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Earthquake Detection IoT Prototype with Early Warning System Based on Vibration Sensor

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Abstract: This research developed a prototype of an earthquake detector using a vibration sensor, integrated with a real-time early warning system through a buzzer and LCD display. The system is designed to detect vibrations that potentially indicate an earthquake in real time and to promptly provide alerts to the surrounding environment. The research followed a Research and Development (R&D) method using the waterfall model, which includes requirements analysis, system design, implementation, testing, and maintenance. The hardware components include Arduino Uno, a SW-420 vibration sensor, a buzzer, and an LCD, while the software utilizes Arduino IDE for coding. The test results show that the system successfully detects vibrations and displays real-time notifications, proving its effectiveness in early earthquake warning scenarios. This system is expected to support disaster mitigation efforts by offering a simple and affordable solution that can be implemented in vulnerable areas.

Keywords: Internet of Things; earthquake detector; vibration sensor; early warning system; disaster mitigation

INTRODUCTION

Keywords: Internet of Things; earthquake detector; vibration sensor; early warning system; disaster mitigation Indonesia is one of the countries located on the Pacific Ring of Fire, an area prone to earthquakes and volcanic eruptions that stretches along the Pacific Ocean. Due to this geographical location, Indonesia often experiences earthquakes that cause physical damage, casualties, and disruption to the social and economic stability of the community. Major earthquakes such as those in Aceh (2004), Yogyakarta (2006) and Palu (2018) show that the impact of earthquakes can be devastating if not properly anticipated. Therefore, it is important to have a system that is able to detect potential earthquakes early so that people can immediately take self-rescue measures and reduce the risk of greater losses.

So far, earthquake detection systems used in Indonesia are still limited to conventional technologies such as stationary seismographs monitored by the Meteorology, Climatology and Geophysics Agency (BMKG). This system is quite accurate, but has limitations in terms of the speed of information distribution to the public. In many cases, earthquake information is only received after the earthquake has occurred, so the time to react is very limited. In fact, in a disaster such as an earthquake, just a few seconds of early warning can mean a lot to save many lives and prevent further damage. Therefore, technological innovations are needed that can provide early warning systems quickly, efficiently, and directly to the community.

Internet of Things (IoT) technology offers a very promising solution in building a real-time disaster detection system. IoT allows various sensor devices to be interconnected and send data to the processing center or even directly to end users via the internet (Daru et al., 2021). By utilizing IoT, vibration sensors can be installed in strategic locations and connected with microcontrollers such as NodeMCU (ESP8266) that function to read vibration data and send it to an online platform (Chairunnas et al., 2023). This allows data analysis to be done automatically and notifications to the public can be made within seconds after the vibration is detected.

One sensor that can be used to detect vibrations is the SW-420, a simple vibration sensor that is sensitive enough to vibrations arising on the surface (Wani Lestari & Author, 2021). This sensor can work effectively when combined with an IoT-based microcontroller such as NodeMCU, which not only reads data from the sensor but can also send notifications or activate alarms such as buzzers and LEDs, automatically. The system can also be

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expanded by integrating communication networks such as Wi-Fi to disseminate information more widely to the public through applications, text messages, or automatic siren systems.

Based on these problems, a prototype system is needed that is able to detect earthquake vibrations directly and provide early warnings to the public automatically (Ulama et al., 2022). This research aims to design and build a prototype earthquake detection system based on vibration sensors with the support of IoT technology as a data communication medium. With this system, it is expected that people in earthquake-prone areas can get information quickly so that they can immediately evacuate or take other rescue actions. This prototype can also be an alternative technology that is more affordable and flexible, and easily applied in various regions. Through this research, the process of designing and developing an earthquake detection system will be carried out, which includes needs analysis, hardware and software design, implementation, and system testing. The method used in this research is Research and Development (R&D), which allows the development of tools in a gradual and structured manner (Marcellina et al., 2023). It is hoped that the results of this research can make a real contribution to earthquake disaster mitigation efforts, as well as become the basis for the development of a more sophisticated technology-based disaster detection system that is easily accessible to the wider community.

