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A Smart Safety Framework: Developing an IoT-Based Landslide Monitoring System for Enhanced Disaster Preparedness in Biak na Bato National Park

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Abstract

Landslides are a recurring hazard in regions with complex geological conditions, intensified by climate change, seismic activity, and unsustainable land use. Biak na Bato National Park, with its limestone formations and steep slopes, is highly vulnerable to these events, posing risks to residents, tourists, and infrastructure. This study presents the development of a smart safety framework through an Internet of Things (IoT)-based landslide monitoring system designed to enhance disaster preparedness in the park. The system integrates sensors for soil moisture, rainfall intensity, and ground movement, enabling real-time monitoring of slope conditions and early warning notifications. Following the IoT Project Development Process, the research employed an applied methodology that included requirement analysis, prototype building, and user testing. Thirty respondents, composed of park staff, local residents, and tourists, evaluated the system's functionality, reliability, and usability. Testing demonstrated sensor accuracy with error rates below 3%, confirming strong performance. User assessments yielded high ratings for functionality (4.23), reliability (4.21), efficiency (4.17), and maintainability (4.11). These results confirm the prototype's capability to provide valid and consistent outputs across varying environmental conditions with minimal maintenance requirements. The device effectively addresses the lack of established landslide preparedness tools in the park and shows strong potential for broader application in landslide-prone areas. Future improvements will focus on refining the algorithm for pattern recognition and conducting long-term deployments to validate sustained performance. Overall, the proposed IoT-based framework offers a practical and robust solution for enhancing disaster preparedness and ensuring the safety of communities in vulnerable environments.

Keywords: Climate change; Disaster preparedness; Monitoring system; Biak-na-Bato

1. Introduction

The growing frequency and severity of natural disasters, including landslides, make it essential to develop efficient early warning systems that can respond to them promptly to reduce human losses and material damage (Park et al.). Indonesia, as one of the countries including some with many heights, diverse and complex geological conditions, is prone to all types of disasters that can befall, including landslides, which are frequent events, including Java (Idhom et al., 2021). Difficulty in Mitigating the Landslide Disaster in Indonesia. Some of the difficulties in mitigating the landslide disaster in Indonesia originate from the fact that there is less residential development planning in the prone landslide areas, and less utilization of the landslide susceptibility maps for regional development (Ngadisih et al., 2017; Zamroni et al., 2020). The intricate interaction

between environmental parameters and unsustainable land use leads to an increased risk of landslides that threaten the lives of millions of inhabitants and bring forth important financial loss (Ngadisih et al., 2017). The increase in landslide event occurrences in Indonesia is due to the land use, which is not environmentally sound, long duration of

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rainfall, and the higher seismic activities (Ngadisih et al., 2017). The events of climate change and geological surface deformations are the cause of the rise of disasters such as landslides and floods (Sastra & Idham, 2019). In view of the lethal effects of landslides, especially in the tourist-prone areas, a disaster preparedness attitude is imperative (Aji et al., 2021).

The Philippines has been experiencing a surge in climate-related disasters, including landslides, in recent years. The Biak na Bato National Park in Bulacan is one such area that can be especially at risk to such events given its geosystem, which includes limestone formations. Landslides can cause major environmental and human damage, particularly in areas of steep topography and high rainfall. This study is intended to have an IoT-based landslide indicator system that gives real-time monitoring and notifies on-site of landslides at Biak na Bato National Park, resulting in the safety of lives and resistant infrastructures.

The general problem addressed by this study is the lack of an effective landslide detection system in Biak na Bato National Park, which increases the risk to park visitors and residents. The study focuses on developing a system that integrates sensors to detect soil moisture, rainfall intensity, and ground movement—key indicators of landslides.

2. Methodology of research

Establishing a robust and effective landslide indicator system within Biak na Bato National Park represents an approach to mitigating the inherent risks posed by landslides, which can negatively impact the safety and well-being of the people in the area. This chapter delves into the methodology employed to develop a comprehensive landslide indicator system to assess and predict landslide susceptibility within the park's diverse and dynamic landscape.

The aim of this methodology section is to present the systematic approach and methodologies employed in crafting a reliable and precise landslide indicator system. By outlining the research design, data collection methodologies, analysis techniques, and the integration of relevant indicators, this chapter offers a detailed understanding of the methodologies shaping the development of the study.

