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SEA WAVE HEIGHT MONITORING PROTOTYPE AS AN EARLY WARNING SYSTEM FOR TIDAL FLOOD DISASTER

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ABSTRACT

Indonesia is an archipelagic country located between the Indian Ocean to the south and the Pacific Ocean to the north. As a consequence, during the rainy and transitional seasons, extreme weather occurs, especially in the southern coastal areas. According to data from the National Disaster Management Agency, in the last six years, more than 200 tidal waves and abrasions have hit the Indonesian coastal areas. These conditions can lead to various disasters, particularly tidal flooding. Therefore, the development and design of a wave height monitoring device as an early warning system for tidal flooding is necessary. This device is expected to play a vital role in disaster mitigation, as it can provide information about the potential for tidal flooding based on the changes in wave height. The design of this device uses the LPD3806 encoder as a sensor and the nRF24L01 to send information to the monitoring station. Furthermore, tests have been conducted, and based on the results of the maximum distance test, information delivery can reach 800 meters in an open area. For sensor accuracy, a value of 99.7% was obtained, indicating the sensor has a small measurement error rate. Additionally, during field tests, the device demonstrated durability in adverse weather conditions, with no loss of data transmission. This shows that the device can operate reliably under extreme weather environments.

Keywords: disaster mitigation; tidal flooding; early warning system

INTRODUCTION

Indonesia is an archipelago situated between the Indian Ocean to the south and the Pacific Ocean to the north. Therefore, during the rainy season and the transition period, weather conditions in Indonesia are quite extreme, especially in the southern coastal areas. According to data from the National Disaster Management Agency (known as BNPB), over the last six years, more than 200 tidal waves and erosion events have affected the coastal areas of Indonesia. This phenomenon occurs due to strong winds causing tidal waves to hit the land [1]. Basically, ocean waves are formed when wind interacts with the sea surface [2]. Wind speed, wind duration, and the area of the sea surface affected by the wind all impact the wave height. So when strong winds for a long time hit a large sea surface, high waves will form [3].

Based on the disaster infographics of West Nusa Tenggara Province over the last four years, 21 tidal flood incidents have been recorded, with the highest number occurring in 2021—the primary cause of tidal flooding in coastal areas is island subsidence [4]. Every year, the coastal area is increasingly eroded, leading to higher tidal flood inundation as the land continues to sink [5]. Storm surges [6] and the supermoon phenomenon during the ebb and flow phase can increase the wave height [7] and raise the inundation tidal flood height in coastal areas. Moreover, tidal flooding harms physical, social, economic, and environmental aspects [8], as it can damage infrastructure and public facilities, and cause losses to the community [4]. Also, land inundated by seawater can reduce the quality of groundwater, characterized by increased concentrations of E. coli and TDS [9], which can lead to disease outbreaks and a polluted environment [10].

Therefore, adaptation and mitigation are needed in the form of raising houses[8], building sea walls [11], planting mangroves [12], arranging buildings around the coast [13], and early warning systems [14]. In particular, early warning refers to the provision of warnings as soon as possible by authorities to the public about the potential for a disaster in a specific area [15]. Wave height monitoring devices in Indonesia are limited in number, and as a result, they cannot cover all coastal areas. This device is a crucial component in disaster mitigation efforts in coastal areas. Along with the development of technology, various innovations have emerged in the development of effective disaster mitigation systems [16]. The development of an Internet of Things (IoT)-based monitoring and early warning system is one of the innovations in disaster mitigation technology [17]. In fact, the development of early warning systems for various types of disasters, based on the Internet of Things (IoT), has been widely carried out in Indonesia, including one for tidal flooding. Also, many information delivery models have been developed, including via SMS [18], RF modules [19], and even IoT platforms [20].

However, IoT systems are not entirely free from constraints, such as adverse weather conditions. Several communication systems, such as cellular networks, are disrupted or even disconnected. Additionally, many devices utilize ultrasonic sensors, and drastic weather changes can significantly impact the measurement results [21]. Therefore, in this research, a direct measurement model and a real-time information delivery system that are resistant to drastic weather changes were developed. Direct measurement using an LPD3806 encoder as a sensor can minimize errors caused by environmental influences. In addition, the data transmission utilizes a WiFi module that can transmit data over a distance of 1.1 km. This device is also equipped with a three-color light indicator and sound on both the transmitter and receiver, allowing the public to determine the potential for tidal flooding.

