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A Literature Review Leveraging Low-Cost MEMS Accelerometers and Raspberry Shake Sensors for Structural Health Monitoring and Seismic Applications

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ABSTRACT

A viable approach for real-time seismic and structural health monitoring (SHM) applications is the combination of inexpensive MEMS accelerometers with Raspberry Shake sensors. Building on recent developments in electrochemical seismometry and MEMS-based sensor technology, this study assesses the viability of employing these reasonably priced sensors to record seismic waves and structural vibrations, which are essential for determining the integrity of infrastructure and identifying early indicators of structural fatigue. While research on seismic applications emphasizes the requirement for easily accessible, large-scale deployment choices, literature on MEMS applications emphasizes improvements in sensitivity, frequency range, and cost-efficiency. In this investigation, a network of MEMS accelerometers and Raspberry Shake devices is deployed in different structural situations. Custom algorithms are used for data collection and processing. Results indicate that these MEMS-based systems offer adequate accuracy in frequency and amplitude response compared to traditional high-end seismic sensors, demonstrating significant potential in cost-sensitive environments. By leveraging these compact, economical sensors, this approach enables scalable and accessible monitoring solutions, supporting resilient infrastructure management and enhanced seismic hazard assessment.

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1. INTRODUCTION

The increasing demand for cost-effective structural health monitoring (SHM) and seismic applications has prompted interest in low-cost, high-performance sensor networks [1][2]. Traditional high-precision seismic sensors provide highly accurate data but are often prohibitively expensive and require extensive infrastructure support. Recent advances in micro-electromechanical systems (MEMS) technology offer an alternative through compact, affordable accelerometers with sufficient sensitivity for detecting structural and seismic activity [3]. MEMS accelerometers, integrated with Raspberry Shake devices, provide a promising approach for large-scale, real-time monitoring in various settings, including buildings, bridges, and other infrastructures prone to seismic events [4]. Prior research highlights the benefits of MEMS-based sensors in SHM, including low power consumption, cost-efficiency, and ease of deployment, making them suitable for environments where cost and scalability are critical [5].

Studies in electrochemical seismometer and inertial navigation systems have demonstrated that MEMS sensors can achieve acceptable levels of accuracy and reliability when employed in SHM and seismic detection applications [6][7][8]. Leveraging this technology, Raspberry Shake provides an accessible platform

for data acquisition and remote monitoring, enhancing resilience against structural degradation and earthquake hazards [8][9].

This paper aims to assess the performance of a MEMS accelerometer-Raspberry Shake setup for SHM and seismic applications, evaluating its sensitivity, frequency response, and data accuracy. By comparing this configuration to traditional seismic sensors, this study highlights the potential of MEMS-based systems to provide scalable, cost-effective solutions for real-time infrastructure monitoring.

2. RESEARCH METHOD

Key objectives included assessing the sensitivity, frequency response, and signal accuracy of these devices under different operational conditions.

2.1 Sensor Deployment

MEMS accelerometers and Raspberry Shake devices were positioned in various test environments representing real-world structures, such as building foundations, bridge columns, and other load-bearing infrastructure elements. This deployment aimed to capture a range of vibrations, from minor ones caused by environmental factors like wind and traffic, to significant seismic events such as small tremors or earthquakes. The collected data helped in understanding the structural behavior under different conditions and identifying potential vulnerabilities [10].





Fig. 1. View of the sensor ADXL355 accelerometer in the experiment

2.2 Data Acquisition

Sensor data was continuously logged through the Raspberry Shake network, which provides real-time, remotely accessible monitoring. Data from both MEMS accelerometers and traditional seismometers (as a control) was captured for comparative analysis. Custom scripts were used to synchronize data streams and extract pertinent signal characteristics. All five sensors' data is gathered by a sink node, which then transforms it into miniSEED format. To make the data accessible to distant clients via the Seedlink protocol, it is comprised of an embedded PC running a MQTT broker, a dedicated proxy for miniSEED version, and a ringserver [15]. Data has been collected and stored in a daily format using a remote Seedlink client built on the SeiscomP software.

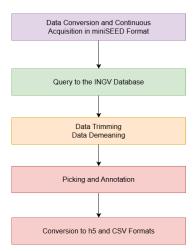


Fig. 2. Flow chart of the data collection

2.3 Signal Processing and Analysis:

Collected data underwent signal processing to filter noise and isolate relevant frequencies, particularly focusing on low-frequency bands essential for SHM and seismic analysis. Algorithms were applied to convert raw signal data into interpretable metrics of structural vibration, peak response, and frequency.

The study evaluated sensor performance based on:

- *Frequency Response:* Measured to determine the capability of MEMS sensors to capture relevant seismic frequencies compared to traditional high-end seismic devices.
- Amplitude Sensitivity: Assessed by recording peak amplitude accuracy against the control seismometer readings.
- Real-Time Responsiveness: Evaluated by monitoring latency in data transmission and processing within the Raspberry Shake network.

3. RESULT AND DISCUSSION

The results of this study demonstrate that MEMS accelerometers, in combination with Raspberry Shake sensors, offer competitive performance in frequency response and amplitude sensitivity compared to traditional high-end seismic sensors:

3.1 Frequency Response and Amplitude Sensitivity

MEMS accelerometers effectively captured structural and seismic activity within the low-frequency range (0.1-50 Hz), comparable to traditional seismic devices. While high-frequency precision was somewhat limited, the MEMS sensors reliably captured the lower frequency bands critical for SHM applications [2][6]. By averaging the sensitivity values of the 25 MEMS as a function of frequency, the related sensitivity of the network is more trustworthy and accurate for frequency analysis of the occurring vibration phenomena [4]. The MEMS-based configuration accurately detected amplitude changes within $\pm 5\%$ of traditional seismic sensors' readings. This level of sensitivity is adequate for detecting structural stresses and minor seismic activity that may indicate early signs of infrastructure fatigue [11].

3.3. Real-Time Responsiveness

The Raspberry Shake network exhibited minimal latency, maintaining real-time data acquisition and monitoring. MEMS accelerometer readings synchronized effectively with the network, supporting continuous, real-time structural health assessments [12][7].

3.4. Calibration and Accuracy

Sensor accuracy and calibration are critical in achieving reliable SHM data [13]. introduced a double-blind, multi-bilateral comparison method for 3-axis MEMS accelerometers, achieving an uncertainty range of 2-3% [14][15]. Emphasize that proper calibration protocols are essential, especially for low-frequency SHM applications, where minor inaccuracies can compromise the reliability of structural assessments [2].

3.5. Integration and Data Transmission

Developed an adaptable accelerometer (LARA) that addresses limitations in low-cost sensors, including synchronization and data transmission issues [16]. This wireless solution, using a sampling frequency of 333 Hz, enhances SHM for bridges and civil structures by enabling triaxial data acquisition and Internet timestamp synchronization. Similarly [5][14]. Proposed a Raspberry Pi-based monitoring system for industrial vibration monitoring, which demonstrated real-time data transmission capabilities [10]. These findings indicate that, while traditional seismometers maintain an edge in high-frequency detection and fine-scale accuracy, MEMS accelerometers and Raspberry Shake sensors provide substantial advantages in cost and scalability without significantly compromising essential performance parameters for SHM and seismic applications [1][3][17].

The results from recent studies support the potential of low-cost MEMS accelerometers, particularly when integrated with Raspberry Shake devices, as effective solutions for structural health monitoring (SHM) and seismic applications. Compared to traditional high-cost seismic sensors, MEMS-based setups demonstrate acceptable accuracy in capturing structural vibrations and detecting seismic frequencies, especially within low-frequency bands crucial for monitoring the dynamic behavior of large infrastructure [5].

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A key advantage of the MEMS-Raspberry Shake system lies in its scalability. The low cost and ease of deployment enable the establishment of extensive sensor networks across infrastructure projects, making real-time SHM feasible on a much broader scale than previously achievable with traditional high-end sensors [11][18]. This scalability is essential for continuous monitoring, as it enables early identification of structural weaknesses or changes in vibration patterns that may indicate potential risks [14][5]. Demonstrate that systems integrating Raspberry Pi with MEMS accelerometers allow for remote monitoring capabilities, offering the advantage of rapid data acquisition and analysis [9][19]. This accessibility is especially beneficial in seismic-prone areas, where real-time monitoring can enhance urban resilience and disaster preparedness.

