

Prototype of Landslide Disaster Early Warning System in Tomohon City Using Raspberry Pi

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Abstrak. Indonesia menghadapi risiko tinggi terjadinya tanah longsor, terutama di wilayah dengan curah hujan tinggi dan topografi curam, seperti Kota Tomohon di Sulawesi Utara. Kawasan Tomohon, khususnya pada jalur antara KM 12 hingga KM 17 di Desa Tinoor 1, dikenal sebagai daerah yang rawan longsor sehingga menimbulkan ancaman serius bagi keselamatan penduduk dan pengguna jalan. Oleh karena itu, sistem peringatan dini tanah longsor (Early Warning System/EWS) yang mampu memberikan peringatan secara real-time sangat dibutuhkan untuk membantu mengurangi dampak dari peristiwa tersebut. Penelitian ini bertujuan untuk mengembangkan prototipe sistem peringatan dini tanah longsor berbasis Raspberry Pi, yang dilengkapi dengan sensor kemiringan (tilt sensor) dan akselerometer untuk mendeteksi pergerakan tanah di daerah rawan longsor di Kota Tomohon. Data dari sensor dikumpulkan dan diproses oleh Raspberry Pi, kemudian hasil pengukuran disebarkan melalui platform web secara real-time, sehingga masyarakat dan pihak berwenang dapat merespons dengan cepat. Sistem ini menunjukkan kemampuan deteksi yang memadai dan dapat berkontribusi dalam upaya mitigasi bencana tanah longsor di Tomohon. Penerapan prototipe ini tidak hanya meningkatkan kesiapsiagaan teknis terhadap bencana, tetapi juga mendorong ketangguhan masyarakat melalui strategi mitigasi berbasis teknologi. Dengan mengintegrasikan perangkat Internet of Things (IoT) dan pemrosesan data secara waktu nyata, sistem ini menawarkan solusi proaktif yang dapat secara signifikan mengurangi jumlah korban jiwa dan kerusakan infrastruktur. Selain itu, aksesibilitas data secara real-time melalui platform web memberikan kekuatan bagi masyarakat dan otoritas lokal untuk membuat keputusan yang tepat selama keadaan darurat. Dengan demikian, penelitian ini dapat menjadi model praktis bagi wilayah lain di Indonesia yang memiliki kondisi geografis serupa, sekaligus menegaskan pentingnya adopsi teknologi inovatif dalam menghadapi tantangan bencana alam yang semakin meningkat.

Kata kunci: Tanah longsor, Sistem Peringatan Dini (EWS), Raspberry Pi, Sensor

Abstract. Indonesia faces a high risk of landslides, particularly in areas with heavy rainfall and steep topography, such as Tomohon City in North Sulawesi. The area of Tomohon, especially the route between KM 12 and KM 17 in Tinoor 1 Village, is known for its landslide susceptibility, posing a constant threat to the safety of residents and road users. Therefore, a landslide early warning system (EWS) capable of providing real-time alerts is essential to help reduce the impact of such events. This research aims to develop a prototype EWS based on Raspberry Pi, equipped with tilt sensors and accelerometers to detect soil movement in landslide-prone areas in Tomohon City. Sensor data is collected and processed by the Raspberry Pi, with measurement results distributed via a web platform in real-time, enabling the community and authorities to respond promptly. This system demonstrates adequate detection capabilities and can contribute to landslide disaster mitigation efforts in Tomohon. The implementation of this prototype not only enhances technical disaster preparedness but also promotes community resilience through technology-based mitigation strategies. By integrating IoT devices with real-time data processing, the system provides a proactive solution that can significantly minimize casualties and infrastructure damage. Furthermore, the real-time accessibility of data through a web platform empowers both residents and local authorities to make informed decisions during emergencies. This research thus serves as a practical model for other regions in Indonesia with similar geographical conditions, reinforcing the importance of adopting innovative technologies in addressing the growing challenges of natural disasters.

