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Using Sensors with Internet of Things for Landslide Detection System: A Systematic Literature Review

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Abstract: Landslides are among the most common natural disasters in regions with high rainfall and unstable geological conditions. To improve the effectiveness of mitigating this disaster, various Internet of Things (IoT)-based early detection systems have been developed. This research uses Systematic Literature Review (SLR) approach to analyze various sensor technologies and IoT in landslide monitoring system. Based on the analysis, it was found that soil moisture sensor, accelerometer, and piezometer are the most commonly used technologies in the monitoring system. Soil moisture sensors measure the moisture content in the soil, accelerometers detect unstable soil movement, while piezometers measure soil pore pressure. In addition, communication technologies such as LoRa and IoT enable real-time data transmission with low power consumption and wide coverage. The results show that the use of IoT technology can improve the accuracy of landslide early detection. However, there are still some major challenges in implementing this system, mainly related to the limited network infrastructure in remote areas and the relatively high cost. Therefore, this research recommends the development of a more efficient early detection system, adaptive to extreme environmental conditions, and considering integration with artificial intelligence technology to improve prediction and response to potential landslides. Thus, IoT-based detection systems can contribute significantly to landslide mitigation and risk reduction efforts.

Keywords: Landslide, Internet of Things (IoT), Early Warning System, Systematic Literature Review (SLR).

1. Introduction

Safety is a fundamental aspect of human life that covers a wide range of fields and daily activities. In the contemporary epoch, marked by technological progress and mounting environmental hazards, the imperative for systems that can safeguard human well-being from peril has grown paramount. A variety of initiatives have been undertaken to enhance safety,

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encompassing educational efforts and the implementation of technologies for risk detection and mitigation. A rapidly evolving approach involves the application of Internet of Things (IoT)-based technologies and information systems to detect potential natural disasters, such as landslides [12]. This approach not only fosters community preparedness but is also integral to enhancing the overall safety culture.

Safety is an important aspect of human life as it is directly linked to survival and well-being. Maintaining safety allows people to avoid the risk of various injuries, illnesses and even death. The application of safety principles is necessary in everyday life, whether at home, school, workplace and on the road. Maintaining safety means not only protecting ourselves, but also protecting others around us in order to form a safety culture. Safety culture is a combination of safety-focused awareness, values, norms and behaviors, compliance with established rules and procedures, and the adoption of a proactive attitude in detecting and reducing potential risks [1]. Therefore, safety culture must be instilled early so that it becomes an inherent habit in every action.

Nevertheless, despite the extensive research and implementation of the concept of safety culture in various contexts, concerns persist regarding its application in natural disaster mitigation efforts, particularly in the context of landslides. A significant gap in understanding exists regarding the consistent and effective promotion of awareness and early detection habits within communities, particularly through the integration of modern technologies such as the Internet of Things (IoT) [37]. Furthermore, there is a lack of consensus regarding the efficacy of integrating technology with local cultural approaches in fostering proactive attitudes towards risk. Consequently, there is a need for additional research and development to address this knowledge gap.

Indonesia is one of the most vulnerable countries in the world to natural disasters. Indonesia is a country that has complex geographical, geological and climatological conditions, making it prone to various types of natural disasters. [3] mentioned that natural disasters are a serious threat to human life, especially in vulnerable areas such as Agam, West Sumatra. The impacts of these disasters not only include environmental damage, infrastructure damage, transportation disruption, and loss of productive land, but also significant psychological, social and economic impacts that even threaten and affect people's lives and livelihoods. This makes disaster mitigation very important to do in order to minimize the negative impacts of disasters. Two of the five basic substances of disaster risk reduction are the importance of using knowledge, innovation and education to increase awareness of personal safety and disaster resilience at all levels of society and to strengthen disaster preparedness [4].

Landslides are a common disaster in Indonesia every year, especially in hilly areas. In line with the opinion of [5] that Indonesia has many hills and is prone to landslides. Landslide is a phenomenon of mass movement of soil or rock down the slope due to disruption of slope stability [6]. The impact is very dangerous, ranging from infrastructure damage to life-threatening. In addition, landslides can affect economic activity and damage transportation access. Human safety is of paramount importance, plus landslides often occur suddenly. To deal with this risk, a proactive approach in the form of mitigation is essential.

