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Design an Earthquake Early Warning System Based on Arduino Uno Microcontroller with Accelerometer-MPU6050 sensor and NodeMCU-ESP8266

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ABSTRACT.

Geographically, Indonesia is located in three rings of active plates and surrounded by various active mountains that make Indonesia prone to earthquakes. When the earthquake occurred, there were still many people who were late in getting information to carry out the early evacuation process. This research aims to provide solutions to people who are late in receiving earthquake information by developing a microcontroller-based earthquake early warning system alarm with MPU6050 accelerometer sensors and NodeMCU ESP8266 to minimize possible losses. This research uses the Research and Development method with the ADDIE development model, to develop an Arduino uno-based earthquake alarm from previous research. This research uses a literature study system for analysis of earthquake problems when an earthquake occurs. The results of this study are in the form of a tool equipped with an Arduino Uno microcontroller system, where the earthquake warning system is run according to the system design. The tools developed were validated by three expert lecturers using validation questionnaires. Data analysis was carried out quantitatively to determine the feasibility of Arduino-based earthquake early warning tools using the Likert scale. Based on the average results of validation tests by experts, 91% of earthquake early warning tools developed are in the very decent category. Based on the trials carried out, the tool can provide warnings to the public directly.

INTRODUCTION

Human life is always connected with the Earth's aspect because the Earth has provided all human facilities and needs: natural gas, oil, water, metallic and nonmetallic minerals, and other natural resources. Sometimes, people are caught off guard by all the facilities and needs the Earth provides. However, the Earth also has various potential disasters that humans must know about. This incident is natural because the Earth carries out the process of natural balance. The incident is categorized as a disaster if it disrupts human life, damages infrastructure or cultural products, or causes casualties (Rizal et al., 2022).

Disasters are events or series of events that threaten and disrupt the lives and livelihoods of the community, which are either caused by natural or non-natural factors or human factors resulting in human casualties, environmental damage, property losses, and psychological impacts (Law No. 24 of 2007). Indonesia is an earthquake-prone country because, geographically, it is not at the confluence of four tectonic plates, namely the Asian continental plate, the Australian continental plate, the Indian Ocean plate, and the Pacific Ocean plate. For this reason, Indonesia is a country that is prone to tsunami disasters. It always causes losses in the form of material, and psychology can also cause casualties.

Plate tectonics is a cycle of rocks on Earth that occurs on a geologic time scale. The rock cycle occurs from the movement of the Earth's dynamic plates. The movement of tectonic plates that occur can shape the Earth's face and cause symptoms or natural events such as tectonic earthquakes, volcanic eruptions, and tsunamis. Tectonic earthquakes are earthquakes caused by tectonic activity, which is characterized by the movement of tectonic plate plates with different directions and speeds. This earthquake caused much damage. Strong earthquake tremors can spread to all parts of the earthquake (Sains et al., 2016). Volcanic earthquakes are earthquakes of this type occurring in connection with volcanic activity. Volcanic earthquakes can be caused by tectonic faults or the movement of magma in volcanoes. It can be an early warning of volcanic eruptions, such as during the 1980 eruption of Mount St. Helens. Earthquake swarms can be a marker of the location of magma flows throughout the volcano. This activity can be recorded by seismometers and used as sensors to predict future or upcoming eruptions (Siswanto et al., 2022).

The size of an earthquake can be expressed in terms of the Richter scale (M) or the Modified Mercalli scale (MMI). The Richter scale measures the magnitude of earthquakes based on the amplitude that occurs so that it is more objective. At the same time, the Modified Mercalli scale measures the intensity of an earthquake based on its effect on humans or buildings, so it is more subjective. Because the Mercalli scale is subjective, observations made by several people will have different opinions about the extent of damage to determine the damage caused by an earthquake (Irawan et al., 2020). Intensity can be interpreted as a non-institutional measurement of structural damage, ground surface effects, cracks and landslides, and human reaction to earthquake shocks. The intensity scale was first introduced in Europe by Rossi Forel (1883), consisting of 10 scales. The Sieberg scale (1912,1923) laid the foundation of all modern 12-level intensity scales. The latest version of the intensity scale is known as the Mercalli Cancani Sieberg scale or MCS scale (Sieberg, 1932), which is still used in southern Europe (Ghifari et al., 2018).

