
Low-Cost IoT-Based Landslide Early Warning System

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Abstract — EWS (Early Warning System) or commonly called an early warning system is an electronic circuit designed to detect systematically that will be monitored online. In this early warning system, it designs a landslide or landslide disaster. This tool uses two microcontrollers including Arduino Nano as a support for data results from both sensors and ESP32-DevKit V1 as a data receiver that has been processed on Arduino Nano and sending data to Blynk Console via 4G LTE WiFi Modem Module with a delay of 48 seconds to get a good signal and a delay of 30 seconds to initiate a connection with the ESP32 DevKit V1 microcontroller. The Slide Potentiometer Sensor which is used to determine the indication of a landslide shift, which has 2 parameters Alert (2-3 cm) and Warning (4-6 cm) with a sensor accuracy level of 98.48%, and has a Soil Moisture Sensor which plays an additional role and indication and humidity conditions in the soil with a sensor accuracy of 90.15%. Thus, both sensors are delivered in an integrated manner with the MQTT Blynk Console application which can provide real-time notifications.

Keywords – Integrated, real-time, landslide, EWS, low-cost

I. INTRODUCTION

Indonesia is an archipelagic country located at the confluence of three major global plates: the Indo-Australian Plate, the Eurasian Plate, and the Pacific Plate [1]. The presence of volcanic belts in this region has resulted in the formation of mountains and hills with slopes varying from gentle to steep. This condition makes Indonesia prone to landslides, which can result in loss of life, material loss, and environmental damage [2].

Natural disasters, also known as natural disasters, are natural events that significantly impact the human population. Types of natural disasters include floods, volcanic eruptions, earthquakes, tsunamis, landslides, snowstorms, droughts, hailstorms, heat waves, hurricanes, tropical storms, typhoons, tornadoes, forest fires, and disease outbreaks [3]. According to data from the National Disaster Management Agency (BNPB), between 1815 and 2011, approximately 5,500 disasters occurred in Indonesia. Floods dominated the disasters with 3,450 incidents, followed by landslides with 1,282 incidents. Meanwhile, geological disasters such as earthquakes, tsunamis, and volcanic eruptions account for only about 4% of the total number of events, yet they cause approximately 265,431 fatalities and significant losses [4].

Landslides are geological phenomena in which large masses of soil or rock move downward due to gravity. The causes of landslides can vary, including

unstable ground conditions and human activity. While gravity is the primary factor, other factors such as erosion, excessive rainfall, earthquakes, volcanic activity, and excessive loads on the ground also contribute [5]. The threat of landslides often increases in November when rainfall intensity increases. The long dry season causes water to evaporate from the soil surface, which then creates cracks. When it rains, water enters these cracks, causing the soil to expand rapidly and increasing the risk of landslides, especially if the soil is saturated with water for a short period of time. The presence of trees on slopes can help prevent landslides because tree roots absorb water and bind the soil. However, other factors such as weaknesses in rock slopes, earthquakes, human activity, and excessive loads can also trigger landslides [5].

An Internet of Things (IoT)-based landslide early warning system with ultrasonic sensors and soil moisture sensors uses an ESP8266 microcontroller module for internet network access. This system is capable of monitoring soil movement and water content in real time via a web server and sending instant notifications. If the ground shift exceeds 15 cm, the system will issue a warning signal in the form of a buzzer, thus increasing preparedness in anticipating landslides. A weakness of this system is its reliance on ultrasonic sensors, which can incorrectly detect objects approaching the sensor. If such interference occurs, the sensor may send false signals to the web server,

indicating a potential landslide when none actually occurs. [6]

The Internet of Things (IoT)-Based Landslide-Prone Zone Monitoring and Early Warning System uses an MPU6050 accelerometer sensor to detect landslide symptoms. When the sensor detects danger signs, the system sounds an alarm and sends sensor data to a cloud database. This data can then be accessed through an Android-based monitoring application, providing a warning signal to the user. The advantage of this system is its ability to provide early warnings directly to smartphones. However, the main drawback of this system is the use of Raspberry Pi as a publisher, which has a high cost and makes it unaffordable [7].