On the island of Sumatra, landslides occur in almost all regions. One of the areas that often experience landslides is located in West Sumatra because it is passed by the Bukit Barisan Mountains and the rainfall in the region ranges from 5,498 to 11,749 mm/year [7]. Based on data NDMA (National Disaster Management Agency) in 2023, 591 landslide events were recorded in Indonesia with West Sumatra as one of the high-risk areas due to its mountainous topography and intense rainfall. In this province, more than 150 landslide events were reported throughout 2023, with Solok, Agam and Lima Puluh Kota regencies being the most affected areas [8]

Disaster mitigation efforts are a strategic step to reduce the risk of landslides. Through an approach that is not only emergency response, but also technology-based prevention. One innovative solution to this problem is the use of sensor technology for landslide early detection. This enables the integration of various smart sensors that can connect and communicate in real-time, providing more comprehensive and accurate monitoring of soil conditions through the use of soil moisture sensors, accelerometers, and inclinometers, which can detect physical changes in the soil as indicators of landslide potential [9]. The data collected by these sensors is analyzed using intelligent algorithms such as machine learning or fuzzy logic to provide warnings [10].

Landslide detection systems are technologies designed to monitor ground movement and provide early warning before a landslide occurs. These systems typically use sensors such as tiltmeters, rain gauges, and accelerometers installed in landslide-prone areas. The data from the sensors is then sent to a monitoring center for real-time analysis. With this system, people can be given early warning so that they can evacuate and avoid casualties. The use of this technology is an important part of landslide mitigation efforts. This is in line with [11] who stated that the application of a landslide detection system will increase public awareness and preparedness for potential landslides, so that preventive action can be taken more quickly and effectively.

Research on sensors for landslide detection has been conducted in Indonesia. One of them is research by [12] who used Node-MCU module in early warning system of land movement based on Internet of Things (IoT). This research focuses on designing a landslide detection system. Similar research was conducted [11] who developed a prototype landslide detection system using IoT-based sensors with Lo-RA communication. Furthermore, research by [13] developed a landslide early warning system using Android-based sensors. Various sensor approaches used show that wireless technology-based soil monitoring systems are growing rapidly. In addition, the integration of sensor data with predictive analysis is also being applied to improve the accuracy of landslide early detection.

The *Internet of Things* (IoT) is one of the most prominent technological trends in recent years because it can combine physical objects with the internet that allows *real-time* data exchange [14]. [15] added that technology can be utilized to streamline the observation of landslide disaster symptoms to reduce the risks arising from the disaster. The results of his research show that all stages of disaster management can be integrated with IoT technology. These are some of the factors that cause a lot of research on disaster detection based on IoT technology. The systematic review of landslide early detection systems is necessary because research on IoT-based landslide detection systems is scattered in various journals and conferences, with diverse focuses, such as sensor types, communication methods, and data processing algorithms. This hinders researchers and practitioners from obtaining a comprehensive overview of technological developments and best practices in this field. Furthermore, numerous preceding studies employed a variety of IoT [6][9][10][36] methodologies and technologies, including soil moisture sensors, accelerometers [13], as well as diverse communication protocols such as LoRa [11][24], GSM, and Wi-Fi. However, there is a lack of consensus on the critical parameters, system architecture, or validation methods employed. This complicates the process of comparing and evaluating the effectiveness of different landslide detection systems.

Conversely, the Internet of Things (IoT) and sensor technologies are undergoing rapid advancements, which suggests that the information and methodologies employed in prior research may become obsolete. A systematic review facilitates the identification of the latest trends, cutting-edge technologies, and best practices that can be applied in the development of landslide detection systems that can improve the accuracy, effectiveness, and reliability of detection systems. By systematically compiling and analyzing extant literature, researchers and practitioners can gain a more profound understanding of the strengths and weaknesses of the approaches that have been used [38]. This finding paves the way for the development of enhanced and more efficient systems in the future. This assertion aligns with the seminal work of [39], who underscored the pivotal role of an integrated technological framework in facilitating data-driven IoT systems for landslide monitoring. The framework encompasses critical domains such as system design, data communication, and information analysis. However, it was also noted that challenges persist in terms of interoperability and standardization between disparate systems. Consequently, the systematic review not only facilitates the identification of gaps in the extant literature but also provides a solid foundation for the development of more effective and efficient IoT-based landslide detection systems in the future.