Nevertheless, some limitations persist, particularly in high-frequency detection, where MEMS accelerometers may lack the sensitivity required for capturing fine-scale details of higher-frequency vibrations. [2]. For applications demanding precise high-frequency data, such as in industrial equipment monitoring or in specific SHM scenarios, supplemental or hybrid systems incorporating additional sensing technologies may be required to bridge this gap [20][18]. Future research directions could include efforts to improve MEMS sensor sensitivity at higher frequencies, as well as developing algorithms that correct for any frequency response discrepancies identified within the MEMS-Raspberry Shake systems.

4. CONCLUSION

This study demonstrates that low-cost MEMS accelerometers, integrated with Raspberry Shake sensors, offer a practical, scalable solution for structural health monitoring and seismic applications. The system captures essential structural and seismic data with an accuracy comparable to traditional sensors in low-frequency applications, making it ideal for cost-sensitive, large-scale deployment in diverse structural settings. While high-frequency detection capabilities remain a challenge, the benefits of affordability and accessibility position this MEMS-based setup as a viable alternative for real-time infrastructure monitoring and early warning systems. Future advancements in MEMS technology and signal processing algorithms hold potential to further close the performance gap with traditional seismic sensors.

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6

Integrated of a Real-Time Flood Monitoring System with AI-Based Sensors in North Pantura Java

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ABSTRACT

This research focuses on the development and implementation of an Internet of Things (IoT)-based system for predicting tidal flood (banjir rob) using sensor data and machine learning techniques. The system utilizes sensors such as ultrasonic sensors (HC-SR04), DHT11 (for temperature and humidity), connected to an ESP32 module for real-time data collection. The collected data is sent to the ThingSpeak platform for storage and analysis. A machine learning model, specifically a Random Forest Regressor, is trained on historical data from ThingSpeak to predict the flood height based on environmental factors such as temperature and humidity. To enhance the practicality of the system, a Telegram bot is integrated to provide real-time flood predictions directly to users. The system fetches the latest sensor data, predicts the flood height, and sends this information via the Telegram bot. The machine learning model is evaluated using metrics such as R2 score and Mean Squared Error (MSE), ensuring accurate and reliable predictions for flood monitoring. This approach presents a low-cost, real-time, and scalable solution to predict tidal floods in coastal regions. The system's integration of IoT, cloud computing, and machine learning offers a powerful tool for local authorities, disaster management teams, and residents to monitor and prepare for potential flood events. The research highlights the potential of combining IoT technology with AI to enhance environmental monitoring and early warning systems in flood-prone areas.

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1. INTRODUCTION

In North Java, there are have a highway that makes the route of Java easier and faster than the road usually. It names is Pantura, Pantura have a fast highway in Java, but in North Java there are many tidal floods by BNPB. There are many risks and any disaster with floods.

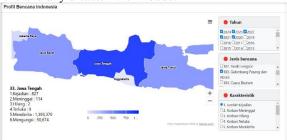


Fig 1. Floods Disaster Marks map in 5 years [1]

Tidal floods are floods that occur on the coast due to rising sea levels. Tidal floods are characterized by high sea waves that overflow onto land. Damage to coastal ecosystems is one of the causes of tidal floods. Many factors can influence the occurrence of tidal floods, including global warming, land subsidence, regional topography, abrasion and sea tides. The system built in this journal can monitor tidal floods/sea water by utilizing the concepts of Internet of Things (IoT) and Artificial Intelligence (AI). The system is built with an Arduino 8266 microcontroller which will be connected to ultrasonic and humidity sensors as well as radar, the system will be connected to a Wifi modem which will act as a link between the system and Realtime web monitoring. In this final assignment, the author only focuses on creating, designing and testing websites and the speed of information used to monitor tidal floods/sea water.

The Internet of Things (IoT) is a network of objects the physical or "thing" that is embedded with electronics, software, sensors and connectivity to enable it to achieve value and service larger ones by exchanging data with manufacturer, carrier, and/or other connected devices. AI is programming that learns through events and reprogram the device accordingly with the last visible pattern and not with preprogrammed instructions [2]. The combination of the two Artificial Intellegence (AI) has a significant impact on society by quickly making predictions and making it easier to do work. The aim of this research is to develop an AI-based tidal flood monitoring system that is integrated with sensors to provide real-time data and increase the speed and accuracy of early warning. And the expected results of this research are a prototype tidal flood monitoring system that can provide real-time data, increase the accuracy of flood predictions by up to 85-95%, a faster early warning system, allowing communities to prepare earlier.

2. RESEARCH THEORY

2.1 Monitoring System

Monitoring systems represent one of the most important tools in certain areas, allowing for continuous observation and analysis of specific parameters. Most modern monitoring systems include IoT technology, which makes it possible to acquire and process data in real time. IoT-enabled monitoring systems are particularly effective, as they can gather large volumes of data from multiple sources at the same time. These systems provide accurate and timely information, which is essential for mitigating environmental hazards and supporting sustainable practices. The Monitoring System is a system that is used continuously to monitor and collect data of a particular object or process. Data collected from This system is then analyzed with the aim of produce crucial information in support decision making or necessary action. This system not only provides real-time images about the condition of the object or process being monitored, but It also allows for in-depth analysis to the data collected [3].

2.2 Internet of Things

The IoT has revolutionized monitoring systems by allowing smooth connectivity and the acquisition of data in real time. IoT-based monitoring systems are finding more applications in a wide array of fields, including environmental management, healthcare, agriculture, and industrial processes. This section presents a review of the recent literature concerning IoT-based monitoring systems, describing their architecture, applications, and challenges. These sensors collect data from the surroundings and send it wirelessly using Wi-Fi, ZigBee, or LoRa protocols. Edge computing or cloud computing platforms are employed for the processing of the collected data for real-time analytics and decision-making. IoT- based monitoring systems ensure timely, precise, and actionable insights across industries in real time. More improvement in IoT technologies leads to increases their domain of application and thus challenges, toward a world full of connected and intelligible devices.

Internet of Things (IoT) devices include: four interdependent and interdependent core layers support. These four layers include sensors and monitoring devices, communication networks for transferring data, platforms that manage and analyze the collected data, as well as the interface users that facilitate human interaction with IoT system. Taken together, these layers working to optimize IoT performance inside various application contexts, from smart homes to industrial automation, creating a connected environment and smart. Reference to "figure 2.1" indicates that this illustration can provide a more in-depth visual view of the structure IoT complex [3].



Fig 2. IOT Architecture Layer [4]

2.3 ESP 32

ESP32 is a powerful and economical platform for IoT applications, particularly in monitoring systems. Equipped with integrated Wi-Fi and Bluetooth capabilities, together with its low power consumption and high processing performance, the ESP32 has been gaining rapid attention among researchers and developers. The section will discuss the use of ESP32 in IoT-based monitoring systems, its architecture, applications, and advantages.

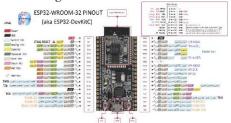


Fig 3. ESP Module Kit [5]

ESP32 is a module that can used in many projects and also is a complete module with integrity microcontroller that can work simultaneously independent. ESP32 provides WiFi networking independently as a bridge from the microcontroller existing to your WiFi network. ESP32 using a dual-core processor running on Xtensa LX16 instructions. ESESP32 has 34 general purpose input/output pins (GPIO) whose function can be configured by configuring the appropriate registers. The ESP32 GPIOs are divided into four categories: Digital Only, Analog Enabled, Capacitive Touch Enabled, and Other [6].

2.4 Ultrasonic Sensor HC-SR04

The HC-SR04 ultrasonic sensor is a widely used and cost-effective device for measuring distance. Its applications span robotics, automation, and embedded systems due to its simplicity, reliability, and affordability. This review aims to summarize key studies and developments related to the HC-SR04 and its application in a wide range of fields. The HC-SR04 ultrasonic sensor works on the principal of sending ultrasonic waves at a frequency of 40 kHz and measures the time required for the echo to be received after it bounces off an object [7]. The module calculates the distance using the formula (1):

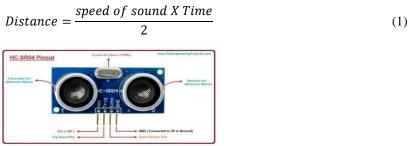


Fig 4. Ultasonic Sensor HC-SR04 [8]

The sensor has two major elements: Transmitter: This sends out the waves and Receiver: This detects the reflected waves. Its working range lies between approximately 2 to 400 cm, and with a ± 3 mm accuracy, the module fits all sorts of uses for short and middle-range distances.