Keywords: Landslide, Early Warning System (EWS), Raspberry Pi, Sensor



INTRODUCTION

Indonesia is located right on the equator and is a disaster-prone country due to its tropical climate. The topographic condition of some parts of Indonesia is characterized by steep mountain contours. This is the cause of the increase in hydrometeorological disasters, especially landslides in Indonesia [1]. A landslide is the up-and-down movement of a slope caused by the loss of stability of the soil or rock. Landslides are caused by the texture and shape of the soil, rainfall, and climatic conditions. Tomohon City is an area that has a high risk of landslides. The Manado-Tomohon highway, which is located in Tinoor Village, North Tomohon District, Tomohon City, North Sulawesi Province, has a length of about 8 km and along it there are residential buildings and restaurants. This location is on a steep hillside with a slope between 2 to 20%, belonging to the steep category, and composed of layers of rock with a type of latosol soil that is prone to erosion. In addition to the steep topography, high rainfall intensity, reaching 0 to 2000 mm per year with a percentage of about 65%, as well as wind speeds that blow quite strongly, show that Tomohon City is an area prone to landslides [2].

High rainfall in the North Sulawesi region causes a decrease in soil shear strength and an increase in soil moisture content. As a result, the effective voltage decreases, which has an impact on the decrease in shear stress in the soil, resulting in landslides in 2022 along the Manado-Tomohon Highway. This incident caused the road to be cut off and trees to fall [3]. This incident resulted in the death of two people, and 20 other people have not been found because they are still buried by landslides. Many motorcyclists and cars were trapped due to landslide material that covered the road body along 300 meters with a soil thickness of up to 6 meters.

In this incident, as many as 30 families had to evacuate, 25 houses were severely damaged, and 20 units of motorcycles and cars were severely damaged. Landslides are natural disasters that cause significant damage to infrastructure and threaten life safety, especially for people living in landslide-prone areas and road users [4]. Based on the results of the survey that researchers have conducted, it can be seen that people living around landslide-prone areas do not have access to information or an early warning system regarding the potential for this disaster. As a result, they are not prepared to face the risks that exist, resulting in significant material losses, including loss of property and damage to their homes [5].

In addition to the impact on the community, landslides also bring losses to road users. When a landslide occurs, road access is cut off, causing a very long traffic jam so that traffic on Jl. Raya Manado – Tomohon is completely dead and the worst thing is that it causes accidents, taking lives, until the missing victims are not found. Losses experienced by road users can be in the form of vehicle damage due to landslides [6]. Therefore, the existence of an effective early warning system is very important to provide accurate and fast information to the public and road users [7]. With adequate information, they can take the necessary mitigation measures to reduce the risks posed by landslides, as well as minimize the possible impact.

This research aims to build a prototype of an early warning system that is able to detect soil movement in landslide-prone locations using Raspberry Pi technology and MPU6050 accelerometer sensors [8]. This system is expected to reduce the risk and loss due to landslides through real-time warnings that can be accessed by the public and authorities through the WhatsApp application. In addition, this research makes a real contribution to mitigating and improving disaster preparedness in Tomohon City, which often experiences landslides.

The proposed prototype utilizes the integration of Internet of Things (IoT) technology to monitor soil movement in real time. The MPU6050 accelerometer sensor will detect any changes in the slope angle and ground vibration, while the Raspberry Pi functions as the main controller to process and transmit data to a cloud-based monitoring platform [9]. When a significant movement is detected that indicates potential landslide activity, the system will automatically send warning notifications via the WhatsApp application to residents, local disaster management agencies, and



relevant authorities [10]. This integration ensures that the early warning system operates efficiently, providing timely alerts even in areas with limited communication infrastructure.

Furthermore, this research not only focuses on the technical development of the device but also on the involvement of the local community in disaster preparedness education. By conducting training and awareness programs, residents living in landslide-prone areas will be better equipped to interpret early warnings and respond appropriately. Community participation is an essential element of disaster risk reduction, as it builds a culture of awareness and shared responsibility between citizens and authorities. This participatory approach ensures that technology does not stand alone but functions as part of a comprehensive mitigation strategy involving multiple stakeholders. Finally, the expected outcome of this research is a scalable and replicable model that can be implemented in other regions of Indonesia facing similar geological and climatic conditions. The success of this early warning system prototype can serve as a foundation for broader disaster risk management initiatives, integrating real-time data analytics and artificial intelligence for predictive modeling. In the long term, the system has the potential to support national disaster mitigation efforts, aligning with Indonesia's vision for resilience and sustainable development in the face of increasing natural hazards.

