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Email:
adm.jocpes@gmail.com
admin@physan.org

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Application of Himawari-9 and Radiosonde Data in Analyzing Extreme Rainfall Events (Case Study: Malang, November 25, 2023)

Rini Arista¹, Muhammad Alvin Faiz¹

¹Undergraduate Program in Applied of Instrumentation Meteorology, Climatology Geophysics (STMKG)

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ABSTRACT

This study uses Himawari-9 meteorological satellite data and radiosonde data to examine the severe rain event that happened in Malang on November 25, 2023. The Japan Meteorological Agency's (JMA) Himawari-9 satellite collects high-frequency atmospheric data, and radiosonde data provide vertical atmospheric information. This study determines the distribution of major convective clouds and meteorological characteristics that suggest the possibility of severe weather by analyzing satellite photos using the RGB technique and radiosonde data. Convective clouds identified by satellite images at 07:40 UTC started to blanket the Malang City area and spread until they filled the entire East Java region at 09:00 UTC, according to the analysis's findings. Weather metrics including the Showalter Index (SI), Lifted Index (LI), and Convective Available Potential Energy (CAPE) are displayed in radiosonde data to support the possibility of heavy rain. There is a significant chance that flooding in Malang will result from heavy rains due to these unstable atmospheric conditions.

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Corresponden Author:

Rini Arista,

Undergraduate Program in Applied of Instrumentation Meteorology, Climatology Geophysics (STMKG)

Tangerang City, Banten, Indonesia Email: riniarista1308@gmail.com

1. INTRODUCTION

Indonesia is among the world's biggest archipelagic nations. Due to its geographical location between two continents (Asia and Australia) and two major oceans (the Indian and Pacific), Indonesia has a very complex and dynamic climate system that is impacted by numerous global atmospheric and oceanic cycles [1]. Indonesia experiences two distinct seasons throughout the year, namely the rainy season and the dry season [2]. The country's climate and weather patterns are heavily influenced by the change between these two seasons. The Indonesian archipelago experiences the most intense convective activity, resulting in frequent occurrences of heavy rainfall [3]. Strong updrafts and the upward movement of heat and moisture in the atmosphere cause convective clouds to form. Extreme rainfall events may result from the heavy and localized precipitation that these clouds, especially cumulonimbus, can produce in a brief period of time.

In general, rainfall in Indonesia can be divided into three types: equatorial rainfall, which occurs in regions such as Sumatra, Kalimantan, Sulawesi, Maluku, and Papua; monsoon rainfall, which covers Java, Bali, and Nusa Tenggara; and reverse monsoon rainfall, which is found in limited areas of Sulawesi and Maluku[2]. Understanding extreme precipitation, which is a key contributor to hydro-meteorological hazards, is vital for society as it can result in prolonged disasters, including flooding, landslides, and soil erosion during intense wet periods, as well as droughts and forest fires during extended dry periods [4]. The Indonesian archipelago experiences intense convective activity, leading to frequent occurrences of heavy rainfall [3]. The rising intensity of rainfall has contributed to an increase in the frequency of flood disasters from year to year [5].

Intense convective activity can produce heavy rainfall, which can cause catastrophic flooding in a number of Indonesian locations. When a lot of rain falls quickly, the current drainage systems frequently can't handle the volume of water, especially in cities with plenty of impervious surfaces like concrete and asphalt. Additionally, waterlogging is more likely to occur in regions close to rivers or with low-lying topography. The likelihood of flooding is enhanced when severe rainfall occurs more frequently due to extreme weather events since the amount of water is more than what the land can absorb or the rivers can hold [6]. In addition to the risk of infrastructure damage, places that experience heavy rainfall are also vulnerable to interruptions in social and economic activities.

On November 25, 2023, around 07.40 UTC or 14.40 WIB, flooding occurred in Malang city as a result of heavy rains. Several parts of Malang, East Java, experienced flooding due to the day's heavy rainfall. These events can be analyzed in more depth by utilizing remote sensing data from Himawari-9 satellite imagery, along with radiosonde data that provides vertical atmospheric information. Researchers can learn how distinct atmospheric layers can encourage the creation of heavy rainfall by using radiosonde, which measures temperature, humidity, and air pressure at different atmospheric heights [7]. The Himawari-9 satellite, which is the next generation of Himawari-8 and operated by the Japan Meteorological Agency (JMA), is equipped with advanced technology for atmospheric monitoring [8]. The data advantage of the Himawari-9 satellite lies in the high frequency of data acquisition, which is every 10 minutes for full coverage and 2.5 minutes for areas around Japan [9]. The satellite is equipped with an advanced sensor called the Advanced Himawari Imager (AHI), which has a total of 16 bands, including visible (VIS, 3 bands), near infrared (NIR, 3 bands), and infrared (IR, 10 bands) [10]. Both satellite and ground-based measures can be used to gather rainfall data [11]. Rainfall variability has a significant impact on many facets of the lives of those who reside in the area, making rainfall research crucial. Rainfall variability is an important topic for scientific investigation since it impacts many aspects of the lives of the millions of people who live in the region. Furthermore, Indonesia's most frequent natural disasters, such as floods and landslides, are mostly caused by periods of intense rainfall. In order to improve the precision and comprehension of weather and climate forecasts and to develop Decision Support Systems (DSS) that lessen the probability of disaster impact, research on rainfall in this region is necessary. As a result, accurate rainfall measurements are critically needed, particularly better methods for estimating rainfall from remotely sensed devices [12].

In this research, the Red Green Blue (RGB) method is used, which is processed through the SATAID application. This application, developed by the Japan Meteorological Agency (JMA), is widely used by researchers and professionals in the field of weather and climate to interpret satellite data and make better decisions related to weather and the environment [13][14]. By using the RGB method, we can identify the clouds that cause rain leading to flooding in Malang City, as well as uncover certain factors that contribute to the formation of these clouds [15][16].

2. RESEARCH METHOD

The method applied in this study is through a literature review, which involves collecting and reviewing various relevant reading sources. These sources consist of books, academic journals, research reports, articles, and other documents related to the issue under study. These sources were then used as references for the design of the Radiosonde System for Air Quality Monitoring in Tangerang City.

In addition, this method also includes a critical assessment of the existing literature to find gaps in the research, as well as summarising previous results to strengthen a more in-depth analysis. This approach aims to gain in-depth insight into the topic of study and create a strong theoretical foundation to support the research results.

2.1 Location and Time of Research

Malang City is located in East Java Province, with coordinates between 112.06° - 112.07° East Longitude and 7.06° - 8.02° South Latitude. The city is bordered to the north by the Singosari and Karangploso subdistricts of Malang Regency; to the south by the Tajinan and Pakisaji sub-districts of Malang Regency; to the west by the Wagir and Dau sub-districts of Malang Regency; and to the east by the Pakis and Tumpang subdistricts of Malang Regency. The research location map was sourced from the Malang City Administration data [17]. The heavy rain event occurred from 07:30 UTC (14:30 WIB) to 09:00 UTC (16:00 WIB) on November 25, 2023.

2.2 Research Procedure

The Meteorological, Climatological, and Geophysical Agency (BMKG) provided the Himawari-9 satellite imagery data. The following channels or bands are used for processing: Band 3 (0.6 μ m), Band 5 (1.6 μ m), Band 7 (3.7 μ m), Band 8 (6.2 μ m), Band 10 (7.3 μ m), Band 11 (8.6 μ m), Band 12 (9.6 μ m), and Band 13 (10.4 μ m). The Red Green Blue (RGB) technique is used in this study, and the SATAID application is used

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to process the data [18]. Researchers and experts in the domains of weather and climate utilize this program, which was created by the Japan Meteorological Agency (JMA), extensively to analyze satellite data and make better weather and environmental decisions. The SATAID system's primary purpose is to show binary satellite data as pictures.

The SATAID system's primary purpose is to show binary satellite data as pictures [19]. Using the RGB approach, we can determine which clouds produced the rain that resulted in floods in Malang City as well as some of the contributing causes to their creation. The meteorological conditions over Malang City during periods of intense precipitation are examined using upper air observation data (Radiosonde) from the Wyoming Sounding website https://weather.uwyo.edu/ in order to support the RGB technique [20][21].

3. RESULT AND DISCUSSION

3.1 Himawari-9 Satellite (RGB)

Based on Himawari-9 satellite image data processed using the Day Convective Storm method, observations are produced in the form of convective cloud distribution. Using satellite image data, the Day Convective Storm technique analyzes convective clouds during the day. By concentrating on the hue and features of the clouds that suggest the presence of dense clouds and strong updrafts, this technique finds convective clouds. Bright yellow clouds are a sign of severe weather, which can bring storms and a lot of rain [22][23]. Strong updrafts and thick clouds that portend terrible weather or clouds containing ice particles are indicated by vivid yellow clouds. Bright yellow convective clouds were observed to have started to envelop the Malang City region at 07.40 UTC. Then, at 9:00 UTC, the convective cloud dispersion blanketed nearly the whole East Java region.

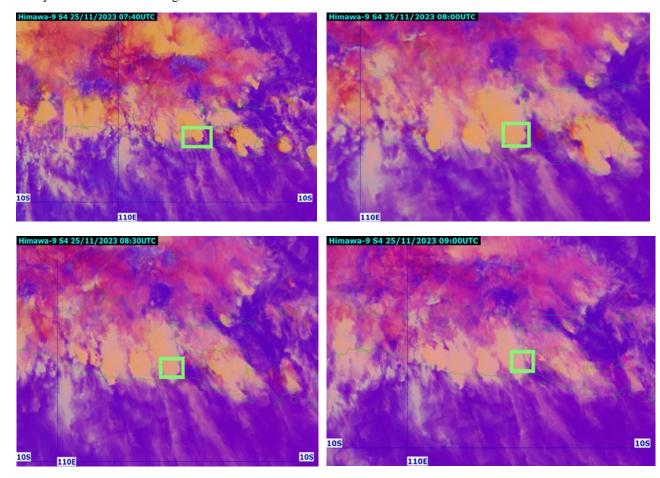


Fig. 1. Himawari-9 RGB *Day Convective Storm* image on 25 November 2023 at 07:40 – 09:00 UTC.