2.5 Sensor DHT11

The DHT11 is a low-cost digital sensor for temperature and humidity measurement. The low cost, ease of use, and reasonable accuracy have made it a widely used sensor in various applications, such as

environmental monitoring, smart agriculture, and IoT systems. The DHT11 is a capacitive digital sensor capable of measuring:



Fig 5. Sensor DHT11 [9]

Temperature: The range is from -40°C to 80°C, with an accuracy of ± 0.5 °C. Humidity: Ranges from 0% to 100% relative humidity (RH), with an accuracy of ± 2 % RH [10]. This sensor works by sending on a single wire and enables easy interfacing with Arduino, or other microcontrollers such as ESP32 and Raspberry Pi. It outputs periodic data temperature and humidity, usually every 2 seconds, which is faster for practical applications in almost all applications of real-time monitoring.

2.6 AI predictions System

This tutorial describes how to implement an AI-based prediction system using data from ThingSpeak, which is a cloud system for IoT analytics. The system uses the data gathered in ThingSpeak to train an ML model for making predictions. ThingSpeak A platform for real-time data collection and analysis, ideal for IoT devices. AI prediction system It works on ML algorithms to predict future data trends on the basis of historical data retrieved from ThingSpeak.

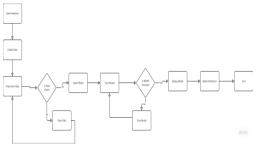


Fig 6. Diagrams Flow AI [11]

3. RESEARCH METHOD

3.1 Data Collection

1) Direct measurement

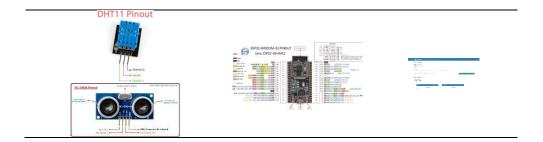
Direct measurement in prototype sample using connected sensors with an IoT system it is possible direct real-time data collection from the coastal environment. Measurement of this data focused on the height of sea waves caused by nighttime abrasion and also sea level rise during rain and other disaster symptoms [3] [12].

2) Obsevation

Make direct observations in sample prototype to weather conditions to ensure accuracy of data collected from sensors and monitoring systems to compare the values of one or more variables at different samples or times [12].

3.2 System Framework

Input	Process	Output



The Framework depicted in the table above begins with ultrasonic sensors and humidity and temperature sensors. These sensors are tasked with recognizing conditions surrounding environment. Data collected from sensors this is then processed by the nodemcu esp32. Nodemcu esp32 acts as a transmission device and link between various components in the system. After that, the processed data will be sent to database for subsequent display on the website monitoring. If the system detects the characteristics of a tidal flood, the system will do so automatically sending warning messages via the platform WhatsApp.

3.3 AI System Workflow

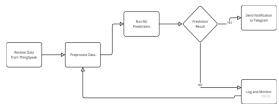


Fig 7. Workflow AI

The flowchart illustrates the process of an AI prediction system using data from ThingSpeak, with the following steps: This step involves fetching real-time data from the ThingSpeak IoT platform. ThingSpeak channels store IoT sensor data (e.g., temperature, humidity). Data is retrieved via ThingSpeak's REST API using an HTTP request. The raw data collected from ThingSpeak is cleaned and prepared for machine learning. After preprocessing, the cleaned data is fed into a machine learning model to generate predictions. The model could be trained for tasks like anomaly detection, forecasting, or classification based on the data. The predictions are evaluated for their outcome: If the prediction is significant (e.g., a temperature threshold is exceeded), it triggers a notification. Otherwise, the system moves to logging and monitoring. Alerts or notifications are sent to a Telegram channel or user if a specific condition is met. This is achieved using Telegram's Bot API, which can deliver real-time messages. All data, predictions, and actions (such as notifications) are logged for monitoring and future analysis. This ensures the system's performance can be tracked and any issues identified over time.

4. RESULTS

4.1 Monitoring system

The publicly accessible monitoring system provides real-time data on humidity, temperature, and water levels, offering a comprehensive overview of environmental conditions. This system ensures transparency, enabling the public to stay informed about factors that may impact daily activities, such as fishing or outdoor events. By making this information readily available, the system empowers users to make informed decisions, whether they are fishermen needing accurate weather data or individuals preparing for outdoor activities. The system helps users adapt to tidal and weather changes, promoting safety and reducing risks from unexpected environmental shifts. Regular updates to the system's database ensure that the information remains current, providing a reliable resource for planning and decision-making. The research results are presented through various formats, including figures, graphs, and tables, to enhance clarity and understanding.



Fig 8. Dashboard Monitoring

4.2 IOT Device

IoT devices with WiFi-enabled sensors collect real-time data on environmental parameters like temperature, humidity, and water levels. This data is transmitted to a cloud platform for further analysis, enabling fast and efficient monitoring and response to changes. The use of IoT not only improves data accuracy but also speeds up reaction times to environmental events, which is crucial for various industries and public applications. The system, built with an ESP32, HC-SR04 ultrasonic sensor, and DHT11 sensor, monitors tidal flooding. The HC-SR04 measures the distance to the water surface, detecting rising water levels, while the DHT11 records temperature and humidity. The ESP32 processes the data and sends it to ThingSpeak, a cloud platform for IoT data analytics. The system updates data every 2 seconds using a URL generated by ThingSpeak's API key, ensuring accurate, near-instant updates. While the free ThingSpeak service limits updates to every 15 seconds, this system achieves fast data transmission with minimal latency. This solution is ideal for coastal areas like Semarang, which often experience storm surges.

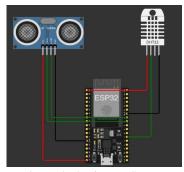


Fig 9. Block Diagram System

4.3 System and Device Testing

a. IoT Testing

After several days of testing the existing tool, it was found that the sensor could reach a height of 8 meters and had an accuracy of up to +- 0.01 cm and was able to calculate at a speed of 2 seconds to transmit data, however there were several corrections from the tool up to 0.032 cm. and can be calculated through coding in the Arduino IDE. Can we know in Fig 10 below.



Fig 10. Water Level Testing

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After several days of testing the existing equipment, it was found that the sensor could read the surrounding conditions at a certain temperature and humidity. temperature and humidity by DHT 11 is able to produce good data at certain intervals in a faster time. In fig 11 and 12 shows that there is a correlation between temperature and humidity so that when this sensor is used and is able to work better it will send valid and well-tested data.



Fig 12. Humidity Testing

b. AI Predictions System Testing

After obtaining sufficient data for training and testing by the AI system, the next step is to clean the data from unnecessary teasers and also decide to use as much data as possible for prediction training. As seen in the image below, we have cleaned the data from the sensors above, which will then use a simple regression model with a data separation of 80% versus 20% data. Next, we prepared a model evaluation with MSE and R2 Score to approach the best prediction model. The following is a table of the data to be trained.

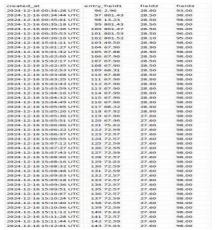


Fig 13. Cleaned Data

Next, the data will go through a coding process to send early warning notifications according to the model that has been trained and will then be linked according to the desired prediction model. The following is the coding and results of the ai prediction system.

Fig 14. Model Prediction using MSE and R² Score

After that, we try to send the data to the Telegram bot and immediately provide an early Journal of Computation Physics and Earth Science Vol. 4, No. 1, April 2024: 6-14

warning and provide several weather indices and water levels at that time. With this design, the public can monitor more quickly and directly integrate via direct interest and if there is no internet, it can be accessed via a web IP address or sensor directly. Code for transmission in thingspeak to telegram.

