIM800L module is a GSM/GPRS module designed for affordable and easy wireless communication. It supports sending and receiving SMS messages, making phone calls, and transferring data over the GSM/GPRS network. The communication protocol used by the SIM800L is AT Command, a standard for modem communication. The module features a VCC pin with a power supply range of 3.4 - 4.4 volts, an integrated antenna, a Micro SIM card slot, and a serial port for microcontroller communication. The TX (Transmit) and RX (Receive) pins on the SIM800L are used for serial communication with the microcontroller, where TX is for sending data from the SIM800L to the microcontroller and RX is for receiving data from the microcontroller. The SIM800L module is highly useful for projects requiring wireless communication, such as monitoring systems, remote control, and alarm systems [29].

SMS (Short Message Service)

SMS (Short Message Service) is a service for sending short text messages from one device (mobile phone) to another via a cellular network. An SMS includes information such as the mobile phone numbers of both the sender and the recipient, the time, and the message content. Typically, an SMS can contain up to 160 characters. SMS is widely used in various countries and is a preferred option for simple and quick communication. Additionally, SMS can be utilized to send messages when network conditions are unstable or when internet connectivity is unavailable [30].

Battery

A battery is an electrochemical device used to store and generate electrical energy through a chemical reaction within the battery cells. It consists of two or more electrodes (typically an anode and a cathode) separated by an electrolyte and connected by an internal circuit. Inside the battery cells, a highly efficient reversible electrochemical process occurs. This reversible electrochemical process involves the conversion of chemical energy into electrical energy (discharge process) and also the conversion of electrical energy back into chemical energy (charging process) [38].

General System Design

The general system design encompasses the overall proposed requirements based on both the functional and non-functional needs of the designed system. The general system design can be seen in Figure 9.

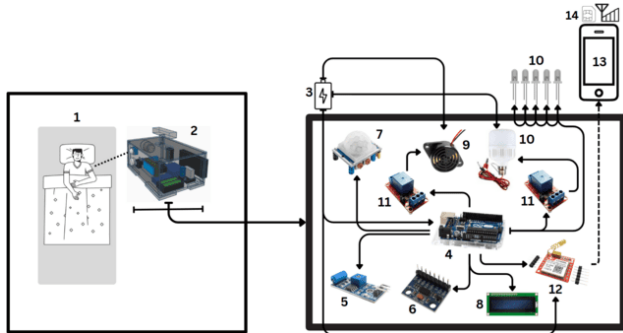


Figure 9. General System Design

Based on the general system design in Figure 9 above, there are several elements and components with the following descriptions:

1. System User
2. Earthquake Detection System
3. 9-Volt Battery (1) & 18650 Battery (2)
4. Arduino Uno ATmega328P
5. SW420 Vibration Sensor
6. ADXL345 Accelerometer
7. HC-SR501 PIR Sensor
8. I2C LCD 16x2
9. Buzzer (Alarm)
10. LED (5) & 5-Watt DC Light
11. 5-Volt Relay (2)
12. GSM SIM800L Module
13. Mobile Phone
14. Micro SIM Card (Telkomsel)