The amount of research on IoT-based landslide early detection system makes it necessary to conduct a more in-depth study on the topic. One of the solutions is through *Systematic Literature Review* (SLR) approach. This SLR method is very suitable for use because it allows researchers to identify, evaluate, and synthesize previous research results systematically so as to provide a more comprehensive understanding of the topic under study [8]. By analyzing various studies, SLR allows the identification of innovation trends, the most effective technologies, and research gaps that can be used as opportunities for further development [16]. In line with [17] who revealed that the database used to search for articles in the form of Google Scholar allows comprehensive information about the use of sensors in modern technology that can increase efficiency and innovation in various fields. SLR research on disaster detection has been conducted by [18] who studied earthquake detection systems using sensors with IoT with the SLR approach. The method used in this SLR research is the PRISMA design. However, the research only examines earthquake disasters, so there is no SLR research that examines landslide early detection systems using sensors with IoT.

A substantial corpus of recent studies has contributed to the enhancement of knowledge and the evolution of Internet of Things (IoT)-based landslide early detection systems [6][10][12][13][15][23][24][33][35][36]. These recent studies encompass a broad array of innovative approaches, ranging from the integration of sensor technology with communication networks to the utilization of artificial intelligence for data analysis. Recent studies in the domain of Internet of Things (IoT)-based landslide early detection systems demonstrate the rapid advancements being made in this field, particularly in the areas of sensor technology, communication protocols, analytics platforms, and disaster mitigation strategies. Consequently, the necessity for a systematic literature review (SLR) arises from the rapid advancements in this field. While there are several literature reviews that address related topics, the majority are either too general or focus on specific aspects, thereby failing to offer a comprehensive overview of the developments and challenges in the application of IoT for landslide detection. Therefore, the purpose of this research is to study landslide detection system using sensors with *Internet of Things* (IoT) with *Systematic Literature Review* (SLR) approach.

2. Materials and Method

This research uses the Systematic Literature Review (SLR) method. This method aims to analyze studies that discuss the use of IoT technology in landslide detection systems [19]. The method used follows the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) approach which ensures the selection of literature is done systematically [19]. This method aims to answer specific research questions through many processes, including identifying, analyzing, synthesizing, evaluating, and comparing all literature related to the question or subject under investigation [21].

The article selection process in this study was carried out in several stages. The stages include identification, screening, eligibility, and inclusion. In the identification stage, article searches were conducted through Google Scholar, IEEE, Xplore, and ScienceDirect databases using the keywords "landslide detection" within the 2014-2024 timeframe, resulting in 51 articles. After the initial screening process, the number of articles was reduced to 42 articles based on the relevance of the title and abstract. Further screening was conducted by narrowing the keywords to "landslide detection" and "landslide early detection system," resulting in 36 articles. Then, the application of inclusion and exclusion criteria resulted in 17 articles that were eligible for further analysis. The flow of the article selection process is shown in Figure 1.

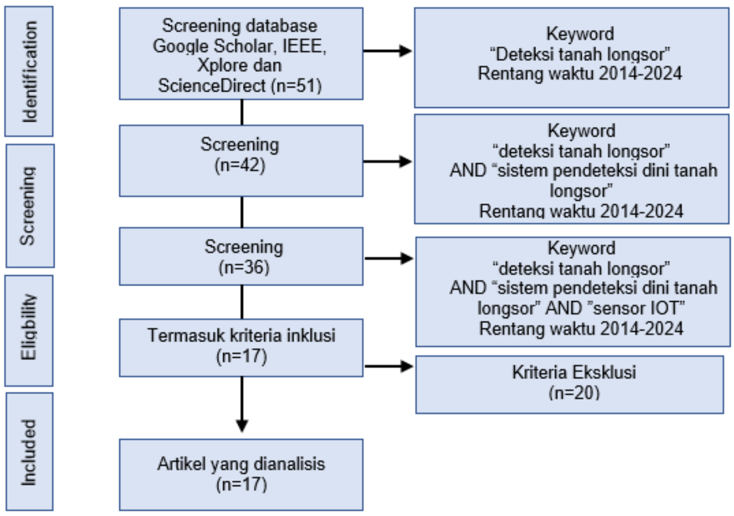

Figure 1. PRISMA stages

Figure 1 shows the article screening process in this study. The steps of this research started with identifying articles through Google Scholar database based on the keyword "landslide detection" which resulted in 51 relevant articles from 2014-2024. After going through the initial screening stage, the number of relevant articles was reduced to 42. At the eligibility screening stage, only 36 articles met the criteria for further analysis. Of the 36 articles, 17 met all inclusion criteria and were selected for detailed analysis in this SLR study. This process demonstrates the importance of rigorous screening to ensure the feasibility and relevance of research results.

