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Development of Landslide Sentry Prototype with IoT Monitoring System

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Abstract

An Internet of Things (IoT) Landslide Sentry system has been developed to address the critical need for real-time landslide risk assessment in geohazard-prone areas. The system integrates advanced sensors, including soil moisture, ultrasonic distance, and vibration sensors, with the ESP32 microcontroller. Through extensive calibration testing, the accuracy of each sensor has been validated, with minimal average percentage errors recorded. The project further explores the Blynk dashboard outcomes, showcasing the system's responsiveness to varying soil conditions and potential landslide risk factors. The study aims to design and develop a prototype of an early warning system for landslides using IoT technology, facilitating timely alerts in the event of potential landslide risks. Secondly, the aim is to integrate Blynk for IoT monitoring, enabling the publication of data from the Landslide Sentry system and lastly to ensure the accuracy and effectiveness of landslide detection, allowing for swift response.

1. Introduction

1.1 IoT Landslide Sentry

The IoT Landslide Sentry project addresses critical challenges in geohazard monitoring, particularly in areas prone to landslides [8]. Landslides pose significant risks to infrastructure, ecosystems, and human lives, making proactive monitoring and early warning systems crucial [12]. Traditional monitoring methods lack the precision and real-time capabilities required for effective risk mitigation [6]. In contrast, the proposed Landslide Sentry leverages advanced technologies, including the ESP32 microcontroller and an array of sensors such as soil moisture, ultrasonic distance, and vibration sensors, to provide a comprehensive solution [4].

Geohazard-prone regions demand continuous monitoring to assess soil conditions, detect vibrations, and measure moisture levels accurately [11]. The demand for advanced monitoring systems is crucial due to potential landslide-related losses. Accurate data plays a key role in improving risk reduction strategies and response measures. The Landslide Sentry project aims to bridge the gap by offering a sophisticated monitoring system that not only detects early signs of slope instability but also contributes to informed decision-making and efficient risk management in geohazard-prone regions.

1.2 System Calibration

1.2.1 Calibration of Sensors Testing

Sensor Calibration is indispensable for validating the accuracy and effectiveness of the Landslide Sentry system's sensor readings in real-world conditions [9]. Calibration testing allows us to assess how well the system responds to varying moisture levels and changes in the landscape. To achieve this, a series of controlled tests are conducted where the soil moisture, ultrasonic sensors and vibration sensors are subjected to different environmental conditions. Readings are recorded at each stage, and differences between the expected and recorded values are observed. These variations provide insights into the performance of the calibration constants set during the coding phase.

Subsequently, the percentage error is calculated by comparing the observed differences with the expected values [2]. This step is crucial for quantifying the accuracy of the sensor readings and fine-tuning the calibration constants if necessary. The testing phase, with its meticulous recording and analysis, ensures that the Landslide Sentry system responds with precision to diverse conditions, providing reliable data for effective risk assessment.

1.2.2 Repeatability Testing

Repeatability Testing involves subjecting the system to repetitive scenarios, each stage representing specific environmental conditions. This phased approach is crucial for assessing how consistently the system responds to the same set of conditions across different stages.

In each stage of Repeatability Testing, controlled environmental conditions are replicated, and the system's response is observed. The sensors' readings are recorded at each stage to evaluate their performance under varying conditions. This recorded data allows for a comprehensive analysis of how well the system maintains consistency throughout the different stages.

The Repeatability Testing, conducted in stages with recorded data, serves as a critical measure of the system's robustness and resilience [10]. It ensures that the Landslide Sentry system can consistently deliver accurate readings across a spectrum of environmental conditions, making it a reliable tool for continuous landslide risk assessment.

1.3 IoT Data System Dashboard

Blynk, a versatile [7] and user-friendly platform [1], plays a central role in establishing seamless connections and facilitating real-time monitoring. Its intuitive interface simplifies the process of configuring dynamic links between hardware components, ensuring efficient communication and control.

Blynk's user-friendly setup is instrumental in visualizing and interacting with sensor data effortlessly [3]. The platform offers a variety of widgets that can be easily customized to display key information, including soil moisture levels, ultrasonic sensor readings, and vibration alerts [13]. The real-time capabilities of Blynk are particularly crucial for monitoring ever-changing environmental conditions, providing instant updates for timely decision-making [5].