Cloud observations in the Malang City area indicate the existence of clouds, which are represented by the color white, according to the Airmass method processed using Himawari-9 satellite picture data. The cloud's white hue suggests that it is a thick convective cloud that was created by a warm air mass. Using satellite data, the Airmass technique is a great way to identify the kinds of clouds and air mass structures that are present in a given area. This method allows us to examine the impact of warm air masses on the development of dense convective clouds. Since warm air masses allow the air to rise quickly, creating clouds that might result in intense rainfall, these thick convective clouds are typically linked to extreme weather conditions like heavy rainfall. Thus, it is crucial to make observations using the Airmass approach in order to comprehend the possibility of severe weather events, such as storms or heavy rain, which could impact a region, including Malang City. Strong updrafts and high cloud thickness are indicated by the white representation of thick convective clouds in satellite photos [24]. Then, there is a slight dark green color that indicates the clouds are slightly thick and contain warm air masses. These warm air masses cause water vapor from the Java Sea region to be carried into the area. The development of Airmass clouds covering the Malang City area can be observed from 07:40 UTC to 08:00 UTC. This process shows that these slightly thicker clouds could contribute to the potential formation of more intense rainfall due to the interaction between the warm air mass and the high humidity carried from the Java Sea. In other words, the change in color and the development of these clouds serve as an important indicator in predicting weather conditions that may lead to adverse weather in the area.

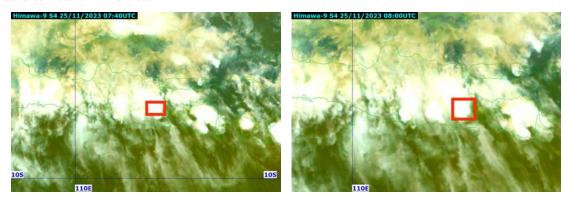


Fig. 2. Himawari-9 RGB Airmass image on 25 November 2023 at 07:40 - 09:00 UTC.

This data provides insights into the temperature of the cloud tops, which is derived from radiation observations at a wavelength of 10.4 micrometers. This particular parameter is essential in satellite-based weather observation as it helps in identifying cloud formation and assessing its potential severity, which is crucial for understanding weather patterns. The temperature of the cloud tops is then categorized using a color scheme to make it easier to interpret. For example, black or blue colors indicate areas with minimal cloud formation, where the clouds appear bright and thin. On the other hand, as the temperature of the cloud tops decreases, the color shifts towards orange and red. This color change suggests that the clouds are growing significantly in height, which is a strong indicator of developing storms. When cloud tops show such cooler temperatures, it often signals the formation of Cumulonimbus clouds, which are known for their association with severe weather conditions. These clouds can bring extreme weather events, including intense rainfall, thunderstorms, and even the possibility of flooding. At 07.30 UTC, the cloud top temperature in the Malang City area was observed to show a red color, indicating the potential development of Cumulonimbus clouds. This provides a clear indication that significant weather disturbances were possible in the area at that time.

3.2 Himawari-9 EH Products

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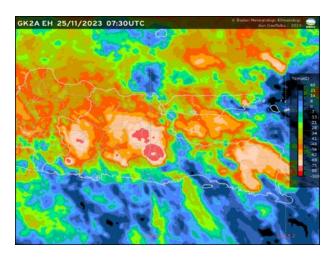


Fig. 3. EH temperature image on 25 November 2023 at 07:30 UTC.

3.3 Wyouming Sounding (Radiosonde)

Based on data obtained from the Wyoming weather website at 00 UTC, several key parameters were calculated to assess the potential for thunderstorms in the Malang City area. The Showalter Index (SI) yields a value of -0.05, indicating a tendency for thunderstorm development. The Lifted Index (LI) shows a value of -2.09, signaling an unstable atmosphere and the possibility of lightning. Additionally, the K Index (KI) gives a value of 25.7, which suggests a potential for thunderstorms in the region. The SWEAT (Severe Weather Threat) parameter results in 231.59, further confirming a high likelihood of thunderstorms. The Convective Inhibition (CIN) value of -22.33 suggests that there is a significant potential for severe weather events. Moreover, the Convective Available Potential Energy (CAPE) parameter is recorded at 1186.67, indicating a high possibility of strong thunderstorms developing. With these parameters pointing to wards unstable and conducive conditions for severe weather, it is expected that the Malang City area could experience heavy rainfall at 00 UTC.

4. CONCLUSION

On November 25, 2023, Malang City had significant rain that caused flooding in various regions. Different methods that integrate satellite data and other meteorological measurements are used to detect different types of clouds. The RGB approach, which enables more detailed monitoring of the distribution of convective clouds, is one of the techniques employed. Data from upper-air observations (Radiosonde) that suggested the possibility of heavy rain in Malang at the time was supported by the low cloud-top temperatures derived from Himawari 9-EH products, which showed rather intensive cloud formation.

The meteorological conditions at the time were extremely conducive to extreme weather, as evidenced by upper air observations, satellite data measurements of atmospheric factors, and cloud observations. Based on temperature and humidity, the air masses in the atmosphere can be analyzed and categorized using the Airmass method. This technique aids in determining the kinds of clouds and air mass features that are present in an area when using satellite pictures. Thick convective clouds, which can result in extreme weather conditions like intense rainfall, are typically linked to warm air masses. Strong updrafts and high cloud thickness are indicated by the white representation of thick convective clouds in satellite photos.

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IoT-Based Seismic Sensor Network Design for Early Warning System in Kalimantan: Literature Review

Ilham Muthahhari¹, Muhammad Dzakwan Firdaus¹

¹Undergraduate Program in Applied of Instrumentation Meteorology, Climatology Geophysics (STMKG)

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ABSTRACT

Kalimantan is not commonly associated with significant seismic activity due to its relative distance from major tectonic plate boundaries; however, it remains vulnerable to earthquakes that pose risks to human safety and the integrity of infrastructure. A recent seismic incident in the region has raised alarms about the adequacy of current preparedness and mitigation measures. This review seeks to establish a robust early warning system (EWS) for earthquakes by incorporating seismograph technology and IoT-based sensor networks tailored for Kalimantan. Despite its traditional classification as a low-seismic area, the region is susceptible to risks stemming from nearby active faults and tectonic dynamics. By analyzing recent research, this paper highlights the distinct geographical and environmental factors that must be considered when implementing a seismic sensor network in Kalimantan. It also examines the critical elements of seismographic devices for earthquake detection and discusses the role of IoT in enhancing real-time monitoring and early warning capabilities. The proposed IoT-based EWS utilizes affordable, distributed sensors to improve response times and detection precision, thereby providing timely notifications to vulnerable areas. This strategy presents a scalable and economically viable model for regions at risk of earthquakes, emphasizing the significance of both sophisticated instrumentation and accessible IoT technology for communities.

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Corresponden Author:

Ilham Muthahhari,

Undergraduate Program in Applied of Instrumentation Meteorology, Climatology Geophysics (STMKG)

Tangerang City, Banten, Indonesia Email: ilhammuthahhari@gmail.com

1. INTRODUCTION

Kalimantan, while not typically recognized for significant seismic activity due to its distance from major tectonic plate boundaries, still faces considerable risks from earthquakes that threaten both human safety and infrastructure integrity. A recent seismic event in the area has highlighted the need for improved preparedness and mitigation strategies. Specifically, Kalimantan is situated on the Sunda plate, bordered by the Philippine Sea plate and the Indo-Australian plate [1], [2], [3], [4]. Geologically, the island's core consists of Paleozoic and Mesozoic formations characterized by complex folds and fractures, which are irregularly overlaid by Cenozoic sediments. The timing and causes of active deformation in both the onshore and offshore regions of the island remain ambiguous, particularly in the context of the transition from compressive to gravitational tectonics, raising questions about the island's tectonic activity [5], [6].

Unlike cyclones and tsunamis, which can be forecasted hours in advance, earthquakes present a unique challenge as they can only be detected seconds before their impact. The brief interval between the detection of an earthquake and its resultant effects complicates the establishment of an effective earthquake early warning system (EEWS) [7]. An Early Warning System (EWS) is a multifaceted framework that integrates hazard monitoring, forecasting, predictive analysis, disaster risk assessment, and the promotion of communication and preparedness efforts. This system aims to enable individuals, communities, governmental entities, businesses,

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and other stakeholders to take timely actions to reduce disaster risks before hazardous events occur [8]. The earthquake early warning system (EEWS) is crucial for detecting ground shaking during seismic events and notifying the public and authorities to implement necessary safety measures, thereby minimizing potential harm to lives and property [9].

The Internet of Things (IoT) constitutes a comprehensive framework that interconnects a variety of objects, thereby allowing for their management, data analysis, and access to the information generated by these entities. The primary aim of IoT is to integrate devices, actuators, and sensors to execute a multitude of functions, including customized environmental monitoring [10]. A basic and universal architecture of IoT is structured into three layers: (i) the local environment, which consists of intelligent objects or sensors that engage in communication with one another and collect data from their surroundings; (ii) a transport layer that enables communication between the end-nodes of the first layer and the higher layers and infrastructures; and (iii) a layer focused on storage, data mining, and processing, usually hosted in the cloud, which may encompass systems and interfaces for user access and data visualization. In the context of disaster management and Early Warning systems, the Internet of Things (IoT) enhances extensive environmental monitoring through various data sources, facilitates low-latency communication, and supports real-time data processing. These functionalities are crucial for generating accurate and timely alerts during disasters or when predicting potential threats

This review aims to amalgamate contemporary seismograph technology with an Internet of Things (IoT)-based seismic sensor network to create a more dependable and scalable earthquake early warning system (EEWS). Effective EEWSs require a network of widely distributed ground motion sensors to detect seismic events and issue real-time alerts. By utilizing various sensors and sensing devices, these systems can proficiently monitor ground vibrations and movements, generating alarms to inform individuals in affected areas before seismic waves arrive. Even a short warning period of several seconds or minutes can be vital for saving lives. The primary method for detecting earthquakes relies on the identification of P-waves. During seismic activity, both compressional P-waves and shear S-waves are released from the epicenter. Since Pwaves travel faster and are less destructive, their early detection enables timely warnings to be communicated before the more harmful S-waves reach a specific location. A straightforward IoT-based system proposed by Alphonsa et al. [11], employs accelerometers connected to microcontrollers to collect and analyze ground vibration data, which is then transmitted via Zigbee to a computer receiver that alerts users. Furthermore, GSM modules can be used to send warnings to a base transceiver station, which subsequently informs mobile phone users. Although many countries have implemented earthquake monitoring systems, ongoing initiatives are dedicated to improving sensor networks, ensuring reliable and low-latency communication, and minimizing data processing delays, which frequently contribute to the overall latency in earthquake alert systems [12].