Geographically, Indonesia is located on three active ring plates: the Pacific Ocean plate in the east, the Indo-Australian plate in the south, and the Eurasian plate in the north. With these conditions, Indonesia can be categorized as one of the countries at risk of various geological disasters, such as earthquakes, landslides, floods, and volcanoes. Indonesia is a province prone to earthquakes. This makes Indonesia's geological conditions in the path of the ring of fire (Walidah* et al., 2023). In 2018, there have been 2572 major disasters with human casualties of 4,814 died, 10 239 million were affected, and more than 2 million houses were destroyed. Earthquakes were destroyed or damaged (BNPB, 2019). When viewed from its magnitude, Small Earthquakes (magnitude less than 4.0) as many as nine times, Light Earthquakes (magnitudes between 4.1-5.0) 2,273 times, Medium Earthquakes (magnitudes between 5.1-6.0) 210 times, Strong Earthquakes (magnitudes between 6.1-7.0) 12 times, Large Earthquakes (magnitudes between 7.1-8.0) once, namely the Palu Earthquake September 28, 2018 (M = 7.5) (BMKG, 2020).

Information obtained from BMKG Info is considered more reliable because the data comes from the Meteorology, Climatology and Geophysics Agency (BMKG), which is an official institution tasked with providing information on matters related to disaster events, including earthquakes. Even so, the information provided by the application is sometimes still late received by residents because of the factors from the BMKG itself or also influenced by internet network factors from the community (Fajriyah, 2019). One of the main factors that cause many casualties from disasters such as earthquakes is the lack of public knowledge about disasters and preparedness in anticipating these disasters. In addition, the number of victims was also caused by falling rubble due to collapsed buildings (Daud et al., 2014). In this case, how can the BMKG Info application be used precisely due to the need to obtain information about earthquakes? Furthermore, researchers learned from the earthquake how to make early warning tools so that residents are always late to evacuate or flee to a safe place.

In this study, researchers obtained data on making earthquake early warning tools using Arduino-based technology to develop earthquake early warning tools. Arduino is an open-source electronic prototyping platform based on interdependent, flexible, easy-to-use hardware and software. Hundreds of thousands of designers, engineers, students, developers, and makers worldwide use

Arduino to innovate in music, games, smart homes, agriculture, autonomous vehicles, artificial intelligence and more.(Martin & Susandi, 2022).

To overcome the problem of earthquake warning, in this study, an earthquake early warning tool was made with the help of an accelerometer sensor MPU6050 as a tool to detect the acceleration of seismic waves from earthquake vibrations that occur and NodeMCU ESP8266 as a receiver and sender of sensor data. MPU6050 motion sensor is a sensor with a 16-bit ADC that has a 3-axis gyroscope, 3-axis accelerometer, and a Digital Motion Processor (DMP) that functions to measure the position of an object. The microcontroller and interface with 16-bit output data make the sensor's accuracy very high (Setiawan et al., 2021). NodeMCU ESP8266 is one of the Internet of Things-based platforms consisting of hardware in the form of System On Chip ESP8266. Currently, NodeMCU has undergone three upgrades. The *processor* speed ranges from 80~160 MHZ and has 32KB + 80KB RAM and flash memory up to 16 MB, making NodeMCU V1 more efficient than the previous version. NodeMCU has 17 GPIO Pins that can be integrated with other electronic components. This ESP8266 node works at a voltage of 3.3V–5V, with power consumption between 10uA and 170mA. In this study, Node ESP8266 was used to connect devices directly with Wi-Fi and to telegram bots to transmit output from Richter scale quantities detected by tools. (Manullang et al., 2021).