RESEARCH METHODS

1. Place and Time of Research

The research activities, including hardware assembly, sensor calibration, software programming, and system testing, were carried out in the laboratory facilities of the Electrical Engineering Study Program, Faculty of Engineering, North Sulawesi University of Technology .

The study took place over a period, allowing sufficient time for prototype development, data collection, and performance evaluation of the Early Warning System (EWS) under controlled and field conditions.

2. Hardware and Software

The Raspberry Pi 4 8Gb is used as the main processing unit to process data from the sensor. The sensor used is a type MPU6050 accelerometer sensor which functions to measure or read the slope of the soil. Power Banks are used as a power source for Raspberry Pi and sensors, especially in the use of systems in the field. Micro SD Card is used as a storage medium and installation medium for the Raspberry Pi operating system. A 4G modem is used to connect the system with the internet [11], [12].

The software that will be used is Python which will process all incoming data then send it in real-time to the cloud, in this case Twilio as a third-party service connected to the Whatsapp API.

3. Research Stages

The research stages describe the systematic steps undertaken to design, develop, and evaluate the landslide Early Warning System (EWS) prototype [13], [14]. Each stage is carefully planned to ensure that the system functions effectively, from initial data collection and hardware configuration to software programming, testing, and analysis. These stages provide a comprehensive overview of the entire research process, highlighting how each component contributes to achieving the overall objective of developing a reliable and real-time landslide monitoring system using Raspberry Pi and sensor technology.



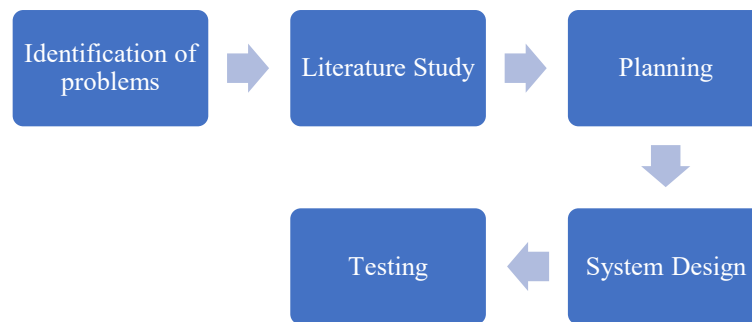


Figure 1. Planning Flow [15]

In this study, there are several stages carried out, namely [16]:

- a. Problem Identification
At this stage, problems that need to be overcome are identified, namely limited public access to receive early warnings about landslides and monitoring the condition of land slopes that are at risk of landslides.
- b. Literature Studies
At this stage, researchers study various literature from journals, books, and articles to develop a landslide early warning system that suits the needs.
- c. System Development Methods
At this stage, the most appropriate method will be selected to develop a monitoring and early warning system in landslide-prone zones.

4. System Planning

At this stage, the researcher will use a Raspberry pi mini computer as the main driver for the accelerometer sensor to detect the slope of the ground and function as a data transmitter. For software, it will use Python as a programming language as a hardware support [17]–[19]. For this study, an accelerometer sensor was chosen as a source to determine the angle of inclination. Then in the process stage itself consists of several stages, namely Python installation, installation of several supporting libraries, application design, hardware design, connection to the internet, and connection to Twilio third-party services that will send Whatsapp messages to the destination.

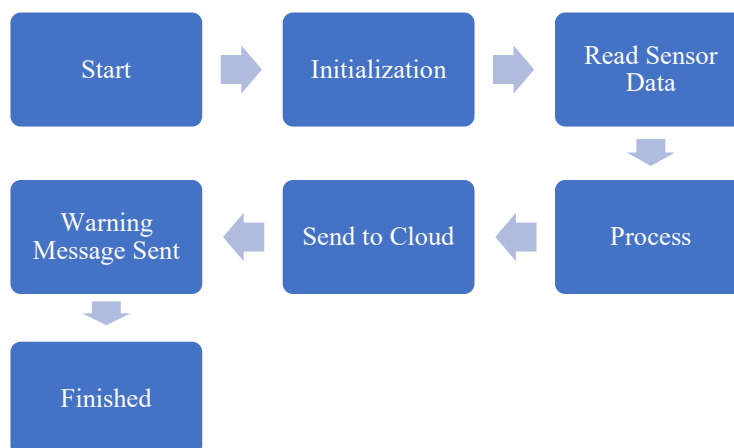


Figure 2. Flowchart of Landslide Disaster Early Warning System

5. Device Design

Hardware schematics are needed to help researchers have an idea of how to implement hardware in the system. This scheme will later be a reference so that the hardware design is in accordance with the purpose. The schema in this study was made using the Fritzing application and is based on the Windows operating system.

