RESSTECH

Vol. 02, No. 02, pp. 20-28, 2025
RESEARCH ON INSTRUMENTATION
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LoRa and IoT Based Landslide Early Detection System

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ARTICLE INFO

Article history:
Received May 22, 2025
Revised March 4, 2026
Accepted March 6, 2026
Available online March 10, 2026

Keywords:
Arduino, NodeMCU ESP32, MPU6050 GY-25, Slope

ABSTRACT

Safety constitutes a fundamental priority in disaster risk mitigation through the implementation of safety protocols, preparedness training, monitoring technologies, and early warning systems. A disaster is defined as an event that generates significant losses and suffering across physical, economic, social, and environmental dimensions. Landslides represent one of the most frequent natural hazards, commonly triggered by deforestation on slopes and unpredictable natural factors. Such events can severely impact residential areas and lead to casualties. This study proposes the development of an Internet of Things (IoT)-based landslide early detection system utilizing LoRa communication technology with real-time internet connectivity. The system is designed to enable continuous monitoring of slopes susceptible to landslides without requiring direct on-site observation. The primary objective of this research is to determine the design parameters and performance specifications of the proposed system. The performance specifications encompass the mechanical construction, electronic circuitry design, and the operational characteristics of the displacement sensor based on a sliding potentiometer and the tilt sensor MPU6050 GY-25. Sensor data are visualized through the serial monitor in the Arduino IDE and via the Blynk application on Android platforms. The design evaluation includes accuracy and precision assessments. The average percentage error for displacement and tilt measurements is 0.447% and 0.924%, respectively. The corresponding average accuracy values are 98.147% and 97.252%, while the average precision values reach 97.251% and 99.553%. These findings demonstrate that the proposed system exhibits reliable performance and is suitable for implementation as an IoT-based landslide early warning system.

1. INTRODUCTION

Safety is a top priority with the implementation of safety protocols, preparedness training, surveillance technology and early warning systems [1]. A disaster is an event that causes losses, suffering and accidents in the form of physical, economic, social and environmental losses [2]. One of the disasters that often occurs is landslides. Landslides occur due to the shifting of a number of land masses on a large or small scale with spontaneous movement [3]. Factors causing landslides include erosion, vibrations, increased groundwater capacity, slope gradients, and illegal logging [4]. The need for action to reduce disaster risk by seeking vigilance and preparedness activities through disaster mitigation [5].

Several studies on the development of landslide early detection systems have been reported. Study [6] designed a prototype of a landslide early warning system based on a sliding potentiometer and soil moisture sensor with SMS notification output, achieving an accuracy of 0.217% and delivering information through an LCD and SMS. However, the use of SMS as the warning transmission method is considered less effective because it relies on GSM network availability, limiting operation in areas without stable GSM coverage. Similarly, research conducted by [7] developed an early warning system using Hygrometer and Piezoelectric sensors, producing three hazard classifications: safe (vibration <5% and humidity <3.5%), alert (vibration <5% and humidity >3.5%), and danger (vibration >5% and humidity >3.5%). Nevertheless, the system only measured humidity and vibration parameters, which may reduce the overall accuracy and comprehensiveness of landslide detection.

Another study conducted [8-9] implemented landslide detection using the FC-28 Soil Moisture Sensor based on NodeMCU ESP8266. The system provided soil moisture values in percentage form, slope gradient measurements, and condition status information categorized as alert or danger. The soil moisture measurement demonstrated relatively good performance, with an error value of 9.30%, a linear regression equation of $y = 0.9929x - 2.5336$, and an R^2 value of 0.9965. However, the notification mechanism exhibited an average delivery delay of 8.60 seconds. This delay indicates that although the measurement performance was adequate, the communication aspect still requires improvement to support more responsive real-time early warning applications.