Therefore, the author developed an earthquake early warning system tool to increase public awareness of disasters. An Arduino uno-based earthquake early warning tool with the help of an MPU6050 accelerometer and NoDE MCU ESP866 can provide direct warning notifications to the community.) In addition, the accelerometer sensor and MCU NODE used have a high level of sensitivity and are faster in providing notifications. An accelerometer is a sensor used to measure the acceleration of an object, which measures static and dynamic acceleration. An accelerometer is used as a component to detect the amount of wave acceleration resulting from the vibration of an earthquake in the earthquake early warning system. (Setiawan et al., 2021).

RESEARCH METHODOLOGY

Research Approach

The research method used in this study is R&D (Research and Development). According to (Sugiyono, 2019), the R&D research method is used to produce new products, test the effectiveness of existing products, and develop and create new products. Research and development is based on the problem and research objectives to be achieved. The product developed in this study is an earthquake early warning device. The ADDIE development model is structured based on complex and sequential procedures. The addie model is used in research to produce a product in 5 stages Asma et al., 2022). The following is Figure 1 of the relationship chart for each stage of the addie approach model.

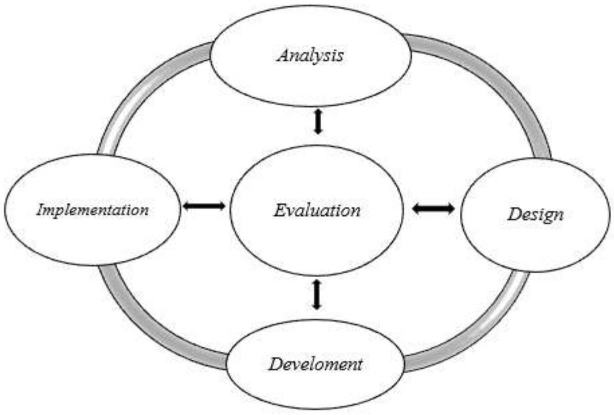

Figure 1. ADDIE model development chart

In the first stage, namely, The Analysis stage (analysis), is a stage to obtain important information from various previous studies to consider in making earthquake early warning tools. The problems presented in the study should be shown in the empirical data. In this case, the potential and problems are shown through the needs analysis results (Hamid et al., 2023). The design stage (design) is the stage of designing products in accordance with the desired specifications and the results of the analysis stage. The development stage is the development stage that produces the desired product. The next stage is the implementation stage, divided into two steps: validation tests by material and media experts. The evaluation stage (evaluation) is an evaluation stage of the practicality of the tool.

Research Participants

The subjects in the study are expert lecturer validators who assess the feasibility of the tools developed for development trials. Validators consist of 3 physics lecturers who become validators in researching the tools developed.

Research Instruments

According to Sugiyono (2019), research instruments are measuring instruments used to collect data through tests, questionnaires, interview guidelines, and observation guidelines in a study. This study collected data using a questionnaire given to a team of experts. The questionnaire is a data collection technique carried out by providing a number of questions or statements in writing to be answered by respondents. The questionnaire instrument in this study is in the form of a validation sheet. This instrument obtains data from expert validator lecturers to assess the tools developed, including tool efficiency, durability, aesthetics, precision value, and safety. The questionnaire contains aspects that will be assessed according to the specified scale.

In the research, the design of an earthquake early warning system based on Arduino Uno microcontroller with accelerometer sensors MPU6050 and NodeMCU ESP8266 was carried out from start to finish. This stage has three design forms: hardware design, software design, and mechanical design. A diagram of the hardware design blocks is shown in Figure 2.