METHOD

This research developed a prototype of a wave height measuring device as an early warning system for tidal flooding. The wave height sensor utilized the LPD3806, a closed-loop infrared rotary encoder, which is unaffected by extreme environmental conditions. The research consisted of three stages: design, calibration, and field testing.

Device Design

The designed instrument is divided into two parts: a sensor system and a monitor system. The sensor system comprises a wave height sensor, a data logger, and an nRF24L01 module for data transmission to the monitoring system. For the sensor wave height measurement, the sensor system is equipped with a buoy and a straight gear that lifts and lowers the gear to rotate the sensor. A diagram of the sensor system is illustrated in Figure 1.

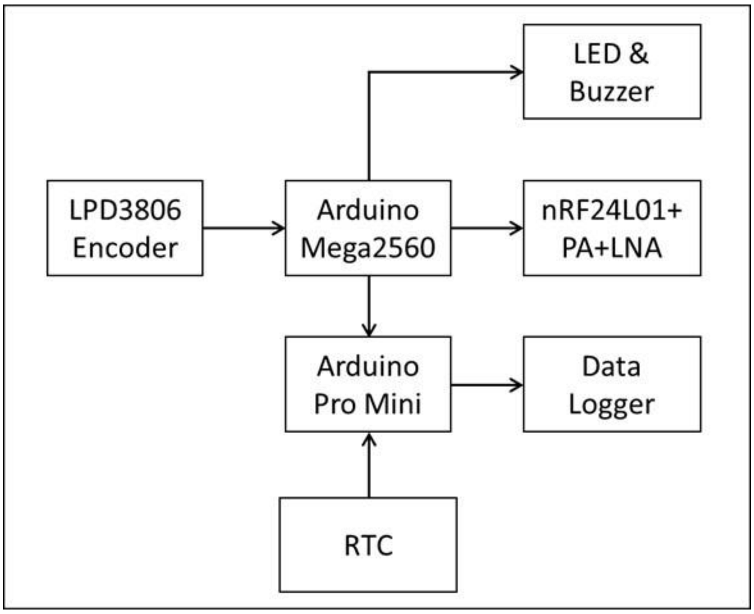


Figure 1. Sensor System Block Diagram

The monitoring system then consists of an nRF24L01 as a data receiver, which is then displayed on a 20x4 I2C LCD and recorded by a data logger. A diagram of the monitor system is illustrated in Figure 2.

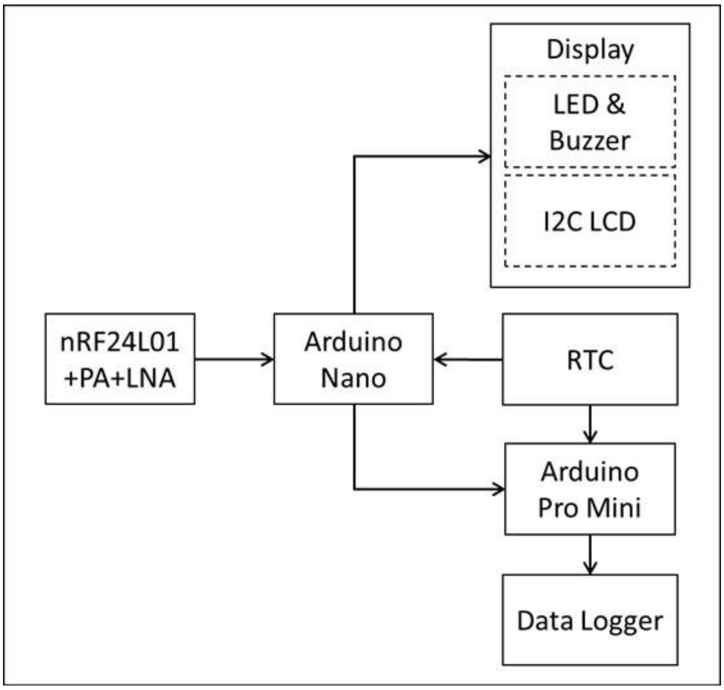


Figure 2. Monitor System Block Diagram

Sensor Calibration

Sensor calibration was performed by comparing the results of distance measurements using the sensor with those obtained using a ruler as a standard instrument. The steps are as follows: First, mount the sensor and the straight gear on the stand. Second, place the ruler parallel to the straight gear movement. And third, shift the straight gear as far as 1 cm, starting from 0 cm to 100 cm with reference to the ruler.

