IoT-Based Real-Time Tide Monitoring Tool: Design and Case Study at Kenjeran Beach, Surabaya

Andi Kusuma, Viv Djanat Prasita, Robert Tambun

The dynamic nature of tides poses significant challenges for coastal management and navigation, particularly in regions with high maritime activity. This study focuses on the design and implementation of an IoT-based real-time tide monitoring system, used in a case study at Kenjeran Beach, Surabaya. The methodology involved three main phases: system design, hardware implementation, and software integration. The hardware setup included ultrasonic water level sensors, Arduino-based microcontrollers, and NRF24L01 for data transmission. On the software side, a cloud platform was utilized for data storage, visualization, and alert mechanisms. The system was designed to be energy-efficient and capable of operating in remote coastal areas with minimal maintenance. The system utilized a NodeMCU ESP8266 microcontroller, an NRF24L01 wireless data communication module, and the Blynk application for real-time monitoring via smartphones. The system consisted of a sensor module that measured tidal data using NRF24L01 and a server module that transmitted the data via NodeMCU ESP8266. The sensor module used an SRF05 sensor to measure water surface height and converted it into water data. Field tests were conducted at Kenjeran Beach to evaluate the accuracy, reliability, and resilience of the system in real-world conditions. The results demonstrated that the system can accurately measure tidal variations with a margin of error below ±1.3175 cm and provide real-time data updates every fifteen minutes. Sensor data accuracy was tested and found to be 99.554%, with maximum distance measurement of 330 cm and an error rate of 1.43%. The Blynk application was tested for seven days and showed that the Kenjeran Beach Tourism Area experiences two high tides and two low tides in 24 hours. This research highlights the potential of IoT technology for advancing real-time environmental monitoring and offers valuable insights for stakeholders in coastal zone management, fisheries, and maritime navigation.

KEYWORDS
~ Blynk
~ IoT
~ Radio wave wireless
~ Sea level
~ Tidal tool

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doi: 10.7225/toms.v14.n01.010

Received: 24 Jan 2024 / Revised: 25 Dec 2025 / Accepted: 8 Mar 2025 / Published: 20 Apr 2025

1. INTRODUCTION

The increase in global surface temperature has a detrimental impact on the Earth's population, including Indonesia, as documented by Dasanto et al. (2020). In the last century, the Earth's surface temperature has increased by approximately 0.74°C, and experts predict a further increase of 1.4°C - 5.8°C by 2100, as noted by Syaifullah (2015). The melting of ice sheets at the poles, caused by rising average temperatures, has contributed to the rise in sea levels, as observed by Prawira & Pamungkas (2014). This has led to tidal flooding, also known as flooding due to tides, which endangers coastal areas almost every rainy season, as reported by Sauda et al. (2019). This phenomenon has significant negative impacts, such as damage to homes and psychological stress resulting from the continuous occurrence of these events, as documented by Nurdiantoro & Arsandrie (2020).

Rising sea levels are caused by a range of factors, including human-induced climate change, hydrological cycle fluctuations, and vertical land movement. Understanding and predicting these changes is crucial for making informed decisions about coastal adaptation (Nicholls, 2015). Adaptation measures can include protecting, accommodating, or retreating from the coast and should be viewed as an ongoing process that requires integrated coastal management (Hinkel et al., 2017).

Modern, efficient and effective tide measurements can be made using innovative techniques and modern technologies. One approach is to upgrade traditional mechanical tide gauges by incorporating non-contact capacitance water level sensors and digital data storage (Salama, et al., 2019). Another method is to conduct regular quality control tests, such as the Van de Casteele test, to assess the performance and accuracy of tide gauge measurements (Miguez, et al., 2008). Additionally, the modernization of tide gauge networks using advanced technologies can improve efficiency and accuracy (Kvamme, et al. 2015). Overall, these advancements in technology and techniques contribute to the development of modern, efficient, and effective tide gauges (Cupic, et al., 2011).

Sea water is as important as river water (Uddin, et al., 2024). Although rivers are an important source of fresh water, important for supporting aquatic life, irrigation, industry, environmental conservation and beverages, sea water is also important in various aspects of life. Therefore, real time monitoring of sea water is needed, especially tide monitoring. Real-time monitoring is crucial for tide monitoring tools to ensure accurate and timely data collection, analysis, and decision-making. Popli et al. (2021) emphasize the importance of real-time data in marine environments for various applications and discuss the challenges of efficient data communication in underwater wireless sensor networks. Camilleri et al. (2022) investigate the use of deep learning techniques to fill gaps in the current real-time sea surface data recorded by High Frequency Radar networks.