Seismographs play a crucial role in the detection of seismic waves; however, traditional configurations often encounter obstacles such as substantial maintenance expenses and restricted coverage. Furthermore, Earthquake Early Warning Systems (EEWS) require a network of widely distributed ground motion sensors to effectively identify earthquakes and issue real-time alerts. Consequently, the establishment and operation of EEWS can be financially burdensome. The integration of Internet of Things (IoT) technology allows for the deployment of numerous low-cost sensors over extensive areas, thereby enhancing both the precision of data collection and the immediacy of detection. Although the warning time may be limited, EEWS can serve as a significant resource for enhancing safety in areas susceptible to severe ground shaking [13]. The duration of the warning may be sufficient for pre-programmed systems to execute emergency protocols, such as shutting down machinery to mitigate potential losses and closing gas distribution valves [14]. In regions where conventional EEWS have already been implemented, low-cost Micro-Electro-Mechanical Systems (MEMS)-based networks can function as supplementary systems. Numerous examples exist where a low-cost EEWS acts as a backup for primary high-end systems, including locations such as Taiwan, the US West Coast, and various parts of mainland China [15], [16]. Additionally, a brief public alert can empower individuals to undertake basic safety measures, such as the drop-cover-hold technique, and mentally prepare for an imminent earthquake [17], [18], [19].

2. RESEARCH METHOD

2.1. Research Questions

This review poses five research questions to guarantee that all critical elements concerning the integration of seismic instrumentation and IoT technology in Kalimantan are addressed:

- What are the environmental and geographical considerations for deploying a seismic sensor network in Kalimantan?
- What are the key components and functions of seismograph instrumentation used in early warning systems?

- How is IoT technology being integrated with seismic sensor networks for real-time monitoring and early warning systems?
- How do IoT-based early warning systems improve response times and accuracy in detecting seismic activities?
- How can seismograph data be processed and analyzed using IoT platforms for efficient early warning in earthquake-prone areas?

2.2. Search for Relevant Article

The identification of pertinent articles within the existing literature was performed through a keyword search in the Google Scholar and Web of Science databases, initiated due to the limited availability of relevant studies prior to 2017. Consequently, only those articles published after this date were included in the analysis. To effectively address the review questions, the primary search terms employed were "earthquake early warning" and "IoT-based." Additionally, alternative terms such as "seismograph," "earthquake instrumentation," "network design," and "seismic sensor" were incorporated into the search strategy. Publications not written in English, along with grey literature, including governmental and corporate reports as well as non-scholarly research, were systematically excluded from the review. After applying the established inclusion-exclusion criteria and conducting the necessary filtering, a total of 20 articles were selected for this review.

2.3. Extract Relevany Data and Analyse The Literature

The next stage of the methodology, after identifying relevant articles, entails the extraction of significant information followed by its analysis to respond to the research questions. A key approach for analyzing qualitative data involves comparing the data through naming and classification processes [20], [21]. This approach establishes a framework for the data using Microsoft Word, which aids in developing a thorough understanding of the issue, the field, and the data itself. Continuous comparative analysis of the articles is conducted to identify the different methodologies utilized concerning EEWS and IoT-based systems, thereby creating a classification framework [22], [23].

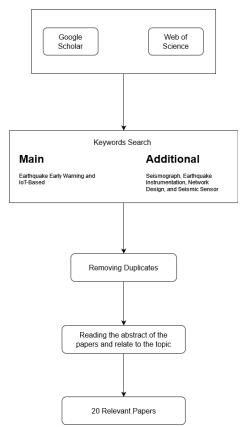


Fig. 1 Flowchart of Systematic Literature Review

3. RESULT AND DISCUSSION

3.1. Three Core of Discussion

Earthquake

Several studies focus on tectonic activity in Kalimantan. For example, the paper titled "Major Strike-Slip Faults Identified Using Satellite Data in Central Borneo, SE Asia" (2018) [5] investigates whether Kalimantan has active geological faults. The study uses Google Earth satellite data and USGS earthquake instruments, emphasizing geomorphological features like river flow shifts and sediment deformation to identify the main fault systems in Kalimantan, such as NW-SE dextral and NE-SW sinistral faults. The study highlights the importance of remote sensing in geological studies.

Another study, "Shuttle Radar Topography-Based Analysis Reveals The Active Borneo Island Fault in Borneo, SE Asia" (2024) [24], uses shuttle radar topography and geodetic data to map fault lines and geological structures, revealing tectonic activity caused by the interaction between the Australian and Sunda plates.

For detection of small earthquakes using new technology, the study titled "Small Local Earthquake Detection Using Low-Cost MEMS Accelerometers: Examples in Northern and Central Italy" (2021) [25] investigates the effectiveness of low-cost MEMS accelerometers in detecting small earthquakes. The study demonstrates that MEMS sensors, deployed across Italy, successfully detected nine small earthquakes with magnitude less than 3.0, providing valuable insights for integrating these sensors into seismic monitoring networks.

Early Warning System

Several studies explore the development and implementation of earthquake early warning systems. The paper "A Real-Time Early Warning Seismic Event Detection Algorithm Using Smart Geo-Spatial Bi-Axial Inclinometer Nodes for Industry 4.0 Applications" (2019) [26] presents the SWEDA algorithm, which successfully detects seismic waves in 1.7 milliseconds, analyzes 1.6 million data samples from sensors, employing signal processing techniques for accurate detection. The algorithm detects seismic waves with minimal latency, offering early warnings within microseconds after an earthquake's initiation.

Another paper, "A Distributed Multi-Sensor Machine Learning Approach to Earthquake Early Warning" (2020) [27], develops the DMSEEW system, which integrates GPS and seismometer data. The system uses ensemble stacking methods for classification and utilizes distributed computing for efficiency. This system shows more accuracy in detecting medium and large earthquakes than traditional methods.

The study of community-based earthquake warning systems "The Earthquake Network Project: A Platform for Earthquake Early Warning, Rapid Impact Assessment, and Search and Rescue" (2020) [28] illustrates the effectiveness of using smartphone accelerometers for detecting seismic events globally. The project involves 500,000 users and has successfully issued over 3,000 alerts in regions without traditional seismometer networks. On paper "Earthquake Early Warning: Recent Advances and Perspectives" (2020) [29] reviews existing EWS globally, analyzing their effectiveness in risk mitigation. The study Synthesizes findings from various systems, focusing on algorithms for rapid detection and ground motion prediction. The findings is highlights significant improvements in EWS, emphasizing the need for better risk communication strategies.

• Internet of Things (IoT)

Several papers focus on how IoT can enhance earthquake early warning systems. The study "Employing Machine Learning and IoT for Earthquake Early Warning System in Smart Cities" (2023) [30] integrates IoT devices with machine learning models for real-time earthquake detection. The study highlights how IoT networks can trigger disaster mitigation measures, such as automatically shutting down power grids during an earthquake.

Another paper, "Design Concept of an IoT-Based Earthquake Early Warning Platform" (2021) [31], demonstrates the capability of IoT-based sensors embedded in consumer electronics to detect ground motion and predict earthquake intensity in real-time with

employing a neural network for intensity prediction, optimizing detection speed and accuracy, highlighting the system's potential for widespread deployment.

The paper that study prototype design for IoT-based early warning systems "BLESeis: Low-Cost IoT Sensor for Smart Earthquake Detection and Notification" (2020) [32] discusses the development of a low-cost IoT-based seismic network. The system, using MEMS accelerometers and Raspberry Pi units, showed fast response times in detecting earthquakes and issuing early warnings, making it a viable option for both urban and rural areas.

3.2. Additional Topics

• Earthquake Early Warning Systems and Risk Management

"Earthquake Early Warning Systems as an Asset Risk Management Tool" (2021) [33] focuses on using historical data from significant earthquakes, such as the 2008 Sichuan Earthquake, the study underscores EEWS's role in alerting populations and enabling rapid protective actions. EEWS is presented as essential in mitigating economic impacts by giving advance warnings, thus allowing individuals and automated systems to take preventive actions, which can save lives and reduce damage.

Community and Crowdsourced Early Warning Systems

"The MyShake Platform: A Global Vision for Earthquake Early Warning" (2020) [34] leverages smartphone accelerometers to detect earthquakes, creating a global seismic network with over 300,000 users. This study examines the app's capability to distinguish earthquake-like movements from everyday activities and issue alerts within seconds. MyShake represents an innovative, low-cost solution to EWS by leveraging widely available smartphone technology, enhancing earthquake response in regions with limited traditional seismic monitoring systems.

• Security and Reliability in IoT-based Early Warning Systems

"A Security Transmission and Early Warning Mechanism for Intelligent Sensing Information in Internet of Things" (2022) [35] addresses security risks within IoT networks, especially focusing on unauthorized access and data tampering. It introduces a three-stage security mechanism that includes data encryption, secure transmission, and an early warning algorithm to detect anomalies. By enhancing data security, this approach aims to protect the integrity of sensing information, ensuring that IoT-based early warning systems can reliably function without vulnerability to cyber threats.

"Recent Advances in Internet of Things Solutions for Early Warning Systems: A Review" (2022) [36] reviews on the literature concerning the incorporation of Internet of Things (IoT) technologies into early warning systems (EWS) for a range of natural disasters, such as earthquakes, floods, and landslides. It categorizes IoT-based EWS into layers—perception, communication, and application—to illustrate how each layer functions, from data collection using sensors to real-time response generation. The study highlights the promise of IoT-integrated EWS in mitigating disaster risks through scalable monitoring solutions, though it also calls for improvements in sensitivity, power management, and minimizing false alarms.