2. Materials and Method

In this project, the focus is on designing and simulating a prototype IoT Landslide Sentry system. Fig. 1 depicts the circuit diagram visualized through Fritzing, providing a comprehensive overview of the electronic connections within the system and Fig. 2 illustrates the complete landslide sentry prototype. Calibration of sensors testing is carried out by the prototype system.

To ensure the accuracy of the sensor readings across diverse environmental conditions, the prototype conducts sensors calibration tests involving soil moisture, ultrasonic, and vibration sensors. For the soil moisture sensor, varying moisture levels (25%, 50%, 75%, and 100%) are applied to distinct soil samples, and the readings are compared to expected levels. Similarly, the ultrasonic sensor's accuracy is verified by placing known objects at different distances (50 cm, 40 cm, 30 cm, 20 cm, and 10 cm) in front of it. This process assesses whether the readings align with the actual distances. Regarding the vibration sensor, its reliability in detecting low, medium, and high vibration intensities is validated under different conditions.

The Landslide Sentry system operates in four stages: Sentry (normal moisture), Alert (moisture above trigger), Warning (moisture above trigger and vibration), and Critical (present of vibration and ultrasonic sensor detect something within 10cm) or (present of vibration and ultrasonic sensor detect something within 10cm and moisture above trigger value). These stages allow the system to respond effectively to varying levels of landslide threats.

The repeatability test was conducted with meticulous attention to each monitoring level: Sentry, Alert, Warning, and Critical. The primary objective was to evaluate the sensors' consistency and reliability, ensuring that they deliver precise and reproducible readings throughout the distinct phases of the monitoring process. This stage-specific analysis provides a comprehensive understanding of sensor reliability at each level, assuring that the Landslide Sentry system maintains its accuracy and dependability consistently throughout its operational lifecycle.

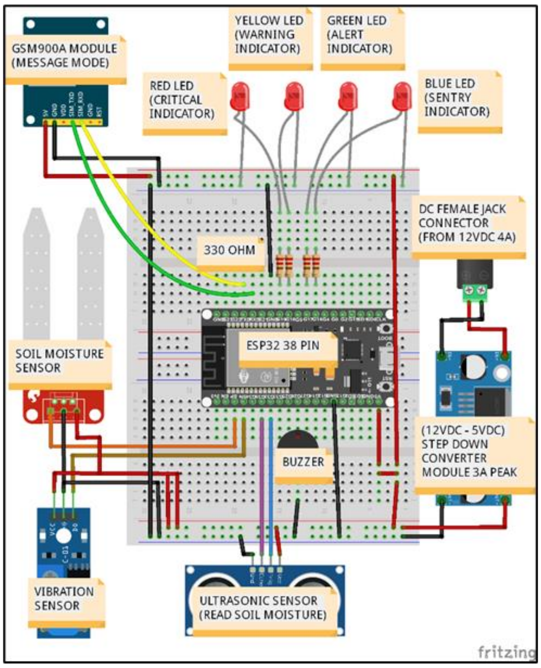
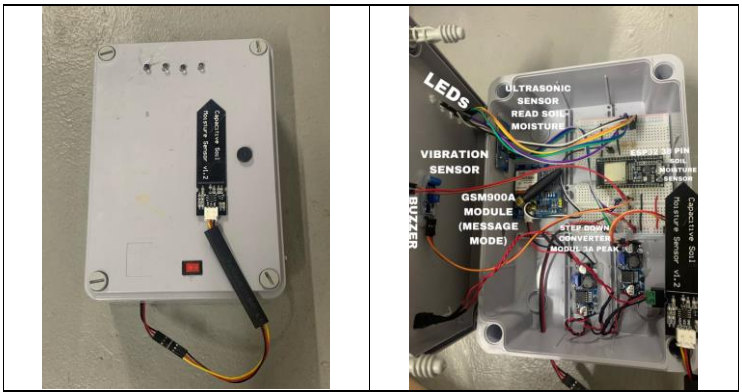


Fig. 1 *Circuit diagram visualized through Fritzing*



(a)	(b)

Fig. 2 *Landslide sentry prototype (a) Outer part of prototype (b) Inner side of prototype*

In this project, the Blynk platform played a pivotal role in creating a real-time data system for process automation. Fig. 3 provides an illustration of the Blynk dashboard, highlighting the essential properties of each virtual pin that require configuration. Essential for precision, configuring Blynk virtual pins involves adjusting parameters such as value ranges, visual design, and input data binding, ensuring accurate value display upon deployment.