The criteria used in the selection of articles are articles that discuss the use of IoT-based sensors for landslide detection, studies that use experimental or simulation methods, and articles published in reputable journals or conferences [22]. In addition, the article should have a clear structure, including research objectives, methods, results and discussion. The criteria for articles reviewed in the PRISMA method using the SLR approach must be met to ensure that the results of this research are valid and accounted for. The selection process is systematically carried out by the stages of identification, screening, eligibility, and inclusion. By using the PRISMA approach, researchers can ensure that the articles analyzed are comprehensive and support the research objectives. Conversely, articles that did not specifically address landslide detection or were not IoT-based were excluded from the analysis.

After going through the selection stage, 17 articles were selected to be analyzed in depth to identify the technology *trends* used, advantages, and limitations of each system [19]. The *review* was conducted by analyzing the articles based on the technology used, the sensors used, the IoT communication used, and the analytics platform used. Based on this description, there are four fundamental differences in this article review. In each analysis result, the advantages and disadvantages of each article are also described. These results are expected to illustrate a detailed review of research related to IoT-based landslide early detection system.

3. Results and Discussion

Based on *review of* several articles that discuss the use of sensors and IoT for landslide detection. There are several analysis results that are differentiated based on the technology used, based on the sensors used, based on the IoT communication used, and the analytical platform used.

3.1 Analysis Results Based on Technology Used

Based on the analysis of the article, it is known that the technology used in the landslide early detection system is in the form of sensor technology, IoT system, and mini pc. The sensors used in the landslide early detection system consist of ESP8266 sensor, accelerometer, piezometer, inclinometer, MPU6050, and ADXL345. The technology used in the landslide early detection system in the form of IoT system includes LoRa, IoT, Artificial Neural Network, fuzzy logic, cloud computing, and mobile application. While the technology in the form of mini pc used in landslide early detection system is Raspberry Pi. The results of the analysis based on the technology used can be seen in Table 1.

Table 1. Results of article analysis based on the technology used

Article Title	Sensors and Technologies Used	Advantages	Disadvantages
Landslide Early Detection System Using Internet of Things-Based Vibration Sensor	Vibration sensor and ESP8266	Real-time data with iot-based delivery	Low accuracy in high vibration environments
Landslide Detection Prototype Design Using Piezoelectric Sensor Based on ESP32	Humidity sensor, rain sensor, and vibration sensor.	Wide coverage and power saving	Depends on internet connectivity
Landslide Early Warning System Using Accelerometer Sensor and Soil Moisture Sensor Based on Android	MPU6050 and LoRa Sensor	Stable for remote areas	Higher development costs
Internet of Things Based Landslide Detection System Prototype Using Long Range	Piezometers and vibration sensors	Highly precise data	High cost