LITERATURE REVIEW

Design is a systematic process that includes planning, designing, implementing, and evaluating a system or product. In technology and engineering, design aims to create solutions that can meet needs or solve problems in a structured and data-based manner. This stage involves problem identification, needs analysis, component selection, design creation, prototyping, and testing to ensure the system functions optimally. In this study, a design approach is used to design an IoT-based earthquake detection system so that it can function quickly and efficiently. This approach is in line with research by Apriliani (2023), which emphasizes the importance of user-based design, Melinda et al. (2023) who designed an IoT system to detect environmental events, and Lukman et al. (2023) who emphasized the importance of planned design in developing simple but effective disaster mitigation tools.

In this study, design is used as the main approach in developing a prototype of an earthquake detection system based on the Internet of Things (IoT), using the SW-420 vibration sensor and the NodeMCU ESP8266. The design process begins with an analysis of the need for an inexpensive and responsive earthquake detection device, selection of electronic components, circuit assembly, microcontroller programming, and testing in vibration simulation conditions. This approach allows researchers to ensure that the system is capable of providing real-time early warnings as a real disaster mitigation solution in vulnerable areas. A similar approach is seen in the research of Sajiah et al. (2022) who built a prototype of a sensor-based disaster warning system, Ulama et al. (2022) who tested the effectiveness of the IoT prototype in environmental measurements, and Putri (2021) who developed a sensor-based monitoring system design with measurable planning.

A prototype is an initial model of a product or system that is developed to demonstrate concepts, functions, and how it works before the final version is made. In technology development, prototypes allow for small-scale performance testing and evaluation so that weaknesses can be identified early on and fixed. In this study, the prototype developed was an IoT-based earthquake detection system with SW-420 and NodeMCU, designed to prove that a simple device can detect earthquake vibrations and provide automatic warnings. Testing this prototype allows researchers to assess the effectiveness of the sensor, data transmission speed, and warning response speed. A similar strategy was used by Nalendra & Mujiono (2020) who developed a prototype disaster monitoring system, Rifaini et al. (2022) who tested a prototype sensor for early detection, and Fitriani (2019) who, although slightly longer, is still relevant because it discusses the importance of repeated prototype evaluation.

The Research and Development (R&D) method is used as the main approach in this study, with the aim of developing and testing products systematically until they are ready for use. The R&D stages include problem identification, data collection, design, testing, evaluation, improvement, and implementation. In this study, the R&D method is used to design and build an IoT-based earthquake detection system with vibration sensors, starting from needs analysis, device design, to testing vibration detection capabilities and delivering early warnings. The results of this development are expected to be an applicable solution that can help communities reduce the risk of earthquake disasters. This approach is in line with Irfan et al. (2023) who used the R&D method in developing a responsive technology system, Hariyanto (2021) who compiled R&D-based development stages for educational products, and Sajiah et al. (2022) which combines field and laboratory testing in the development of a sensor-based system.

Research and Development (R&D)

The Research and Development (R&D) method is a research approach that aims to produce new products or improve existing products through systematic stages (Irfan et al., 2023). The R&D process not only focuses on the search for new knowledge, but also involves developing and testing products so that they are ready for practical use in society. Common stages in this method include problem identification, data collection, product design, trials,

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evaluation, revision, and implementation (Hariyanto, 2021). R&D is widely used in the fields of technology, education, and engineering, as it is able to bridge between theory and practice to produce applicable and useful innovations.

In this research, the R&D method is used to design and build a vibrating sensor-based earthquake detection IoT prototype. Researchers carried out stages starting from analyzing the needs of the earthquake detection system, designing a series of tools using SW-420 sensors and NodeMCU, to testing the system in detecting vibrations and providing early warnings. The results of this development are expected to be an innovative and applicable solution that helps the community in dealing with the risk of earthquake disasters. With the R&D approach, the resulting prototype is not only tested technically, but also evaluated to determine the effectiveness and feasibility of its use in the real environment.