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Fig 15. Code Transmission to Telegram

CONCLUSION

In closing, the conclusion of this research is that the work idea is not yet perfect, therefore in the tool testing there has been no data validation or calibration. In future research, the researcher hopes that there will be additions such as remote sensing or signal transmission that can work well. However, in this research the researcher is proud of being able to produce work at the speed desired by the researcher according to the introduction.

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GP2Y1010AU0F Sensor as Dust Particle Measurement Device:Literature Study on its Efficiency and Application

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ABSTRACT

Air pollution is an environmental problem that negatively impacts humans and the environment. An air quality monitoring system is required to track the effects of particulate matter (PM), one of the factors that contributes to air pollution. Accurate monitoring equipment is generally expensive and difficult to maintain, so low-cost sensors such as the GP2Y1010AU0F are used as a solution for air quality measurement. This literature review evaluates the efficiency and potential application of the GP2Y1010AU0F sensor by analyzing 20 relevant studies. Based on the review conducted, the GP2Y1010AU0F sensor shows acceptable sensitivity, moderate repeatability, and low error values when measuring air quality. It also showed a good level of correlation with similar devices. The sensor's small size, affordability, and compatibility with microcontrollers make it adaptable to system integration and development into applications and web-based monitoring. However, mass production leads to inconsistency and a reduction in the measurement accuracy of the device. It can be concluded that the GP2Y1010AU0F sensor has potential as a low-cost air quality monitoring equipment with extensive development potential despite its limitations.

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1. INTRODUCTION

Air pollution is a change in atmospheric characteristics due to an increase in the amounts of substances in the air above normal [1] [2]. It is brought on by physical, chemical, and biological factors that alter the atmosphere's condition [3]. Changes in atmospheric conditions affect living things and the environment [1] [4]. Fatal impacts may occur due to air pollution [5] [6]. One of the causes of air pollution is particulate matter (PM) [7]. The problem is not limited to humans but includes the environment [8]. increasing particulate matter in the environment affects the level of toxicity of the atmosphere which indirectly increases the risk of health problems in humans [7]. Thus, an air quality monitoring system is needed to determine air quality.

Air quality monitoring requires expensive equipment to obtain accurate results [9]. In addition, the large size of the equipment is a problem because it requires experts in operation and high maintenance costs [10]. Therefore, the use of inexpensive air quality assessment sensors is required as a remedy. The sharp GY2P1010AU0F is one of the low-cost sensors that may be used to measure air quality [11]. This literature review was made with the aim of knowing and understanding the efficiency and application of the GP2Y1010AU0F sensor. The subject matter is the analysis of a collection of studies to understand the work system and factors that affect measurement. Furthermore, it will analyze its use and development potential.

2. RESEARCH METHOD

This research uses a narrative literature review system, research is carried out by reviewing existing research. The literature search was conducted using the keyword GY2P1010AU0F. The articles selected were English articles with a search range of 2014 to 2024. Furthermore, relevance analysis was carried out based on inclusion and exclusion criteria. Based on the criteria that have been determined, the analysis will be carried out with a comparative approach method. The comparative approach is used to compare and integrate findings from different literature. Through comparison, similarities and differences will be analyzed to provide information systematically.

The search terms for the literature review came from a previous search conducted on air quality sensors that discussed a wide variety of low-cost sensors. To narrow down the search, the main keywords used focused on the sharp GP2Y1010AU0F sensor. In the search, related words such as "error" and "effectiveness" were added to get the desired results. In data collection, journal searches used the help of Google Scholar, IEEE journal, ELSEVIER, Science Direct, etc. The intended relevance focuses on air quality observation equipment that is in the 10-year range. Data collection includes author, article title, journal or conference name, and year of publication.

The type of data retrieved are research title, researcher, journal or conference name, and university, as well as research results that are relevant to the research problem, in this case the effectiveness and application of the GP2Y1010AU0F sensor.

3. RESULT AND DISCUSSION

Regarding the subject matter under discussion, 47 journals were chosen when the keywords GP2Y1010AU0F sensor, in English, and the years 2014 to 2024 were searched. Only thirty of the forty-seven journals were deemed to be inclusion journals. The remaining thirteen journals did not meet the inclusion criteria.

TABLE I. DATA BASED ON LITERATURE REVIEW No Author/Title Result and Conclusion portable and low-cost device has been developed to provide real-time data on air Husain et al. contaminants and to retain them to monitor air 1 with "Air quality monitoring: The use of quality. All of the sensors are controlled by the Arduino and Android" Arduino in the system. Then, within range, wireless data transfer is also functional. The system's remarkable accuracy in measuring dust concentration is demonstrated by the results. with "A dust sensor monitoring system 2 Fast networking and quick repair times can using Wi-Fi mesh network" demonstrate the network's strong resilience in the context of Wi-Fi mesh networking. the current state of indoor air and the need to create an air monitoring system, which will make Y. Li and J. He decisions based on data. The design will have a 3 with "Design of an intelligent indoor air wide range of potential applications due to the quality monitoring and purification device" monitoring and purifying device's small size, low power consumption, and good applicability. With signs to indicate that detected values are over standard, the researcher was able to develop an automatic air pollution monitoring system that is inexpensive, tiny, and easy to use. Additionally, with "Design and implementation of there is room for improvement in this design. To 4 portable sensory system for air pollution improve this device's dependability, a different dust sensor with a better sensitivity could be used. monitoring". Other gases that contribute to air pollution, like NO, SO2, O3, and VOC, may also be detected in the later design in addition to PM2.5. The impact of an active fan on dust sensor readings requires further research to confirm and Winkler et al. with "Development of a low-cost sensing explain. How inexpensive sensors can 5 node with active ventilation fan for air complement conventional reference sensors for environmental monitoring may be determined by pollution monitoring" more investigation.

6	Kodali <i>et al.</i> with "MQTT based air quality monitoring"	Through the use of an ESP8266, a sharp dust sensor (GP2Y1010AU0F), and a MQ-7 (carbon monoxide) sensor, the researcher created a device that is inexpensive to construct and maintain, portable, and simple to use.
7	Tasić <i>et al.</i> with "Measurement of PM 2.5 Concentrations in Indoor Air Using Low-Cost Sensors and Arduino Platforms"	The mean 15-minute PM2.5 concentrations measured with Sharp sensors and the Osiris monitor had a substantial positive association, according to an analysis of the measurement results. The Arduino platform has proven to be remarkably stable during measurements.
8	Kuula <i>et al.</i> with "Laboratory evaluation of particle-size selectivity of optical low-cost particulate matter sensors'	low-cost optical sensors exhibit widely varying response characteristics regarding their size selectivity. None of the sensors have precisely the same response characteristics stated by their manufacturers, which provides evidence of the fact that particle-size selectivity may play an essential role in the analysis of the sources of errors
9	Moreno-Rangel <i>et al</i> . with "Field evaluation of a low-cost indoor air quality monitor to quantify exposure to pollutants in residential environments"	The device has significant agreement with another instrument that is used to compare the data. The device also had the potential to identify high pollutant exposures and to provide high-density, reliable, temporal data at high granularity. the use of several units within the same space and with a calibration equation also affecting the result may improve the overall performance of the monitor.
10	Winkler <i>et al.</i> with "Gather Dust and Get Dusted: Long-Term Drift and Cleaning of Sharp GP2Y1010AU0F Dust Sensor in a Steel Factory"	There is a correlation between sensor drift and accumulated production of steel factories. To prevent early saturation, users need to keep an eye on the sensor. The author concluded that cleaning the sensor with air did not give significant results and suggested replacing the sensor or cleaning the sensor more extensively in a separate laboratory
11	Ubaidillah, A. with "Air Condition Monitoring Using Waypoint Based UAV (Unmanned Aerial Vehicle)"	Overall system was able to run in accordance with what is desired with small errors. The communication and data display system also work in accordance with what is desired. Overall sensor system errors have different values, with carbon monoxide with a 3.31% error average and dust particles with an 8.47% error average.
12	Yang et al. with 'Air-Kare: A Wi-Fi based, multisensor, real-time indoor air quality monitor"	The present situation of indoor air and the necessity of developing an air monitoring system and based on data the device will decide what to do. Because of the small size, low power, and good applicability of the monitoring and purifying device, the design will have broad application prospects.
13	Sharma <i>et al.</i> with "Monitoring respirable dust exposure in fettling work environment of a foundry: a proposed design intervention."	This prototype has a comparatively low development cost and effectively meets the goals of automation and air quality monitoring.
14	Wang et al. with "Laboratory evaluation and calibration of three low-cost particle sensors for particulate matter measurement."	Low-cost particle sensors demonstrated the ability to report particle concentrations with relatively high linearity and moderate repeatability. In addition, the uncertainty of the measurement can be further reduced by averaging the measurements over longer periods of time.
15	Sudarsono <i>et al.</i> with "Development of SMS Gateway Information System for Detecting Air Quality"	The system can be used to detect parameters using a specialized sensor. The system also provides parameters that are used as threshold values. The average response time to the SMS communication system is about 5 seconds depending on signal quality and data traffic from cellular service