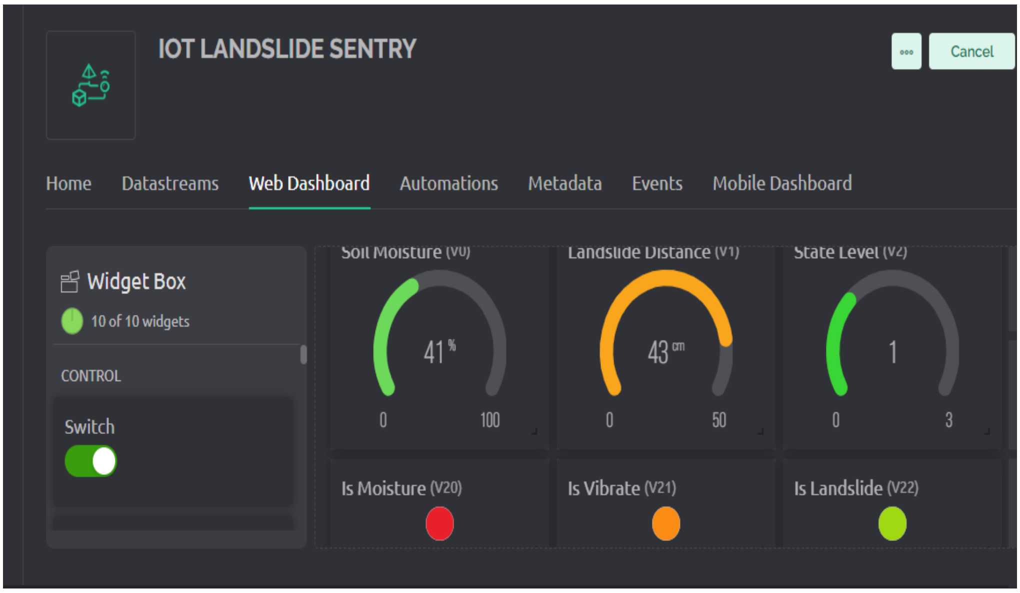


Fig. 3 *Blynk dashboard*

3. Result and Discussion

3.1 Sensor Data Calibration Testing

In this project phase, sensor data testing assessed the performance of integrated sensors, including soil moisture, ultrasonic distance, and vibration. The goal was to validate sensor accuracy at different monitoring stages, ensuring reliable data for landslide risk assessment.

3.1.1 Soil Moisture Sensor Calibration Testing

Table 1, 2, 3 and 4 illustrate the findings of the Soil Moisture Sensor Calibration Test for 25%, 50%, 75%, and 100% moisture levels.

Table 1 *Soil Moisture Sensor Calibration Test Results (25% Moisture Level)*

Soil Moisture Reading (%)	Expected Reading (%)	Sensor Reading (%)	Percentage Error (%)
25	25	25	0
		24	-4
		24	-4
		25	0
		25	0

Table 2 *Soil Moisture Sensor Calibration Test Results (50% Moisture Level)*

Soil Moisture Reading (%)	Expected Reading (%)	Sensor Reading (%)	Percentage Error (%)
50	50	49	2
		50	0
		50	0
		50	0
		51	2

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Table 3 *Soil Moisture Sensor Calibration Test Results (75% Moisture Level)*

Soil Moisture Reading (%)	Expected Reading (%)	Sensor Reading (%)	Percentage Error (%)
75	75	75	0
		75	0
		75	0
		74	1.33
		75	0

Table 4 *Soil Moisture Sensor Calibration Test Results (100% Moisture Level)*

Soil Moisture Reading (%)	Expected Reading (%)	Sensor Reading (%)	Percentage Error (%)
100	100	100	0
		100	0
		99	1
		100	0
		100	0

The average percentage error for table 1, 2, 3, and 4 are -1.6%, 0.8%, 0.27% and 0.2%. With consistently low average percentage errors, the prototype demonstrates reliable measurement accuracy, reinforcing its effectiveness for risk assessment in geohazard-prone regions. Figure 4 illustrate the graph of soil moisture reading vs sensor reading for 20%, 50%, 75% and 100% moisture level.