The application of LoRa communication, which has a wide range and allows data transmission over long distances, even in areas with limited internet connectivity, so that its use in remote areas that are not covered by GSM signals is resolved [10]. While previous studies have utilized either SMS-based alerts or single-parameter sensors, this research introduces a novel integration of a dual-parameter sensor suite (displacement and tilt) with a LoRa communication module for data transmission to an IoT-based dashboard. This specific combination aims to provide a more reliable and comprehensive early warning solution for remote, infrastructure-limited areas, addressing both the communication gap and the need for multi-parametric monitoring in a single, low-cost device [11]. The tilt sensor applied to detect ground movement using a gyroscope sensor has proven effective in identifying ground movement that detects landslides [12].

The constraints on the landslide early detection system presented indicate the need for further technological development, especially in terms of communication and accuracy. The use of SMS as a communication medium still has limitations, especially in remote areas that are not covered by GSM signals. In addition, the IoT base also faces challenges in terms of latency (delays in network communication) and dependence on a stable internet connection [2]. The next obstacle is in the sensors used by previous researchers. For example, in [9] research using the FC-28 Soil Moisture Sensor, it works to read the amount of water content in the soil. However, the YL-69 sensor is more suitable for use in design tools because it is cheaper, more stable and precise, while the FC-28 sensor only has the advantage of a 1024-bit ADC value range starting from 0–1023 bits [13].

Currently, landslides frequently occur in Indonesia, particularly in mountainous and high-rainfall regions. Common contributing factors include deforestation and tree felling on slopes, as well as unpredictable natural conditions such as prolonged rainfall and soil instability, which can trigger slope failure. These events often impact residential areas, resulting in infrastructure damage and, in severe cases, fatalities. To address this issue, an early detection system with reliable and real-time internet-based communication is required to improve disaster preparedness. Therefore, this research was conducted to design and evaluate the performance specifications of a landslide early detection device intended to enable remote monitoring of potentially unstable slopes without the need for direct on-site observation.

2. METHOD

The research conducted is engineering research. Engineering research applies science into a plan to obtain performance that meets specified requirements. The steps of engineering analysis research include ideas and definition of requirements (literature study), initial tool plan, geometric and functional arrangement, detailed design, tool making and testing [14]. The quantities included in the data in this study are landslides, slope gradients, LoRa error data transmission distance, accuracy, and precision of the landslide early detection tool. This landslide early detection tool will use several electronic components such as Arduino UNO microcontroller, NodeMCU ESP32 microcontroller, LoRa Module, slope gradient sensor and ground displacement sensor. At the arrangement, geometry, and function stages, all components of the designed system will be arranged geometrically based on their functions. The geometric arrangement of the landslide early detection tool block diagram can be seen in Figure 1.

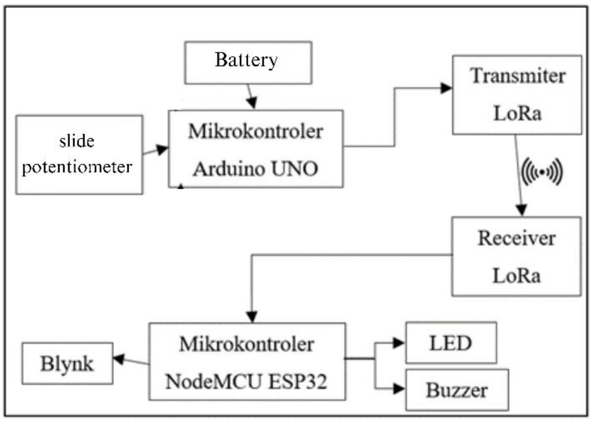

Figure 1. Block diagram of landslide early detection tool

In Figure 1, Arduino UNO will read the values of the sensors installed on the Arduino UNO. The results of the sensors will be forwarded to the LoRa Transmitter. The LoRa Transmitter sends the data results to the LoRa Receiver and then forwarded again to the NodeMCU ESP32. The data received by the ESP32 is then processed and sent to Blynk. When the data read shows signs of a landslide, the buzzer and LED will be activated as a danger indicator.