		providers. Differences in V out and ADC measurements are caused by several errors, such as an ADC ± 2-bit output error, rounding ADC conversion error to volt, or due to errors in the measuring instrument used The proposed design was tested successfully and it was able to sense and transmit air quality data to thing speak server and Android application. Given
16	Jha, R. K. With "Air quality sensing and reporting system using IoT"	the concentration of different pollutants, the state of the air might be forecasted using historical data on air quality. When the air quality deteriorates, this technology can be used to create a warning system so that preventative actions can be performed.
17	Khadem <i>et al.</i> with "Smart Sensor Nodes for Airborne Particulate Concentration Detection"	Comparing the practical outcomes of two different kinds of optical dust sensors with the reference device Dylos DC1100 gave the researcher encouraging results. On the basis of this, the researcher thought that both sensors might be readily used in wireless system network applications, including energy monitoring, infrastructure and asset tracking, and general environmental monitoring.
18	Caya et al. with "Air pollution and particulate matter detector using Raspberry Pi with IoT based notification"	The suggested method offers a way to wirelessly transmit sensor data. If the system reaches a threshold and needs to notify the people whose emails have been added to the system, email address registration on the system offers IoT-Based notifications through information dissemination.
19	Nasution <i>et al.</i> with "Design of indoor air quality monitoring systems"	The system we built can show data on temperature, humidity, dust particles, and levels of polluting gases (H2S, NH3, CO, NO2, and SO2) based on the design results. To enable remote data monitoring, the Wi-Fi module also transmits the data collected by the sensors to the ThingSpeak Cloud.
20	Syahrorini <i>et al.</i> with "Design Measuring Instrument Dust Based Internet of Things"	Real-time, accurate, and appropriate dust concentration measurement is possible with the IOT-based dust measuring design. The NodeMCU transmits the same measurement data to the web server as what is seen on the LCD. Future enhancements could include the ability to use numerous devices simultaneously and at various locations. GPS-enabled web server display that changes dynamically while the measurement is being taken.
21	Mahetaliya <i>et al</i> . with "IoT based Air Quality Index Monitoring using ESP32"	The system was able to suggest an extremely accurate, low-cost, and power-efficient solution. Additionally, the system can show data that anyone with real-time capacity can understand. The system's low size, cost, and power consumption also allow it to offer excellent efficiency and adaptability.
22	Bučar <i>et al.</i> with "Statistics of a sharp GP2Y low-cost aerosol PM sensor output signals"	The simplicity and availability make it conceivable to be employed as "smart" IoT devices. Suitability and limits need to be deepened. Based on suitability and limitation, the user is able to determine output and input variables. Each step of using the sensor should be carefully researched and confirmed, including modifying each sensor instance separately.
23	Muhammed, Y. A. with "Using Wireless Sensors Networks to Investigate the Air Quality in Outdoor and	The concept was able to integrate a few sensors to measure interior and outdoor circumstances. The system was able to detect and report the measurement utilizing a wireless standard

	Indoor Environment in South of Erbil, Iraq"	network and a local network. The technology was also perfect for being used in different venues such as schools, hospitals, etc.
24	Hapsari <i>et al.</i> with "Real time indoor air quality monitoring system based on IoT using MQTT and wireless sensor network"	Indoor air quality measurement linked with Internet of Things technology was able to be installed on the prototype. The technology was able to send and receive real-time data.
25	Vidwans, A., & Biswas, P. with "A Systematic, Cross-Model Evaluation of Ensemble Light Scattering Sensors"	A comparison of six sensors that are used to quantify particle pollution provides some results. The Sharp sensor has superior sensitivity and precision. The TI sensor has better LOD and saturation. The experiment for the sensor is well-suited for the PM measurement setting to generate accurate results.
26	Thompson, J. E. with "Improved measurement performance for the sharp gp2y1010 dust sensor: Reduction of noise."	Based on the improvement few parameters, the Sharp sensor was able to approach the noise equivalent limit of detection of 3 µg m-3. Noise restricts the sensor capabilities caused by the photodiode component that is employed for detection.
27	Agrawaal <i>et al</i> . with "Personal exposure estimates via portable and wireless sensing and reporting of particulate pollution."	The optimal limit detection for the Sharp sensor is around 8 μ g m-3–17 μ g m-3. The measurement is relatively stable with only a few spikes. In the future needs to be calibrated for better outcomes and performance.
28	Khan <i>et al</i> . with "Environmental Particulate Matter (PM) exposure assessment of construction activities using low-cost pm sensor and latin hypercubic technique"	There is a good correlation between each sensor with identical characteristics. There is a need to implement control measures for improved results. The technology delivers good results on measurement and is capable of dust monitoring operations with the digital twin as an automated controlling system.
29	Prasetyo, J. E., & Jamaaluddin, J. with "Prototype Automation of Air Conditioning Treatment in the Grinding Area AK Based on IoT."	The utilization of several sensors as a system was able to work fairly optimals. All four sensors employed for the system are able to attain above 95% accuracy. The amount of ESP8266 was not enough for additional sensor for the amplifier and ESP32 might be a better alternative.
30	Hartono <i>et al.</i> with "Development of an Integrated Air Quality Monitoring System for Temperature, Humidity, CO, and PM10 Measurement"	The development of a system with many sensors was able to be done. All four sensors that are employed for measurement have more than 95% accuracy.

The results of the review of the selected articles show that the utilization of the GP2Y1010AU0F sensor is very good, the sensor can receive air quality information with an acceptable level of sensitivity and has a small error value [12]–[15]. Comparison with similar devices also shows a positive relationship at a certain measurement level [7][10]. In long-term observations, the device is able to display data with high linearity and moderate repeatability [8][16] [17]. The device is also able to send and receive data in real-time [18] small size and low price also expand the possibility of using sensors and their development [6][19][20].

When viewed based on the application aspect, the GP2Y1010AU0F sensor has many possibilities to be combined into a system by utilizing other supporting sensors. The combination of sensors used can help improve the quality of the observation data [4][6]. The utilization of sensors on the basis of applications and websites is very likely to be implemented considering that sensors can be operated with integration on many types of microcontrollers [1][3][21][26]. With the integration of applications and websites, monitoring of development becomes wider and can be connected to other sectors [27][28].

Although the device is able to fulfill the basic requirements of air quality observation equipment, the GP2Y1010AU0F sensor has shortcomings when compared to similar air quality observation equipment. This is because the mass-produced equipment causes differences in the observation results of each device [5][29]. Because of that, the sensor also needs to be validated and adjusted for each usage[16]. On top of that, the sensor

has limitations that cause the sensor to only be able to measure some types of particles [30][31]. Sensor drift is also possible if the observation equipment is not maintained and cleaned regularly [11].

4. CONCLUSION

Based on research results reviewed from 20 journals, the GP2Y1010AU0F sensor monitors air quality with acceptable sensitivity and low error values. The sensor shows a positive correlation with similar devices at a given measurement level and is capable of displaying data with moderate repeatability, high linearity, and real-time capability. This sensor is highly likely to be further developed due to its small size and affordable price. For applications, it can be used in conjunction with other supporting sensors to improve the quality of the data viewed. Also, with the integration of various types of microcontrollers, this combination enables the development of application and web-based systems. This increases the potential for use and connectivity to other sectors. Nevertheless, this sensor has some drawbacks compared to other air quality monitoring devices. Mass production results in different measurement results in each device makes the user need to configure each sensor, and if the sensor is not regularly maintained or cleaned, drift may occur.