The pressing issue of rising sea levels and the resulting threat of tidal flooding necessitates the development of an automated, remote, and real-time tide monitoring system. Such a solution would build upon the principles of tidal signs and daily tide gauges, while also incorporating the capability for remote monitoring via smartphones. The data required are tide heights that can be read by a sensor. Data collected by sensor are transmitted through a robust communication network to a centralized monitoring platform that utilizes cloud-based storage and analytics (Forhand, et al., 2024). Creating a sea level increase monitoring tool capable of sending sea level notifications to a monitoring post through an Android application is imperative, as this can serve as an effective early warning system for tidal flooding. Early detection is a critical first step in efforts to mitigate the impact of such flooding, as highlighted by Oktaviani et al. (2020).

Previous researchers have conducted studies on various tide monitoring tools based on the Internet of Things (IoT). Several studies have focused on the HC-SR04 ultrasonic sensor as the Arduino-based tidal meter. Missa et al. (2018) developed a tide measuring instrument with graphic output in Delphi 7 software, with offline and online functionality. Fadly & Dewi (2019) investigated the development of the HC-SR04 ultrasonic sensor as an automatic and real-time tide gauge, resulting in a tide-measuring instrument with an error rate of 1.833%. However, the research only utilized SMS and did not include an online, interactive display.

Other studies have explored the use of different sensors for tide monitoring. Quraish et al. (2019) researched a tide monitoring system that used a PING sensor, and developed a web-based tide-measuring instrument, but the data had a large error, with the largest difference between sensor results and comparison data being 60 cm. Supriyadi et al. (2021) conducted research on an Arduino-based tide monitoring system, but the data were only stored offline using an SD card. Juniarko Prananda et al. (2021) designed a tide monitoring system using an accelerometer and ESP8266 Wi-Fi module for online connectivity to the web. However, the Wi-Fi module was not integrated with the microcontroller and the results were only displayed on the ThingSpeak™ web, not yet connected to an application on an Android or IoS-based smartphone. Agustin et al. (2022) studied tide monitoring tools using NodeMCU and HC-SR04, but the results were still simulated by detecting water in a tank having the maximum height of 50 cm.

Previous research has primarily focused on the development of various tide monitoring devices, including the HC-SR04 ultrasonic sensor and other sensors such as the PING sensor, accelerometer. However, there is a need for further research to enhance the accuracy and functionality of these tools, particularly in terms of online connectivity and interactive displays. The objective of this study was to develop and construct a tide monitoring device that utilizes the NodeMCU ESP8266 microcontroller, transmits data by radio waves using the NRF24L01 wireless communication module, and incorporates the Blynk mobile application to enable real-time, remote monitoring of the device through smartphones, based on the principles of the Internet of Things (IoT).

2. METHODS

The design and development of the Internet of Things (IoT)-based tide monitoring tools involved several technological stages and components. The first was the design stage. This stage included defining requirements, i.e. determining tide monitoring system objectives, scope and requirements; technological research, including researching suitable IoT technologies, sensors, and development platforms; system design, including creating a system block diagram, together with hardware and software components; and user interface (UI) design, namely creating an intuitive user interface for data visualization. The second stage was the technological component. This stage included choosing the low tide sensor component (SRF05), the microcontroller component (Arduino Nano), the wireless communication module (NRF24L01), the Wi-Fi module (NodeMCU ESP8266), the IoT platform (Blynk), and the programming language (C++). The third stage was development and involved hardware development, i.e. hardware assembling and testing, software development, i.e. writing the code for collecting sensor data, sending the code to the IoT platform and data visualization, integration with the IoT platform, i.e. configuring and integrating the device with the IoT platform, system testing and validation to ensure accuracy and reliability, as well as implementation by installing devices at tide monitoring locations. The fourth stage focused on features and functions, which include real-time tide monitoring in the form of latest tidal data visualization, sending the data to the IoT platform for analysis and storage, alarms and notifications to send warnings when water levels exceed limits, data analysis by creating reports and charts for monitoring tidal trends, as well as remote settings by setting the device through an app or web interface. The fifth stage was security and privacy, and included ensuring data safety through data encryption, authentication to allow only authorized users to access the system, as well as regular software updates to fix vulnerabilities.