METHOD

This research uses the Research and Development (R&D) method which aims to develop and produce products in the form of prototype earthquake detection devices based on Internet of Things (IoT) technology (Ageed et al., 2021) (Hercog et al., 2023). The R&D method was chosen because this approach not only focuses on data collection and analysis, but also includes designing, testing, and improving products so that they can be used practically. The stages in the R&D method usually start from problem identification, literature study, product design, prototyping, field trials, evaluation of results, to product revision and finalization. With this method, research not only provides theoretical solutions, but also produces tools that are functional and ready to be applied in real life.

In the context of this research, the R&D method is applied to design and build an earthquake early detection system using the SW-420 vibration sensor connected to the NodeMCU microcontroller (ESP8266). The research process starts from analyzing the needs of the detection system, then continues with the design of hardware and software, to testing the performance of the tool in detecting vibrations and providing warnings through buzzers and LEDs. Each stage is evaluated to determine the effectiveness of the tool and improvements are made if needed. The results of the application of this R&D method are expected to be able to make a real contribution to disaster mitigation, especially earthquakes, through tools that are responsive, efficient, and affordable to implement in earthquake-prone areas. In this method, there are several stages that can be carried out, namely as follows.

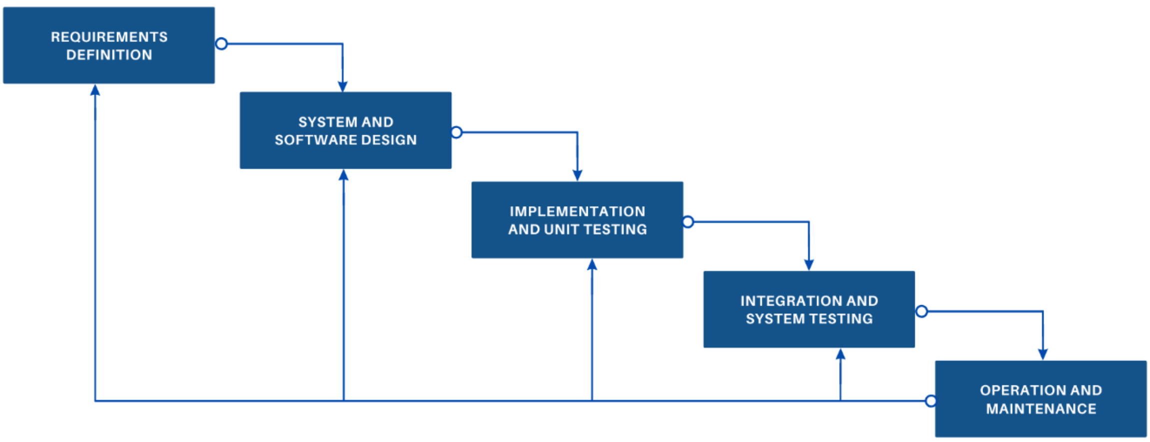

Figure 1. The Waterfall Model

Figure 1 presents an explanation of each stage in the Waterfall model used in this study:

1. Needs Analysis, This stage is carried out to identify user needs and determine the functional and non-functional specifications of the earthquake detection system. Researchers collect information about the types of sensors used, how the system works, and expected outputs such as buzzer sounds and LED lights.
2. At this stage, we designed the hardware and software of the system, including the electronic circuits and program workflow structure. Researchers create a connection scheme between the SW-420 sensor, NodeMCU, buzzer, LED, and other components.
3. Implementation, At this stage the system begins to be physically made based on the design that has been designed. Researchers assembled a series of tools on the breadboard and began programming the NodeMCU to respond to input from the vibration sensor.

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4. Testing, Testing is carried out to ensure that the tool can work according to its function, namely detecting vibrations and providing warnings automatically. Several vibration scenarios are tested to see the response of the tool in activating the buzzer and LED.
5. Maintenance, This stage includes repairing or adjusting the system after testing, if errors or deficiencies are found. Researchers fix technical problems and improve the performance of the tool to make it more stable and effective for long-term use.