Field Test

The final stage conducted field testing, placing the sensor approximately 30 meters from the shore. The limited height of the support frame and the length of the straight gear were factors in determining the placement distance. The testing was conducted at Thamarind Port, West Sekotong, West Nusa Tenggara, on March 22, 2025. The data collection steps were as follows: First, place the sensor at the specified distance and the monitor in the coastal area. Second, turn on the monitor and ensure the microSD card is recognized by the data logger; then, turn on the sensor. And third, let the device measure the wave height for one hour.

Sensor Accuracy Calculation

The measurement data from the sensor and ruler are plotted in a chart to determine their linearity. Then, calculate the accuracy of the sensor with Eq. (1)[22].

$$A = \left(\frac{|X_n - Y_n|}{Y_n}\right) \times 100\% \tag{1}$$

Where *Yn* is the measurement value by a standardized measuring instrument, a ruler was used as the standard instrument. It is used as a comparison for the sensor measurement results, while *Xn* is the measured value by the sensor. These two variables are used to calculate accuracy (*A*), which is expressed as a percentage (%). Accuracy refers to the precision of the measuring instrument.

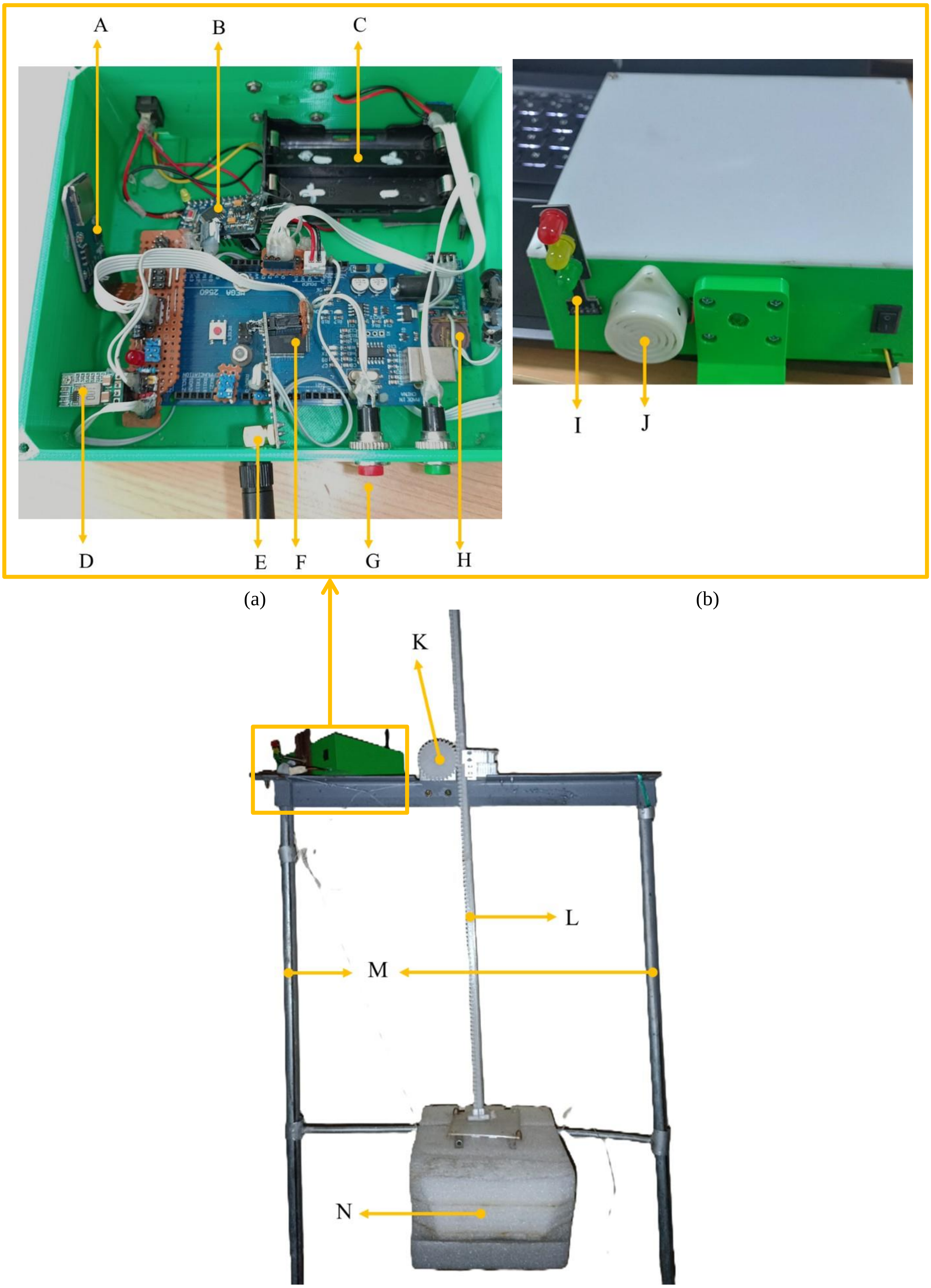
RESULTS AND DISCUSSION

Design of the Device