II. RESEARCH METHOD

A. Research Approach

This research adopts an experimental and prototyping approach, focusing on the design, development, and performance evaluation of an integrated landslide early warning system (EWS). The system combines multiple sensors with Internet of Things (IoT) technology to detect early soil displacement and soil moisture variations. The research method consists of five main stages: (1) literature review and requirements identification, (2) hardware design, (3) software design, (4) system integration and testing, and (5) data analysis and performance evaluation. Each stage is executed iteratively to ensure the prototype meets both functional and technical specifications defined by national standards (SNI 8235:2017 and SNI 9021:2021).

B. Hardware Design

The system employs two microcontrollers: Arduino Nano, which processes analog sensor data from the Potentiometer Slide and Soil Moisture Sensor (YL-69). ESP32-DevKit V1, which serves as the main controller for data transmission to the cloud via a 4G LTE WiFi modem. Both modules communicate using serial protocol (UART) to ensure reliable data transfer between microcontrollers. The power supply uses a 12 V DC adapter with regulated 5 V for sensor operation.

Potentiometer Slide Sensor: Detects ground displacement within 0–10 cm. Displacement levels are classified into three alert categories following SNI 8235-2017: Safe (0–3 cm), Alert (3–6 cm), and Danger (6–10 cm). The sensor achieved an accuracy of 98.48% with a regression correlation of $y = 0.9576 + 0.00405x$. **Soil Moisture Sensor YL-69:** Measures soil humidity from 0–100%. Data are converted from ADC readings into percentage values with an accuracy of 90.15%. Moisture levels are classified as Safe (0–35%), Alert (35–70%), and Danger (70–100%).

C. Interface Design

The interface design focuses on developing an intuitive and responsive monitoring dashboard that allows users to easily interpret sensor data and system alerts in real time. The interface was implemented using the Blynk IoT platform, which provides a cloud-based

environment for visualizing data transmitted from the ESP32 microcontroller via MQTT protocol. The design includes several key widgets such as real-time value displays for soil moisture (%) and ground displacement (cm), status indicators for Safe, Alert, and Danger conditions, and a notification panel for automatic warnings. A color-coded scheme (green for safe, yellow for alert, and red for danger) was applied to ensure immediate recognition of critical conditions. This interface layout was optimized for both mobile and desktop views, enabling field operators or users to access monitoring data anytime and anywhere through smartphones or computers connected to the internet.

In addition to visualization, the interface provides a data logging and history feature, allowing users to track environmental changes over time. This feature assists in analyzing long-term trends that may indicate potential landslide risks. Furthermore, the system supports push notifications, ensuring that users receive alerts even when the monitoring dashboard is not actively opened. The design also incorporates security features by using authenticated Blynk tokens to prevent unauthorized data access. Through this interface, the overall system enhances usability and reliability, allowing for proactive decision-making in landslide-prone areas.

III. RESULT

Figure 3.1 shows that this system consists of seven components. The system uses an ESP32-DEVKIT V1 as the main microcontroller for data transmission and processing from the Arduino Nano, as well as data communication via a 4G WiFi modem to the Blynk Console application. The system utilizes two sensors: a Slide Potentiometer and a YL-69 Soil Moisture Sensor, which operate at 5V to detect soil movement and moisture. Data from both sensors is sent via serial communication between the Arduino Nano and the ESP32-DEVKIT V1, then forwarded to the Blynk Console application.