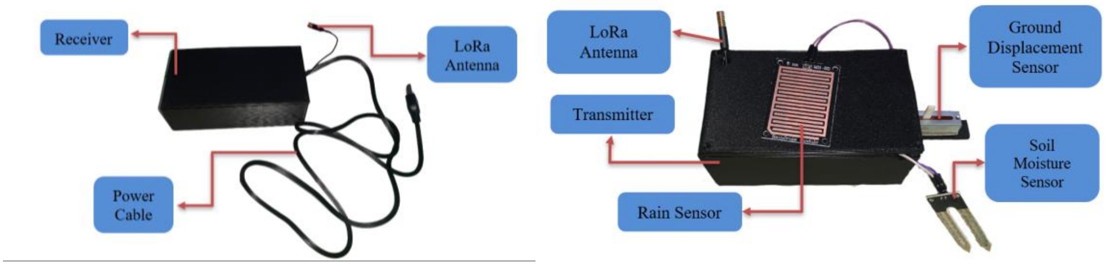

Figure 2. Design of Early Detection Tool for Landslides

Based on Figure 2, it can be seen that the initial design of the landslide early detection tool consists of a transmitter box and a receiver box. In the transmitter section, there is a LoRa module that functions as a signal sender, a tilt sensor that functions to detect changes in slope angle, and a sliding potentiometer that is used to detect ground movement. All data from the sensor is processed by Arduino Uno as the main microcontroller on the transmitter. Meanwhile, in the receiver section, there is a LoRa module that functions as a signal receiver from the transmitter, a buzzer and LED as warning indicators, and a NodeMCU ESP32 that acts as a processor of all components in the receiver section

Based on the flowchart in Figure 3, the initial step is to declare LoRa communication by the receiver and transmitter. Then the transmitter reads the sensor data and then sends it to the receiver. Next, the receiver receives the data and processes it and then sends it to Blynk.

Data collection techniques and tool performance testing include tool precision and accuracy. In this study, ADC parameters, ground shift and slope were tested by looking at the data read by the microcontroller via a serial monitor on the Arduino IDE program or the Blynk application on Android. Furthermore, data collection and the second test were to determine ground shift and slope using standard tools so that ground shift and slope data could be characterized which aimed to ensure the accuracy of the tool's work. However, before testing, several components were first characterized to improve the accuracy and consistency of measurements on the ground shift sensor and the MPU6050 GY-25 sensor. After the characterization process was implemented on the detection tool, the tool was tested by collecting test data and analyzing experimental data to obtain conclusions from the measurement system