The methods and procedures for designing and developing IoT-based tide monitoring tools are explained in detail below, namely: (1) the method for designing the tide monitoring tool system, (2) the electronic circuit development method, (3) hardware design and development method, (4) water level measurement testing method using the SRF05 Sensor, (5) the method for designing and developing software in Blynk, (6) the sensor module and server module development method, and (7) the tide monitoring tool performance testing method.

2.1. Method for Designing the Tide monitoring Tool System

The ultrasonic sensor SRF05 was deployed at the lowest tide point in the sea. The sensor was used to determine tidal height (H1) by measuring the distance between the sensor's height position (H0) and the lowest low tide position that was still inundated, and then subtracting (H0) from (H1) to obtain tidal height. The sea level data was read by the sensor module every second and transmitted to the server module on the coast wirelessly. The sensor module also sent the data to the Blynk cloud, an Internet of Things application, where it was accessible in real-time and remotely on the mobile phone Blynk app. The sea level data were stored on the microSD card on the server module every hour and notifications were sent to smartphone and email users. As long as the server module had an internet connection and the sensor and server module batteries were not depleted, the monitoring system continued to function. A diagram of the tide monitoring tool system design is given in Figure 1.

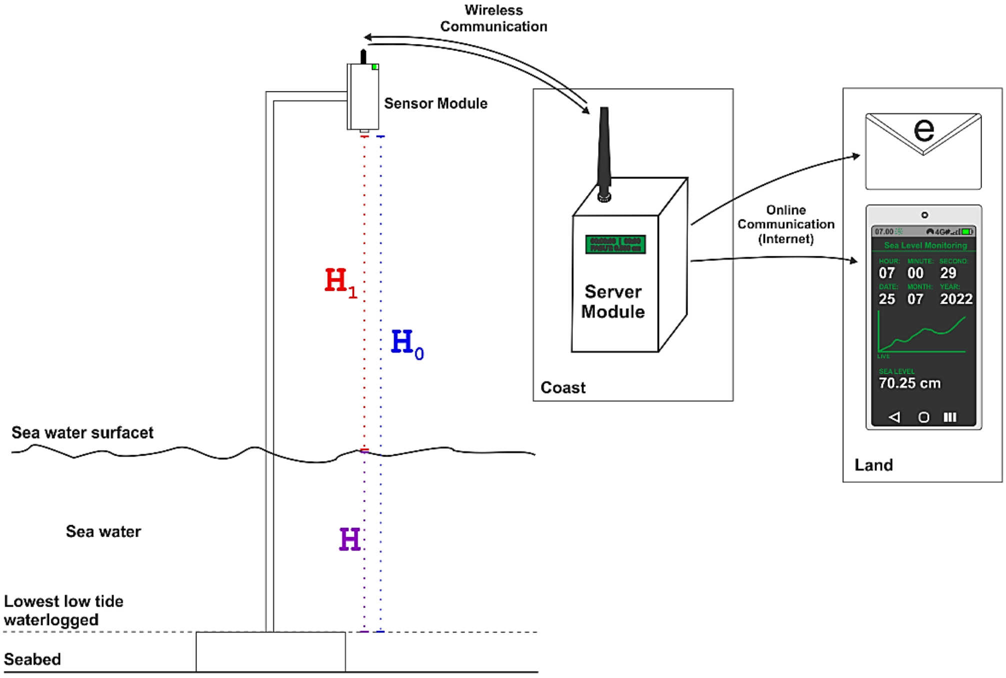

Figure 1. Diagram of the tide monitoring tool system design

2.2. The Electronic Circuit Development Method

Electronic circuit design was divided into two parts – first, a sensor module circuit containing SRF05, Arduino Nano as controller, SRF05 and NRF24L01, power bank, and NRF24L01 as the transmitter; second, a series of server modules with various components, such as NRF24L01 as the receiver, NodeMCU ESP8266 as controller and wifi module, Arduino Nano, RTC DS3231SN, Micro SD, 16x2 LCD, and power bank. The details of the block diagram of the tide monitoring system are given in Figure 2.