The device consists of two parts: the sensor system and the monitor system. The following explains these parts.

Sensor System

Using appropriate sensors in early warning systems could increase the accuracy of the information received. Various sensors, such as ultrasonic sound-based, infrared, accelerometers, and GPS, are used to measure water levels. In previous research, ultrasonic sensors were the type of sensor most frequently used due to their practical installation [20][23]. The sensor system directly measures wave height and then transmits the resulting data to the monitor. It's also equipped with a hazard indicator light, a buzzer, a buoy, and a data recorder, allowing continuous recording of wave height and time. When the measured wave height reaches a warning level, the siren will sound continuously. It is also equipped with a wave height indicator consisting of a lamp and a buzzer. Complete details for the sensor system are shown in Figure 3.



(a) (b)

(c)

Figure 3. Sensor System: (a) Inside View; (b) Outside View; (c) Complete View

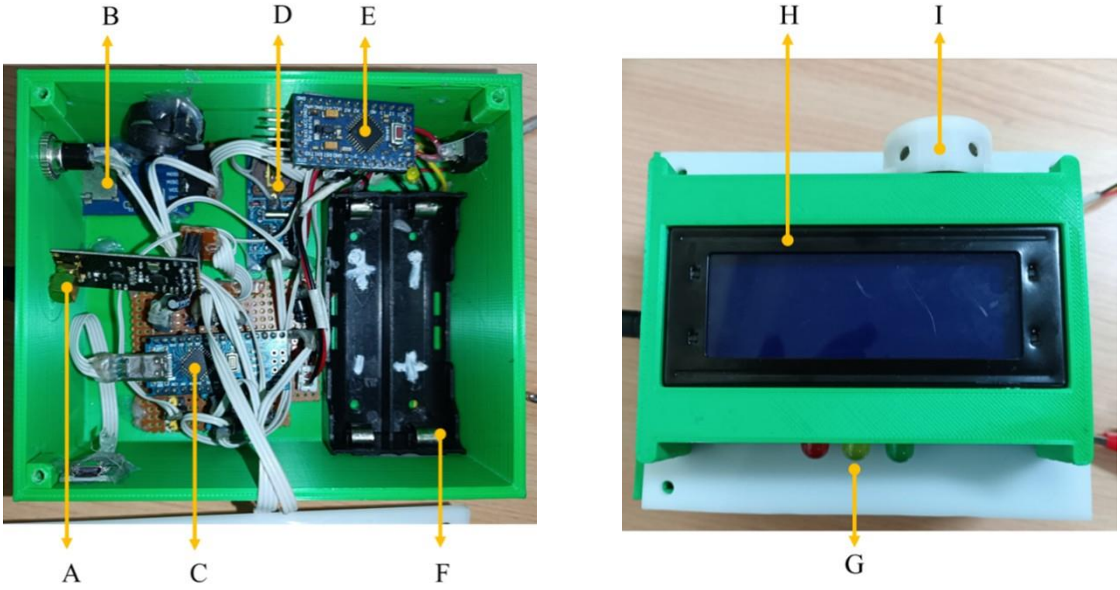
Figure 3 illustrates the components of the sensor system, which comprise a controller, sensor, data recorder, data transmission system, buoy, and support frame. The controller functions as the overall system controller. The function of each component is described in Table 1.