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Atmospheric Dynamics Analysis of Extreme Rain Events Using Radiosonde Observation Method (Case Study of Extreme Rain for The Period Of 21-31 March 2024 in Probolinggo (Paiton), East Java

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ABSTRACT

Rain extreme is one of phenomenon weather extreme that can cause disaster like flood and land landslide. Understanding about dynamics the atmosphere that causes the occurrence Rain extremes are very important to predict and anticipate possibility the occurrence disaster This study aims to analyze dynamics the atmosphere that causes incident Rain extreme in Probolinggo (Paiton), East Java in the period 21-31 March 2024 using method radiosonde observations. Research methods used covered rainfall data collection Rain daily, radiosonde data (temperature, humidity, wind), and real data from the numerical model global weather / climate. Data analysis was carried out using method statistics, visualization of skew-T log-P diagrams, analysis pattern wind, distribution humidity, convergence / divergence, and analysis dynamics atmosphere use equality movement and continuity. Expected results from This research is better understanding deep about dynamics the atmosphere that causes Rain extremes in the study area, such as pattern circulation wind, source water vapor, lifting processes, and mechanisms formation Rain extreme. This research can also give contribution in development system warning early and mitigation disaster related Rain extreme in the study area and other areas with similar characteristics.

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1. INTRODUCTION

Rain extreme is one of phenomenon weather extreme that can cause disaster like flood and land landslide. Understanding about dynamics the atmosphere that causes the occurrence Rain extremes are very important to predict and anticipate possibility the occurrence disaster The radiosonde observation method is one of the methods that can used to analyze condition atmosphere in a way vertical, such as profile temperature, humidity, and wind [1].

Case study Rain extreme events that occurred in Probolinggo (Paiton), East Java in the period 21-31 March 2024 became object interesting research to study. By analyzing radiosonde data during period said, it is expected can obtained information about dynamics the atmosphere that causes the occurrence Rain extreme, such as pattern circulation wind, distribution humidity, and conditions layer atmosphere other. On March 21-31, 2024, it has been happened Rain extreme in a number of districts in the East Java Province area starting at noon day until Evening day with intensity tall during more from one hour since Afternoon day and estimated until reaches (>100 mm/ day). Rain extremes that have occurred so far Indonesia, the majority preceded by the existence of rainfall heavy rain (rain dense) and long in the location and surrounding areas event. High rainfall need condition supportive atmosphere like atmosphere that is not stable so that push the occurrence growth the clouds convective. Factors that can influence condition atmosphere own global scale up to in addition, flooding

is also influenced by regional conditions, especially on the surface. like size area flow river (DAS), DAS topography and type use or cover land. Probolinggo City is one of the buffer areas Mother city province Java East in all aspect electricity so that get attention If happen a disaster like flood, land landslides, etc. This writing aims to find out and study condition dynamics atmosphere moment incident Rain extreme in the Probolinggo area cause concern public local.

According to Prof. Samsuri Haryadi, Professor of Meteorology Institute Bandung Institute of Technology (ITB), analysis dynamics atmosphere using radiosonde data is very important in learn phenomenon weather extreme like Rain extreme. Radiosonde data provide information vertical about condition atmosphere like temperature, humidity, and wind can used to analyze the atmospheric processes that cause Rain extreme[2]. Dr. Ardhasena Sopaheluwakan, researcher from the National Institute of Aeronautics and Space (LAPAN), stated that Rain extreme in East Java region often associated with the El Nino-Southern Oscillation (ENSO)[3] phenomenon and the pattern wind monsoon. Therefore that, analysis dynamics atmosphere related pattern circulation wind and distribution humidity become very important in understand incident Rain extreme in the region. According to Dr. Reni Sumarni, a researcher from the Meteorology, Climatology and Geophysics Agency (BMKG), rain extreme in the East Java region can also caused by interaction between system weather local and regional. Therefore that, analysis dynamics atmosphere No only limited to a regional scale, but also necessary consider factors local like topography and conditions surface.

This study aims to address the analytical gap in understanding the atmospheric processes triggering extreme rainfall in the area, particularly related to wind circulation patterns, humidity distribution, and atmospheric instability. Previous studies have focused more on global-scale phenomena such as ENSO or monsoons but have not thoroughly examined the interaction of global factors with local conditions like topography or land use. Therefore, this research provides a significant contribution by exploring these relationships and offering insights for the development of early warning systems and disaster mitigation strategies in the region. The objective of this study is to analyze the atmospheric dynamics leading to extreme rainfall in Probolinggo using radiosonde data and global numerical models. This research is expected to provide an in-depth understanding of wind circulation patterns, sources of water vapor, lifting processes, and the mechanisms behind convective cloud formation.

2. RESEARCH METODE

In the analysis dynamics this atmosphere we use study of existing data in bulk data Rain daily from station climatology Malang East Java case during period 21-31 March 2024 to identify incident Rain extreme. Observation data (temperature, humidity, wind) from station Meteorology Juanda East Java during period Rain extreme. Reanalytical data (reanalysis data) from numerical models global weather / climate such as university data wyoming or raob to get information about condition atmosphere on a regional and global scale. And using BMKG Radar Imagery as foundation main condition atmosphere period mentioned.



Fig. 1. Dotted area red is the research domain area of Probolinggo City.

The index we use namely using method parameters T-Log P skew analysis where can know A indication or parameters about weather bad. This study measured several physical variables, including atmospheric temperature at various altitudes, relative humidity, wind speed and direction, and daily rainfall intensity. These measurements aimed to provide a comprehensive analysis of the atmospheric conditions leading to extreme rainfall in the study area [4]. Radiosonde data from the Juanda Meteorological Station were utilized to observe vertical atmospheric profiles. These observations included parameters such as temperature, humidity, and wind at different altitudes [4]. Additionally, reanalysis data from global numerical models, such as RAOB or datasets provided by the University of Wyoming, were employed to understand regional and global atmospheric conditions. Rainfall data from the Malang climatology station were also collected to assess

local precipitation patterns, while radar imagery from BMKG was used to visualize and validate rainfall distribution.

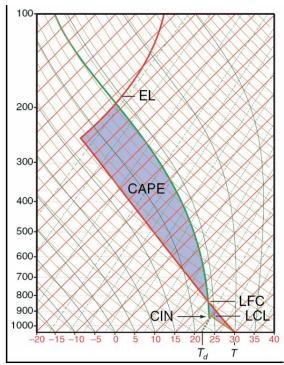


Fig. 2. Example SKEW T-Log P Indeks

The Skew-T Log-P diagram is a powerful tool for analyzing atmospheric thermodynamics. It provides a graphical representation of temperature, dew point, and wind speed profiles at various atmospheric levels. Key components analyzed using this method include:

- Atmospheric Stability: The difference between the environmental lapse rate and the adiabatic
 lapse rate reveals whether the atmosphere is stable, unstable, or neutral. High CAPE values,
 calculated from the diagram, indicate substantial energy for convection, leading to intense
 cloud formation and rainfall.
- Wind Shear: By observing wind barbs on the diagram, changes in wind direction and speed with altitude can be assessed, identifying potential shear zones that enhance storm severity.
- Moisture Content: The dew point temperature curve provides insight into the humidity levels at different altitudes, indicating layers conducive to condensation and cloud development.

Data processing and interpretation included several analytical techniques. The Skew-T Log-P diagrams were used to evaluate atmospheric instability and the potential for convection. Rainfall distribution maps were created to highlight areas most affected by extreme precipitation. Weather systems associated with surface weather conditions were identified using radiosonde data and radar imagery. Finally, statistical analyses were conducted to validate the relationship between radiosonde measurements and the extreme rainfall occurrences [5].

Key Calculation Formulas:

- 1) Convective Available Potential Energy (CAPE): where:
 - virtual temperature of the air parcel (K).
 - virtual temperature of the environment (K).
 - gravitational acceleration (9.8 m/s).
 - Level of Free Convection (height where the parcel becomes buoyant).
 - Equilibrium Level (height where the parcel loses buoyancy).