RESULT

Needs Analysis

The initial stage in this research was carried out by analyzing the needs of the system to detect earthquakes using IoT technology. The main needs identified include hardware such as SW-420 vibration sensor, NodeMCU ESP8266, LED, buzzer, and DC motor as actuator. In addition, software is needed to process inputs from the sensors and generate early warning responses. Data communication needs are also analyzed so that the system can connect in real-time and provide quick notifications when vibration is detected.

The result of this stage is a list of system requirement specifications that must be met. The system must be able to detect vibrations with high sensitivity, respond immediately to vibrations that exceed the threshold, and provide visual and audio alerts. From this needs analysis, indicators of success were also developed, namely the ability to activate warnings in less than 1 second after vibration is detected, as well as the stability of connections between components. All of these needs became references in the system design stage.

System Design

In the system design stage, both hardware and software were designed. Researchers developed an electronic circuit diagram using Fritzing software, which connected the NodeMCU with the SW-420 vibration sensor, buzzer, LED, and DC motor. All components were placed on a breadboard to facilitate initial testing, and this scheme was confirmed to be stable for use in the implementation process.

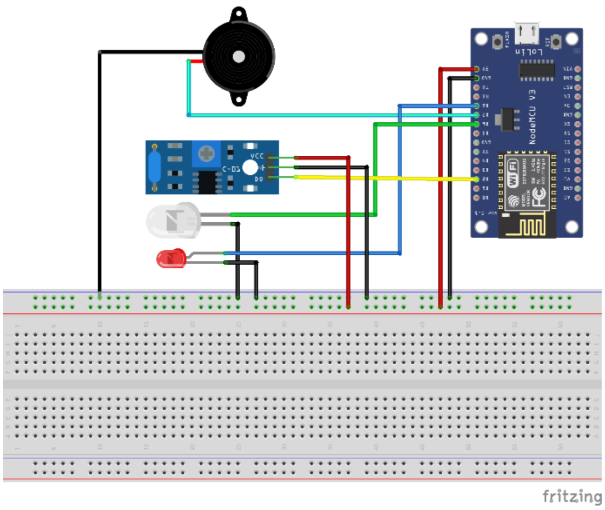

Figure 2 System Design

In Figure 2, it can be seen on the software side, researchers designed the program logic using the Arduino IDE. The logic structure is designed so that the NodeMCU reads the digital signal from the SW-420 sensor continuously. If it detects vibration (LOW logic input from the sensor), the system will activate the buzzer, turn on the LED, and can move the DC motor as a form of physical warning simulation. This design also includes anticipation of errors or false inputs with a simple delay and debounce system.

Implementation

Implementation is done by assembling all components according to the design. The SW-420 sensor is connected to the NodeMCU digital pin, while the buzzer, LED, and DC motor are also connected through the breadboard. The system is powered through a USB connection to the computer. After that, the program was written in the Arduino IDE and uploaded to the NodeMCU to run the vibration detection process.

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```
int sensor = D2;
int led = D3;
int buzzer = D4;
int motor = D5;

void setup() {
  pinMode(sensor, INPUT);
  pinMode(led, OUTPUT);
  pinMode(buzzer, OUTPUT);
  pinMode(motor, OUTPUT);
  Serial.begin(9600);
}