3.3. Guide from Research Questions

 What are the environmental and geographical considerations for deploying a seismic sensor network in Kalimantan?

Environmental and geographical factors are crucial in deploying seismic sensor networks, especially in Kalimantan, where fault lines and tectonic activity influence the layout of sensors. According to "Major Strike-Slip Faults Identified Using Satellite Data in Central Borneo, SE Asia" (2018) [5], Kalimantan has active shear faults, including NW-SE and NE-SW directional faults, which create challenges in the consistent positioning of sensors due to variable geological formations such as river flow shifts, hill slopes, and sediment deformations. Additionally, the study "Shuttle Radar Topography-Based Analysis Reveals The Active Borneo Island Fault in Borneo, SE Asia" (2024) [24] confirms tectonic activity influenced by plate interactions that affect the topographic formations, such as the Oroclinal

- Bend in Sarawak. These considerations highlight the need for sensor networks to accommodate various elevations and soil conditions to ensure accurate data collection.
- What are the key components and functions of seismograph instrumentation used in early warning systems?
 - Seismograph instrumentation in early warning systems typically includes accelerometers, gyroscopes, GPS modules, and signal processing units, each contributing to real-time earthquake detection and data analysis. In the study "Implementation Early Design of Prototype EEWS Development in Indonesia" (2019) [37], seismographs deployed across Indonesian regions utilize accelerometers and intensity meters integrated with eBEAR modules for ground motion analysis. This configuration enables real-time alerts and efficient dissemination of warnings through mobile and web applications. Furthermore, the "The Multi-Parameter Wireless Sensing Systems (MPwise): Its Description and Application to Earthquake Risk Mitigation" (2017) [38] study details a multi-sensor approach, incorporating GNSS, accelerometers, and cameras, forming a wireless network capable of early earthquake detection. These components work together to enhance data accuracy and ensure timely alerts for public safety.
- How is IoT technology being integrated with seismic sensor networks for real-time monitoring and early warning systems?
 - IoT technology enhances seismic monitoring by enabling distributed data collection and processing, as illustrated in the paper "Employing Machine Learning and IoT for Earthquake Early Warning System in Smart Cities" (2023) [30]. This study integrates IoT networks with machine learning algorithms, where IoT devices collect and send seismic data to central servers. These servers then process the data in real-time to detect potential earthquakes. Similarly, "Design Concept of an IoT-Based Earthquake Early Warning Platform" (2021) [31] uses MEMS sensors embedded in IoT devices, establishing a sensor network that communicates seismic activity information to central processing units. The connectivity enabled by IoT allows for rapid data transfer and seamless monitoring across vast geographical areas, making it especially useful in regions prone to seismic hazards.
- How do IoT-based early warning systems improve response times and accuracy in detecting seismic activities?
 - IoT-based early warning systems significantly enhance response times and accuracy by enabling continuous, real-time monitoring and automated data analysis. For instance, the "BLESeis: Low-Cost IoT Sensor for Smart Earthquake Detection and Notification" (2020) [32] paper demonstrates that IoT sensors, equipped with MEMS accelerometers and connected to Raspberry Pi units, can detect P-wave arrivals and rapidly estimate earthquake intensity. These IoT systems can issue early warnings within seconds, which is crucial in reducing the time lag typically associated with traditional seismographic methods. Moreover, the "The Earthquake Network Project: A Platform for Earthquake Early Warning, Rapid Impact Assessment, and Search and Rescue" (2020) [28] study shows that IoT systems utilizing smartphone accelerometers provide nearly instant alerts to communities in areas without established seismic infrastructure. This rapid response capability is integral to minimizing damage and safeguarding lives in earthquake-prone regions.
- How can seismograph data be processed and analyzed using IoT platforms for efficient early warning in earthquake-prone areas?
 - IoT platforms provide a scalable solution for processing and analyzing seismograph data through machine learning and real-time data transmission. According to the study "A Distributed Multi-Sensor Machine Learning Approach to Earthquake Early Warning" (2020) [27], seismograph data from IoT devices are processed using the DMSEEW method, which combines GPS and seismometer data through distributed computing. This method enhances detection accuracy and computational efficiency. Additionally, "Employing Machine Learning and IoT for Earthquake Early Warning System in Smart Cities" (2023) [30] illustrates that IoT platforms can use machine learning algorithms (e.g., Random Forest,

SVM) to interpret seismic data, enabling systems to automatically classify events and determine the need for an alert. Such integration of IoT with machine learning allows for a more efficient and robust early warning system, especially valuable in densely populated or highly vulnerable areas.

4. CONCLUSION

The reviews presented in the document collectively enhance the understanding of earthquake dynamics, the evolution of early warning systems, and the incorporation of Internet of Things (IoT) technologies in seismic monitoring. The amalgamation of IoT with seismograph networks marks a notable progression for earthquake early warning systems (EEWS), especially in areas such as Kalimantan, where seismic threats may not be adequately addressed due to economic or infrastructural constraints. This methodology facilitates swift data processing and real-time surveillance, which are crucial for delivering prompt alerts. By utilizing a network of affordable sensors and IoT devices, the accuracy and scalability of data are significantly improved, enabling a wider distribution of monitoring locations. Through the detection of seismic occurrences via diverse data types, including ground motion and intensity readings, this IoT-enhanced system offers a viable solution for bolstering preparedness in regions susceptible to earthquakes. Each category emphasizes vital advancements within their respective domains, highlighting the significance of interdisciplinary strategies in improving earthquake preparedness and response initiatives.

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Unveiling Seismic Patterns in Kalimantan: Insights into Earthquake Events Over the Last Two Decades (2000-2024)

Ilham Muthahhari¹, R. Grata Sabdo Yudhopratidino², Eva Darnila³

¹Undergraduate Program in Applied of Instrumentation Meteorology, Climatology Geophysics (STMKG)

²Undergraduate Program in Applied of Geophysics (STMKG)

³Department of Computer, Universitas Malikussaleh, Aceh, Indonesia

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ABSTRACT

Seismic activity in Kalimantan, once considered to be relatively minimal, has garnered increased scrutiny due to the presence of active fault lines, including the Mangkalihat, Meratus, and Tarakan faults. This research examines earthquake occurrences in Kalimantan from 2000 to 2024, utilizing seismic data from the USGS and analytical tools such as QGIS and Microsoft Excel. The findings reveal that earthquake occurrences are predominantly located in the northeastern and southeastern parts of the region, with magnitudes varying between 3.9 and 6.1. Notably, the year 2015 experienced a marked increase in seismic events. The results emphasize the critical need for disaster preparedness, the resilience of infrastructure, and the establishment of Early Warning Systems (EWS) to alleviate potential hazards. This study advocates for ongoing monitoring and enhanced public awareness to diminish seismic vulnerability in Kalimantan.

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Corresponden Author:

Ilham Muthahhari,

Undergraduate Program in Applied of Instrumentation Meteorology, Climatology Geophysics (STMKG) Jl. Meteorologi RT 003/RW 013, Tanah Tinggi, Kec. Tangerang, Kota Tangerang, Banten 15119, Indonesia. Email: ilhammuthahhari@gmail.com

1. INTRODUCTION

Seismic activity on the island of Borneo has been documented over the past few decades. According to data published by AllQuakes in 2024, the North Kalimantan region has recorded a total of 49 earthquake events since 1970, with magnitudes ranging from 2 to 6.1. In general, Kalimantan is perceived to exhibit lower seismic activity in comparison to its neighboring regions. However, the existence of active faults, such as the Tarakan fault and the Mangkalihat fault, suggests a potential for seismic events that warrants attention [1]. Research indicates that this area is not entirely devoid of earthquake risks. A study by Ninis et al. (2022) [2] successfully identified an active fault in Kalimantan that could potentially induce seismic activity. Furthermore, information from the Indonesia Re website in 2019 highlights that Kalimantan is home to numerous faults that may serve as sources of earthquakes. Earlier, Heryanto et al. (1995) [3] had recognized the surface manifestations of elongated faults within Kalimantan.



Fig. 1 Borneo Island

Kalimantan or Borneo, the third largest island in the world, is located in Southeast Asia and is divided into three countries: Indonesia, Malaysia, and Brunei. The island's geological structure is influenced by complex interactions between tectonic plates, including the Indo-Australian Plate, Sunda Plate, and Philippine Sea Plate [4]-[7]. Studies conducted successfully identified that the presence of active faults in Kalimantan has the potential to trigger seismic activity [8]. These tectonic dynamics contribute to the island's seismic activity, although Kalimantan is generally considered to be less seismically active than its neighboring regions.

The preceding discussion highlights that, despite Kalimantan not being situated directly within a subduction zone, akin to other Indonesian islands, the seismic activity in this area warrants careful consideration owing to the existence of multiple active faults [9]. Over the past twenty years, the increasing frequency of earthquakes in this region has piqued the interest of researchers, prompting them to undertake more comprehensive investigations [10].

Earthquakes represent a natural occurrence that can be examined for their potential risks and underlying mechanisms. These seismic events are characterized by vibrations of the Earth's surface, resulting from the abrupt release of energy within the Earth's crust, typically associated with the movement of tectonic plates. The energy discharged during an earthquake produces seismic waves that propagate through the Earth, leading to ground shaking. Various categories of earthquakes exist, including tectonic, volcanic, and collapse earthquakes. Measurements of earthquakes can be conducted using several scales, such as the Richter scale and the moment magnitude scale [11]. A study by Suhartono et al. (2023) investigated the earthquake risk in the Kalimantan fault region employing the Least Square method [12]. Earthquakes characterized by moderate to strong intensity have the potential to inflict significant destruction, primarily due to the direct consequences associated with the origin of the seismic activity [13]. The subsequent effects that arise following an earthquake can lead to diverse levels of risk and further intensify pre-existing damage [14]-[16].

The United States Geological Survey (USGS) is a scientific agency of the federal government tasked with the examination of the nation's topography, natural resources, and natural calamities. Specifically concerning earthquakes, the USGS is engaged in the monitoring and documentation of seismic events, evaluating their impacts and associated risks, and performing research that investigates the underlying causes and consequences of these phenomena [17]. A study featured in the Geophysical Journal International highlights the importance of comprehending the uncertainties surrounding earthquake locations for effective seismic hazard evaluation [18].