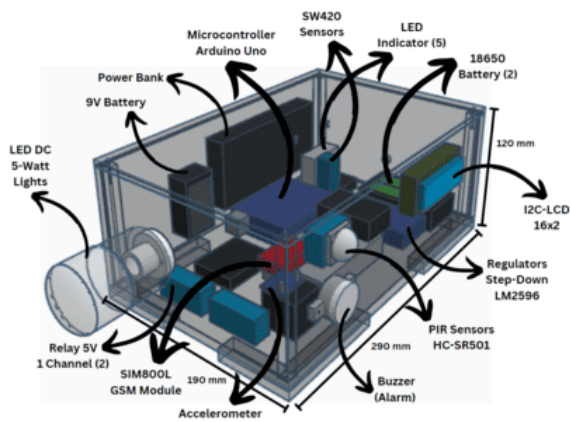


Figure 10. 3D Earthquake Magnitude Detection and Measuring System Design

Process Design

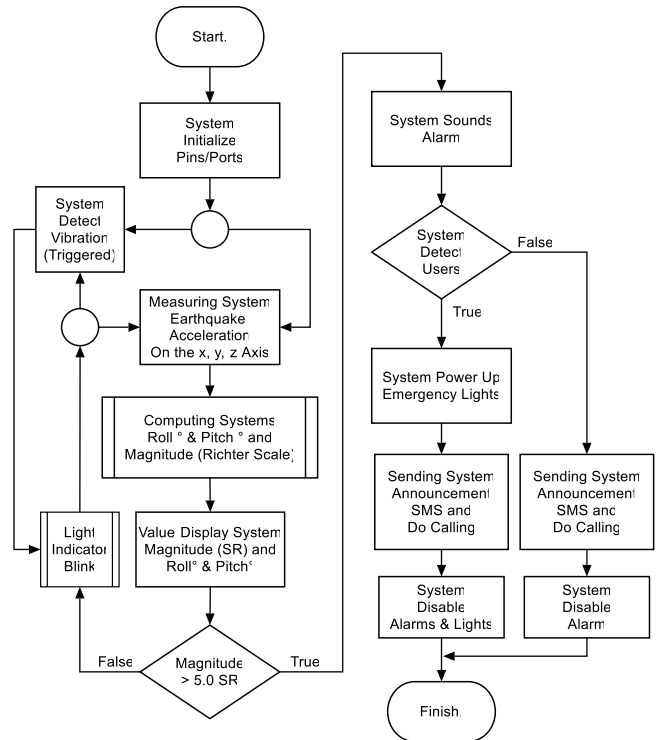


Figure 11. Flowchart Process Design

Hardware Design

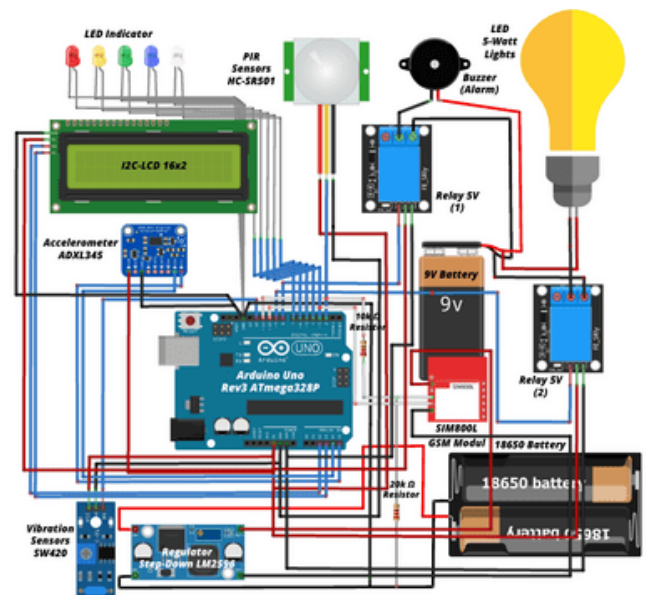


Figure 12. Hardware Design

Based on Figure 12, there are hardware components connected to the Arduino Uno ATmega328P as the microcontroller. Each component has a distinct function for operating the designed system. Here is a detailed explanation of the functions of these components:

1. The SW420 Vibration Sensor is used to detect triggered vibrations.
2. The ADXL345 Accelerometer is used to detect and measure earthquake acceleration along the x, y, and z axes. The measurement outputs are computed into roll° and pitch° values, as well as magnitude (Richter scale).

3. The I2C LCD 16×2 is used to display measurement data (monitoring) of earthquake magnitude and other relevant information.
4. LEDs serve as indicator lights for each earthquake magnitude parameter.
5. The Buzzer functions as an alarm to mitigate earthquake risks when the detected magnitude exceeds 5.0 on the Richter scale.
6. The PIR HC-SR501 Sensor detects the presence of system users based on their infrared radiation.
7. The 5-Watt DC LED Light serves as an emergency light to mitigate earthquake risks when the user's presence is detected by the PIR HC-SR501 sensor.
8. The 5-Volt Relay acts as an electric switch to open or close the electrical circuit leading to the buzzer and light.
9. The GSM SIM800L Module is used to send SMS notifications and make calls through the GSM (Global System for Mobile Communications) network.
10. The LM2569 Step-Down Regulator converts input DC voltage to a lower output DC voltage (step-down).
11. The Batteries (9-Volt & 18650) are power sources used to store and supply electrical energy to the system components.

Software Design

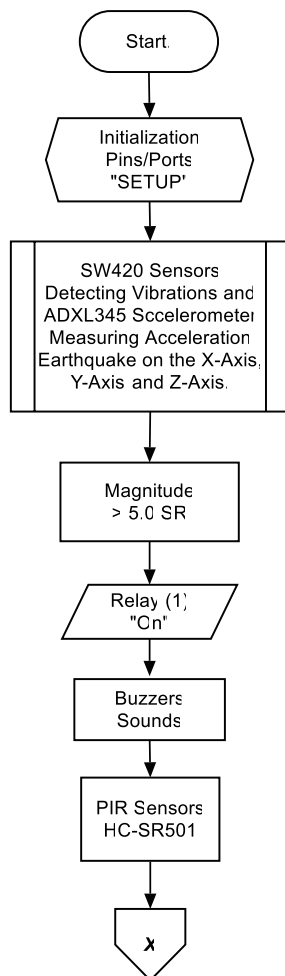


Figure 13. Flowchart Software Design (i)

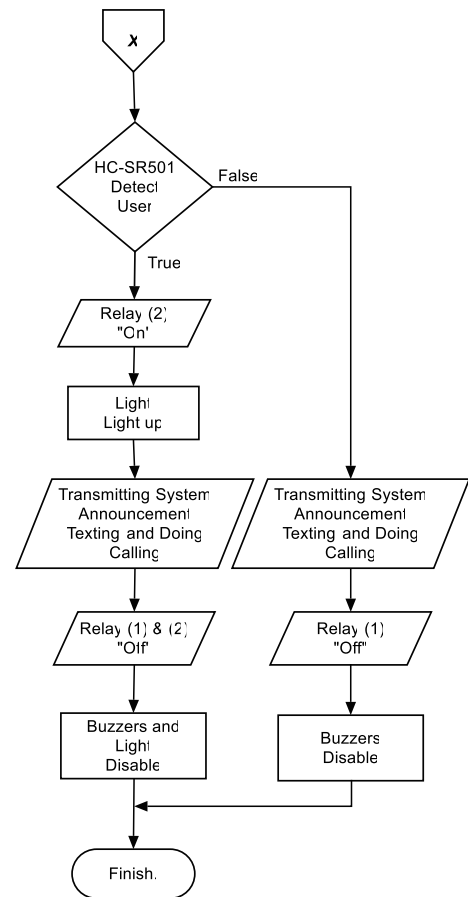


Figure 14. Flowchart Software Design (ii)