Table 1. Sensor System Component Function

Label	Component Name	Function
A	MicroSD Data Logger Module	Wave height data, date, and time recorder
B	Arduino Pro Mini	Recorder controller
C	Battery Holder	Battery holder
D	Step Down Module	Step down the voltage to 3.3 V for the communication module
E	nRF24L01+PA+LNA	Communication module between the sensor and the monitor
F	Arduino Mega 2560	Sensor and communication controller
G	Reset Button	For system reset
H	RTC PCF8563 Module	Real-time clock
I	LED	Hazard category indicator
J	Buzzer	Warning siren
K	LPD3806 IR Encoder with gear	Wave height measuring sensor
L	Straight Gear	Sensor drive
M	Support Frame	Panyangga sensor dan pelampung
N	Buoy	Straight gear buoy

Monitor System

The monitor system is equipped with an LCD, indicator lights, and a buzzer as a siren. This section can display wave height, time, and wave height status. When the wave height information received falls within the hazard category, the siren will sound, indicating the need for evacuation. Furthermore, this part is equipped with a data recorder that can continuously record. This allows every wave height incident that could potentially cause tidal flooding to be recorded, along with the date and time. Complete details for the monitor system are shown in Figure 4.



(a) (b)

Figure 4. Monitor System: (a) Inside View; (b) Outside View

Figure 4 illustrates the components of the monitor, which comprise a controller, display, data receiver, and data recorder. The function of each component is described in Table 2.

Table 2. Monitor System Component Function

Label	Component Name	Function
A	nRF24L01+PA+LNA Module	Communication module between the monitor and the sensor
B	MicroSD Data Logger Module	Wave height data, date, and time recorder
C	Arduino Nano	Sensor and communication controller
D	RTC PCF8563 Module	Real-time clock
E	Arduino Pro Mini	Recorder controller
F	Battery Holder	Battery holder
G	LED	Hazard category indicator
H	LCD Alphanumeric 20x4	Display wave height, date, time, and hazard category
I	Buzzer	Warning siren

Accuracy of the Sensor

The accuracy of sensor measurements is critical in designing an early warning device. A ruler was used as a standard and as a comparison instrument for the LPD3806 IR encoder during calibration, resulting in high accuracy in distance measurements. This is evident from the linearity of the measurement results in Figure 5. To ensure the accuracy of the sensor readings, calculations are necessary.

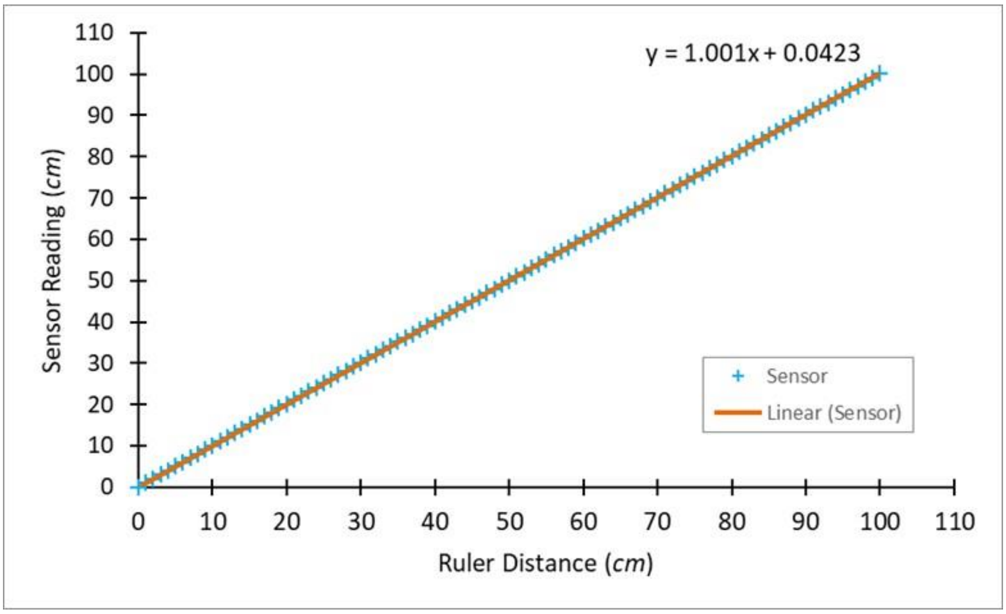


Figure 5. Linearity of the Sensor

The accuracy of the sensor, calculated using Eq. (1), is 99.7%, indicating that the sensor reading results are close to the standard measuring instrument value. The suitability of the measurement results significantly affects the data produced, especially in measuring disaster parameters [24]. Accurate sensor readings can help minimize system failures that lead to false alarms. So, it is necessary to test the suitability of the sensor measurement results.