Fig. 2 QGIS Software

QGIS is a free and open-source software application designed for the visualization, management, and analysis of spatial data. It accommodates a wide range of data formats and offers tools for vector analysis, geoprocessing, and database management. These capabilities empower users to conduct thorough analyses of spatial data [9]. Microsoft Excel is widely recognized as a prominent spreadsheet application utilized for the analysis of data. Setiyanto (2023) examines the application of Excel within the realm of data science, highlighting functionalities such as error identification, elimination of duplicate entries, and management of missing data [19].

QGIS software was established in 2002, originally named Quantum GIS, and was developed by Gary Sherman. Its primary function is to provide an interface for the visualization of geospatial data [10, 20]. In their research, Lestari et al. (2019) employed QGIS for the analysis of seismicity data [21]. Research indicates that GIS tools are effective in generating risk maps for regions susceptible to earthquakes, highlighting their significance in disaster management [22]. Through the integration of various data layers, QGIS enables thorough analyses that aid in decision-making processes related to urban planning and emergency preparedness.

Given the potential for heightened seismic activity in Kalimantan in the future, it is essential to evaluate systemic interdependencies and integrate cascading effects into simulation tools or prototypes. This approach is vital for enhancing our understanding and bolstering disaster mitigation preparedness and post-disaster recovery efforts [23, 24]. Furthermore, contemporary societies face significant vulnerability to disasters, largely attributable to the intricate interconnections among various regions and infrastructure systems [25].

2. RESEARCH METHOD

2.1. Data Retrival



Fig. 3 USGS Website

To effectively analyze patterns of seismic activity, it is essential to gather accurate and pertinent data that can help identify areas at risk and facilitate early disaster mitigation efforts [26, 27]. The primary source of data utilized in this analysis is the United States Geological Survey (USGS), which offers a range of information, including the location of epicenters, magnitude, depth, and time of occurrence. This data is available for access and download in various formats, including CSV, XML, and GeoJSON.

2.2. Data Cleansing

The objective of data cleaning is to rectify inaccuracies, maintain data uniformity, and enhance the quality of analytical outcomes [28]. The initial phase of the cleaning process involves critical data validation, which ensures that values such as magnitude and depth fall within a reasonable range. Subsequently, data is filtered according to geographical location and temporal parameters. In this filtering process, only data pertaining to the Kalimantan region (defined by specific geographical coordinates) within the years 2000 to 2024 is retained.

2.3. Data Visualization

The significance of data visualization lies in its ability to elucidate patterns of earthquake distribution, the spatial relationships with active fault lines, and trends in seismic activity [29]-[31]. This capability is particularly beneficial for effectively communicating analytical results to the general public.

3. RESULT AND DISCUSSION

3.1. Data Visualization Results

• Graph of Frequency of Earthquake Occurrence in Kalimantan Island

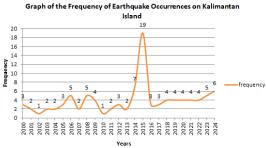


Fig. 4 Graph of Eathquake Frequency

Earthquake activity in Kalimantan is low and stable, with some peaks of activity. Peak activity occurred in 2015, which was the period with the highest seismic activity in Kalimantan, with 19 earthquakes. The average earthquake frequency is around 4-5 events per year. A stable trend emerges in the period 2018-2022, while a gradual increase is seen in the periods 2004-2006 and 2022-2024.

• Ratio Chart of Earthquake Occurrence in Kalimantan Island for the Period 2000-2024

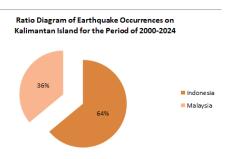


Fig. 5 Ratio Diagram

The Indonesian region dominates in the frequency of earthquake events with a percentage of 64%, while the Malaysian region with a percentage of 36%. This distribution is influenced by geological factors, tectonics, and different areas in both countries.

• Magnitude Ratio Diagram of the Occuring Earthquake

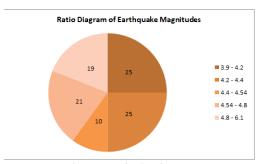


Fig. 6 Magnitude Diagram

Small magnitude earthquakes (3.9 - 4.4) are more frequent and dominate the data. Medium to large magnitude earthquakes (4.4 - 6.1) have lower numbers but are worth noting as their potential impact is more significant. The 4.4 - 4.54 range has the least frequency of occurrence (10), while the 3.9 - 4.4 category has the highest frequency.

• Earthquake Distribution Map of Kalimantan Island for the Period 2000-2024

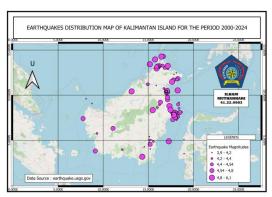


Fig. 7 Earthquake Distribution Map

The region of Northeast Kalimantan shows the highest density of earthquake activity, with many bright magenta coloured circles indicating earthquakes with significant magnitudes (4.8 - 6.1). Most of the earthquakes occurred in coastal areas and waters around the northeast. In the region of South and Southeast Kalimantan, there is a distribution of earthquakes with varying magnitudes, although the density is lower compared to the northeast. Some earthquake points have magnitudes between 4.54 and 4.8. Earthquake activity in West and Central Kalimantan are relatively rare. The small black and light purple circles indicate that most earthquakes have low to moderate magnitudes (3.9 - 4.4).

3.2. Borneo Island Faults

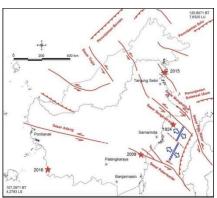


Fig. 8 Borneo's Fault Map

Kalimantan, positioned between the Eurasian and Indo-Australian tectonic plates, experiences considerable geological movement [32]. Research has indicated that the likelihood of faulting is especially notable in the island's mountainous areas [33]. Key faults identified in this region include the Barito Fault and the Kapuas Fault. The Barito Fault runs centrally through Kalimantan, extending from the northern to the southern regions along the Barito River. According to Satyana et al. (1999) [34], this fault exhibits sufficient activity to potentially trigger substantial earthquakes. Conversely, the Kapuas Fault, located in the western section of Kalimantan, aligns with the trajectory of the Kapuas River and is thought to possess a significant capacity for tectonic disturbances.

The faults located in Kalimantan are classified as ancient and are regarded as inactive; however, they may have undergone seismic activity throughout extensive geological timeframes. Notably, certain ancient faults play a role in influencing geological occurrences within the region.

The likelihood of reactivation of these faults is influenced by various factors, including regional tectonic stresses, interplate tectonic forces, and the geological properties of the surrounding rock formations. While researchers have employed seismic modeling, geological surveillance, and analysis of rock structures to assess the earthquake risk associated with these ancient faults, precise predictions regarding the timing or intensity of potential reactivation remain unattainable.

3.3. Seismic Activities in Kalimantan

Although earthquakes are infrequent in Kalimantan relative to neighboring regions, they do occur, particularly in areas near tectonic plate boundaries. Records from the Meteorology, Climatology, and Geophysics Agency (BMKG) over recent years demonstrate that Kalimantan possesses earthquake potential. Notably, the South Kalimantan Sea Island earthquake on February 5, 200 had a magnitude of 5.8, which was felt across various locations, including Laut Island, Sebuku Island, Sembilan Island, Pagatan, and Batulicin. Additionally, on December 21, 2015, at 01:47:37 a.m., a magnitude 6.1 earthquake struck the Tarakan region, occurring at a depth of 33 km and registering an intensity of MMI V-VI, followed by 26 aftershocks. Another seismic event transpired in the same vicinity on June 24, 2016, at 08:41:36, when a magnitude 5.1 earthquake occurred. The epicenter was located at coordinates 2.77°N and 110.09°E, approximately 10 km southwest of Kandawangan, Ketapang, with a hypocenter depth estimated at around 10 km and an MMI intensity scale ranging from V-VI.

The Sampit earthquake of 2023 struck at 01:21:44, with its epicenter located 25 kilometers northeast of Sampit in Central Kalimantan. This seismic event registered a magnitude of 4.3 and occurred at a depth of 13 kilometers. The tremors were experienced with a Modified Mercalli Intensity (MMI) of approximately III in the Baamang and Mentawa Baru Districts of Ketapang, as well as in other regions including East Kotawaringin and Palangkaraya. Subsequently, on February 13, 2024, at 08:22 WIB, South Kalimantan experienced three additional earthquakes with magnitudes of 4.7, 3.3, and 4.1. These quakes originated from the Meratus fault at a depth of 10 kilometers, and were sufficiently intense to inflict damage on structures in Sungkai Baru Village, located in the Simpang Empat District of Banjar Regency.

While the majority of seismic activity in Kalimantan tends to be minor and infrequently results in significant consequences, historical events underscore the necessity for local populations to maintain vigilance and preparedness for potential future earthquakes. It is crucial to enhance public awareness regarding the significance of risk mitigation strategies as part of emergency preparedness initiatives, which are vital for reducing the adverse effects of forthcoming seismic events in Kalimantan [35].

4. CONCLUSION

Kalimantan is generally regarded as a region with lower seismic activity in comparison to its neighboring areas; however, an examination of earthquake data spanning from 2000 to 2024 reveals the occurrence of notable seismic events that warrant attention. The majority of earthquake epicenters are situated near relatively active faults, including the Mangkalihat Fault, Meratus Fault, and Tarakan Fault. The eastern and northern parts of Kalimantan Island, particularly East Kalimantan in Indonesia and Sabah in Malaysia, have experienced the highest concentration of these seismic events.

The findings from this analysis have significant implications for disaster mitigation strategies in Kalimantan. They can inform the enhancement of disaster preparedness initiatives, such as the establishment of an Early Warning System (EWS) and the formulation of regional development plans that are equipped to address potential earthquake occurrences. Given the existence of active faults like the Meratus Fault, which poses a risk of substantial earthquakes, it is essential that mitigation strategies also focus on raising public awareness regarding earthquake risks and constructing infrastructure that is resilient to seismic activity in vulnerable areas.