Communication (LoRa)			
Early Warning System for Landslide Potential in Manado City Based on Internet of Things	Raspberry pi, accelerometer sensor and vibration sensor	Supports more complex data processing	Higher power consumption
Design of Ground Movement Monitoring System Using Multi Segment Inclinometer Based on Accelerometer and Moisture Sensor (Case Study of Slope Model)	Accelerometer MPU6050 and humidity sensor dfrobot	Sensitive to changes in ground angle	Vulnerable to physical damage
IoT-based Monitoring System for Land Movement and Slope as an Early Warning against Landslides	ADXL345 sensor, localhost web and SMS gateway	Rapid response to changes in ground movement	Requires a localhost and credit to send data.
Development of Landslide Disaster Mitigation System Using Localhost Web-Based ADXL345 Accelerometer	MPU6050 sensor, humidity sensor, GPS module and LoRa	Data can be accessed in real-time	Requires stable internet connectivity
Implementation of Wireless Sensor Network on Landslide Detection Based on Internet of Things (IoT) and LoRa	Fuzzy logic and pressure sensors	Definitive data handling	Difficulty in parameter adjustment
Implementation of Fuzzy Logic System on IoT-based Landslide Prone Area Monitoring	Mobile application, humidity sensor and accelerometer sensor	User-friendly, IoT integration	Requires a compatible device
IoT-enabled Landslide Detection Mitigating Environmental Impacts	Rainfall sensor, humidity, vibration, slope movement, wireless communication	Detect multi-parameter environment, improve system accuracy	High complexity in integration of multiple sensors
IoT-based Landslide Monitoring and Early Detection Mobile Application	Humidity sensor, rain, MPU6050 accelerometer, NodeMCU, mobile application	Mobile monitoring, multi-sensor detection, alerts via buzzer and app	High power consumption, prone to noise
IoT-based Landslide Detection Tool Design with NodeMCU ESP8266 and MPU6050	MPU6050 sensor, NodeMCU ESP8266, cloud platform	Real-time acceleration and tilt, "safe-alert-watch" status system	Sensor needs accurate calibration; sensitive to non- landing position changes
Android-based Landslide Early Warning System	Rainfall sensor, soil moisture,	Android-based system, web-displayed data,	Shift accuracy may be compromised by environmental

	displacement sensor	Telegram notifications	conditions
Utilization of Internet of Things for Landslide Detection Monitoring	Soil moisture sensor, accelerometer	Real-time monitoring, simple interface	Does not detect shifting or vibration
IoT Based: Landslide and Flood Detection System	Rain sensor, vibration sensor, IoT cloud platform	Effective for landslides & floods, data sent to the cloud	Does not detect land slope/shift
Implementation of IoT-based Land Shift Monitoring System in Kahayan Watershed	Ground displacement sensor (unspecified), IoT module	Community education, real-time local monitoring	No details of the sensor or scientific validation of the results

From the data in Table 1, it can be explained that the technology used in landslide early detection system includes sensors, IoT system, and mini pc. Landslide early detection system that uses sensor technology such as ESP8266, MPU6050, ADXL345, Piezometer, inclinometer, and accelerometer has advantages such as high precision data, fast response to changes in ground movement. This is because these sensors, especially those based on Micro-Electro-Mechanical Systems (MEMS) technology, are able to detect small shifts and changes in ground slope in real-time, enabling more accurate and timely early warning [12]. However, the use of this sensor technology has the disadvantage of high cost and requires stable internet connectivity. Although efforts have been made to develop cost-effective and replicable IoT-based geo-sensors by Gamperl (2023), significant initial investment is required for hardware production and installation, as well as training of local communities for system operation and maintenance.

In addition, landslide early detection systems that use IoT-based technologies such as LoRa, IoT, Website, and mobile applications have advantages including wide coverage and power saving, stable for remote areas, more accurate analysis, real-time accessible data, and user-friendly. It is in line with that the LoRa system can operate reliably in hard-to-reach environments, such as mountainous or forested areas, thanks to its strong wireless communication capabilities [24]. The disadvantages of this IoT-based technology include reliance on internet connectivity, higher complexity and development costs, and the need for compatible devices. [25] explain that IoT-based systems require a stable internet connection for data transmission and cloud access, which can be a challenge in areas with limited network infrastructure.

3.2 Analysis Results Based on Sensors Used

Based on the analysis, it is known that sensors employed to assess environmental parameters that serve as indicators of landslides typically encompass tilt sensors (inclinometers), soil moisture sensors, rain gauges, and vibration sensors. Soil moisture sensors used in the landslide early detection system consist of FC-28 sensors. Vibration or ground movement sensors used in the landslide early detection system include MPU6050, ADXL345, and piezometer. The results of the article analysis based on the sensors used can be seen in Table 2.