Field Test Result

Field testing was conducted in Sekotong Barat Bay, West Lombok Regency. During the test, based on the early weather warning issued by the Meteorology, Climatology, and Geophysics Agency (known as BMKG) on March 22, 2025, from 3:45 pm to 6:45 pm, the test area is expected to be hit by moderate to heavy rain and accompanied by strong winds. The field test of the early warning system device in moderate rain conditions is shown in Figure 6.

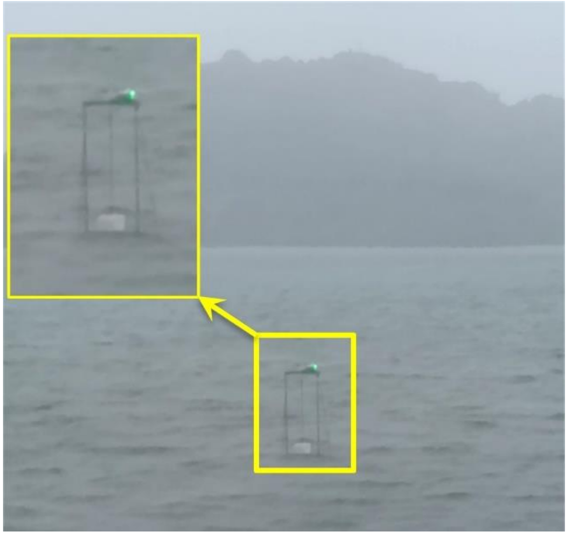


Figure 6. Early Warning System Device Field Test in Moderate Rain Conditions

Referring to previous research by Suharyo, the results of field testing showed that the accuracy of ultrasonic sensor readings decreased from 97.36% to 95.82% [19]. This decrease significantly affected the accuracy of the data obtained. Estu et al.'s research showed that ultrasonic sensor readings were greatly influenced by weather changes, resulting in unstable readings along with changes in environmental conditions [17]. Additionally, ultrasonic sensors have reading limitations if the reflection angle is not appropriate. Therefore, in this study, a sensor that is resistant to the effects of extreme weather was used. The use of an LPD3806 IR rotary encoder as a sensor allows it to withstand heavy rain and strong winds. It can be used as an alternative sea wave height measuring instrument. Figure 7 shows the data recorded during the field test. Between 5:44 and 5:55 pm, a stronger wind occurred, as indicated by the BMKG weather forecast, causing a change in wave height of more than 30 cm. The green line in Figure 7 is the early warning limit for hazards in the alert category, which has been set for testing the designed prototype.