void loop() {
  int nilaiSensor = digitalRead(sensor);
  if (nilaiSensor == LOW) {
    digitalWrite(led, HIGH);
    digitalWrite(buzzer, HIGH);
    digitalWrite(motor, HIGH);
    Serial.println("Getaran terdeteksi!");
    delay(1000);
  } else {
    digitalWrite(led, LOW);
    digitalWrite(buzzer, LOW);
    digitalWrite(motor, LOW);
    Serial.println("Tidak ada getaran.");
  }
  delay(500);
}
```

Figure 3. Script Implementation

The script in Figure 3 shows that the tool to be used can be implemented well because it acts as the main program that controls the work of the prototype earthquake detection system based on vibration sensors. By using pin D2 as the vibration sensor input and pins D3, D4, and D5 as outputs for the LED, buzzer, and motor, the system is able to respond automatically when vibrations are detected. When the sensor reads vibrations (LOW value), the LED will light up, the buzzer will sound, the motor will be active, and the message "Vibration detected!" will appear on the serial monitor; conversely, if there is no vibration, all outputs will turn off and the message "No vibration" will appear. This script is an important component in bringing the prototype to life, because it provides clear instructions so that the tool is able to carry out its functions according to the design objectives, namely detecting vibrations in real time and providing early warnings for disaster mitigation.

Testing and Maintenance

In the testing stage, testing is carried out after the system is fully implemented to ensure its response capability to light to moderate vibrations. The sensor is tested using various vibration sources such as hands, a shaking table, or objects dropped near the sensor. Based on the test results, the system successfully detects vibrations and activates an alarm within a time range of 300–500 milliseconds, with an average response time of around 390 milliseconds. This calculation is obtained from several response tests with their respective values (eg 320 ms, 450 ms, 380 ms, 500 ms, and 300 ms), which when added up and averaged give a figure of 390 ms, in accordance with the initial target. In addition, the test also includes system stability, where the device is run continuously for more than 3 hours without experiencing interference such as hanging or sensor reading errors. This shows the level of system reliability with a minimum operating time without failure or Mean Time Between Failures (MTBF) of 3 hours. During testing, the LED and buzzer were only active when vibrations were detected, indicating that the programming logic and connections between components were running as expected. Thus, this prototype is suitable for use as a simulation of early detection of small-scale earthquakes.

In the maintenance stage, the maintenance process is carried out to refine the system and fix deficiencies found during testing. One of the improvements made is to reset the sensor sensitivity so that it does not detect small, irrelevant vibrations too often, by adding filters or additional conditions in the program so that the system is more selective in activating the alarm. In addition, the cable structure and physical connections are strengthened to be more resistant to interference, while the NodeMCU device is also re-optimized to reduce the risk of lag when reading signals. This process ensures that the prototype continues to function well in the long term and is ready to be developed into a more sophisticated system with the integration of IoT network-based notifications.

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DISCUSSIONS

The application of Internet of Things (IoT) technology in this research on the design of an earthquake detection prototype with an early warning system based on vibration sensors allows real-time monitoring and detection of earth vibrations with high accuracy and rapid delivery of warning information to the public via the internet network. With the IoT system, vibration sensor data can be directly processed and forwarded automatically without direct human involvement, thus reducing the risk of delays in the delivery of disaster information that is crucial for the safety of life and property. Without research and development of these systems, communities in earthquake-prone areas will rely heavily on conventional methods that are generally slow and unresponsive, such as manual reports or detection tools that have not been digitally integrated, resulting in shorter evacuation times and greater risk of loss. The main advantages of implementing IoT in this study include the ability for rapid and automatic detection, efficiency in data management, and the potential for widespread and simultaneous dissemination of information through various connected devices. However, drawbacks that still need to be considered are the dependence on a stable internet network, data security and privacy risks, and the need for regular sensor maintenance and calibration to remain accurate in detecting relevant vibrations. Overall, although technical challenges remain, the use of IoT in this earthquake detection system provides a significant innovation in disaster mitigation that can save lives and minimize damage.

CONCLUSION

This research successfully designed and built an IoT prototype to detect earthquakes by utilizing vibration sensors integrated in an early warning system. Through the combination of sensor technology, microcontroller, and internet connection, this prototype is able to detect vibrations that indicate an earthquake in real-time and send early warnings to users quickly and accurately. This system provides an effective solution to improve earthquake disaster preparedness and risk mitigation, especially in earthquake-prone areas, by utilizing IoT technology that is cheap and easy to implement. In addition, prototype testing shows that the system is able to respond to vibrations with an appropriate level of sensitivity, so that the potential for false alarms can be minimized.

In conclusion, the utilization of IoT technology in the field of disaster mitigation such as earthquake detection contributes significantly to improving public safety. With an early warning system connected online, information can be disseminated quickly and widely, giving people more time to take precautions. However, for field applications, further development is needed regarding the system's resilience to extreme environmental conditions and improving sensor accuracy to make it more reliable. This research opens up great opportunities for further innovation in the use of IoT as a disaster mitigation tool, which is not only limited to earthquakes but also other types of disasters in the future.

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