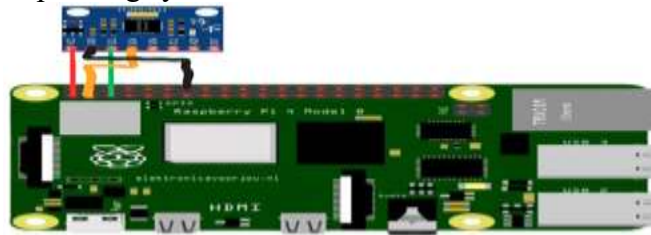


Figure 2. Device Design

This study uses the main components of the Raspberry Pi 4 as a processor and data processor. Raspberry Pi is a mini computer that can perform functions like a PC/Laptop computer. The sensor used to read physical data in the form of soil slope is the accelerometer sensor MPU6050. As an auxiliary tool, a standard breadboard is also used as an initial test of the connection between the pins between the main component and the sensor [20].

The sensor MPU6050 connected to the Raspberry Pi by using I2C communication in a sequence of connections: The sensor's VCC pin is connected to the Raspberry Pin 1, the sensor's GND Pin is connected to the Raspberry Pin 6, the sensor's SCL pin is connected to the Raspberry Pin 5, and the sensor's SDA Pin is connected to the Raspberry Pin 3.

6. Output Design

The output design for the Landslide Disaster Early Warning System using the Raspberry Pi has the ultimate goal of automatically sending Whatsapp messages based on sensor reading conditions and sending them to a specific number.

There are four types of message statuses depending on the angle of inclination [21]

- a. Status 1 Alert if the sensor reading has shown or passed the value of 3°
- b. Status 2 Standby if the sensor reading has shown or passed the value of 7°
- c. Hazard status 3 if the sensor reading is already showing or passing the value of 10°
- d. Status 4 Disaster if the sensor reading has shown or exceeded the value of 15°

RESULTS AND DISCUSSION

1. Hardware Development

Hardware is a component used in this study because it will read the results of physical changes in the slope of the soil in real-time and process it to produce output according to the research objectives. The hardware components used in this study consist of a Raspberry Pi as the main microcontroller, an MPU6050 accelerometer and gyroscope sensor for detecting soil movement, a power supply module, and a communication module for data transmission. The MPU6050 sensor functions to measure acceleration and angular velocity, which will be used to detect even small movements or shifts in the soil layer. The Raspberry Pi then processes this data and determines whether the detected movement exceeds the predetermined threshold value that indicates a potential landslide. When the threshold is reached, the system will automatically trigger an alert message that will be sent through the WhatsApp notification system.

In addition, the hardware system is designed with reliability and durability in mind to ensure stable operation under outdoor environmental conditions. All electronic components are placed in a waterproof and dustproof enclosure to prevent damage caused by rain, humidity, or extreme temperatures. The system is also equipped with a backup power source in the form of a rechargeable battery that allows continuous operation during power outages. This design ensures



that the early warning system can function optimally and provide real-time monitoring data continuously, which is essential for mitigating landslide risks effectively.

2. Sensor Testing

To display the measurement data of the accelerometer sensor connected to the Raspberry Pi for tilt angles of 0° , 3° , 7° , 10° , and 15° , the output data from the sensor is read in three axes: X, Y, and Z. The accelerometer sensor MPU6050 will produce an output in digital form and this data will communicate with the Raspberry Pi using the I2C method.

First, the sensors are placed at different angles (0° , 3° , 7° , 10° , and 15°). Then the Raspberry Pi will read the acceleration value and calculate the angle of inclination in the forward-backward direction and the angle of inclination in the left-right direction. The latter is done recording the results in a table for further analysis.