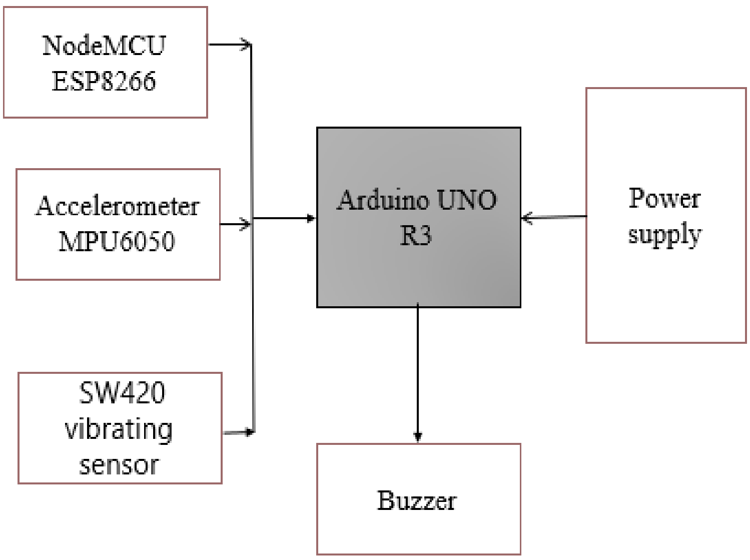

Figure 2. Earthquake early warning system hardware design

After design, the next stage is the development of products designed in this study, which is an uno-based earthquake early warning tool. Developing an Uno-based earthquake early warning tool involves preparing electronic components consisting of Arduino Uno, accelerometer sensor, SW-420 sensor, buzzer module, NodeMCU ESP8266, power supply, android, and jumper cable. The electronic components of the prototype earthquake early warning device are assembled according to the design. After the device has been connected to the electronic components, the tool will run according to the flowchart. Here is Figure 3 of the earthquake early warning system flowchart diagram.

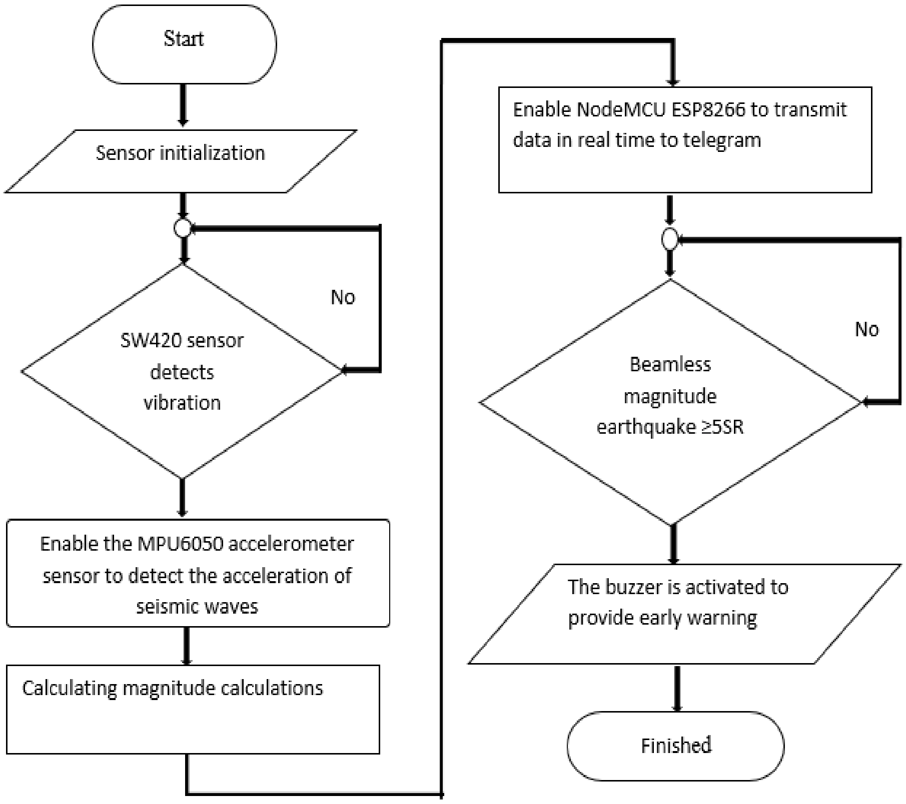

Figure 3. Earthquake Early Warning System Flowchart

Input program code into Arduino Uno. The code inputted to Arduino Uno is the sensor program code Sensor accelerometer, SW-420 sensor, buzzer module, and NodeMCU ESP8266. After completion, conducting trials of early warning tools and Expert Validation, physics lecturers will validate the products to be developed to determine the presentation of the material; besides that, there will be expert tests from Physics Education lecturers in terms of media and language display. This validation test is used to assess the product to be developed by the researcher into an internally tested product before being used for the next stage.