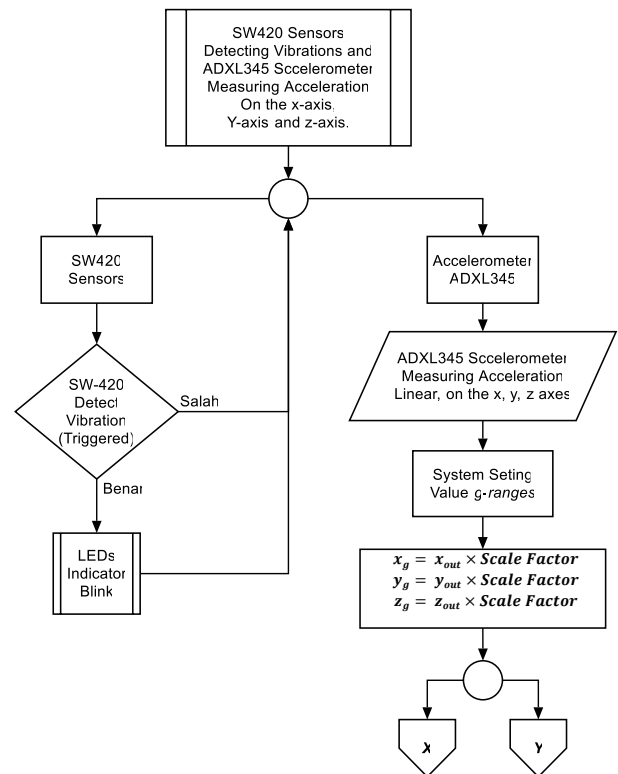


Figure 15. Flowchart Sensor Getar dan Accelerometer

Next, in Figure 15, the Flowchart for Vibration Sensor and Accelerometer starts after the system initializes the pins/ports (setup) on the Arduino Uno microcontroller. Subsequently, the SW420 sensor will detect if there is a triggered vibration or not.

If a vibration is detected, the indicator LED will blink. At the same time, the ADXL345 accelerometer will measure acceleration along the x, y, and z axes. Afterwards, the system will configure measurement ranges (g-ranges) for the acceleration values on the x-axis (xout), y-axis (yout), and z-axis (zout) using the formula:

$$axis(x, y, z)_g = axis(x, y, z)_{out} \times Scale\ Factor \quad (5)$$

Where (x_g), (y_g), and (z_g) are the acceleration values after configuring the g-ranges. The g-ranges have 4 variations based on the datasheet: $\pm 2\text{ g}$, $\pm 4\text{ g}$, $\pm 8\text{ g}$, $\pm 16\text{ g}$, with scale factors of: $\pm 2\text{ g} = 0.0039\text{ g/LSB}$, $\pm 4\text{ g} = 0.0078\text{ g/LSB}$, $\pm 8\text{ g} = 0.0156\text{ g/LSB}$, $\pm 16\text{ g} = 0.0312\text{ g/LSB}$. The unit g/LSB means that, for example, at ± 2 , each Least Significant Bit (LSB) of the sensor (ADXL345) output represents an acceleration change of 0.0039 g.

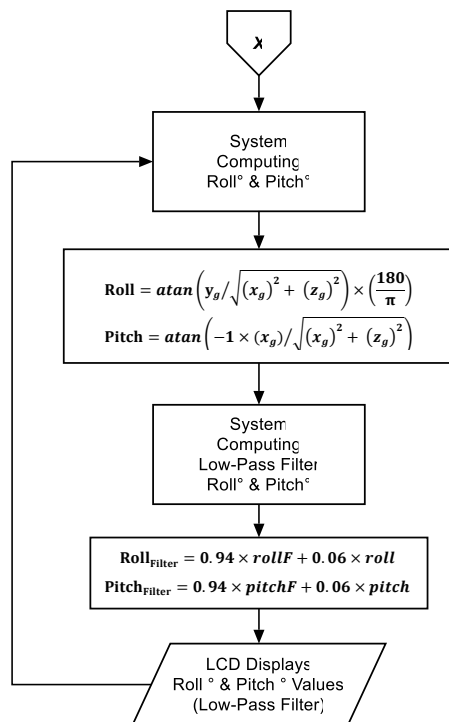


Figure 16. Roll° & Pitch° Value Formula Flowchart

Next, in Figure 3.8 Flowchart for Roll° & Pitch° Calculation, the acceleration values on the x-axis (x_g), y-axis (y_g), and z-axis (z_g) after configuring the g-ranges are computed into roll and pitch values in degrees (°) using the formula:

$$\text{Roll} = \text{atan}\left(y_g / \sqrt{(x_g)^2 + (z_g)^2}\right) \times \left(\frac{180}{\pi}\right) \quad (6)$$

$$\text{Pitch} = \text{atan}\left(-1 \times (x_g) / \sqrt{(x_g)^2 + (z_g)^2}\right) \times \left(\frac{180}{\pi}\right) \quad (7)$$

Roll represents the rotation around the x-axis and Pitch represents the rotation around the y-axis, with degrees (°) relative to the z-axis (vertical line). After obtaining the roll and pitch values, the system will apply a filter, specifically a Low-Pass Filter, to smooth out rapid changes or noise in the roll and pitch data. The filtered values will then be displayed on the LCD. The formula for the low-pass filter used is:

$$\text{Roll}_{\text{Filter}} = 0.94 \times \text{roll}_F + 0.06 \times \text{roll} \quad (8)$$

$$\text{Pitch}_{\text{Filter}} = 0.94 \times \text{pitch}_F + 0.06 \times \text{pitch} \quad (9)$$