2.1. Project Design

The study adopts an Applied Research approach and follows the IoT Project Development Process, which includes six steps:

- Identifying Requirements
- Designing a Solution
- Building a Prototype
- User Testing

2.2. Specifying and Developing

2.2.1. Manufacturing

A quantitative descriptive-comparative design is employed to assess the system’s functionality and accuracy through data comparison.

2.2.2. Population and Sample

The study involves 30 respondents, including:

- 10 staff members of Biak na Bato National Park
- 10 local residents
- 10 tourists

These participants evaluate the system’s usability, reliability, and effectiveness.

2.3. Data Collection

Sensors are deployed in landslide-prone areas to collect data on rainfall intensity, soil moisture, and ground movement. The data is used to detect potential landslide triggers. Surveys and questionnaires assess the system’s performance and user satisfaction.

2.4. Data Processing and Statistical Treatment

Data analysis includes percent error calculations to measure accuracy, as well as the use of Likert scale responses to evaluate system performance in terms of functionality, reliability, efficiency, maintainability, and usability.

3. Results and discussion

This chapter focuses on the detailed process of designing and developing the proposed system using the IoT Project Development Process, a framework consisting of six sequential steps:

- Identifying Requirements;
- Designing a Solution;
- Building a Prototype;
- User Testing;
- Specifying and Developing; and
- Manufacturing.

This chapter also includes the analysis and interpretation of data gathered from testing observations and respondent evaluations of the developed system However, the last two phases are removed from the model since the study only requires the development of a prototype of the system and will not be deployed to its intended use.

The system's performance is evaluated through preliminary and final testing of the sensors (accelerometer, ultrasonic, soil moisture) against standard measuring devices. All sensors demonstrated a percent error of less than 3%, indicating accuracy within acceptable limits.