The collected data from each tilt angle is then analyzed to determine the sensor's accuracy and sensitivity in detecting changes in slope. By comparing the measured values with the actual tilt angles, calibration can be performed to minimize measurement errors and improve system reliability. This calibration process is crucial for ensuring that the early warning system can accurately identify small soil movements that may precede a landslide. The resulting dataset also serves as a reference for developing threshold parameters that trigger warning notifications, thereby enhancing the overall precision and effectiveness of the landslide detection system.

Table 1. Accelerometer Sensor Testing

Angle (o)	Accelerometer			Angle Slope (o)
	X	Y	Z	
0	0.01	0.02	1.00	
3	0.05	0.10	0.99	
7	0.12	0.15	0.98	
10	0.17	0.20	0.97	
15	0.25	0.30	0.95	

Table 2 presents the results of the Early Warning System (EWS) test conducted to evaluate the system's ability to detect changes in slope angle and send corresponding alert messages. The purpose of this test is to verify the performance of the MPU6050 accelerometer sensor and its integration with the Raspberry Pi in generating early warning notifications at various tilt angles. Each test was performed by gradually increasing the slope angle from 0° to 15° , simulating different levels of soil movement that could potentially lead to a landslide.

At 0° , the system remains in a stable condition with no alerts generated, indicating that the slope is safe. However, as the angle increases to 3° , 7° , 10° , and 15° , the system sequentially activates EWS messaging levels 1 through 4. This progressive alert mechanism allows authorities and residents to respond proportionally to the severity of the detected slope change, ensuring that early preventive actions can be taken before a major landslide occurs.

This feature is critical for real-time monitoring in landslide-prone areas, as it enables the system to provide gradual alerts rather than a single, generalized warning. By differentiating between minor and severe slope movements, the system enhances decision-making for both local authorities and residents. For example, at lower alert levels, the system can prompt early inspections or temporary evacuation preparation, while higher alert levels can trigger immediate evacuation procedures. This stepwise response model greatly contributes to reducing casualties and property losses during potential landslide events.



Table 1. Test N Message

No	Angular Slope	System Status
1	0°	None
2	3°	EWS messaging 1
3	7°	EWS 2 messaging
4	10°	EWS 3 messaging
5	15°	EWS 4 messaging

3. Raspberry Connection Testing

The first step is to check the local network connection to make sure that the Raspberry Pi is already connected to the router or the local gateway by ping the local gateway. After ensuring that the Raspberry Pi is successfully connected to the local network, the next step is to test the stability and speed of the connection. This process involves sending continuous ping requests to the router or local gateway over a set period to monitor packet loss, response time, and overall network reliability. A stable and consistent connection is essential for the early warning system to function properly, as it ensures that real-time data from the MPU6050 sensor can be transmitted without interruption. If any significant delay or data loss occurs, it may affect the timeliness of alert notifications, potentially reducing the effectiveness of the warning system during critical situations.

Once the local network connection has been verified, the system's ability to communicate with external servers and send messages via the WhatsApp API is tested. This step ensures that the Raspberry Pi can not only collect and process sensor data locally but also transmit alerts to designated recipients through an internet-based communication channel. Successful completion of this test confirms that the data flow, from sensor readings to cloud processing and final message delivery, is functioning seamlessly. This validation is crucial before deploying the system in the field, as it guarantees that warning messages will be promptly delivered to authorities and residents when a potential landslide is detected.



Figure 3. Internet Connection Testing [22]

When the Raspberry Pi reads the data from the MPU6050 accelerometer sensor, the data will then be sent to Whatsapp using Python code. The text sent is "Early Warning System: There has been a landslide and a landslide is likely". The process of sending messages through WhatsApp is handled using the Python programming language, which provides a reliable and flexible means of integrating the hardware and communication systems. The Python script connects the Raspberry Pi to the WhatsApp API, enabling the automatic transmission of alerts when the sensor detects slope movement beyond the set threshold. This automation ensures that early warning messages are



delivered instantly without the need for manual intervention, minimizing response time during emergencies. By using Python, developers can also easily modify or enhance the message format, include sensor data, or attach timestamps for more detailed reporting in future system iterations.