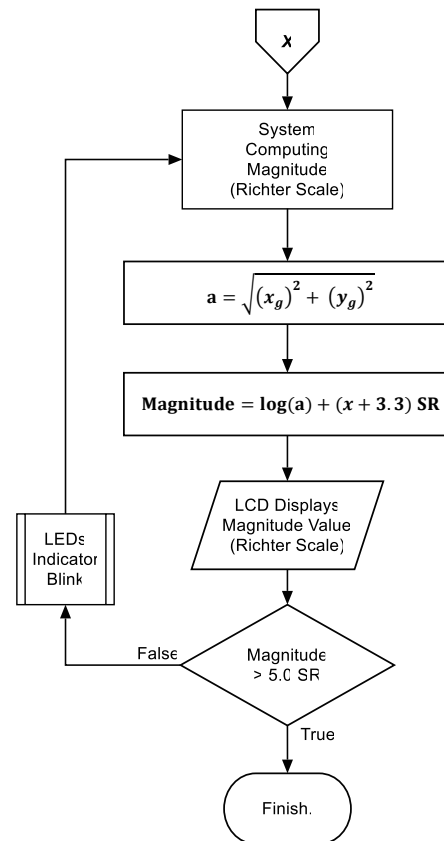


Figure 17. Flowchart of Linear Acceleration Formula (a) and Magnitude Value Formula (Richter Scale)

Next, in Figure 3.9 Flowchart for Linear Acceleration (a) Formula and Magnitude (Richter Scale) Formula, for roll° and pitch° values, the output or acceleration values from all three accelerometer axes are used. Meanwhile, to calculate linear acceleration (a), only the acceleration values from the horizontal axes, namely the x-axis (x_g) and y-axis (y_g), are used. The z-axis (z_g) is affected by the constant gravitational force of $\pm 1\text{g}$ (Gravitational Acceleration 9.8 m/s^2). Therefore, the formula used to obtain the linear acceleration (a) is:

$$a = \sqrt{(x_g)^2 + (y_g)^2} \quad (10)$$

After obtaining the linear acceleration (a) value, the system will then compute the earthquake magnitude in Richter scale units using the formula:

$$\text{Magnitude} = \log(a) + (x + 3.3) \text{ SR} \quad (11)$$

Where (x) represents the relationship between magnitude and linear acceleration. Once computed into the magnitude value in Richter scale units (SR), this value will be displayed on the LCD. There are two conditions: if the magnitude is less than 5.0 on the Richter scale, the indicator LED will blink (details will be explained later), and the system will recompute the magnitude value. If the magnitude exceeds 5.0 on the Richter scale, the system will forward this output to the microcontroller to proceed

to the next process, as explained in Figure 3.5 Flowchart of Software Design (i).

Next, in Figure 3.10 Flowchart of Earthquake Magnitude Parameter Indicator LED, the flowchart shows that when the SW420 sensor reads 'HIGH', the White LED will blink. For the earthquake magnitude parameter indicator LEDs, if the magnitude is less than 5.0 on the Richter scale, the LED indicators will blink according to the magnitude (Richter scale) of the earthquake.

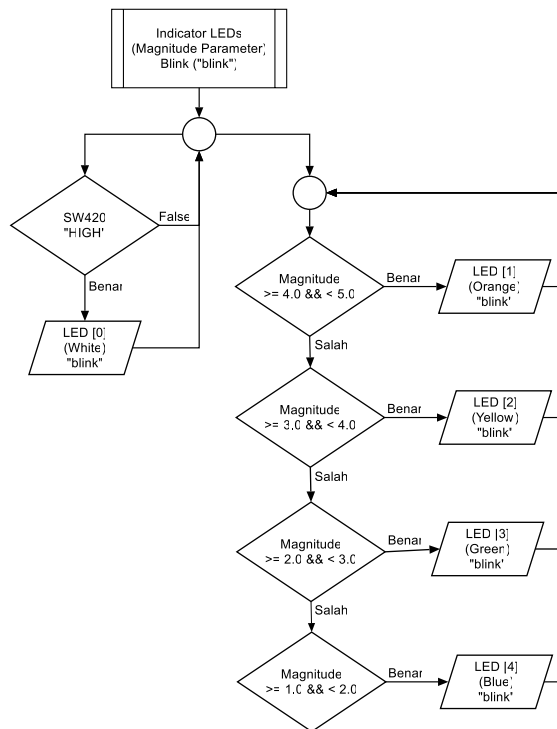


Figure 18. Earthquake Magnitude Parameter Indicator LED Flowchart

RESULTS AND DISCUSSION

Hardware Implementation

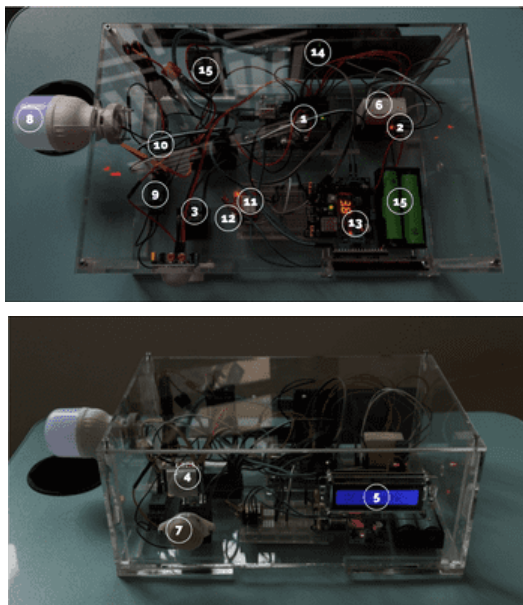


Figure 19. Hardware Implementation

The explanation of the components or hardware used in Figures 4.1 to 4.6 Hardware Implementation is as follows:

1. Arduino Uno Rev3 ATmega328P serves as the microcontroller for receiving, processing, and transmitting data in the designed system.
2. Sensor Getar SW420 is used to detect triggered vibrations.
3. Accelerometer ADXL345 is used to detect and measure earthquake acceleration on the x-axis, y-axis, and z-axis.
4. Sensor PIR (Passive Infrared Receiver) HC-SR501 is used to detect the presence of the system user.
5. I2C-LCD 16×2 is used to display data (monitoring) of roll and pitch measurements, earthquake magnitude, and other information.
6. LED acts as an indicator light for each earthquake magnitude parameter.
7. Buzzer is used as an alarm to wake the user.
8. LED DC 5-Watt light is used as an emergency light for the user.
9. Relay 5V 1 Channel (1) is used to automatically open or close the electrical path to the buzzer (alarm).
10. Relay 5V 1 Channel (2) is used to automatically open or close the electrical path to the LED DC 5-watt light.
11. GSM SIM800L Module is used to send SMS notifications about the user's condition and earthquake magnitude and to make calls to the user's registered emergency contacts.
12. Micro SIM Card Telkomsel is used for the identification and authentication of the SIM800L module on the Telkomsel telecommunication network.
13. Regulator Step-Down LM2596 is used to convert the input DC voltage to a lower output DC voltage (step-down), in this case, reducing the 5V output voltage from the 18650 battery to 3.3 volts - 4.4 volts for the input (VCC) voltage of the GSM SIM800L module.
14. Powerbank is used to store and provide power (energy source) for the Arduino UNO Rev3 ATmega328P microcontroller.
15. Batteries (9-Volt & 18650) are used to provide power for the buzzer, LED DC 5-watt light, and GSM SIM800L module.
16. Mobile phone is used to receive SMS and incoming calls.

Software Implementation

The software implementation for the Earthquake Detection and Magnitude Measurement System (Richter Scale) based on the microcontroller for risk mitigation includes embedded system software. This is the Arduino program (.ino file) designed to operate and control the hardware using the Arduino Uno Rev3 ATmega328P as the microcontroller. The implementation of the Embedded System Software on this system includes the .ino program to operate the SW420 Sensor, ADXL345 Accelerometer, HC-SR501 PIR Sensor, and SIM800L GSM Module. The following is a more detailed explanation.

System Implementation

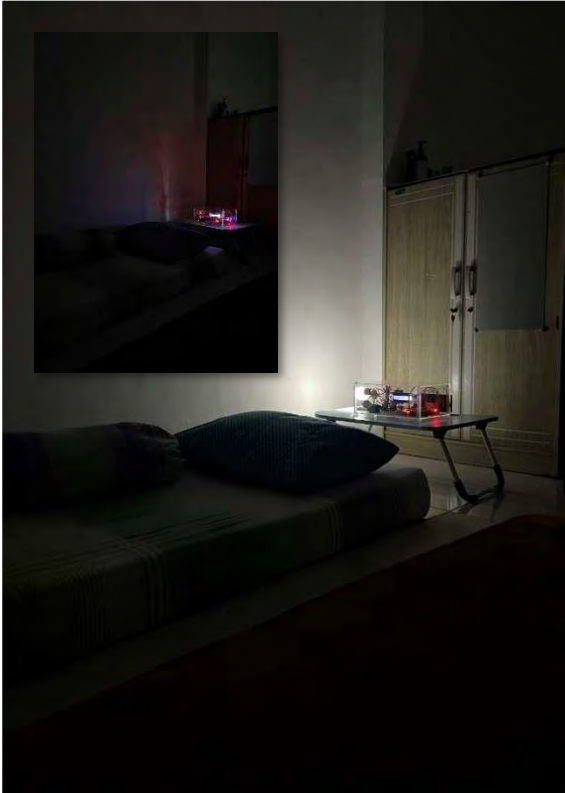


Figure 20. System Implementation

Figure 4.16 shows the system implementation, where the system is positioned close to the user's bed. The purpose is that if an earthquake with a magnitude exceeding 5.0 SR (Richter Scale) is detected, the system can immediately detect the user's status and mitigate the earthquake risk using the alarm and light.

Hardware Testing and Analysis

SW420 Sensor Testing and Analysis

Table 3. SW420 Sensor Testing and Analysis

No	SW420 Distance to Center of Vibration (Triggered)	Test	Value SW420
1	5 cm	1	HIGH
		2	HIGH
		3	HIGH
		4	HIGH
		5	HIGH
2	15 cm	6	HIGH
		7	HIGH
		8	HIGH
		9	HIGH

3	30 cm	10	HIGH
		11	HIGH
		12	HIGH
		13	HIGH
		14	HIGH
4	45 cm	15	HIGH
		16	HIGH
		17	HIGH
		18	HIGH
		19	HIGH
5	60 cm	20	HIGH
		21	HIGH
		22	HIGH
		23	HIGH
		24	HIGH
		25	HIGH

ADXL345 Accelerometer Testing and Analysis

Table 4. ADXL345 Accelerometer Testing and Analysis

No	All g-Ranges, 10-bit Resolution (LSB/g)		All g-Ranges, 10-bit Resolution (LSB/g)		All g-Ranges, 10-bit Resolution (LSB/g)	
	x-Axis		y-Axis		z-Axis	
	ADXL345	Datasheet (Typ-x)	ADXL345	Datasheet (Typ-x)	ADXL345	Datasheet (Typ-x)
1	256	256	255	256	257	256
2	257	256	256	256	257	256
3	256	256	255	256	256	256
4	256	256	255	256	257	256
5	256	256	255	256	256	256
6	257	256	255	256	256	256
7	256	256	256	256	256	256
8	256	256	255	256	256	256
9	257	256	256	256	256	256
10	257	256	256	256	257	256