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A Literature Review of Low-Cost Accelerometer Sensors for Earthquake Detection: Performance Analysis and Accuracy Assessment

Muhammad Rafi Athallah Disastra¹, Adhe Abdurrafi²

¹Undergraduate Program in Applied of Instrumentation Meteorology, Climatology Geophysics (STMKG)

²Undergraduate Program in Applied of Industrial Engineering (Bhayangkara University)

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ABSTRACT

This literature review synthesizes findings from 20 studies that explore earthquake detection systems using low-cost accelerometer-based sensors integrated with microcontrollers, such as Arduino, and other IoT technologies. The comparative analysis focuses on sensor selection, sensitivity, noise levels, and system efficacy across various implementations. The ADXL355, LIS3DHH, MPU6050, and ADXL345 accelerometers emerged as commonly tested sensors, each demonstrating unique strengths in seismic activity monitoring. Studies highlight the ADXL355 and LIS3DHH for their low noise and high sensitivity, making them preferred for detecting subtle ground movements, while the MPU6050's six-axis functionality offers versatility in multi-dimensional motion analysis. Additionally, research underscores the importance of accurate calibration and noise mitigation techniques to enhance data reliability. The review concludes that low-cost accelerometers, particularly when combined with IoT frameworks, provide feasible solutions for scalable earthquake early warning systems. However, challenges persist in balancing sensitivity and stability in noisy environments, indicating a need for further refinement in sensor technology and signal processing algorithms to improve detection accuracy and reduce false alarms in real-world applications.

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Corresponden Author:

Muhammad Rafi Athallah Disastra, Undergraduate Program in Applied of Instrumentation Meteorology, Climatology Geophysics (STMKG) Tangerang City, Banten, Indonesia

Email: rafi.athallah1@gmail.com

1. INTRODUCTION

In recent years, the development of low-cost Micro-Electro-Mechanical Systems (MEMS) accelerometer sensors has revolutionized earthquake detection and vibration monitoring capabilities. These technological advancements have made it increasingly feasible to deploy widespread sensor networks for early warning systems and structural monitoring at a fraction of the cost of traditional seismological equipment [13][14][17]. This review synthesizes findings from 20 recent studies examining various low-cost accelerometer sensors, their performance characteristics, and their applications in seismic monitoring.

The growing frequency and impact of seismic events worldwide has highlighted the critical need for reliable, cost-effective earthquake detection systems [1]. While conventional seismological instruments provide high accuracy, their substantial cost and complexity often limit widespread deployment, particularly in developing regions or areas requiring dense sensor networks. Low-cost accelerometer sensors have emerged as a promising alternative, offering an attractive balance between performance and accessibility [7].

Several Low-cost accelerometer sensors have been prominently featured in recent research, including the ADXL series (ADXL355, ADXL345, ADXL335), MPU series (MPU9250, MPU6050), and LIS series (LIS3DHH, LIS331DLH). These sensors vary in their specifications, capabilities, and performance

characteristics, making it essential to understand their relative strengths and limitations for specific applications.

This review examines key performance metrics such as noise levels, sensitivity, accuracy, and reliability across different sensor types. Particular attention is paid to comparing their effectiveness in detecting seismic events, measuring vibrations, and providing reliable data for early warning systems [2]. Additionally, we explore how these sensors perform when integrated with various microcontrollers and IoT platforms for real-world applications.

The findings from this review aim to provide researchers, engineers, and system developers with comprehensive insights into the current state of low-cost accelerometer technology for earthquake detection and vibration monitoring. This information is crucial for making informed decisions about sensor selection and system design in future implementations of earthquake monitoring networks and early warning systems.

2. RESEARCH METHOD

This research employs a comprehensive review of existing literature on low-cost accelerometers, focusing on their applications and advancements in earthquake detection. The study centers on low-cost accelerometers and their performance metrics. It explores how low-cost accelerometers can effectively measure vibrations and motion, assessing their accuracy and reliability. The literature review identifies several studies that highlight the effectiveness of low-cost accelerometers in real-time monitoring systems. These studies will be discussed in detail in the results and discussion section, emphasizing their implications for enhancing earthquake detection.

3. RESULT AND DISCUSSION

In this review, we analyzed 20 research papers focusing on various low-cost accelerometer sensors and their applications in earthquake detection and vibration monitoring. These papers provide detailed insights into the performance, accuracy, and practical implementation of different sensor types. The following table summarizes the key findings from each study, including the sensors used, their applications, and specific performance metrics. This compilation offers a comprehensive overview of current research in low-cost earthquake detection systems and highlights the varying capabilities of different accelerometer sensors. Table 1 presents a detailed summary of these research papers and their key findings regarding accelerometer sensor performance.

TABLE I. Literature Review

No	Author	Title	Reviews
1	J. Lee, J. S. Kim, S. Choi, and Y. W. Kwon	A Smart Device Using Low-cost Sensors to Detect Earthquakes	The research paper evaluated four different acceleration sensors for their performance and accuracy. The sensors mentioned are ADXL355, LIS3DHH, MPU9250, and MMA8452. The ADXL355 and LIS3DHH sensors outperformed the other sensors (MPU9250 and MMA8452) in terms of noise level and sensitivity, making them more suitable for detecting earthquakes. The study emphasized that lower noise levels and higher sensitivity are critical for accurately capturing the acceleration changes caused by seismic events [1].
2	J. Lee, I. Khan, S. Choi, and Y. W. Kwon	A Smart IoT Device for Detecting and Responding to Earthquakes	The research paper evaluates four low-cost accelerometer sensors for earthquake detection: ADXL355, LIS3DHH, MPU9250, and MMA8452. The paper discusses the performance of these sensors in detecting earthquakes using a proposed algorithm. The ADXL355 and LIS3DHH sensors generally performed better in terms of noise levels, while the ADXL355 showed high probabilities of detecting earthquakes accurately, despite some false detections due to noise in the other sensors. Overall, the ADXL355 and LIS3DHH sensors outperformed the others in terms of noise and sensitivity, making them

			more suitable for earthquake detection applications [2].
3	I. I. Sianturi, D. Hamdani, and E. Risdianto	Design an Earthquake Early Warning System Based on Arduino Uno Microcontroller with Accelerometer- MPU6050 sensor and NodeMCU-ESP8266	The accelerometer used in this research paper is the MPU6050 sensor. The MPU6050 is a motion sensor with a 16-bit with a 3-axis gyroscope and accelerometer, and also a Digital Motion Processor (DMP), which functions to measure the position of an object. The microcontroller and interface with 16-bit output data make the sensor's accuracy very high [3].
4	Z. M. Cho and W. Z. Hein	Design and Construction of Earthquake Detection and Location Reporting System on Google Map	The accelerometer used in this research paper is the MPU-6050, which is an integrated 6-axis motion tracking device containing a 3-axis accelerometer and gyroscope. The data taken from the accelerometer is described as accurate, as the MPU-6050 sensor provides precise information on acceleration forces and tilt angles. The sensor captures x, y, and z-axis data with 16-bit analog-to-digital conversion for each channel, ensuring high accuracy in the measurements [4].
5	P. K. Sinha, S. Saraiyan, M. Ghosh, and V. Nath	Design of Earthquake Indicator System Using ATmega328p and ADXL335 for Disaster Management	This research paper explores the use of the ADXL335 accelerometer, a low-power, three-axis MEMS device with a range of ±3g, in detecting vibrations for earthquake monitoring. The ADXL335 accurately captures vibrations, which are then processed by an ATmega328p microcontroller, converting analog signals to digital and calculating peak ground acceleration. When vibrations exceed a set threshold, the system triggers an alarm, indicating that the ADXL335 data is reliable for significant seismic activity detection. This integration of the ADXL335 and ATmega328p enables effective monitoring and timely earthquake warnings, demonstrating high accuracy in data collection [5].
6	Gunoro, Suprapto, J. Iriani, B. V. Sundawa, Abdullah, and Cholish	Design of Earthquake Warning Alarm Using Accelerometer Sensor Based on Internet of Things	The research paper utilizes the ADXL335 accelerometer sensor to detect earthquakes. This sensor provides three output coordinate points (X, Y, Z) with analog values that are processed by an Arduino Nano microcontroller to estimate the earthquake's intensity on the Richter scale. The study establishes a correlation between tilt angles and Richter scale values, with analog values ranging from 100 to 400 corresponding to different intensity levels (e.g., 2-3 Richter scale for a 15-degree tilt and 7-10 Richter scale for a 90-degree tilt). However, the paper does not specify the exact accuracy or percentage of error associated with these measurements, indicating that while the system can provide a rough estimate of earthquake intensity, the precision of the data is not quantitatively assessed [6].
7	Z. Sun, S. J. Dyke, F. Pena, and A. Wilbee	Development of Arduino-Based Wireless Control System	The research paper examines the ADXL345 accelerometer from Analog Devices, a tri-axial MEMS sensor with a ±16 g measurement range and 13-bit resolution. Users can select a sampling rate from 6.25 Hz to 3200 Hz, and the device operates

with low power. Accuracy testing reveals that at a 100 Hz sampling rate, the ADXL345 has a measurement error of approximately 0.214, which is low compared to a reference wired accelerometer. This low error rate indicates the ADXL345 provides highly accurate data for the research [7].

8 A. Apriyansa, J. Bintoro, and E. Sandi

Development of Early Real-Time Disaster Mitigation Warning System Landslide with Gyroscope ADXL345 Sensor This research paper presents an early warning system utilizing the ADXL345 accelerometer sensor, which measures tilt and acceleration to detect landslide-prone conditions. Through a calibration process, the system ensures reliable sensor readings, with specific tilt values like 0 degrees yielding 5 bits and 90 degrees reaching 277 bits. Testing confirms the system's effectiveness in determining slope status and sending alerts when angles exceed set thresholds, such as 75 degrees. The results from both lab and field tests demonstrate the system's feasibility and reliability, indicating that the ADXL345 provides accurate data for landslide detection [8].