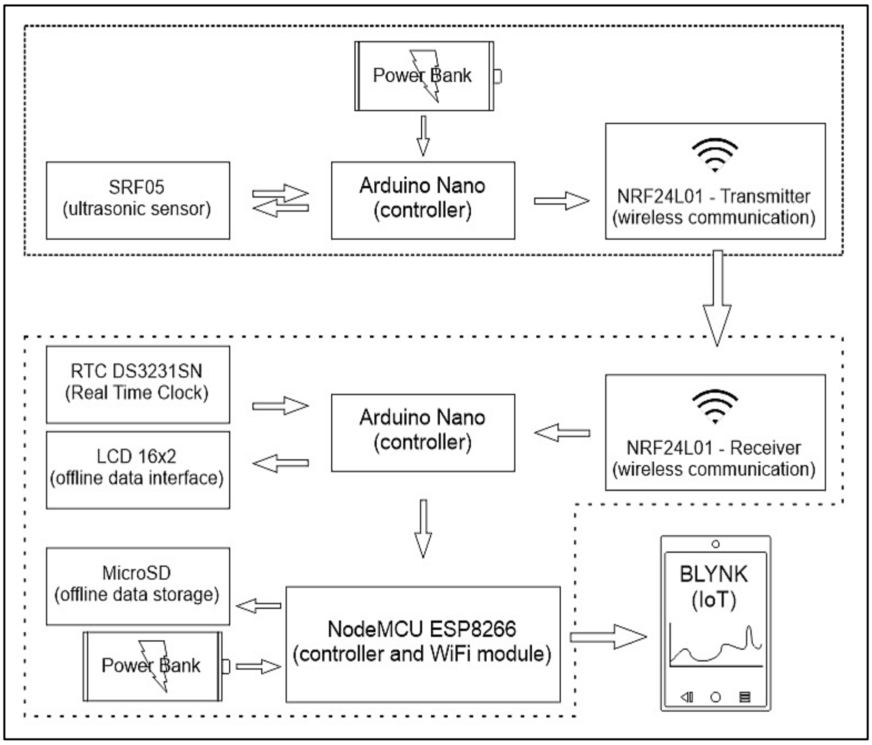

Figure 2. Block diagram of the tide monitoring system

There are four main components integrated in the sensor module. This integration aims to enable the module to retrieve tidal height data. First, there is a power bank that supplies power for the SRF05, Arduino Nano and NRF24L01.

Second, there is an Ardunino Nano that controls the SRF05 to retrieve tidal height data, and process the data obtained, which orders the NRF24L01 to send data to the server module. Third, there is the NRF24L01 which functions as a data transmitter to the server module.

The server module consists of seven integrated components. A power bank which powers all components of the server module. Arduino Nano which controls the NRF24L01 to receive data from the server module, controls the RTC DS3231SN to carry out the clock function, combines it with tidal data, and controls the LCD to display tidal data along with the clock. In addition, Arduino Nano sends processed data to NodeMCU ESP8266. Data received by the NodeMCU ESP8266 are stored on a micro SD and sent to the Blynk cloud.

2.3. Hardware Design and Development Method

Following the design and construction of electronic circuits and hardware, the initial testing stage focused on the evaluation of the NRF24L01 component. This device was a single-chip radio wireless communication system that operated within the frequency band of 2.4 to 2.5 GHz. The transceiver component of the NRF24L01 featured a frequency synthesizer consisting of PA/LNA, a crystal oscillator, a demodulator, a modulator, and an Enhanced ShockBurst™ engine protocol. The module was capable of programming frequency channel signals and protocols via an SPI interface, and its power consumption was remarkably low, with 9.0 mA output power in 6 dBm mode and 12.3 mA in RX mode. Moreover, power-saving measures that ensure further system optimization could involve the deactivation of built-in power and standby mode activation (Ruhyat, et al., 2022).

The initial trial aimed to assess the transmission capabilities of the NRF24L01 module, with special emphasis on connection range and data transmission latency between transmitter and receiver. A straightforward program was used to record the time required for the data to be sent and transmitted, which was displayed on an LCD screen connected to the receiver. The receiver was equipped with a single button which initiated data transmission, while the length of delay in sending data in seconds and milliseconds was displayed at the top of the LCD screen, the data sent were shown at the bottom. The distance between transmitter and receiver was incrementally varied during the trial, with measurements taken at 0 m, 50 m, 100 m, 150 m, 200 m, and 250 m.