Table 5. Average ADXL345 Test Results Based on Datasheet

Average	All g-Ranges, 10-bit Resolution		All g-Ranges, 10-bit Resolution		All g-Ranges, 10-bit Resolution	
	x-Axis		y-Axis		z-Axis	
	ADXL345	Datasheet (Typ-x)	ADXL345	Datasheet (Typ-y)	ADXL345	Datasheet (Typ-y)
Value (LSB/g)	256,4	256,0	255,4	256,0	256,4	256,0
Difference	0,4		0,6		0,4	
Error (%)	0,1		0,2		0,1	

$$\begin{aligned} \text{Rata - Rata Value } \left(\frac{LSB}{g} \right) &= \frac{\sum_{i=1}^{10} ADXL345}{\text{Banyak Data ADXL345}} \end{aligned} \quad (12)$$

$$\begin{aligned} \text{Rata - Rata Selisih} &= \frac{\sum_{i=1}^{10} ADXL345}{\text{Banyak Data ADXL345}} - \\ &(\text{Typ (Datasheet)}) \end{aligned} \quad (13)$$

$$\begin{aligned} \text{Rata - Rata Error (\%)} &= \left(\left| \frac{\sum_{i=1}^{10} ADXL345}{\text{Banyak Data ADXL345}} - (\text{Typ (Datasheet)}) \right| \right) \times \\ &100\% \end{aligned} \quad (14)$$

Table 6. Testing and Comparison of ADXL345 with Accelerometer Software

No	x-Axis (g)		y-Axis (g)		z-Axis (g)	
	ADXL345 (±2g-Ranges)	Software (DC Coupling)	ADXL345 (±2g-Ranges)	Software (DC Coupling)	ADXL345 (±2g-Ranges)	Software (DC Coupling)
1	0,998	0,989	0,998	0,944	0,998	0,994
2	0,998	0,988	0,994	0,943	1,002	0,995
3	0,998	0,989	0,998	0,944	1,002	0,994
4	1,002	0,988	0,998	0,943	1,002	0,995
5	0,998	0,988	0,994	0,942	0,998	0,994
6	0,998	0,989	0,994	0,943	0,998	0,995
7	0,998	0,989	0,994	0,942	0,998	0,994
8	1,002	0,988	0,994	0,943	0,998	0,995
9	0,998	0,989	0,994	0,942	0,998	0,996
10	0,998	0,989	0,994	0,942	0,998	0,996

Table 7. Average Test Results and Comparison of ADXL345 with Accelerometer Software

Average	Axis-x		Axis-y		Axis-z	
	ADXL345 (±2g-Ranges)	Software (DC Coupling)	ADXL345 (±2g-Ranges)	Software (DC Coupling)	ADXL345 (±2g-Ranges)	Software (DC Coupling)
Value (g)	0,999	0,989	0,995	0,943	0,999	0,995
Selisih	0,01		0,052		0,004	
Error (%)	1,0		5,5		0,4	

$$\begin{aligned} \text{Rata - Rata Value (g)} &= \frac{\sum_{i=1}^{10} ADXL345 (\pm 2g - \text{Ranges})}{\text{Banyak Data ADXL345 } (\pm 2g - \text{Ranges})} \end{aligned} \quad (15)$$

$$\begin{aligned} \text{Rata - Rata Selisih} &= P \\ P &= \left(\frac{\sum_{i=1}^{10} ADXL345 (\pm 2g - \text{Ranges})}{\text{Banyak Data ADXL345}} \right) - \\ &\left(\frac{\sum_{i=1}^{10} \text{Software (DC Coupling)}}{\text{Banyak Data Software}} \right) \end{aligned} \quad (16)$$

$$\begin{aligned} \text{Rata - Rata Error (\%)} &= \left(\left| \frac{\sum_{i=1}^{10} ADXL345 (\pm 2g - \text{Ranges})}{\text{Banyak Data ADXL345}} - \left(\frac{\sum_{i=1}^{10} \text{Software (DC Coupling)}}{\text{Banyak Data Software}} \right) \right| \right) \times \\ &100\% \end{aligned} \quad (17)$$

Testing and analysis of the ADXL345 accelerometer's rotation values around the x-axis (Roll) and y-axis (Pitch) aim to observe differences and changes in rotation values with and without filtering. Figure 21 illustrates the 3D processing of roll and pitch values both without filtering and with filtering (low-pass filter). The testing focuses on the rotation values around the x-axis, known as roll, and the rotation values around the y-axis, known as pitch, measured in degrees (°). The testing is performed using Processing 3D software, by processing roll and pitch values with the sketch program provided in Appendix 2, in .ino format for the Arduino IDE software, and the sketch program in Appendix 3, in .pde format for Processing 3D software.

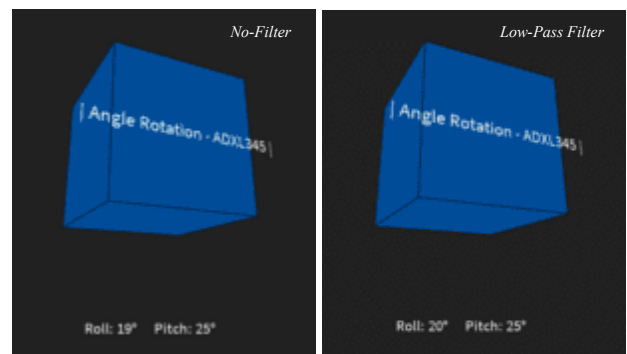


Figure 21. Roll & Pitch Testing, No Filter (Right), Low-Pass Filter (Left)

As observed in Figure 21 above, the differences may not be immediately apparent. However, when viewed directly in the Processing 3D software, the roll and pitch testing results (left side of Figure 21) without using a filter will appear somewhat shaky or unstable. This instability occurs because the accelerometer captures not only gravitational forces but also minor forces from hand movements. To achieve smoother and more stable results, as shown on the right side of Figure 21, a simple and straightforward low-pass filter can be employed.