Table 2. Article analysis results based on sensors used

Sensor Type	Monitored Parameters	Advantages	Disadvantages
FC-28 (Humidity)	Soil moisture	High precision in water content measurement	Vulnerable to physical damage
MPU6050 (Accelerometer)	Vibration/Ground movement/slope angle	High accuracy for detecting small angle changes	Requires high power and regular calibration
SW420 Vibration Sensor	Ground vibrations (frequency/stimulation)	Sensitive to light vibrations, inexpensive	Unable to measure the direction or intensity of vibrations in detail
Piezometer	Groundwater vibration/movement	High precision data, especially effective for water-saturated soil	High cost
ADXL345 (Accelerometer)	Vibration/Ground movement	Fast response to vibration and ground slope	Sensitive to rocky terrain interference
Rain Sensor	Rainfall intensity and occurrence	Quick response to rain, inexpensive	Not accurate for measuring rainfall
Rotary Encoder Sensor	Horizontal shifts	Accurate in measuring rotation or distance	Only suitable for small linear/rotational movements
Barometer Sensor BMP180	Air pressure (vertical movement)	Accurate in height detection, small size	Sensitive to temperature changes, requires calibration
Inclinometer Sensor	Slope angle	High precision, used for slope deformation	Expensive, complex installation

From the data in Table 2, it can be explained that the analysis of landslide early detection system based on the sensor used shows that landslide early detection systems that utilize sensor technology, such as the MPU6050, ADXL345, rain sensor, piezometer, inclinometer, and accelerometer, offer several advantages, including high precision data and rapid response to changes in ground movement. However, [33] and [9] posit that the utilization of this sensor technology is encumbered by two significant disadvantages: the initial financial expenditure is substantial, and the requirement for stable internet connectivity constitutes a substantial impediment. The landslide early detection system that utilizes a moisture sensor offers several advantages, including low cost, high accuracy, wide range, and ease of integration. This is supported by the results of [28] which tested the ability of LoRa with the result that the system with LoRa is able to reach a distance of 4.3 km in urban areas and a distance of 9.7 km above the open field outside the city [28]. In line with [29] that LoRa-WAN based systems offer the benefit of wide coverage with minimal power consumption, making it the right choice to support data collection in areas that have limited infrastructure. The wide coverage is due to the fact that the sensor is equipped with an ADC (Analog to Digital Converter). The results revealed that the ability of the humidity sensor to provide *real-time* information allows users to take timely action in maintaining plants and optimizing their growth [29].

The reliability of sensors in landslide monitoring systems is highly dependent on the robustness and accuracy of the devices used. Whereas systems with moisture sensors have low sensitivity in high rainfall and are prone to physical damage. This causes the data generated to be less accurate, especially during extreme conditions such as heavy rainfall that accelerates soil movement. In addition, moisture sensors often suffer from degraded performance over time due to environmental factors such as corrosion and silt accumulation [35]. Therefore, a combination with other sensors such as inclinometers or piezometers is required to improve the reliability of the detection system [36]. Some studies also recommend the use of sensors based on capacitive or fiber optic technology as an alternative that is more resistant to extreme conditions. Thus, the development of a landslide monitoring system needs to pay attention to the sensor's resistance to environmental factors so that the early warning system can function optimally.

The MPU6050 and ADXL345 accelerometer sensors have proven to be sensitive in detecting ground movement and slope angle changes [10]. However, some studies reveal that these sensors are susceptible to rocky terrain disturbances and require regular calibration to remain accurate [30]. In the results of this study, the system using accelerometer sensors is able to provide a quick response to changes in ground movement, although it still has limitations in terms of sensor durability and sensitivity to extreme terrain. On the other hand, landslide early detection systems that use vibration or ground movement sensors have the advantages of fast response to changes in ground movement, the resulting data is very precise, and can send data in real-time. This is in line with the research results of [13] that the landslide early detection system uses vibration sensors, namely MPU6050 sensor. When tested for danger status in soil conditions with humidity less than 51% and soil shifting, it shows that the sensor can identify the danger status with a 100% success percentage with an average response time of 2.2 seconds. The test results for hazardous status in soil conditions with humidity greater than 51% and soil shifting, show that the system can identify the hazardous status with a 100% success percentage with an average response time of 1.9 seconds. This is also supported by research by [31] showing that the MPU6050 IMU sensor is able to record body acceleration and orientation values accurately according to standards with a classification accuracy rate of 92% and an average computation time of only 2.82 milliseconds which shows high efficiency in data processing.

This vibration or movement sensor has high data accuracy because it integrates an accelerometer and gyroscope. This is in line with the opinion of [32] who revealed that the motion sensor or IMU (Inertial Measurement Unit) is able to detect changes in position, orientation, and movement with high accuracy, making it very suitable for application in motion-based control devices. In line with that, [31] revealed that accelerometer sensors are very sensitive and can accurately measure the slightest changes in acceleration. This makes it very useful in applications that require precision motion tracking. He also added that gyroscope sensor components typically include a rotor, which rotates at a high speed, generating angular momentum. When the device undergoes a change in orientation or rotation, the Coriolis effect causes the rotor to deflect from its original axis and allows the sensor to accurately detect the motion.