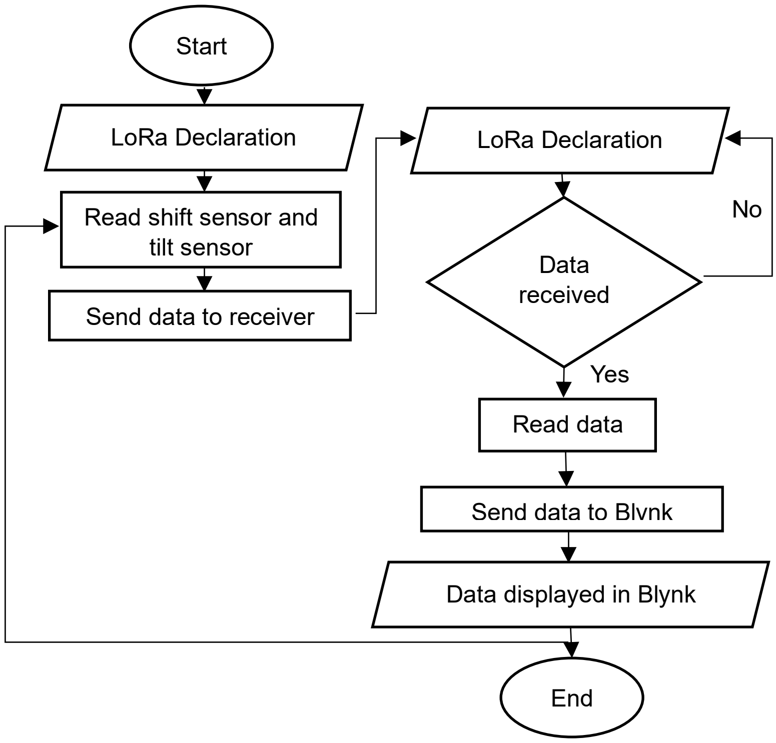

Figure 3. Microcontroller Design Flowchart

3. RESULTS AND DISCUSSION

Based on the results of the experiments and data analysis that have been carried out, both through graphical representation and statistical calculations, the research results are obtained in accordance with the research objectives. The research results are in the form of performance specifications and design specifications. Performance specifications are determined by identifying the function of the components of the landslide early detection tool. While the design specifications are determined from the results of testing which can measure changes in physical parameters (shift and slope) which are early indications of potential landslides.

Performance specifications consist of the manufacture of tool mechanics, tool electronic circuits, characteristics of the sliding potentiometer shift sensor and characteristics of the MPU6050 GY-25 tilt sensor. The tool mechanics were successfully developed and produced a landslide early detection tool that can send data home using LoRa and can be displayed directly on a smartphone. This tool consists of an electronic circuit that can support the measurement of slope, shift, soil moisture and rain conditions with high accuracy and precision. The measurement results obtained by the transmitter will be sent to the receiver. At the receiver the data will be processed and sent for monitoring via Blynk. The results demonstrate that the proposed system is capable of measuring variations in physical parameters, specifically displacement and slope, which function as preliminary indicators of potential landslide occurrence, while enabling real-time monitoring through an Internet of Things (IoT)-based platform.[6].

The first experiment was conducted to determine the relationship between the shift distance and the ADC value of the sliding potentiometer. Based on the results of the sliding potentiometer sensor reading test against the variation of the shift distance, a graph was obtained as in Figure 4 below.

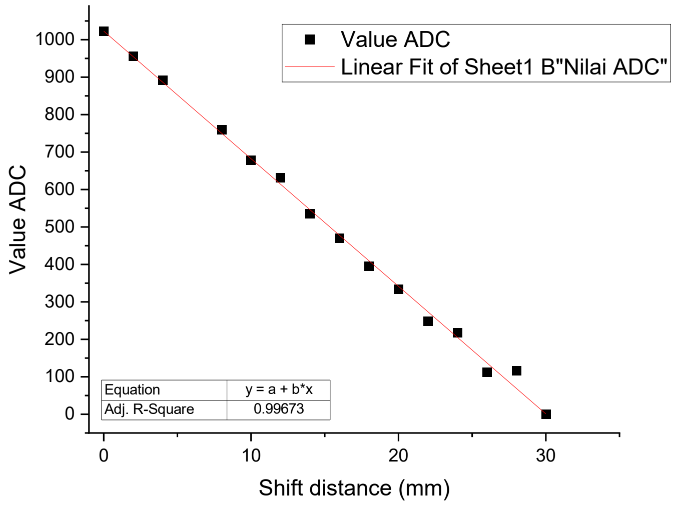

Figure 4. Relationship between Shift Distance and ADC Value of Slide Potentiometer

From the diagram (Figure 4) it can be seen that the shift distance is inversely proportional to the ADC value. The higher the shift distance, the smaller the resulting ADC value. This is because the output of the sliding potentiometer sensor is an analog voltage that is inversely proportional to the shift distance [15].

Next, testing was carried out to determine the characteristics of the MPU6050 GY-25 sensor. This experiment was carried out by comparing the output of the sensor with the actual slope. The purpose of this experiment was to determine the suitability of the sensor output in detecting the output. The results of this experiment are presented in the form of a scatter plot, which can be seen in Figure 5.