2.4. Water Level Measurement Testing Method Using the SRF05 Sensor

The testing of the water level measurement tool was conducted by filling a water tube and placing the SRF05 sensor module on top. The SRF05 ultrasonic sensor, commonly used in distance measurement applications, such as altitude level control, was employed in this experiment. The sensor was capable of detecting the majority of metallic or non-metallic, clear or opaque, and liquid objects (Hasbullah et al., 2020). The SRF05 sensor operated on the principle of sound waves, generating and capturing these waves with a time difference to determine distance or height measurements. The time difference between emitted and received waves was directly proportionate to the distance or height of the reflected object (Hani, 2010). The SRF05 was an improved version of the SRF04, designed to increase flexibility and range. Its measuring range was increased from 3 meters to 4 meters, and the new operating mode (binding the mode pin to the ground) allowed the SRF05 to use a single pin for both trigger and echo, saving controller pins. When the mode pin was left unconnected, it functioned similarly to the SRF04 (Alldatasheet.com, 2022).

The SRF05 sensor successfully received the initial echo from the target object. Upon receiving a brief 10 µs pulse at the trigger input to initiate distance measurement, the SRF05 emitted an 8-cycle ultrasonic wave at the frequency of 40 kHz and raised its echo line accordingly. It then listened for the returning echo and, upon detection, immediately lowered the echo line. Consequently, the echo lines were proportionate to the distance from the object, enabling distance calculations through pulse width measurement.

In the absence of any detected echo, the SRF05 decreased its echo line after approximately 30 µs (Wickramasooriya, et al., 2008). This ultrasonic sensor was capable of detecting obstacles or objects within the surface area of 30° from the center of both the receiver and the transmitter (Nuryanto, 2017). The distance between the sensor and the reflected object was calculated using equation [1]

$$L = \tfrac{1}{2} \cdot TOF \cdot c \qquad [1]$$

where L is the distance between the sensor and the object, TOF is the obtained measurement time and c the speed of sound (340 m/s). However, because this monitoring tool read water level, the sensor had to read the initial height (bottom of the water). This initial baseline data were reduced by sensor reading data on the water surface and then convert into water level data. The water level data were calculated with equation [2]

$H = H_0 - H_1$ [2]

where H is water level data, H0 is the bottom of the water or the initial height and H1 is the height of the water surface. End readings were carried out continuously to get data in real-time. The test was carried out by comparing the H data with a ruler with the levels of 0 cm, 30 cm, 60 cm, 90 cm, 120 cm, 150 cm, 180 cm, 210 cm, 240 cm, 270 cm, 300 cm, and 330 cm calculated from the bottom of the water.

2.5. Method for Designing and Developing Software in Blynk

The software was designed in the Blynk app, which served as an interface for monitoring sea-level data on a smartphone. The smartphone used in this study was an Android. Blynk was an open data platform and application programming interface (API) for the Internet of Things (IoT) that enabled users to collect, store, analyze, visualize, and act on sensor and actuator data readings. Blynk was compatible with a range of devices, including Arduino, ESP8266, NodeMCU Particle Photon and Core, Raspberry Pi, Electric Imp, mobile and web apps, Twitter, Twilio, and others (Wagino & Arafat, 2018). Blynk was also defined as a platform that uses iOS and Android applications to control Arduino, Raspberry Pi, and other devices via the internet (Hasan & Ismaeel, 2020). Blynk functioned as a digital dashboard that allowed users to easily create an interface for any project, and it was not limited to a specific board. Blynk was utilized on numerous hardware devices (Gunawan et al., 2020).

In Blynk, hardware must be connected to the internet through a wi-fi shield to communicate. In this study, the hardware used was NodeMCU ESP8266. Blynk allowed for commands to be executed in both directions, both from the hardware and from the Blynk App. The Blynk server, aided by Blynk Libraries, served as the entry point for all incoming and outgoing commands on the hardware. The Blynk server 2 was responsible for all communication between the smartphone and the hardware. By utilizing Blynk Cloud, the Blynk servers operated privately and locally.