Systems with these vibration sensors have some drawbacks. These include high cost, stable internet connectivity, and low accuracy in high vibration environments. If the network conditions are less stable, then this system does not run well. This is in line with the opinion of [13] that the non-functionality requirement for the system to run well is stable network conditions. In addition, the use of vibration sensors in areas with many external sources of interference, such as heavy vehicles or human activity, can produce false data or noise that worsens system performance. Therefore, integration with data filtering algorithms and incorporation of additional sensors are important to improve the accuracy of landslide detection.

3.3 Analysis Results Based on IoT Communication Used

Based on the analysis, it is known that the IoT communications used in the landslide early detection system include Wi-Fi, LoRa and GSM. The most widely used communication technologies are LoRa and IoT. The results of article analysis based on the IoT communication used can be seen in Table 3.

Table 3. Results of article analysis based on the IoT communication used

Types of Communication	Advantages	Disadvantages
Wi-Fi (ESP8266 / NodeMCU / ESP32)	Easy to implement, inexpensive, suitable for local networks	Depends on a stable Wi-Fi signal and limited range
LoRa (Long Range)	Communication distance is very far (up to several kilometers), energy efficient	Low data rates, requires a dedicated LoRa gateway/receiver
GSM/SMS Gateway	Not dependent on local internet, can reach remote areas	Call charges, data capacity limitations, delivery delays

From the data in Table 3, it can be explained that the analysis of landslide early detection system articles based on the communication system used shows that the platforms used in this analysis include LoRa, IoT, and GSM. Modules such as the ESP8266, NodeMCU, and ESP32 utilize Wi-Fi networks to transmit sensor data to servers or cloud platforms. The primary benefit of this technology is its compatibility with areas that possess stable Wi-Fi infrastructure. In accordance with the findings of [40], the development of a flood early warning system employing NodeMCU ESP8266 and Telegram bot demonstrates that the synchronization of two VMS with disparate internet networks results in an average time difference of 1.16 seconds, whereas with a shared network, this time difference is reduced to 0.03 seconds. This finding indicates that the utilization of Wi-Fi can facilitate a rapid response in the dissemination of notifications.

The LoRa communication system utilizes radio frequency for long-distance communication with low power consumption, making it well-suited for large and remote areas. In accordance with this perspective, the research conducted by [41] on the Landslide Monitor (LSdM) system, which utilizes LoRa technology to monitor landslides in the Greater Malang area, demonstrated that LoRa possesses capabilities in both Line of Sight (LOS) and Non-Line of Sight (NLoS) conditions. The analysis of LoRa frequency revealed discrepancies in packet loss rates, thereby substantiating the system's functionality under diverse network conditions. The LoRa communication system has the advantage of being very effective for remote areas due to its wide range and energy efficiency, but requires additional infrastructure such as communication gateways. In line with the results of [33] research which shows that LoRa and IoT-based systems are proven to be more effective in reaching remote areas than conventional GSM technology

IoT communication systems play an important role in the delivery of sensor data to analytics platforms. LoRa and IoT are the two most frequently used technologies in research due to their power efficiency and wide coverage [34] LoRa has the advantage of low power consumption, but requires additional infrastructure such as communication gateways [35] IoT offers stable connections in areas with weak signals, but requires higher network development costs [33]. The results show that systems using LoRa are more suitable for remote areas with limited communication networks. While the GSM communication system has the advantage of being easy to implement and is a common technology. However, the GSM system is highly dependent on signal strength.

3.4 Analysis Results Based on the Analytical Platform Used

Based on the results of the article analysis, the landslide early detection system based on the analytics platform used, it is known that the analytics platforms that are widely used include Android Application (Mobile App), Telegram API / Bot, Web Localhost / Website Monitoring, Adafruit IO / Cloud Platform, Node-RED Dashboard, Twitter API / Social Media, and CSV File + GUI Desktop (Processing). The results of the article analysis based on the analytics platform used are presented in Table 4.