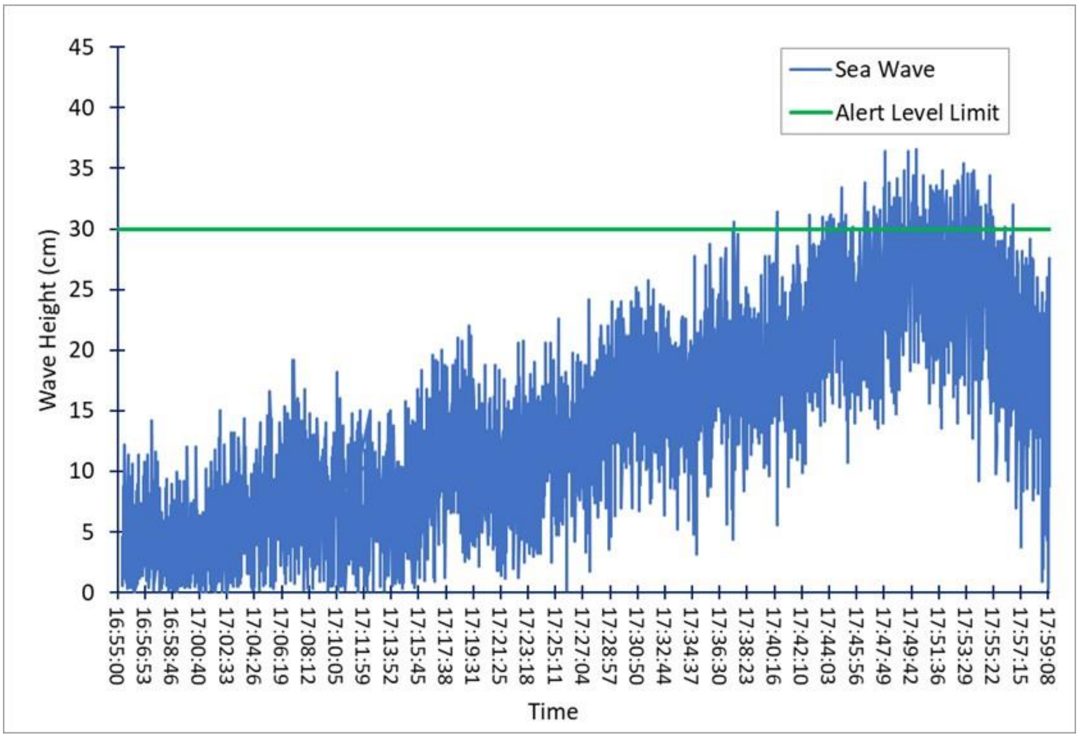


Figure 7. Wave Height Measurement Results on Field Test

The comparison of the data between the sensor and the monitor, shown in Figure 8, demonstrates that the device operates effectively in extreme weather conditions and that the transmission data remains uninterrupted. The durability of this device, which is designed to withstand drastic changes in environmental conditions, has been tested in extreme weather conditions.

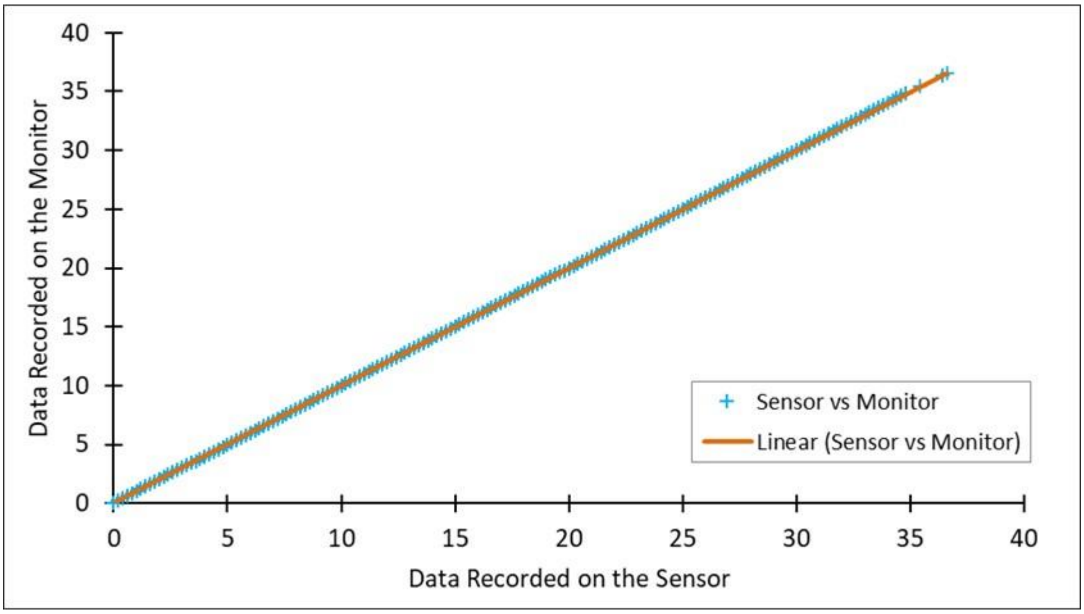


Figure 8. Data Recorded Comparison Between Sensor and Monitor

Weather also impacts internet network stability, as demonstrated in Estu et al.'s research, which used an IoT platform as a monitor [17]. Some data was not sent due to loss of internet connectivity. Therefore, this research uses an RF module to minimize the loss of measurement data sent by the sensor, as in Suharyo's research [19].

CONCLUSION

The test results indicate that the sensor reading's accuracy is 99.7%, suggesting that the measurement results are close to the actual value. Moreover, the device's durability in adverse weather conditions has been tested during the field test and showed no data loss during data transmission. The results demonstrate that the device can operate effectively in extreme weather conditions. To enhance the performance of the designed instrument, improvements to the data transmission system are necessary to expand the range of information dissemination. Furthermore, the sensor's mechanical design needs to be more efficient and safer to withstand more extreme weather conditions. Further development of this wave height measuring instrument is expected to provide a solution to expand the wave height monitoring network in Indonesia. Currently, the number of these instruments is limited, which hinders their ability to provide information, especially on the southern coast of Indonesia.

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