Data Collection

In this study, data collection used a validation sheet questionnaire to test the validity of the developed tool. The questionnaire was translated into qualitative data using the Likert scale. The Likert scale is used to measure the feasibility level of products (tools) that have been developed. The questionnaire used contains aspects that will be assessed according to the specified scale. Data collection in the study was carried out by providing questionnaires to a team of experts to assess the Arduino-based earthquake early warning tools that had been used. The questionnaire used in this study is a closed questionnaire, which is in the form of questions that expect respondents to choose one of the available alternative answers.

Data Analysis

In this research, testing will be carried out by a team of experts, namely lecturers of Physics Education at Bengkulu University. The expert team will be given a questionnaire to validate the Arduino-based earthquake early warning system tool that was developed. The questionnaire was translated into qualitative data using the Likert scale. The Likert scale is used to measure the feasibility level of products (tools) that have been developed.

The development carried out is the development of Arduino-based earthquake early warning tools. The resulting tool was first validated by three expert lecturers of the Physics Education study program to see the tools' feasibility (Rahmani et al., 2022). All instruments compiled are equipped with assessment sheets for expert validation. Based on its form, this validation sheet is in the form of a closed questionnaire with a Likert scale, which has answers that have been prepared. The validation sheet used in the research is the Lembar tool media validation (Tina et al., 2021). Data analysis was carried out quantitatively to determine the feasibility of Arduino-based earthquake early warning tools. Translate the questionnaire into the qualitative form or convert quantitative data into qualitative data using the Likert scale. The Likert scale describes the variables to be measured into variable indicators. Then, the variable indicator is used as a starting point for compiling items through questions or statements (Sugiyono, 2019). The Likert scale used in this research and development is a scale of 4. The interpretation of the Likert scale used in table 1.

Table 1. Interpretasi Scale Likert

Interpretation	Score
Totally agree	4
Agree	3
Disagree	2
Strongly disagree	1

This scale is used to measure the level of validation of experts and practitioners of Arduino-based earthquake early warning tools on earthquake materials designed to be categorized as good or not. To determine the percentage of expert and practitioner validation values using the formula:

$$\text{Score percentage (P)} = (\text{Number of scores obtained})/(\text{Maximum score}) \times 100\%$$

$$\text{Score percentage (P)} = f/N \times 100\%$$

The percentage of validity results can be matched with the criteria that can be seen in Table 2.

Table 2. Validity results criteria

Percentage	Interpretation
0% - 25%	Very unworthy
26% - 50%	Not Worth It
51% - 75%	Proper
76% - 100%	Very Worth It

(Hayati et al., 2015)

From the data from this interpretation, the research can be said to be successful and valid or very valid if, from the processing of questionnaire data, a score between 51% to 75% is in the criteria of "Good / Feasible" and 76% to 100% is in the criteria of "Very Good / Very Feasible.".

RESULTS AND DISCUSSION

Results of the design of earthquake early warning tools

The tool that has been developed consists of several electronic devices designed with the following details. Arduino UNO R3 acts as a microcontroller or brain of an earthquake detection device, NodeMCU ESP8266 as a receiver and sender of sensor data, SW420 vibration sensor as a vibration detector, accelerometer sensor MPU6050 detection of the amount of acceleration of seismic waves and buzzer as a component of the device warning. Figure 5 below is the physical form of an earthquake early shock device.

Figure 5. Earthquake early-warning tools

This development stage is carried out based on the assessment of expert lecturer validators. The results obtained from the validation results are in the form of results without revision. The results of the tool validation developed by experts in this study are reviewed from several indicators of assessment aspects, namely tool efficiency, lat resistance, aesthetic value, precision value, and user safety. The results of the validation of earthquake early warning tools by experts in this study are shown in Table 4.