The design process commenced with registration on the Blynk application, followed by the obtainment of an Auth Token to connect Blynk to the Wifi module or microcontroller. Subsequently, the battery was recharged to purchase the widget on Google Pay. The next step was the creation of a New Project, where the requisite widgets were placed on the New Project page using the Widget Box. These widgets were utilized to develop monitoring functions and application interfaces. The widgets included the Value Display widget for displaying Year, Month, Date, Hour, Minute, and Second data, as well as water level data. Additionally, the Notification widget was employed to send notifications, and the SuperChat widget to display graphs in real-time.

2.6. Sensor Module and Server Module Development Method

The output of an electronic circuit designed for sea tide level monitoring is illustrated in Figure 3. The NRF24L01 wireless communication component (Number 1) facilitated the transmission of sensor data from the sensor module to the server module. The NodeMCU ESP8266 (Number 2) functioned as both a microcontroller and a Wi-Fi module, enabling the transmission of sensor data to Blynk cloud and their display in a smartphone application. Reference number 3 corresponds to the SRF05 sensor. Furthermore, the auxiliary components associated with the sensor module include an Arduino Nano and a power bank, while those connected to the server module consist of an LCD, another Arduino Nano, an RTC DS3231SN, a Micro SD module, and a battery.

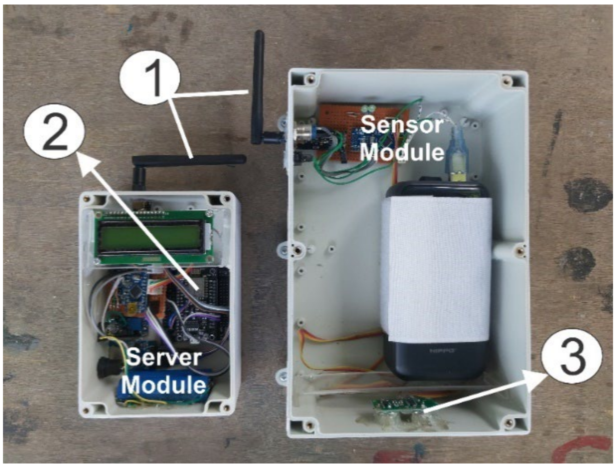

Figure 3. Setup of the sensor module and the server module

The hardware of the tide monitoring tool consisted of two main components: the sensor module and the server module. Both modules were built from a polymer material and painted white to enhance their resistance to heat, as they contained electronic circuits and were situated in an open beach area exposed to direct sunlight. The sensor and server modules were additionally equipped with waterproof rubber to protect against exposure to seawater and rain. The sensor module included an on/off switch, setting button, transmitting antenna, marker light, and an ultrasonic sensor SRF05 located at the bottom. Meanwhile, the server module featured an on/off switch, setting button, receiving antenna, memory card slot, battery charger hole, and an LCD monitor serving as a data interface.

2.7. Tide Monitoring Tool Performance Testing Method

The testing of the tide monitoring tool integrated with the Blynk application was conducted in Nambangan, an area surrounding Kenjeran Beach Tourism in Surabaya. The trial involved comparing sensor data readings in the Blynk application with data measured manually by the staff. The sensor module was placed 2.5 meters above water surface at its lowest point, which was still submerged. The zero altitude position was set by pressing the button. The server module was placed on the coast, in this case in the nearest fisherman's house with an active Wi-Fi service, and the tool took readings for 24 hours. Additionally, tests were conducted on notifications and email delivery as auxiliary and backup data for the offline memory card installed on the server module. The workflow of the tide monitoring tool integrated with the Blynk application is given in Figure 4. The tool continuously monitored tide height and sent notifications and email altitude data at "00" minutes around the clock.