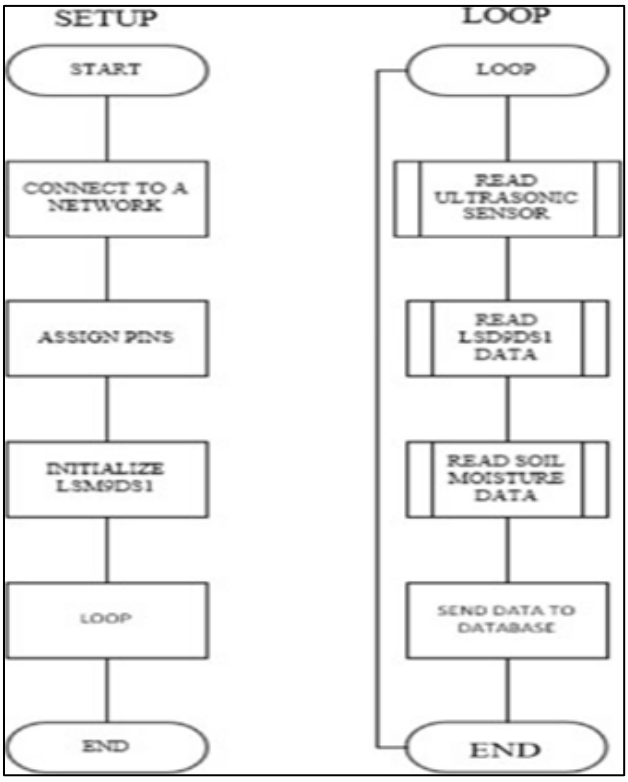


Figure 1 Flowchart of the main setup program of Node MCU

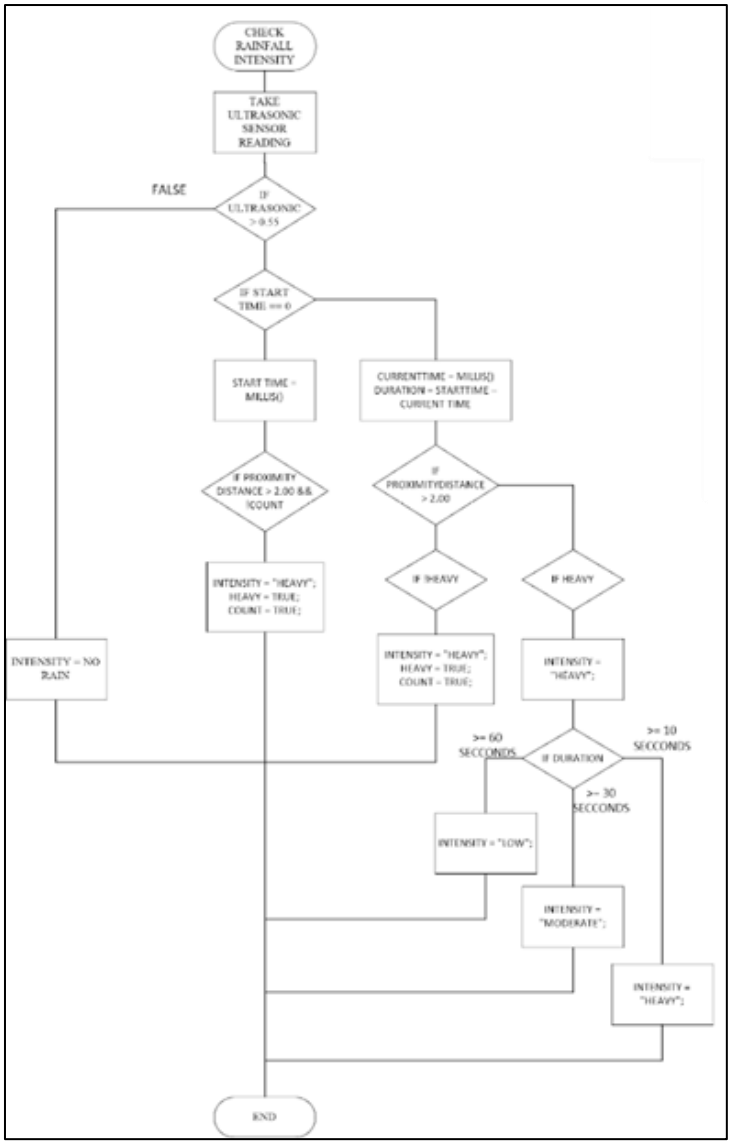


Figure 2 Flowchart of the sub-processes included in the program loop

3.1. Functionality and Usability

The system's functionality was rated highly, with users finding it easy to use and responsive. The system met its objectives in monitoring landslide risks, with a mean rating of 4.23 for functionality.

3.2. Reliability and Efficiency

The system was deemed reliable, with an average rating of 4.21, and efficient in meeting user needs, scoring 4.17 for efficiency. The system performed well under various environmental conditions, with accurate and consistent outputs.

3.3. Maintainability

Maintainability was rated at 4.11, indicating that while the system is reliable with minimal maintenance, there are areas for improvement in long-term upkeep.

The proposed IoT-based landslide indicator system successfully meets the study's objectives by providing an accurate and reliable tool for early landslide detection. The system's sensors, including accelerometers, soil moisture sensors, and rainfall intensity monitors, work in tandem to detect environmental parameters that could trigger landslides. Testing results validate the system's accuracy and effectiveness, with positive feedback from the target users.

4. Conclusion

The system provides a practical solution for landslide risk management in Biak na Bato National Park, with strong performance in terms of functionality, reliability, and efficiency. The positive user feedback highlights the system's potential for broader application in similar areas prone to landslides.

Defining clear objectives and collecting relevant data like ground movement, soil moisture, and rainfall intensity is crucial for detecting potential landslide risks. An algorithm has been developed to analyze this data to identify patterns. Continuous testing of the algorithm's performance, using simulated and real-world data, ensures its accuracy and reliability. Helping the system better understand the area's condition and detect potential landslides more effectively.

The proposed device incorporates various sensors to monitor factors such as ground movement, soil moisture, and rainfall intensity, which are often the main causes of landslides. These sensors are placed in locations susceptible to landslides. Then, it uses an algorithm capable of processing data from these sensors to identify patterns of potential landslides, ensuring action can be taken to mitigate the landslide's impact.

An experiment was conducted in a simulated environment to evaluate the sensors' accuracy in detecting ground movement, soil moisture, and rainfall intensity. To assess the precision of sensor outputs, the readings were compared with real-world data collected during the device's deployment in Biak na Bato.

Given an international standard for evaluation, with an overall assessment result of strong satisfaction for the functionality (4.18), reliability (4.21), efficiency (4.17), maintainability (4.11), and usability (4.18). This signifies that the respondents observe that achieving the required quality is attainable.

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