Table 33. Expert lecturer validation results

Aspects	Percentage (%)	Information
Tool efficiency	86	Very Worth It
Tool durability	83	Very Worth It
Estetics	95	Very Worth It
Precision Value	94	Very Worth It
Safety	95	Very Worth It
Average	91	Very Worth It

Based on the average results of validation tests by experts, 91% are in the very decent category. Refer to the interpretation of the Likert scale in Table 3. So, the final assessment of each validator is that the memory system is based on the microcontroller developed MPU6050, and the ESP8266 NodeMCU developed is worth testing.

Results of testing the tool in providing alerts

At this stage, a tool trial was carried out to determine the overall system's performance results after all sensors were calibrated. This earthquake sensor system varies by dropping loads (3kg, 5kg and 8kg) with a load impact distance to the detection centre (10 cm. 20 cm and 30 cm) of such sensor systems. Then, the results will be determined, including whether the buzzer or SR power display is sent to the telegram or not. In Table 5, the results of testing tools with variations in stone impacts will be explained.

Table 4 Tool testing with rock impact variations

No	Distance (cm)	Massa (kg)					
		3		5		8	
		Buzzer condition	Large earthquake strength (SR)	Buzzer condition	Large earthquake strength (SR)	Buzzer condition	Large earthquake strength (SR)
1	10	Inactive	3,64	Inactive	4,42	Active	5,99
2	20	Inactive	3,15	Inactive	3,58	Active	5,12
3	30	Inactive	2,47	Inactive	3,32	Inactive	4,83

Discussion of the design of earthquake early warning tools

At the development stage, development is carried out based on the design that has been designed at the design stage. The characteristics of earthquake early warning tools are that they can detect the magnitude of the acceleration of seismic waves received by the sensor through observations from the accelerometer sensor MPU6050. During the development process, a series of earthquake early warning tools were produced. The concept developed at this stage is to integrate all components into one circuit to easily carry and maintain the props. Each component on an Arduino device has a specific role.

In previous studies (Ghifari et al., 2018), the earthquake monitoring and warning system used an accelerometer sensor. The sensor triggers each node to transmit ground movement data from the accelerometer. The data that the coordinator receives is directly transmitted to the PC using serial communication. Data will be processed using LABVIEW; if an earthquake is indicated, an SMS warning will be directly sent to the user using a GSM module. The signal sent to the coordinator is in the form of accelerated ground movement from the accelerometer. The project aims to detect P waves on the x and y axes. On the XY axis, the value of the Z-axis is constant, so there is no need to include it in the calculation—the relationship between acceleration and magnitude scale. The relationship between magnitude scale and acceleration is shown in Table 3.

Table 5. The relationship between magnitude scale and acceleration

No	Magnitude scale	Acceleration
1	1	< 0,017
2	2-3	0.017- 0,14
3	4	0,15 - 0,39
4	5	0,39 - 0,92
5	6	0,92 - 1,8
6	7	1,8 - 3,4
7	8	3,4 - 6,5
8	9	6,5 - ,12,4
9	10	>12.4

This research was developed by using a vibrating sensor sw-420 and an accelerometer sensor MPU6050. Sensitive vistas from this sw420 sensor have a high ti vistas sensing detecting vibration. This digital sensor produces logic output at a HIGH level when detecting vibration/vibration, can be applied to security systems, earthquake detection, malfunction detection in mechanical systems, analysis of construction structures based on vibration, and indirect measurement of impact strength (Alam et al., 2020). MPU-6050 is a sensor module with two functions: an accelerometer with a microelectromechanical system (MEMS) and a gyroscope with a microelectromechanical system (MEMS) in a chip. Sixteen analog pins are converted first to determine the axis so this sensor can work optimally. The values of the x, y, and z axes on this sensor can be taken simultaneously at one time (Suprayogi et al., 2019). In this study, the SW 420 sensor detects vibrations at high vibration levels and will activate the accelerometer sensor to calculate the movement of seismic waves received by the sensor.