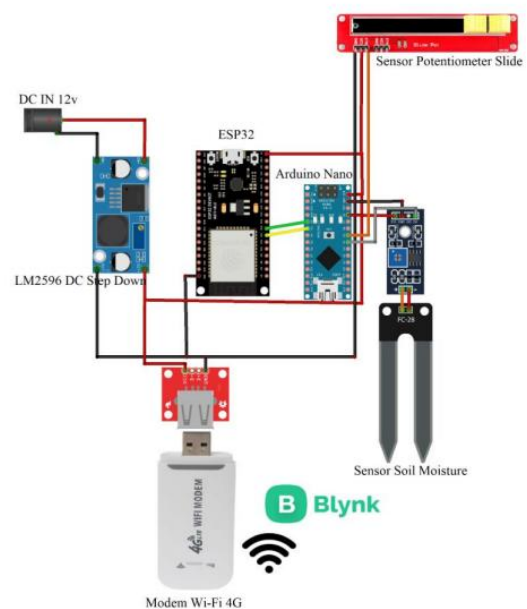


Fig. 1. System electronic of EWS

The system is powered by a 12V DC adapter. Figure 3.2 shows a flowchart of the system design, showing how the devices initiate each other's schematic circuits. There are delays in the initial process, including a 48-second delay for the 4G LTE WiFi modem module when initiating a signal. Then proceed to initiate a microcontroller to connect automatically with a 30 second delay.

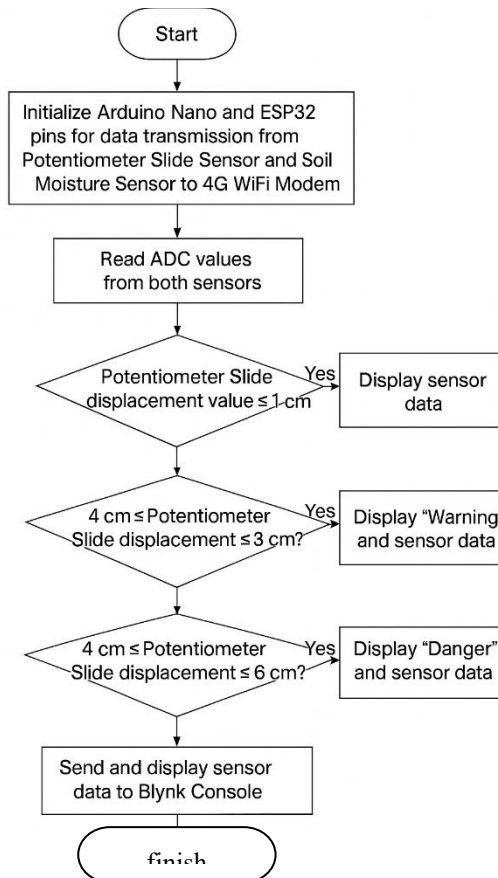


Fig.2. System Flowchart

The flowchart illustrates the working logic of the IoT-based Landslide Early Warning System. The process begins with the initialization of the Arduino Nano and ESP32 microcontrollers, which establish communication between sensors and the cloud via a 4G WiFi modem. Once initialized, the system continuously reads analog values (ADC) from the Potentiometer Slide Sensor and Soil Moisture Sensor. The displacement value from the potentiometer determines the system's alert level: if the ground shift is ≤ 1 cm, the condition is considered Safe; if it lies between 2 cm and 3 cm, the system issues a "Warning" alert; and if the displacement exceeds 4 cm up to 6 cm, the system triggers a "Danger" alert. Each condition also displays the corresponding soil moisture percentage to give context about the environment. Finally, all processed data are transmitted to the Blynk Console in real time, where users can visualize sensor

readings and receive immediate alerts through the connected IoT dashboard.