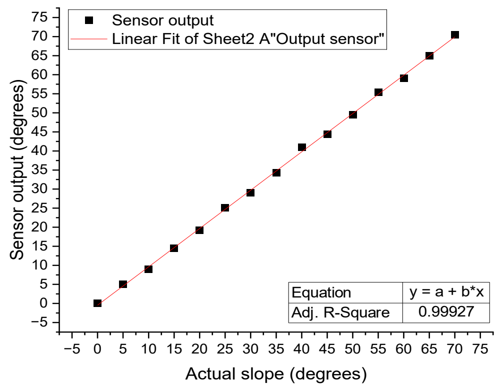

Figure 5. Relationship between MPU6050 GY-25 Sensor Output and Actual Tilt

From the diagram (Figure 5) it can be seen that the output value of the MPU6050 GY-25 sensor is straight with the actual slope. The greater the slope value, the greater the output value of the MPU6050 GY-25 sensor produced. This is because the output of the MPU6050 GY-25 sensor is in the form of linear acceleration on the x, y and z axes which is directly proportional to the slope [16].

Design specifications are a measure that describes the standards or criteria that a product must achieve and how the product works (Hidayat and Yohandri 2021) [17]. Design specifications include the accuracy and precision of tool measurements in detecting shifts and slopes. The accuracy of the shift sensor can be seen from the comparison of the shift distance readings from the measuring instrument with a ruler. The results of the shift sensor accuracy test are presented in Table 1.

Table 1. Results of measuring the estimated value of the tool are tested against the reading results on the ruler

Trial-	Actual Displacement (mm)	Tool Shift (mm)	Difference	Accuracy (%)
1	12	11.47	0.53	95.583
2	14	14.28	0.28	98.0000
3	16	16.22	0.22	98.6250
4	18	18.42	0.42	97.6667
5	20	20.21	0.21	98.9500
6	22	22.70	0.70	96.8182
7	24	23.61	0.39	98.3750
8	26	25.42	0.58	97.7692
9	28	28.06	0.06	99.7857
10	30	30.00	0.00	100.0000

Based on Table 1. the results of the trial data show that the difference in the measurement results of the largest shift distance is at a difference of 0.70 mm with a ruler distance of 22 mm with a measurement accuracy of 96.8182%. The shift value of the tool tested with the same ruler (Difference: 0) is at a distance of 30 mm with a measurement accuracy of 100%. The average accuracy of the shift sensor is 98.147%. This proves that the value between the tested sensor shifts has almost the same value as the ruler. Furthermore, the data from the tilt sensor accuracy test results are presented in Table 2.

Table 2. The tool's estimated value measurements are compared to the arc's reading results.

Trial-	Arc Tilt (degrees)	Tool Tilt (degrees)	Difference	Accuracy (%)
1	0	0.01	0.01	100.000
2	10	9.04	0.96	90.4000
3	15	14.52	0.48	96.8000
4	20	19.15	0.85	95.7500
5	25	25.12	0.12	99.5200
6	30	29.01	0.99	96.7000
7	35	34.37	0.63	98.2000
8	40	40.98	0.98	97.5500
9	45	44.35	0.65	98.5556
10	50	49.52	0.48	99.0400

Based on Table 2. the results of the trial data show that the largest difference in the slope measurement results is at a difference of 0.99 degrees with a slope of 30 degrees with a measurement accuracy of 96.7000%. The slope value of the tool tested with the bow that has the lowest difference is at a slope of 0 degrees with a measurement accuracy of almost 100%. The average accuracy of the slope sensor is 97.252%. This proves that the value between the slopes of the sensors tested has almost the same value as the bow.

The precision of the landslide early detection tool is the accuracy of the reading of the shift and slope values. This accuracy is seen from the approach of the sensor value to the results of repeated measurements. The expected result of this test is that the repeated measurement value does not change and remains the same. The results of the shift sensor accuracy test are presented in Table 3.

Table 3. Measurement Results of the Precision of the Displacement Sensor

Trial-	Actual Displacement (mm)	Tool Shift (mm)	Difference	Precision (%)
1	15	14.96	0.04	99.7333
2		14.99	0.01	99.9333
3		14.96	0.04	99.7333
4		14.99	0.01	99.9333
5		15.01	0.01	99.9333
6		14.66	0.34	97.7333
7		14.93	0.07	99.5333
8		14.90	0.10	99.3333
9		14.99	0.01	99.9333
10		14.96	0.04	99.7333

Based on Table 3, it can be seen that the accuracy of the landslide early detection tool is no different from the ruler value in detecting shifts. Analysis of the results of the experimental data, as many as 10 repeated measurements obtained an average percentage of shift reading error of 0.447% with the highest accuracy level reaching 99.933%. The average accuracy of the shift sensor is 99.553%. Therefore, the performance test of the tool shows that the accuracy of the shift sensor reading provides accurate reading accuracy and functions properly. Furthermore, the accuracy test data for the slope sensor is presented in Table 4.