Testing and Analysis of the HC-SR501 PIR Sensor

Table 8. Testing and Analysis of the HC-SR501 PIR Sensor

No	Condition	Test	HC-SR501 Distance to Object (Motion)	Value HC-SR501
1	Bright	1	50 cm	HIGH
		2	100 cm	HIGH
		3	150 cm	HIGH
		4	200 cm	HIGH
		5	250 cm	HIGH
2	Dark	6	50 cm	HIGH
		7	100 cm	HIGH
		8	150 cm	HIGH
		9	200 cm	HIGH
		10	250 cm	HIGH

Testing and Analysis of the SIM800L GSM Module

Table 9. Testing and Analysis of the GSM SIM800L Module

No	Signal Quality		Signal Condition	SIM800L Sending SMS (Time)	Incoming SMS To Cell Phone (Time)	Time Difference (Seconds)
	Nilai (CSQ)	RSSI (dBm)				
1	14.0	-110 s/d -54	OK	02:41:48 PM	02:41:52 PM	4.0's
2	11.0	-110 s/d -54	OK	02:44:41 PM	02:44:46 PM	5.0's
3	12.0	-110 s/d -54	OK	02:46:57 PM	02:47:02 PM	5.0's
4	16.0	-110 s/d -54	Good	02:50:20 PM	02:50:24 PM	4.0's
5	17.0	-110 s/d -54	Good	02:55:04 PM	02:55:08 PM	4.0's
6	14.0	-110 s/d -54	OK	02:21:12 PM	02:21:16 PM	4.0's

7	13.0	-110 s/d -54	OK	02:26:35 PM	02:26:40 PM	5.0's
8	14.0	-110 s/d -54	OK	02:31:14 PM	02:31:18 PM	5.0's
9	15.0	-110 s/d -54	Good	02:40:15 PM	02:50:19 PM	4.0's
10	10.0	-110 s/d -54	OK	02:42:24 PM	02:42:29 PM	5.0's
Average Time Difference (Seconds)						4.5's

Table 10. Testing the SIM800L GSM Module Making Calls

No	Signal Quality		Signal Condition	SIM800L Making Calls (Time)	Incoming Call To Mobile (Time)	Time Difference (Seconds)
	Nilai (CSQ)	RSSI (dBm)				
1	14.0	-110 s/d -54	OK	02:41:54 PM	02:41:59 PM	5.0's
2	11.0	-110 s/d -54	OK	02:44:48 PM	21:44:54 PM	6.0's
3	12.0	-110 s/d -54	OK	02:47:04 PM	02:47:10 PM	6.0's
4	16.0	-110 s/d -54	Good	21:50:26 PM	21:50:31 PM	5.0's
5	17.0	-110 s/d -54	Good	02:55:10 PM	02:55:15 PM	5.0's
6	14.0	-110 s/d -54	OK	02:21:17 PM	02:21:22 PM	5.0's
7	13.0	-110 s/d -54	OK	02:26:42 PM	21:44:48 PM	6.0's
8	14.0	-110 s/d -54	OK	02:31:19 PM	02:47:25 PM	6.0's
9	15.0	-110 s/d -54	Good	02:50:21 PM	21:50:26 PM	5.0's
10	10.0	-110 s/d -54	OK	02:42:31 PM	02:55:38 PM	7.0's
Average Time Difference (Seconds)						5.6's

Software Testing and Analysis

Testing and Analysis Storage Space Program.ino

The testing and analysis of the .ino program's storage space aim to understand and manage storage efficiently, allowing for the optimization of program performance.

```
RAM: [#####] 39.3% (used 804 bytes from 2048 bytes)
Flash: [#####] 51.9% (used 16742 bytes from 32256 bytes)
```

Figure 22. Sketch Program.ino System Storage Space

Next, the storage space or memory (including RAM) used by each feature of the system program can be seen in Figure 23 for detailed information.

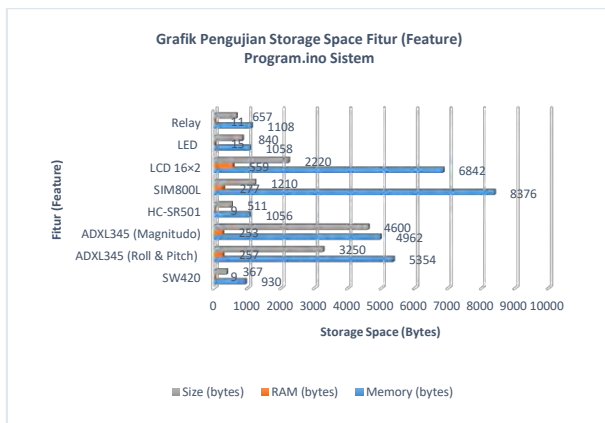


Figure 23 Storage Space Testing Chart Program.ino System Features

Program.ino Run Time Testing and Analysis

The testing and analysis of the run time of the .ino program aim to determine the execution time or run time of each feature of the system program and to ensure that the program operates as effectively and efficiently as possible to meet its objectives.