Table 4. Results of article analysis based on the analytic platform used

Analytical Platform	Advantages	Disadvantages
Dashboard Node-RED	Real-time visualization, open-source, easy MQTT integration	Requires local or cloud setup, not user-friendly for beginners
Mobile App	Practical, user-friendly, instant notifications	Need application development and maintenance
Telegram API / Bot	Real-time, direct to users, cost-effective communication	Depends on internet connection and stability of external services
Web Localhost / Website Monitoring	Flexible and interactive data display	Need web hosting and security
Adafruit IO / Cloud Platform	Store data online, ready-to-use charts	Dependence on third-party services, have limitations
Twitter API / Sosial Media	Wide distribution, ideal for emergency publications	Not suitable for technical data; less secure for critical warning systems
File CSV + GUI Desktop (Processing)	Can be stored and processed offline, customizable user interface.	Not real-time, less efficient for large-scale systems

From the data in Table 4, it can be explained that Android applications can function as landslide early warning systems by collecting data from environmental sensors and disseminating location- and risk-level-based notifications to users. They also enable users to report landslide events within their localities, thereby contributing to the creation of a spatial inventory. Furthermore, the Telegram Bot has been used to disseminate real-time alerts. According to [40], the system incorporating Node-MCU ESP8266 and the Telegram Bot delivers notifications in approximately 4.07 seconds, demonstrating its capacity for rapid communication.

Web Localhost or website-based monitoring systems facilitate real-time visualization of sensor data, presenting it in graphical or tabular formats. The study by [42] demonstrated the capacity of the system to effectively display data from soil moisture and slope sensors via a web interface and LCD. Conversely, cloud-based platforms such as Adafruit IO and Node-RED offer real-time visualization and analysis of sensor data. However, the utilization of cloud platforms in such contexts is contingent upon the availability of a stable internet connection, a factor that can prove challenging in remote and rural regions. Cloud computing-based analytics platforms facilitate the integration of artificial intelligence (AI) algorithms, thereby enhancing the efficacy of disaster detection and prediction. However, the utilization of these platforms is contingent upon the availability of high-bandwidth infrastructure. As [10] have emphasized, the primary impediment to the implementation of such systems in remote regions is the necessity of a stable internet connection for real-time data processing.

Node-RED is a flow-based programming tool that has the capacity to integrate data from a variety of sensors and display it in the form of interactive dashboards. The platform's web-based visual editor and its capacity to store flows in JSON format contribute to its flexibility, rendering it accessible to users with a range of technical backgrounds. Concurrently, the Twitter API is employed to amass and examine data from social media concerning landslide occurrences. Research by [43] demonstrated the efficacy of the Twitter API-based system in filtering out duplicate information, identifying landslide images, and automatically categorizing users. Local approaches, such as CSV files and desktop GUI (Processing), facilitate data analysis in the absence of an internet connection, rendering them well-suited for system prototyping in constrained environments.

4. Conclusion

This study aims to answer the main question: how can sensor technology and IoT be effectively integrated for early detection of landslides? Based on a systematic literature review, this integration has been proven to enhance detection capabilities and provide a technical foundation for more proactive and contextual early warning systems. Sensors such as soil moisture, accelerometers, vibration, rain, barometers, rotary encoders, inclinometers, and piezoelectric sensors can detect physical changes in the soil as early indicators of landslides. Their advantage lies in their ability to detect symptoms before a disaster occurs. Through IoT connectivity (LoRa, GSM, Wi-Fi), sensor data can be transmitted in real-time, enabling rapid response from authorities and the community. However, challenges such as infrastructure limitations in remote areas remain. Proposed solutions include the use of solar energy, edge computing, and power-efficient designs. The effectiveness of this system depends on the seamless integration between hardware (sensors and communication) and analytical software. Platforms such as Node-RED, mobile applications, Telegram Bot, monitoring websites, Adafruit IO, and social media have been used for real-time data visualization and analysis. This opens up opportunities for the development of AI/ML-based systems that are not only reactive but also predictive.

The main contribution of this study is the mapping of cutting-edge technologies in IoT-based landslide detection systems, as well as emphasizing the importance of a holistic approach. Interdisciplinary collaboration between engineering, computer science, and disaster management further strengthens the direction of development. Moving forward, further research is recommended to explore predictive algorithms such as Random Forest, SVM, and LSTM to enhance the system's ability to predict potential landslides more accurately and sustainably.

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