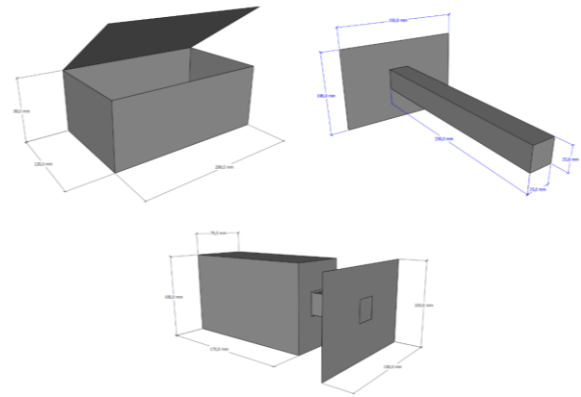


Fig.3. 3D design for electronic component house

Figure 3. shows a three-dimensional design made from acrylic, chosen for its strength and durability. This design was designed to meet long-term strength and durability standards, ensuring aesthetics, functionality, and longevity. This device requires an electronic circuit shield to protect it from environmental conditions. This study designed two acrylic shields: one cube measuring 20 cm x 12 cm x 8 cm for the data transmission device, and one rectangular shield measuring 17 cm x 7 cm x 10 cm with a cross-sectional area of 15 cm x 10 cm for the sensor reading device. The acrylic shield was chosen because it is more durable than the shields used in 3D printers, which use filament and are layered.

IV. DISCUSSION

This chapter presents the results of the hardware and software implementation of the proposed IoT-based Landslide Early Warning System. The discussion focuses on the analysis of the prototype design, software interface performance, and sensor accuracy evaluation. Each result is discussed based on experimental testing and compared with the system's functional objectives established in the methodology. The hardware design results describe the configuration and implementation of the monitoring module integrated with the Blynk Cloud Console, while the software section explains the MQTT-based communication and alert notification process. Furthermore, sensor calibration and validation are analyzed to determine the reliability and accuracy of both the Slide Potentiometer Sensor and the Soil Moisture Sensor (YL-69) in detecting soil displacement and humidity changes. Through these discussions, the system's effectiveness in providing real-time monitoring and early warning alerts for potential landslides is thoroughly evaluated.

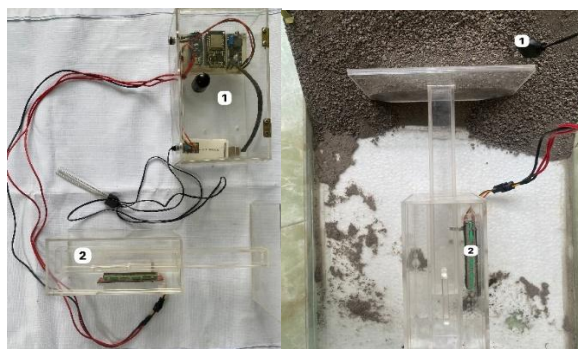
A. Design Results

The resulting tool circuit design is shown in Figure 4a. Point number (1) details several tool designs that act as monitor modules integrated with the Blynk

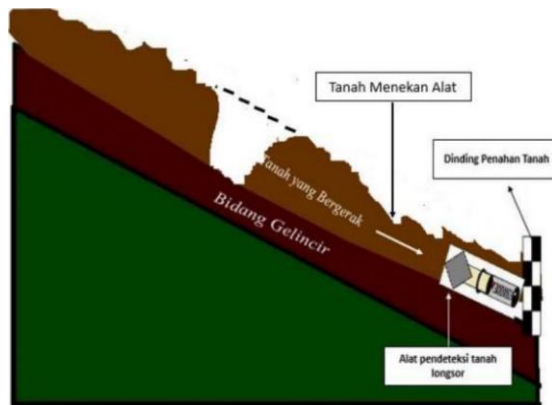
Console, and point number (2) serves as a protector for a Slide Potentiometer Sensor that has a lever to actuate the sensor and also has a cross-sectional area that functions as a cross-sectional container for the area of land to be monitored. The illustration of the implementation at the field is shown in Figure 4b.

B. MQTT-Blynk Console Software Interface

For the software interface used as monitoring that will be used on this tool uses Blynk Cloud Server as data storage and real-time data notification. The design results from the implementation obtained a widget display as shown in Figure 5. This can make it easier for users to monitor the results of this designed tool. If the Slide Potentiometer Sensor has a ground movement of 2-3 cm or 4-6 cm, an alarm notification (Alert) appears as shown in Figure 6.