9 F. H. Chen, H. L. Shieh, and J. F. Tu

Development of Earthquake Detection and Warning System Based on Sensors The research paper utilizes the ADXL345 three-axis accelerometer for earthquake detection and building tilt detection. The ADXL345 is noted for its low power consumption and high resolution, which is 4 mg/LSB. This high resolution allows the accelerometer to measure changes in tilt of less than 1.0°. The accelerometer's digital output data is transmitted in a 16-bit binary code format, making it suitable for precise measurements in various applications, including static acceleration and tilt sensing [9].

10 R. Hoque, S. Hassan, M. A. Sadaf, A. Galib, and T. F. Karim

Earthquake Monitoring and Warning System

The research paper uses the ADXL-345 digital accelerometer to detect ground acceleration during earthquakes, focusing on identifying P-waves, the primary seismic shock waves. Although specific accuracy metrics are not provided, the system is designed to capture low-frequency vibrations (1–3 Hz) typical of P-waves. The ADXL-345's ability to detect these signals accurately is critical to the system, which relies on data matching from multiple sensor nodes to confirm seismic activity and provide timely alerts, emphasizing the importance of data accuracy for effective earthquake detection [10].

11 V. Babu and V. Rajan Flood and Earthquake Detection and Rescue Using IoT Technology The research paper explores the MPU6050 module, a MEMS device combining a 3-axis accelerometer and 3-axis gyroscope, used to measure motion-related parameters such as acceleration, velocity, orientation, and displacement. The MPU6050's Digital Motion Processor (DMP) supports complex calculations, enhancing its functionality. While the paper outlines the module's capabilities, it does not specify data accuracy, noting that accuracy generally depends on calibration, environmental factors, and application context. For precise accuracy information,

manufacturer specifications or controlled empirical testing are typically required [11]. 12 Yulkifli, A. Initial Design of IoT-The research paper talks about the use of the Earthquake MPU6050 accelerometer sensor for measuring Nofriandi, R. Based Triyono, W. Intensitymeter Using earthquake intensity. This sensor can measure Peak Audia, and N. A. MMI Scale Ground Acceleration (PGA) values on three axes (x, Sati'At y, and z) simultaneously. The accuracy of the data Smartphone Display obtained from the MPU6050 accelerometer is indicated by an average linearity test result, which shows a 0.994 R-squared value. This high value indicates that the sensor is functioning well and provides reliable data for the initial design of the earthquake intensity meter [12]. 13 N. Bahari, N. I. M. IoT Based Earthquake The research paper uses the MPU6050 accelerometer Nor Azmi, M. W. sensor for earthquake detection, highlighting its **Detection System** compactness, cost-effectiveness, and adjustable Nasrudin, R. Che sensitivity range starting at $\pm 2g$. The sensor detects Yob, N. H. Ramli, and H. Lago ground vibrations essential for identifying seismic activity, with the system designed to distinguish between earthquake-induced vibrations and other sources. It features ten intensity levels, from minor to dangerous, based on set thresholds that help classify vibration severity accurately. Although specific accuracy metrics are not provided, the paper emphasizes the MPU6050's operational effectiveness and suitability for detecting significant seismic events [13]. The research paper uses the EpiSensor FBA ES-T as A. Taale, C. E. On the feasibility of IoT-based smart meters the reference sensor and the LIS3DSH MEMS Ventura, and J. for earthquake early accelerometer in the smart meters (SMs). The MEMS Marti sensor is deemed unreliable for motion measurements warning with peak accelerations below 148 mg or RMS values lower than 46 mg, while it shows satisfactory coherence for frequencies greater than 1 Hz when compared to the reference sensor. Overall, the accuracy of the MEMS data improves significantly when the acceleration RMS goes above 20 mg, reducing the error to below 20%. [14] 15 J. V. O. Performance evaluation This research paper evaluates the performance of two Rodrigues, M. P. accelerometers accelerometers, the ADXL345 G. Pedroso, F. F. ADXL345 MPU6050, in monitoring low-intensity random MPU6050 exposed to vibrations, particularly in rotating machinery. Data Barbosa Silva, and analysis shows that the MPU6050 provides more R. G. Leão Junior random vibrational consistent and uniform responses, with rectification input error behavior aligning well with established literature, indicating its reliability for vibration monitoring. In contrast, the ADXL345 exhibited anomalies and higher offset shifts—about five times that of the MPU6050—suggesting it is less reliable

for precise measurements. Overall, the MPU6050 is recommended as a stable sensor for mechanical vibration monitoring, while the ADXL345's accuracy

in similar applications is questioned [15].

16	G. Murariu et al.	Personal seismograph a functional prototype	This research paper examines the MPU6050, a module with both gyroscope and accelerometer, capable of detecting motion and intensity across three axes with 16-bit analog-to-digital converters. The MPU6050's sensitivity is sufficient to capture vibrations relevant to seismic events, indicating reliable data for monitoring and assessing seismic activity, though specific accuracy metrics are not provided. The system is designed for real-time earthquake detection and classification, suggesting an accuracy level suited for practical disaster management applications [16].
17	A. D'Alessandro and G. D'Anna	Suitability of Low-Cost Three Axis MEMS Accelerometers in Strong-Motion Seismology: Tests on the LIS331DLH (iPhone) Accelerometer	This research paper compares the LIS331DLH MEMS accelerometer, found in iPhones, with the EpiSensor FBA ES-T accelerometer, used as a reference sensor, for recording seismic activity. Tests show that the LIS331DLH offers excellent frequency and phase response comparable to standard strong-motion seismology accelerometers, though it slightly underestimates actual acceleration. Despite limited sensitivity due to self-noise, it achieves a high signal-to-noise ratio for moderate to strong earthquakes (magnitude >5) near epicenters, with an average correlation over 0.998 to the reference sensor. The study concludes that while the LIS331DLH is promising for strong-motion seismology, further calibration and testing are recommended for scientific use [17].
18	E. Husni and F. Laumal	The Development of an Earthquake Early Warning System Using an ADXL335 Accelerometer	The accelerometers used in this research paper are ADXL335 accelerometers. The data taken from the ADXL335 accelerometer is generally accurate, but it is observed that the vibration values are not stable in a non-vibrating condition. The values sometimes change to 0.010 or -0.010. The noise density is 150 µm for both the X-axis and Y-axis, while it is 300 µm for the Z-axis. The peak noise density values are 0.084 for the X-axis and Y-axis, and 0.064 for the Z-axis. This indicates that the noise levels are within acceptable limits, ensuring the data's reliability for detecting vibrations [18].
19	Y. Pramudya and M. Islamiah	Vibration characteristics study on observatory using accelerometer ADXL345 sensor and Arduino	The accelerometer used in this research paper is the ADXL345 sensor. The data taken from the ADXL345 accelerometer is calibrated using a Vernier Force Dual-Range Sensor. The calibration process entails fitting the data to a damped oscillation harmonic equation and applying a linear regression equation to convert the accelerometer's output into acceleration units (m/s²). The resulting conversion equation is $y = 0.0354 \text{ m/s}^2 \text{ x} + 0.1602 \text{ m/s}^2$, where x represents the amplitude measurement from the ADXL345 accelerometer sensor and y corresponds to the amplitude measurement from the Vernier Force Dual-Range Sensor. This calibration ensures that the data from the ADXL345 accelerometer is accurate

			and reliable for measuring vibrations at the observatory [19].
20	M. Hasibuzzaman, A. Shufian, R. K. Shefa, R. Raihan, J. Ghosh, and A. Sarker	Vibration Measurement & Analysis Using Arduino Based Accelerometer	The research paper utilizes the ADXL-345 tri-axial accelerometer, which is known for its high-resolution capabilities in measuring acceleration across three dimensions. This accelerometer is particularly valued for its precision, providing data with an accuracy of ±4.5%, which is essential for applications that require reliable measurements of mechanical acceleration and vibration. The ability to capture detailed and accurate data is crucial in various fields, such as safety monitoring and machinery condition assessment, as it enables the effective detection of faults and abnormal vibrations. By employing the ADXL-345, the research ensures that the findings are based on robust and trustworthy data, ultimately contributing to the reliability of the study's conclusions and recommendations [20].

4. CONCLUSION

This comprehensive review of 20 research papers has offered important insights into the current status and capabilities of low-cost accelerometers sensors in earthquake detection and vibration monitoring applications. The findings demonstrate that MEMS accelerometer technology has made significant strides in providing viable alternatives to traditional, more expensive seismic monitoring equipment.

Among the sensors evaluated, the ADXL355 and LIS3DHH consistently demonstrated superior performance in terms of noise levels and sensitivity. The MPU6050 emerged as a reliable middle-ground solution, offering good performance characteristics with high linearity (R-squared value of 0.994) and versatility in various scenarios [12]. While some sensors, such as the ADXL335 and MMA8452, showed moderate performance levels, they still proved adequate for basic monitoring applications where cost is a primary consideration [2].

A significant finding from this review is the trade-off between cost and performance in low-cost accelerometer sensors. While these sensors may not match the precision of professional seismological equipment, their cost-effectiveness and reasonable accuracy make them valuable for creating sensor networks and implementing widespread early warning systems, especially in regions with limited resources [3].

The review also highlights several areas requiring further research and development. These include improving false detection rates, enhancing low-frequency response capabilities, and developing more robust calibration methods [2]. Additionally, the incorporation of these sensors with IoT platforms and real-time monitoring systems presents both opportunities and challenges that warrant continued investigation.

The evolution of low-cost accelerometer technology suggests promising developments in earthquake detection. The increasing accuracy and reliability of these sensors, combined with their decreasing costs, indicate a future where comprehensive earthquake monitoring networks could become more accessible to communities worldwide. This democratization of seismic monitoring technology could significantly contribute to improving earthquake preparedness and response strategies globally.