Table 4. Measurement Results of the Precision of the Tilt Sensor

Trial-	Arc Tilt (degrees)	Tool Tilt (degrees)	Difference	Precision (%)
1	45	45.35	0.35	99.2222
2		45.29	0.29	99.3556
3		44.65	0.35	99.2222
4		45.14	0.14	99.6889
5		45.18	0.18	99.6000
6		45.79	0.79	98.2444
7		46.20	1.20	97.3333
8		45.13	0.13	99.7111
9		45.33	0.33	99.2667
10		44.60	0.40	99.1111

Based on Table 4, it can be seen that the accuracy of the slope sensor is not much different from the actual slope. Analysis of the results of the experimental data, as many as 10 repeated measurements obtained an average percentage of slope reading error of 0.924% with the highest accuracy level reaching 99.711%. The average accuracy of the slope sensor is 99.076%. Therefore, the performance test of the tool shows that the reading accuracy of the landslide early detection tool provides accurate reading accuracy and functions well. The results of the performance test show that the accuracy and precision of the parameter readings on the Landslide Early Detection Tool are more than 70%, meaning that the landslide early detection tool works well and provides accurate reading [18].

This landslide early detection tool has advantages and disadvantages in its use. This tool is able to detect important parameters such as slope and land shift with a fairly high level of accuracy and precision compared to standard tools. This system relies on LoRa-based wireless communication and is displayed in real-time via the

Blynk application, making it easy to monitor via smartphone even in areas without GSM or 4G signals [6]. However, this tool has limitations such as the LoRa range which only reaches 100 meters and is not yet equipped with electronic safety components. Further development is highly recommended, such as the addition of high-gain antennas, cloud system integration, and increased power efficiency. With its contribution in applying the principles of instrumentation physics and geophysics, this tool shows great potential in the development of sensor-based and IoT disaster detection systems.

4. CONCLUSION

Based on the test results, data analysis, and discussion of the design of early detection tools for landslides, several conclusions can be put forward from this study, namely: The performance specifications for the design of early detection tools for landslides based on LoRa and IoT consist of two parts, namely mechanical system design and electronic system design. The mechanical system design consists of a receiver box, transmitter box and sensor position along with electronic circuits. The electronic system design consists of a series of system components including Arduino UNO, NodeMCU ESP32, LoRa Module, sliding potentiometer sensor, MPU6050 GY-25 sensor, Buzzer, LED and battery. The results of sensor detection can be displayed on the serial monitor via the Arduino IDE application or on the Blynk application on Android. The design specifications for the LoRa and IoT-based landslide detection tool consist of two parts, namely the accuracy and precision of the landslide detection tool measurements with the following details: The average percentage of error in reading shift and slope values is 0.447% and 0.924% with an average accuracy of 98.147% and 97.252% respectively and an average precision of 97.251% and 99.553% respectively.

ACKNOWLEDGMENTS

The author extends heartfelt thanks to the Department of Physics and, in particular, to the Electronics and Instrumentation Laboratory at Universitas Negeri Padang for providing the research facilities that significantly facilitated the data collection process. The author also does not forget to express his deepest gratitude to all colleagues who have provided assistance, support and contributions in perfecting this article.

DECLARATIONS

Authorship contribution

Vita Nuova: Conceptualization, methodology, formal analysis, software and writing.

Asrizal and Yenni Darvina: Validation, writing-review and editing.

Competing Interest

The authors declareno conflict of interest in this study.

Funding statement

This work has not been funded by any person or organization.

Ethical Clearance

There are no human subjects in this manuscript, and informed consent is not applicable.

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