(a)



(b)

Fig.4. a) Prototype , b) implementation

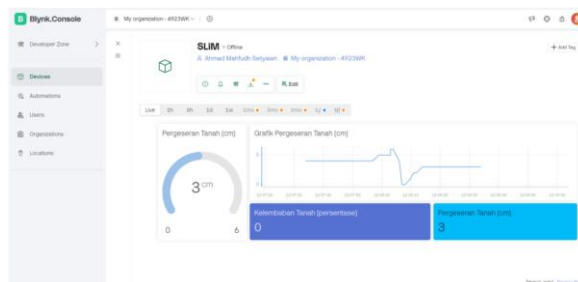


Fig.5. Software Interface Blynk Console

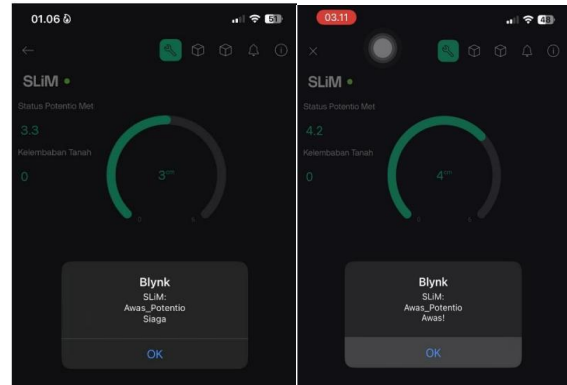


Fig.6. Slide Potentiometer Sensor alarm notification for any ground movement

Table 1. Slide Potentiometer Sensor Error Percentage

Ruler (cm)	ADC to Blynk Coverage Experiment (cm)				Average	Error
	I	II	III	IV		
0	0	0	0	0	0	0
0,5	0,6	0,4	0,5	0,5	0,5	0
1	1	1	1	1	1	0
1,5	1,5	1,5	1,5	1,5	1,5	0
1,7	1,7	1,8	1,7	1,8	1,75	0,05
2	2	2	2	2	2	0
2,1	2,1	2,1	2,1	2,1	2,1	0
2,3	2,3	2,3	2,3	2,3	2,3	0
2,5	2,5	2,5	2,5	2,4	2,475	0,025
2,8	2,8	2,8	2,8	2,8	2,8	0
3	2,9	2,9	3	2,9	2,925	0,075
3,2	3,2	3,2	3,2	3,2	3,2	0
3,5	3,5	3,5	3,5	3,5	3,5	0
3,7	3,7	3,7	3,7	3,7	3,7	0
4	4	3,9	3,9	4	3,95	0,05
4,3	4,3	4,3	4,3	4,3	4,3	0
4,5	4,5	4,5	4,5	4,5	4,5	0
4,8	4,8	4,7	4,8	4,8	4,775	0,025
5	4,9	5	5	5	4,975	0,025
5,4	5,4	5,4	5,5	5,4	5,425	0,025
5,5	5,5	5,5	5,5	5,5	5,5	0
5,9	5,9	6	6	6	5,975	0,075
6	6	6	6	6	6	0
Average Error Difference						0,0152
Percentage Error Difference						1,52%
Sensor Accuracy						98,48%

Table 2. Soil Moisture Sensor Data Test Results

Soil Meter (%)	ADC Value of YL-69	Result at Blynk (%)	Error
50%	350	65%	15
55%	338	67%	12
60%	232	77%	17
65%	292	71%	6
70%	240	76%	6
75%	201	80%	5
80%	125	88%	8
Average Accuracy			9,85
Accuracy			90,15

The YL-69 Soil Moisture Sensor ensures soil moisture measurements by measuring soil resistance and converting it to an ADC value. This ADC value is then converted to a soil moisture percentage using the logic on the Arduino Nano microcontroller with equation (3.4), thus obtaining a data test result listed in Table 3.4. Thus, the sensor accuracy obtained was 90.15%.

V. CONCLUSSION

After design and testing, the Landslide Early Detection System met the proposed specifications, capable of detecting ground shifts and displaying real-time information via the Blynk application with 98.48% accuracy and a 1.52% error rate. The project's objectives were achieved with an effective and efficient system. The landslide classification algorithm performed optimally and provided real-time notifications. However, the accuracy of the soil moisture sensor readings was only 90.15%, so the results were only displayed in Blynk as an additional indicator.

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