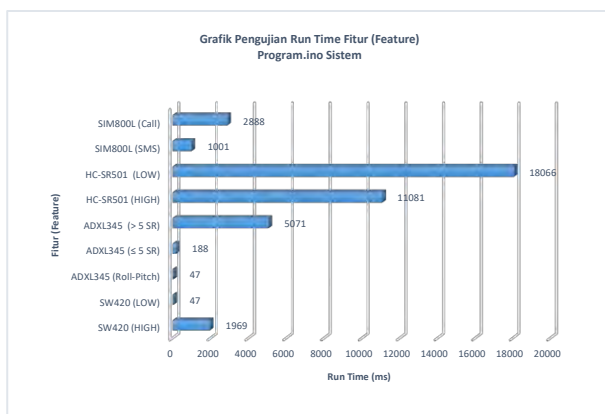


Figure 24. Program.ino System Feature Run Time Testing Chart

System Testing and Analysis

Table 11. Whole System Functional Testing

No	Testing Scenarios	Success Indicators	Results
1	The system detects triggered vibrations.	The system can detect a Vibration that is triggered (Triggered), then the White Indicator LED Flashes (Blink).	- Vibration (Triggered) Detected. - Flashing White LED.
2	System Calculates Roll and Pitch Values (Low-Pass Filter).	The system can calculate Roll and Pitch values in Degrees (°)	System for calculating roll and pitch values in degrees (°)

System for Measuring Magnitude Values.	The system can measure Magnitude values in Richter scale (SR) units	If Magnitude (SR) ≥ 1 and ≤ 2 , the Blue Indicator LED Flashes (Blink)	System for Measuring Magnitude Values in Richter Scale (SR) Units
			- System for measuring magnitude values ≥ 1 SR and ≤ 2 SR - Blue LED Flashing
			- System for measuring magnitude values ≥ 2 SR and ≤ 3 SR - Green LED Flashing
			- System for measuring magnitude values ≥ 3 SR and ≤ 4 SR - Yellow LED Flashing
			- System for measuring magnitude values ≥ 4 SR and ≤ 5 SR - Orange LED Flashing
			System for Measuring Magnitude Values > 5 SR
4	The system sounds an Alarm (On).	The System Alarm sounds (On), if Magnitude (SR) ≥ 5	System Alarm Sounds (On), To Mitigate Earthquake Risk.
5	The System Detects System Users.	If the system detects the presence of a system user, after the system alarm sounds, the emergency light turns on (On).	- System Detects User - Emergency Lights are On, to Mitigate the Risk of Earthquakes.
6	System Does Not Detect User (User).	If the system does not detect the user's presence, after the system alarm sounds, the emergency light does not turn on (off).	- The system does not detect the user - Emergency Lights Do Not Turn On (Off)

7	Emergency Light Turn On System.	The System Emergency Light Turns On (On), If Detected by a System User (User)	The Emergency Light System is On, to Mitigate Earthquake Risk.
8	The system sends SMS notifications and makes calls to the system user's closest contacts.	The system can send an SMS notification that an earthquake has been detected and the Magnitude (SR) value and the condition of the system user (User) at the location where the system is used and then the system can make a call	- The system sends SMS notifications (magnitude value and user condition) - Call Making System.
		If the System User (User) is detected by the system	- The system sends an SMS Notification of Earthquake Magnitude Value and User Condition (User Detected) - Call Making System.
		If the System User (User) is not detected by the system	- The system sends an SMS Notification of Earthquake Magnitude Value and User Condition (User Not Detected) - Call Making System.

Based on Table 11 Functional Testing of the Entire System, it can be observed that the test scenarios from point 1 to point 8 operate according to the success indicators. Thus, it can be concluded that the system designed in this final project, namely the Earthquake Detection and Magnitude Measurement System (Richter Scale) Based on Microcontroller for Risk Mitigation, is functioning and performing as expected and as anticipated.

CONCLUSIONS

Cocclusion

1. The system can detect triggered vibrations up to a distance of 60 cm from the center or source of the vibration.
2. The system is capable of measuring earthquake magnitude in Richter Scale (SR) units and displaying it on the LCD from Magnitude ≥ 1.0 SR. It also aligns with the relationship between Magnitude (Richter Scale) and Linear Acceleration (m/s^2). The system's LED indicators flash according to the magnitude parameters, from Magnitude ≥ 1.0 SR to ≤ 5.0 SR.
3. The system can mitigate earthquake risks by sounding an alarm to wake the user from sleep if the Magnitude exceeds 5.0 SR.
4. The system can detect the user's presence in both dark and light conditions up to 250 cm from the system.
5. The system can mitigate earthquake risks by turning on an emergency light for illumination if the Magnitude exceeds 5.0 SR and the user is detected.
6. The system is capable of sending SMS notifications regarding the earthquake magnitude and the user's status. It can also make calls to the nearest registered contact if the Magnitude is greater than 5 SR.
7. The system's storage space is 16,472 bytes (51.9%), with Global and Local Variables using 804 bytes (39.3%) and 1,244 bytes (60.7%).
8. The overall runtime of the system from start to finish is approximately 18:07 seconds or about 18,070 milliseconds.

Suggestion

1. For future research, to accurately determine the location of the earthquake where this system is implemented, it is recommended to use the Quectel L80-R GPS Module.
2. For further research, to enable implementation for broader coverage and range, such as from "house to house," it is advisable to use the NRF24L01 Module for wireless communication.
3. For SMS notifications and calls in future research, the system should be adapted to support multi-user applications.
4. In the next stage of research, the system can be implemented to mitigate other earthquake risks or in different contexts, while simultaneously connecting and integrating with the Meteorology, Climatology, and Geophysical Agency (BMKG).
5. The program (.ino) for this system still requires evaluation or debugging to ensure it operates as effectively and efficiently as possible, optimizing system performance.

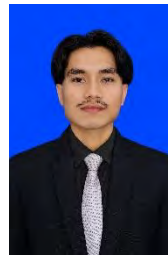
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