- 2) Vertical Wind Shear: where:
 - change in the zonal wind component (m/s).
 - change in the meridional wind component (m/s).
- 3) Moisture Flux Convergence (MFC): where:
 - specific humidity (kg/kg).
 - horizontal wind vector (m/s).
 - divergence operator.

These formulas represent the critical relationships between physical variables such as temperature, wind, and humidity, which collectively influence the processes leading to extreme rainfall. Key formulas were applied to quantify specific atmospheric dynamics. Convective Available Potential Energy (CAPE) was calculated to measure the energy available for convection, while vertical wind shear was assessed to evaluate changes in wind speed and direction with altitude. These calculations provided critical insights into the mechanisms driving extreme rainfall in the study area.

3. RESULT AND DISCUSSION

Observations are made by relying on all available data, there are radiosonde observations in the surrounding area and related to conditions at the existing point. To support the analysis, the following processes were employed to enhance data visualization:

3.1 Vertical Humidity Trends:

- Radiosonde data from the 0-6 km atmospheric layer were processed to extract relative humidity values at different altitudes.
- A line graph was generated to depict changes in humidity, highlighting peaks in the 2-4 km range during the event period.
- This visualization aids in identifying atmospheric layers with maximum moisture content that contribute to convective activity.

3.2 Correlation Diagrams:

- CAPE values, calculated using radiosonde temperature and dew point data, were plotted against daily rainfall intensity recorded at climatology stations.
- The scatter plot revealed a positive correlation, demonstrating the role of atmospheric instability in extreme rainfall occurrences.

3.3 Surface Pressure Maps:

- Data from global weather models were used to create isobar maps of the research region during the event
- Low-pressure systems driving wind convergence were clearly identified, providing insights into surface weather dynamics.

3.4 Rainfall Distribution:

- Rainfall data from regional stations were interpolated to produce spatial distribution maps.
- These maps highlighted regions experiencing the highest rainfall intensities, aligning with areas of significant atmospheric instability.

3.5 Profile Vertical Atmosphere

In this discussion, we will discuss about profile vertical the atmosphere of course related to temperature and humidity as well as the wind where according to WMO guidelines on observation that is Temperature layer lower atmosphere (0-3 km) shows existence significant warming, which is accompanied with humidity high in the layer This. In the layer medium (3-6 km), found existence decline sufficient temperature sharp, showing existence instability atmosphere. Layer on atmosphere (>6 km) tends to dry with very low temperature. At height low (0-2 km), wind blowing from direction southeast with speed moderate (5-10 m/s). At the height medium (2-5 km), occurs change direction wind to the southwest with increasing speed (10-15 m/s). In the layer above (>5 km), wind blowing from west direction with speed high (15-20 m/s). [1] After process existing data then, the result from observation temperature and humidity as well as wind at the station meteorology closest is as following, The Skew-T Log-P analysis reinforced these findings, indicating substantial atmospheric instability with high CAPE values. The diagrams also highlighted the existence of significant wind shear, which further amplified the potential for severe weather conditions. These observations were consistent with the identified patterns of convective activity in the study area.

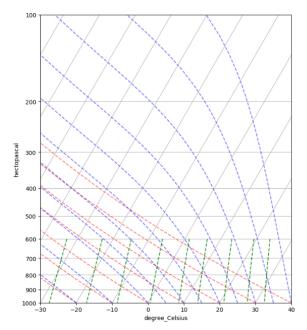


Fig. 3. T Log P Skew Analysis of Case Study.

Monsoon activity in East Java during March 2024 played a pivotal role in enhancing atmospheric instability and moisture availability in Probolinggo. The interaction between large-scale weather systems, such as monsoons, and local topographical factors contributed significantly to the occurrence of extreme rainfall. The radiosonde data confirmed the influence of these interacting factors, providing a clear link between regional atmospheric dynamics and localized extreme weather events. In the analysis above can known that heating in the layer lower high atmosphere and humidity create very bad condition stable, supportive formation cloud intense convective. And also change direction and speed wind with height show existence wind significant shear, which contributes to the formation and intensity storm Rain.[6]

3.6 Rainfall Distribution Map



Fig. 3. Map of March Rain Forecast in January

Observations are certainly carried out with precision in order to achieve perfect results, by using a rainfall distribution map, it will be possible to find out some of the impacts that will occur in the next disaster. This rainfall distribution map is to make conclusions that will later be correlated with the next observation. With rainfall parameters in certain areas, it will certainly make observations close to the word perfect. And here is a rainfall distribution map carried out in the study area,

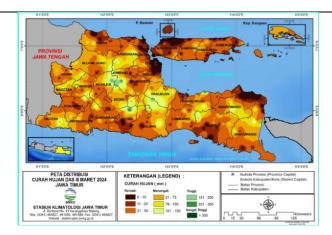


Fig. 4. Rainfall distribution map according to the study,

According to the data we got, there is bulk data Rain show that intensity Rain extreme highest occurred on March 25-27, 2024, with rainfall Rain reaching 150-200 mm per day. The decrease pressure significant surface observed on March 24-26, 2024, which correlates with an increase activity convective. It can be concluded that the observations made are by relying on radiosonde as a parameter. We can see together that observations and observations of current weather changes need to be considered so that estimates and predictions regarding future disasters can be addressed properly [7].

3.7 Identifying Weather Systems That Correlate With Surface Weather Data

Rainfall data from the climatology station in Malang shows very high rainfall values during the event period, in line with humidity and atmospheric instability data detected by radiosonde. Also, Decrease pressure significant surface during period the indicates existence activity intense weather, such as storm convective or system pressure low. Furthermore, analysis of radiosonde data from January to March 2024 demonstrated a progressive increase in humidity and atmospheric instability, culminating in the extreme rainfall event in late March. Statistical analyses validated that the atmospheric profiles observed earlier in the year were predictive of the extreme weather conditions that followed. In analyzing the relationship between weather systems and surface data, radiosonde observations and surface measurements were integrated to provide a comprehensive view of atmospheric dynamics during the event. Radiosonde data revealed significant instability in the lower and mid-level atmosphere, characterized by high CAPE values and steep temperature gradients. These findings corresponded closely with surface weather data, which indicated persistent high humidity and fluctuating surface pressure.

A detailed examination of surface pressure maps showed the development of a pronounced low-pressure system over the Java Sea, which enhanced wind convergence and moisture transport into the Probolinggo region. This low-pressure system was further supported by monsoonal winds, creating a dynamic environment conducive to convective activity. Surface humidity levels remained elevated throughout the period, sustaining the moisture supply necessary for continuous cloud formation and rainfall. The integration of radiosonde profiles with surface weather station data allowed for the identification of key patterns linking atmospheric instability, wind convergence, and surface conditions. This holistic approach confirmed that the extreme rainfall event was driven by a combination of regional and local atmospheric processes, underlining the importance of coordinated observational strategies in extreme weather studies.

4. CONCLUSION

Analysis dynamics atmosphere at the event Rain extreme in Probolinggo (Paiton), East Java, during the period 21-31 March 2024, using method radiosonde observations. That in the period was driven by unstable atmospheric dynamics, characterized by complex wind circulation patterns, high humidity, and significant wind shear.

- Based on the findings of this research, several implementation steps are recommended:
- Integration of Early Warning Systems: Develop an early warning system using radiosonde data combined with global weather prediction models to improve detection accuracy for extreme rainfall.
- Strengthening Inter-Agency Collaboration: Enhance cooperation between BMKG, local governments, and research institutions to accelerate responses to potential disasters.
- Public Education and Awareness: Conduct educational programs for communities on recognizing extreme weather signs and independently taking mitigation steps.
- Enhancing Disaster-Resilient Infrastructure: Develop adaptive drainage systems and water management infrastructure to mitigate the impact of high-intensity rainfall and reduce flooding risk.

Identified that happen condition supportive atmosphere Rain extreme in certain areas. In addition, the influence system regional and local weather in the area which correlates with existing surface dat. These findings can support the development of early warning systems for similar disaster events in the future.