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Implementation of LVGL and LovyanGFX into a Portable Datalogger Embedded System

Daffa Naufal Adhira Putra Safriadi¹

¹Undergraduate Program in Applied of Instrumentation Meteorology, Climatology Geophysics (STMKG)

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ABSTRACT

Integrating a Graphic User Interface (GUI) into an embedded system remains difficult due to hardware limitations and the complexity of graphics programming. This study examines the implementation of LVGL (Light and Versatile Graphics Library) and LovyanGFX to create an efficient and userfriendly interface for portable data logging systems developed with the ESP32-S3 microcontroller. The system is intended to accumulate, process and display environmental data such as the MQ-7 carbon monoxide sensor, DHT21 temperature and moisture sensor, and BME280 temperature and humidity sensor. A structured experimental approach was adopted to evaluate the feasibility and performance of the proposed system. The ESP32-S3 was chosen for its superior memory capacity and wireless communication capabilities, while the ILI9488 TFT screen was selected for real-time data visualization. The research focused on optimizing the GUI for responsiveness, data readability, and user interaction. The results appear that LVGL and LovyanGFX work well together to make an intelligently and valuable GUI that can appear real-time sensor information. This also indicate that LVGL and LovyanGFX effectively render graphical elements, enabling smooth transitions and efficient data representation. Furthermore, the system successfully integrates sensor data, demonstrating its potential for real-time monitoring applications. This study contributes to the development of embedded GUI systems by demonstrating a cost-effective approach to graphical interface design in dataloggers. Future research can explore expanding the system's functionality, optimizing SPI communication, and enhancing graphical rendering capabilities.

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Corresponden Author:

Daffa Naufal Adhira Putra Safriadi,

Undergraduate Program in Applied of Instrumentation Meteorology, Climatology Geophysics (STMKG)

Tangerang City, Banten, Indonesia Email: d4ff4.naufal@gmail.com

1. INTRODUCTION

Dataloggers have been an essential element in all kinds of data processing and retention around the world. Not only recording the data received, today's data loggers also use the latest technology that can provide diagnoses about the condition of the connected sensors, process the data they record, and transmit the data wirelessly in today's IoT era [1]. The existence of a sophisticated datalogger can certainly increase the accuracy and density of data which is the main key in analysis and decision making in the future [2]. On the other hand, air quality has become a hot issue discussed in various world forums lately. As a result of the industrial revolution and the widespread use of fuel oil, air quality monitoring has become crucial. Portable dataloggers can certainly be one of the most promising solutions, considering that technology has made everything more compact nowadays [3].

The high complexity of creating graphical interfaces is also a factor that hinders the development of innovation in this field. Graphical interface programming requires mastery of certain knowledge, which is

quite difficult to obtain. In addition, the lack of existing references is also an inevitable obstacle [4]. In this research, we want to develop and apply the use of LVGL along with LovyanGFX as the basis for creating user display graphics on a portable datalogger system based on the ESP32 microcontroller. With the combination of these two graphics libraries, it is expected to create an interface system that is cost-effective and user-friendly, as well as an answer to the challenges in developing a datalogger with a graphical display embedded on board [5].

However, there are still many challenges that hinder the development of the system, especially in the development of an adequate user interface system on the embedded device [6]. Most of today's dataloggers already use displays, but the displays that can be generated are still quite limited. This has led to the demand for innovation in this area. The high intricacy of establishing graphical interfaces is also a factor that hinders the development of innovation in this field. Graphical interface programming requires mastery of certain knowledge, which is quite difficult to obtain. In addition, the lack of existing references is also an inevitable barrier.

Therefore, in this research we want to develop and apply the use of LVGL together with LovyanGFX as the basis for creating user display graphics on a portable datalogger system based on the ESP32 microcontroller. With the combination of these two graphics libraries, it is expected to create an interface system that is efficient and easy to apply, as well as an answer to the challenge of making a datalogger with a graphic display embedded in it.

2. RESEARCH METHOD

This research uses a hybrid approach oriented towards implementing LVGL and LovyanGFX as graphics processing in the MCU used. There are a number of planning and testing stages to ensure the best performance can be generated.

2.1 Research Approach

This research uses merely an experimental approach to implement LVGL (Light and Versatile Graphics Library) and LovyanGFX as graphic libraries on ESP32 S3 N16R8 series-based devices for datalogger applications with graphical displays. This experiment was held to find out how the two libraries function in configuring the graphical display on the screen and interacting with the data taken from the sensor.

2.2 Research Plan

This research was carried out through several stages of experiments involving the application of ESP32, LVGL, LovyanGFX, and other additional supporting components such as sensors and screens. The research design used consists of:

- Selection of ESP32 Platform as the main microcontroller that has Wi-Fi and Bluetooth capabilities
 for data communication, as well as good graphics capabilities. The series used (S3 N16R8) was
 chosen because it has 16MB Flash memory and 8MB SRAM that supports more complex and larger
 programmes [7].
- 2) The application of LVGL and LovyanGFX to create a graphical user interface (GUI) that allows interaction with data and device control. These two libraries are fairly common and easy to use, but can still produce powerful graphics.
- 3) Integration with sensors used to collect environmental data (such as temperature, humidity, or pressure sensors) that will be displayed on the screen.
- 4) Data processing and storage using ESP32 memory and external storage media (SD Card) for data logging.

2.3 Research Variable

Research variables are characteristics, features, or attributes that can be measured or experimentally changed during a study. Variables are used to describe aspects that influence the research's outcome in both observed studies and experiments. A thorough understanding of variables is necessary for both designing suitable investigations and accurately assessing the data collected.[8]

One standalone variable is the type of graphics library used. In this case, we'll use LVGL that featured into LovyanGFX library. How versatile the system managing sensor data, how easy it is for users to interact with the interface, and how the system evolves are examples of dependent variables. Sensor kind, TFT display type, and ESP32 microcontroller usage are examples of control variables.

2.4 Schematic Circuit

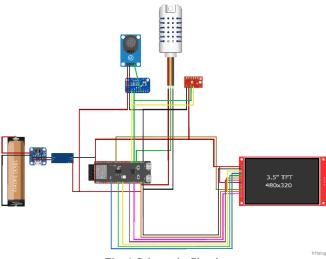


Fig. 1 Schematic Circuit

The circuit consists of three main section, the first one is the power circuit (Left side) which consists of a battery, charger module and also a voltage stabiliser. In the middle and right side is the main circuit consisting of esp32-s3 and tft screen. while on the top side is the sensor circuit used. There is a carbon monoxide (CO) gas sensor, DHT21 temperature and humidity sensor, and BME280 air pressure sensor. In the ads1115 section there are still a number of pins that can be used for more sensors with analogue output types to produce more accurate data.

2.5 Component detail and specifications

The following are all components that used in this research. several components used have the same basic specifications but different features depending on the manufacturer.

1) Esp32-S3 Devkitc-1 N16R8

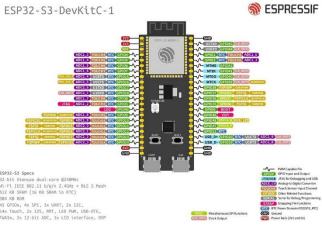


Fig. 2 ESP32-S3 diagrams

Esp32-s3 is one of the esp32 series that is quite capable. in addition to its large sram and flash memory which is larger than other esp32 series, this series also has a pin to connect the antenna using an external antenna to increase its wifi range. This microcontroller has also proven to be one of the favourite microcontrollers of most students who are learning coding.

2) 3.5" TFT ILI9488



Fig. 3 3.5" TFT Screen ILI9488

Ili9488 is a tft screen module with a size of 3.5 inches which has a resolution of 320x480 pixels. the screen on this module also uses a type of lcd screen that is quite good. ease of use is also one of the reasons for using this module.

3) 18650 Battery



Fig. 4 18650 Li-Ion Battery

18650 batteries are a type of lithium ion battery that has been widely used throughout the world. its fairly small size with the energy density it can store is the reason why this type of battery is quite often used.[9]

4) USB Battery Charging Board



Fig. 5 USB Battery Charging Board

This module is a module that can charge 18650 batteries, this module has many types of ports such as mini usb, micro usb, to usb type c. this module can also charge drained batteries such as in cases of too long storage or excessive use, this module is equipped with overvoltage protection, leakage current prevention and led devices for battery indicators.

5) 5V Step Up voltage stabilizer



Fig. 6 DC-DC Buck Converter

This module is used to increase the battery output which is only in the range of 3.3v to a stable 5v for the operation of esp32 and other devices, the way it works is to store a certain amount of power in it so that the output voltage becomes greater.

6) ADS1115



Ads1115 is a module that can convert analogue signals into digital signals, this module has an i2c connection system and has 4 analogue ports, with an integrated amplifier in it so as to increase the accuracy of reading analogue signals from sensors.

7) MQ7 Carbon Monoxide Sensor



Fig. 8 MQ7 Carbon Monoxide Sensor

The MQ-7 gas sensor contains SnO2, which has lower conductivity in clean air. It can eliminate particles other than carbon monoxide, which makes it one of the most capable air quality sensors.

8) DHT21



Fig. 9 DHT21

dht21 sensor is a temperature and humidity sensor that has good accuracy and is reliable. This sensor has been proven to be able to be used in the long term without experiencing significant deviation.

9) BME280



Fig. 10 BME280

BME280 is an air pressure sensor that is able to measure the surrounding air pressure. with its compact size, this sensor is one of the favorites in its kind.

3. RESULT AND DISCUSSION

The application of LovyanGFX and LVGL as an embedded system on esp32 with ili9488 screen shows promising results. ili9488 screen successfully displays good enough graphics and is able to process input into a good enough graphic display with a fairly small size. LovyanGFX also provides a special setting, which facilitates the sensor with the same communication system as the display, namely the serial peripheral interface (SPI) communication system to allow receiving data from the sensor device and sending signals to the display separately.



Fig. 1 WiFi status Result

In the image above, it can be seen that the screen can display words quite well. we can adjust the font, size, and spacing between lines of each text and even the duration of the display on the screen. also we can integrating data that has been processed by esp to display real-time to the screen.



Fig. 2 Data Result

In this picture it can be seen that esp32 can receive data from the sensor which is then processed into a graphical ratio as well. the screen used also produces contrasting colors and is quite optimal.

4. CONCLUSION

Overall, the LVGL and LovyanGFX systems work well together and produce a pretty good GUI. The use of ESP32-S3 is also quite capable of recording, processing, and sending data simultaneously without experiencing errors. Of course, there are still many developments from this system considering the many potentials and also things that have not been further reviewed from the collaboration of the two libraries into other embedded systems. As a suggestion, more in-depth testing can be done regarding the use of the SPI communication system to prove whether it can connect with more SPI devices. Code development to display optimized and high-resolution images can also be done.

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