In addition, the integration of WhatsApp as a notification medium was chosen due to its widespread use and accessibility among local communities. Most residents and local disaster response teams already rely on WhatsApp for communication, making it an effective and practical platform for real-time alerts. This approach allows for a faster dissemination of information, ensuring that everyone within the affected area is immediately informed of potential landslide hazards. As a result, this communication feature significantly improves community preparedness, reduces the risk of casualties, and supports timely evacuation or mitigation efforts in landslide-prone regions such as Tomohon City.



Figure 4. Internet Connection Testing

Before sending the message, the Raspberry Pi processes the raw data received from the MPU6050 accelerometer to calculate the tilt angle and determine whether the detected movement exceeds the defined threshold value. This process involves filtering and averaging the sensor readings to minimize noise and ensure data accuracy. Once the tilt angle indicates potential instability or soil movement consistent with landslide activity, the system automatically triggers an alert mechanism. This ensures that only valid and critical conditions initiate a warning, reducing the chances of false alarms that could cause unnecessary panic among residents or authorities.

The WhatsApp message-sending feature is implemented using an application programming interface (API) that allows the Raspberry Pi to communicate directly with the WhatsApp service through an internet connection. This integration enables automated message delivery to multiple recipients simultaneously, including local disaster management officers, village leaders, and residents in high-risk areas. Each message contains not only the warning text but can also include additional data such as time of detection, sensor ID, and location coordinates. This comprehensive information helps responders quickly assess the situation and take appropriate actions, such as initiating evacuation procedures or closing affected road sections.

In addition, the messaging system can be further developed to include two-way communication, allowing users to acknowledge receipt of alerts or request additional information about the detected event. This feature can significantly improve coordination between communities

and authorities, creating an interactive and responsive disaster mitigation network. The flexibility of the Python-based system also allows for future upgrades, such as integration with mobile applications, database logging, or visual dashboards for real-time monitoring. Through this approach, the landslide Early Warning System (EWS) becomes not only a technological innovation but also a vital tool for building safer and more resilient communities in landslide-prone regions like Tomohon City.

CONCLUSION

After going through several stages, namely planning, designing, and testing, this study concludes that the development of a monitoring and early warning system for landslide-prone zones has been successfully achieved using sensors as data readers and WhatsApp messaging as an early warning medium. Based on the testing results, the sensors were able to read data accurately, and messages were successfully delivered to the target number in a relatively short time. The findings highlight that the lack of access to information and early warning systems in vulnerable areas significantly impacts both communities and road users, resulting in material losses, damaged houses, disrupted transportation, and even casualties. Therefore, the implementation of an effective early warning system is crucial to help communities prepare for potential disasters through timely mitigation actions, thereby minimizing risks and impacts. To support this, it is recommended to enhance human resources, particularly the capacity of village apparatus, and increase community outreach so that residents understand disaster management procedures more effectively. Strengthening food and animal security programs is also necessary to ensure sustainability and equitable resource distribution. Furthermore, future research should focus on analyzing the influence of topography and rainfall, which are major factors affecting landslide thresholds, and develop more precise rainfall threshold models for prediction. Advanced approaches such as machine learning, particularly the Convolutional Neural Network (CNN) and the improved genetic-SMOTE algorithm (GAMCGSA), can be applied to address data imbalance and improve prediction accuracy. Additionally, integrating Analytical Hierarchy Process (AHP) and Geographic Information System (GIS) models based on Frequency Ratio (FR) can provide a more comprehensive assessment of landslide vulnerability by considering multiple environmental and geological factors such as elevation, slope, lithology, soil type, and land use. This combined method not only enhances the accuracy of vulnerability modeling but also offers valuable insights for sustainable land-use planning and effective disaster risk mitigation strategies. In addition, the success of this research demonstrates the potential of combining low-cost IoT technologies with digital communication platforms to build an efficient, community-centered disaster mitigation system. The implementation of Raspberry Pi and MPU6050 sensors proves that advanced monitoring and early warning mechanisms can be achieved with affordable and accessible components, making them suitable for replication in other high-risk regions across Indonesia. The integration of real-time data processing and instant alert delivery via WhatsApp ensures that crucial information reaches both authorities and residents without delay, thus enhancing preparedness and response time during emergencies. This approach not only strengthens local resilience but also aligns with the broader goal of promoting smart disaster management systems that leverage technology for public safety and sustainable development in disaster-prone areas.

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