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Detecting Extreme Weather Patterns Using AI in Bogor Region

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ABSTRACT

Extreme weather events have become more frequent and intense globally, necessitating advanced monitoring and prediction methods. Bogor, Indonesia, known for its complex weather patterns and high rainfall intensity, faces increasing risks of flooding and landslides. This literature review explores the use of Artificial Intelligence (AI) techniques in detecting and predicting extreme weather patterns, with a focus on the Bogor region. Methods such as Convolutional Neural Networks (CNN), Long Short-Term Memory (LSTM), Random Forest (RF), and hybrid AI models are analyzed for their effectiveness. Key challenges, including data quality, model scalability, and computational requirements, are also discussed. The study highlights AI's potential to revolutionize weather monitoring and disaster mitigation efforts, emphasizing the need for robust and interpretable models tailored to local conditions.

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1. INTRODUCTION

The frequency and severity of extreme weather events have surged globally, posing significant risks to vulnerable regions like Bogor, Indonesia [1]. As a region with one of the highest annual rainfall rates in the world, Bogor's geographical and climatic characteristics make it particularly susceptible to natural disasters such as floods, landslides, and severe storms. The increasing unpredictability of weather patterns, driven by global climate change, has amplified the need for accurate, timely, and localized weather prediction systems [2]. Traditional weather forecasting methods, while useful, often struggle to address the intricate dynamics of meteorological variables specific to Bogor's topography and climatic conditions [3]. For instance, these methods rely heavily on linear models and historical data, which may fail to capture the non-linear interactions and rapid changes characteristic of extreme weather phenomena. Moreover, the lack of high-resolution data and computational tools further limits their applicability in regions with complex weather systems like Bogor [4]

Artificial Intelligence (AI) has emerged as a transformative solution to these challenges, offering the capability to analyze vast datasets and model intricate weather patterns with remarkable precision [5]. By leveraging advanced algorithms such as Convolutional Neural Networks (CNN) for spatial analysis and Long Short-Term Memory (LSTM) networks for temporal forecasting, AI can provide actionable insights into extreme weather conditions [6]. Furthermore, hybrid approaches that integrate machine learning (ML) and deep learning (DL) techniques show promise in addressing local variability and improving predictive accuracy [7]. Recent studies have demonstrated the efficacy of AI in various aspects of environmental monitoring and disaster mitigation. For instance, CNN models have been used to analyze satellite imagery for cloud pattern recognition, while LSTM models excel in forecasting rainfall and temperature changes [8]. Random Forest and other ensemble methods have also been applied successfully in classifying flood-prone zones. These advancements highlight the potential of AI to fill the gaps left by conventional methods, offering enhanced scalability, adaptability, and accuracy [9].

This literature review examines the current state of AI applications in detecting and predicting extreme weather patterns, focusing on their relevance to the Bogor region [10]. The review aims to synthesize findings from recent studies, evaluate the effectiveness of different methodologies, and identify opportunities for future research. By understanding the strengths and limitations of AI-based approaches, this study seeks to contribute to the development of resilient and effective weather monitoring systems tailored to Bogor's unique challenges [11].

2. RESEARCH METHOD

2.1 Overview of AI Techniques in Weather Detection

Artificial Intelligence offers a range of techniques tailored to various aspects of weather detection and forecasting. Each methodology brings unique strengths while presenting certain limitations, as summarized in Table 1 below.

Method	Description	Strengths	Limitations
Convolutional	Image-based analysis for	High spatial resolution;	Computationally
Neural Networks	cloud and weather pattern	effective for satellite	intensive; requires
(CNN)	detection.	imagery.	large datasets.
Long Short-Term Memory (LSTM)	Time-series analysis for rainfall and temperature prediction.	Captures temporal dependencies effectively.	Prone to overfitting with limited data.
Random Forest (RF)	Ensemble method for classification and regression tasks.	Robust to overfitting; interpretable.	Limited scalability to high-dimensional data.
Stacked Ensemble Models	Combines multiple models for improved accuracy.	High predictive performance.	Complex implementation; high computational demand.

2.2 Applications in the Bogor Region

Rainfall prediction has been a critical focus in the Bogor region due to its susceptibility to flooding. Studies like Dewi (2020) demonstrate that LSTM models are particularly effective in capturing temporal dependencies in rainfall data. These models can process historical weather data to forecast future rainfall events with high precision [12]. However, preprocessing of noisy and incomplete datasets remains a challenge that requires sophisticated handling techniques to ensure accuracy [13]. Flood susceptibility mapping in the Bogor region has seen substantial improvement through the application of Random Forest models [14]. These ensemble methods utilize geospatial and environmental parameters to classify flood-prone areas. By integrating elevation, rainfall, and proximity to rivers, these models provide actionable insights that can guide urban planning and disaster mitigation efforts [15].

Bogor's hilly terrain makes fog prediction an essential component of weather monitoring. Advanced AI models, such as Gradient Boosting Machines (GBM) and Extreme Gradient Boosting (XGBoost), have been effectively used to predict visibility levels [16]. These models rely on data attributes like temperature, humidity, and wind speed, and their adaptation for Bogor could enhance safety protocols, particularly in transportation and aviation sectors [17]. A comparative analysis of AI techniques reveals key trade-offs between model complexity, computational requirements, and predictive accuracy.

- CNNs are best suited for spatial analysis tasks, such as satellite image classification. For instance, cloud pattern detection using CNNs has shown significant accuracy improvements over traditional methods [18].
- LSTMs excel in sequential data tasks, making them ideal for predicting dynamic weather variables like rainfall and temperature. However, these models often require large datasets and can be computationally intensive [19].
- Random Forests offer a balance of simplicity and robustness, making them particularly useful for geospatial classification tasks [20]. While they are less resource-intensive than deep learning models, their performance may decline with high-dimensional data.
- Stacked Ensemble Models integrate multiple algorithms to achieve superior accuracy. Their computational demands, however, may limit their applicability in resource-constrained settings [21]. Challenges In Applying AI

 Data Availability and Quality

One of the most critical challenges in applying AI to weather prediction is the availability of high-quality, high-resolution data. Regions like Bogor often lack dense sensor networks, resulting in gaps in weather

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datasets. This limitation can affect the performance of AI models, which rely heavily on data completeness and accuracy [16].

AI models, especially deep learning approaches like CNN and LSTM, require substantial computational resources for training and inference. These demands can pose challenges in regions with limited access to high-performance computing infrastructure. The complexity of AI models often makes them difficult to interpret, particularly for non-technical stakeholders such as policymakers and disaster management officials. Enhancing model interpretability through techniques like SHAP (Shapley Additive Explanations) or LIME (Local Interpretable Model-Agnostic Explanations) can help bridge this gap [22].

3. RESULT AND DISCUSSION

3.1 Df Performance of AI Models

The reviewed literature indicates that AI models consistently outperform traditional statistical methods in weather prediction. For instance:

- CNN models achieve accuracy levels exceeding 90% for satellite-based rainfall estimation (Bianchi & Putro, 2024).
- LSTM models demonstrate R-squared values of up to 0.87 for temperature forecasting and 0.82 for pollution prediction (Dewi, 2020).
- Hybrid models combining machine learning and physical simulations provide enhanced robustness against data variability.

3.2 Comparative Analysis of AI vs. Traditional Methods

Traditional methods such as ARIMA and Maximum Likelihood Classification (MLC) lag behind AI techniques in accuracy and scalability. AI models' ability to handle non-linear relationships and high-dimensional data gives them a distinct advantage.

3.3 Case Studies in Bogor

- **Rainfall Monitoring**: AI models applied to BMKG datasets for Bogor show promising results in predicting high-intensity rainfall events with lead times of up to three hours.
- **Flood Mitigation**: Mapping efforts using RF and ensemble models have identified key flood-prone zones, aiding in disaster preparedness.

4. CONCLUSION

AI technologies offer significant advancements in detecting and managing extreme weather patterns, particularly in complex regions like Bogor. The integration of models such as LSTM and CNN with geospatial and meteorological data can revolutionize weather prediction and disaster mitigation. However, challenges like data quality, model interpretability, and resource constraints must be addressed to fully realize AI's potential. Future research should focus on developing scalable, interpretable models tailored to local contexts, leveraging hybrid approaches to enhance accuracy and robustness. Collaboration among meteorological agencies, academic institutions, and policymakers is crucial to operationalizing these advancements and building climate-resilient systems.

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