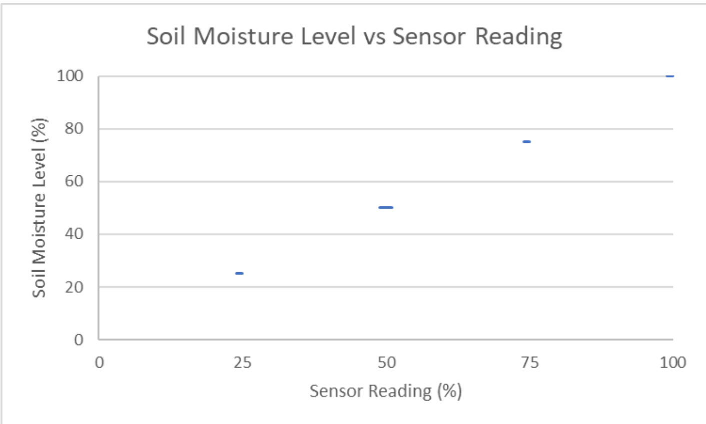

Fig. 4 *Graph soil moisture level vs sensor reading*

3.1.2 Ultrasonic Sensor Calibration Testing

The results in Table 5, 6, 7, 8, and 9 illustrate the outcomes of the ultrasonic sensor calibration test across different distances affirming its accuracy in distance measurement.

Table 5 *Ultrasonic Sensor Calibration Test Result (50 cm)*

Distance (cm)	Expected Reading (cm)	Sensor Reading (cm)	Percentage Error (%)
50	50	50	0

		50	0
		50	0
		49	2
		50	0

Table 6 *Ultrasonic Sensor Calibration Test Result (40 cm)*

Distance (cm)	Expected Reading (cm)	Sensor Reading (cm)	Percentage Error (%)
40	40	40	0
		40	0
		40	0
		40	0
		40	0

Table 7 *Ultrasonic Sensor Calibration Test Result (30 cm)*

Distance (cm)	Expected Reading (cm)	Sensor Reading (cm)	Percentage Error (%)
30	30	30	0
		30	0
		29	3.33
		30	0
		30	0

Table 8 *Ultrasonic Sensor Calibration Test Result (20 cm)*

Distance (cm)	Expected Reading (cm)	Sensor Reading (cm)	Percentage Error (%)
20	20	20	0
		20	0
		19	5
		19	5
		20	0

Table 9 *Ultrasonic Sensor Calibration Test Result (10 cm)*

Distance (cm)	Expected Reading (cm)	Sensor Reading (cm)	Percentage Error (%)
10	10	10	0
		10	0
		9	10
		9	10
		10	0

The average percentage error for table 5, 6, 7, 8 and 9 are 0.4%, 0%, 0.67%, 2% and 4%. These minimal errors highlight the ultrasonic sensor's accuracy in distance measurements, ensuring its reliability in detecting objects within the specified range. Figure 5 illustrate the graph of distance vs sensor reading for 50cm, 40cm, 30cm, 20cm, 10cm.

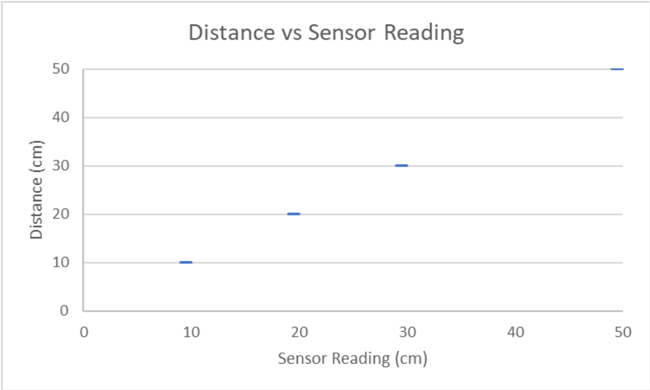

Fig. 5 *Graph distance vs sensor reading*

3.1.3 Vibration Sensor Calibration Testing

The results in Table 10 illustrate the outcomes of the vibration sensor calibration test across different intensity level.

Table 10 *Vibration Sensor Calibration Testing Across Intensity Levels*

Test Condition	Expected Vibration	Observed Vibration
Low Intensity	Present	Present
Medium Intensity	Present	Present
High Intensity	Present	Present

The vibration sensor calibration testing confirmed the sensor's accuracy in detecting varying intensities of vibrations. The consistent and precise outputs ensure the reliability of the Landslide Sentry system in monitoring environmental conditions.

3.2 Repeatability Testing

Table 11, 12, 13, 14 shows the repeatability test according to stages.