The Telegram application is one application that has great potential to develop among the public. The advantage of this Telegram is that there is a foundation for using Application Programming Interface (API) for the wider community. One of the APIs provided is the bot feature. Telegram bots are currently starting to be popularly used, which makes them easier to use. Telegram bots or robots are programmed with various commands to execute the user's instructions. Telegram bots can also provide a service through alerts or notifications (Wijaya & Khariono, 2022). In research, the bot feature on Telegram is used as an application connected to the tool. NodeMCU will ESP8266 connect to the wifi specified in the coding. Figure 6 below is the notification display from the telegram bot.

Figure 6 . Display in Telegram

Discussion of testing the tool in providing alerts

Based on Table 5 of the test results of the tool, it can be seen that the system's readings can detect earthquake vibrations. In large conditions, the earthquake's strength below 3 SR is in the category of microearthquakes that are felt and still recorded by tools. Earthquake conditions of 3-3.9 SR are included in minor earthquakes that are felt but do not damage buildings. Earthquake conditions of 4-4.9 SR are included in mild earthquakes that are felt but do not damage buildings (Ghifari et al., 2018). in earthquake conditions, 5-6 SR are included in moderate earthquakes that can damage buildings. In a device designed, the buzzer is active when the sensor condition detects a Richter scale above 5 SR. The active buzzer will provide early warning to the public about the earthquake. Based on Table 5, the magnitude is getting more minor at 3kg stone mass collisions at distances of 10, 20 and 30 large scales received. The farther the impact is located, the more it will affect the magnitude of the vibration strength. Meanwhile, the greater the mass or impact given, the greater the earthquake's magnitude. From these tests, it can be concluded that if an impact and a vibration occur, the vibration is not certain that it occurred in an earthquake. However, if the system detects a movement and detects a tremor, it does not rule out the possibility that it is an earthquake. At this stage, the earthquake early warning tool will be evaluated both in context and construction to know the advantages and disadvantages of the equipment developed. Based on criticisms, suggestions, and improvements obtained from validation questionnaires against per-memory tools developed, a buzzer with a larger volume of sound is required to provide warnings. In the trial stage, tools to detect quantities above 5 SR require larger collisions, so it is difficult to take data on the magnitude of the Richter scale of earthquakes.

Contribution to Physics Learning

Based on the impact of the earthquake, implementing disaster mitigation programs is one of the needs that must be done through formal and informal education because many still do not understand disaster mitigation. In physics learning, learning about earthquakes is taught in natural disaster mitigation subjects in grade 12 high school. Good disaster mitigation management includes establishing disaster mitigation approaches both structurally and non-structurally, establishing disaster mitigation policies with a clear division of responsibilities, establishing effective disaster mitigation strategies, and handling during disasters and post-disaster recovery. Application of earthquake disaster mitigation. Earthquake disasters, in addition to causing damage and casualties on the surface of the earth's plates, can also damage epicenter buildings with magnitudes above 5 on the Richter Scale.The importance of disaster mitigation education can be done through informal or educational channels according to government regulations. Carrying out effective earthquake disaster mitigation preparedness before a disaster occurs, in this study, an earthquake early warning system is one way as an early warning alarm when an earthquake occurs.

CONCLUSION

Based on the research results, a product was obtained in the form of an earthquake early warning system tool based on an Arduino Uno microcontroller with a MPU6050 accelerometer sensor and NodeMCU ESP8266. The tools developed get an average percentage of validation result by 91% experts in the very decent category. Earthquake warning systems and earthquake detectors can detect earthquake magnitudes and connect to the telegram application, making it easy for users to get earthquake notifications. Based on the trial, the earthquake warning system and earthquake detection run according to the system design. The system will provide early warning when an earthquake greater than 5 SR occurs. In this study, the plan was integrated with electric current. In further research, it is hoped that it can be developed with the addition of batteries; when an earthquake occurs and the electric current goes out, the device can still run and provide early warning to users.

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