Table 11 *Repeatability Test Output for Sentry Level*

Soil Moisture Reading (%)	Ultrasonic Distance (cm)	Vibration Presence	LED Indicator
25	50	No	Blue
24	51	No	Blue
25	50	No	Blue
25	49	No	Blue
25	52	No	Blue

Table 12 *Repeatability Test Output for Alert Level*

Soil Moisture Reading (%)	Ultrasonic Distance (cm)	Vibration Presence	LED Indicator
51	40	No	Green
51	40	No	Green
52	39	No	Green
51	40	No	Green
50	39	No	Green

Table 13 *Repeatability Test Output for Warning Level*

Soil Moisture Reading (%)	Ultrasonic Distance (cm)	Vibration Presence	LED Indicator
75	30	Yes	Yellow
74	31	Yes	Yellow
75	31	Yes	Yellow
75	32	Yes	Yellow
75	30	Yes	Yellow

Table 14 *Repeatability Test Output for Critical Level*

Soil Moisture Reading (%)	Ultrasonic Distance (cm)	Vibration Presence	LED Indicator
100	10	Yes	Red
98	9	No	Red
99	8	No	Red
100	9	Yes	Red
100	10	Yes	Red

In conclusion, the successful calibration and repeatability tests across the four monitoring stages validate the Landslide Sentry system's reliability and accuracy. The system consistently performs accurately, demonstrating its robustness in detecting potential landslide risks and responding effectively to diverse environmental conditions.

3.3 Blynk Dashboard Outcomes

Fig. 6 illustrate the output Blynk dashboard of the IoT Landslide Sentry project. The dashboard serves as a central point, converting sensor data into practical insights for effective geohazard management. It depicts a specific project stage, showcasing the system's adaptability to varying soil moisture, ultrasonic distance, and vibration presence.

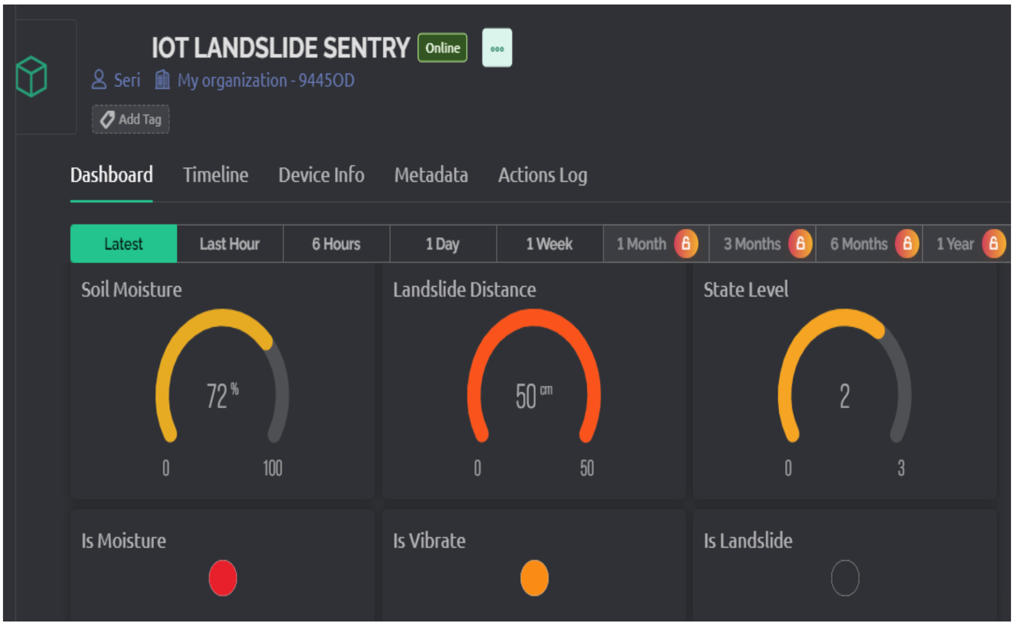

Fig. 6 *Blynk dashboard outcomes*

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4. Conclusion

In summary, the IoT Landslide Sentry project accomplished its primary objectives by creating an advanced monitoring system integrated with IoT. Core components include cutting-edge sensors like soil moisture, ultrasonic, and vibration sensors, alongside the ESP32 microcontroller. The project prioritized real-time landslide risk assessment in geohazard-prone regions and successfully connected the device to the Blynk dashboard, enhancing its achievements.

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Conflict of Interest

The authors, Seri Najihah Marhalim, and Afishah Alias, declare that there is no conflict of interest that could potentially bias the outcomes or interpretation of the research presented in this paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design, data collection, methodology, analysis and interpretation of results:*** *Seri Najihah Marhalim and Afishah Alias. All authors reviewed the results and approved the final version of the manuscript.*

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