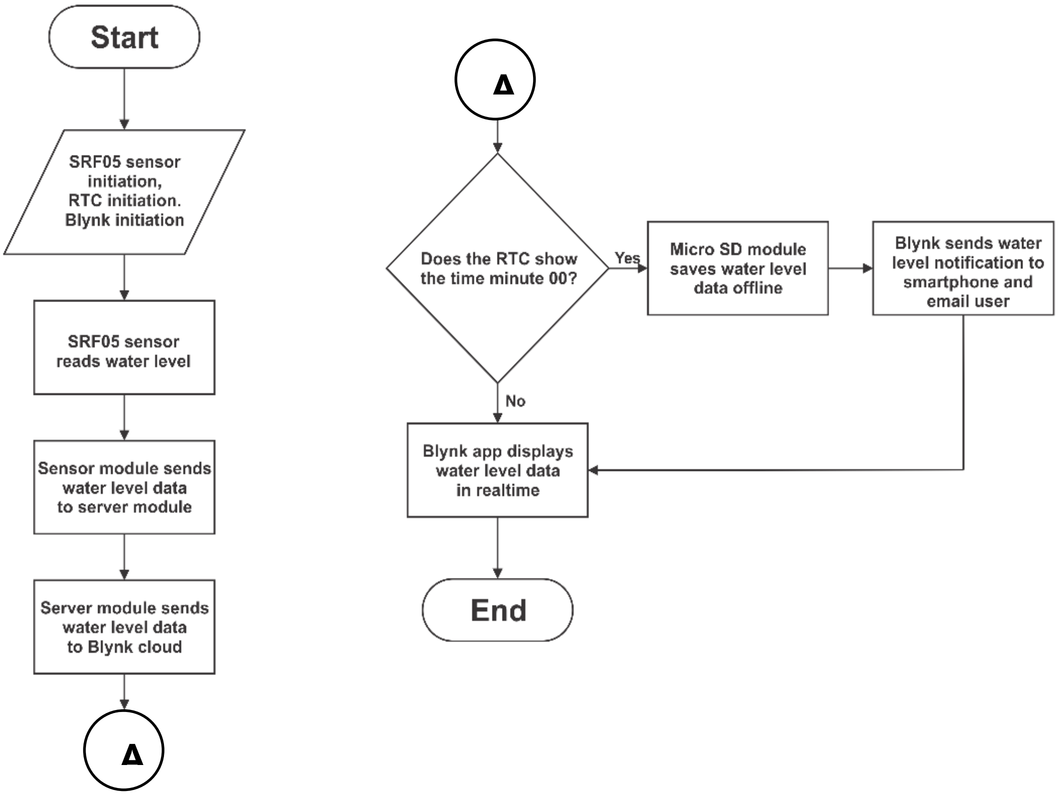

Figure 4. Flowchart of the tide monitoring system

3. RESULTS AND DISCUSSION

3.1. Data Transmission Performance Results

The data transmission connection data between the NRF24L01 transmitter and the NRF24L01 receiver were collected 20 times for each distance, namely 0 m, 50 m, 100 m, 150 m, 200 m, and 250 m. Data status "1" signifies that the transmitter and receiver connection on the NRF24L01 was already established, while data status "0" indicates that the transmitter and receiver connection on the NRF24L01 was disconnected or not connected.

Data transmission testing results for NRF24L01 at distances of 0 - 250 m are given in Table 1. All 20 data transmission tests at the distance of 0 m had the data status 1, indicating a smooth connection and no errors. Similarly, at distances of 50 m, 100m and 150 m, all 20 tests resulted in successful data transmission with no errors. At the distance of 150 m, there was one connection failure in the 12th test, resulting in an error of 5%. At the distance of 200 m, there were two connection failures, in the 14th and 19th tests, resulting in an error of 10%. Notably, at this distance, all 20 tests had data status 0 on the LCD display, indicating complete failure of the NRF24L01 transmitter and receiver to establish a connection and transmit data. The data suggest that the likelihood of connection loss increases with data transmission distance.

NRF24L01 Connection	Distance (m)					
	0	50	100	150	200	250
1	1	1	1	1	1	0
2	1	1	1	1	1	0
3	1	1	1	1	1	0
4	1	1	1	1	1	0
5	1	1	1	1	1	0
6	1	1	1	1	1	0
7	1	1	1	1	1	0
8	1	1	1	1	1	0
9	1	1	1	1	1	0
10	1	1	1	1	1	0
11	1	1	1	1	1	0
12	1	1	1	0	1	0
13	1	1	1	1	1	0
14	1	1	1	1	0	0
15	1	1	1	1	1	0
16	1	1	1	1	1	0
17	1	1	1	1	1	0
18	1	1	1	1	1	0
19	1	1	1	1	0	0
20	1	1	1	1	1	0
Total	20	20	20	19	18	0
Error (%)	0	0	0	5	10	100

Table 1. Data transmission testing results for NRF24L01 at distances of 0 - 250 m

The data transmission delay from the NRF24L01 transmitter to the NRF24L01 receiver were collected twenty times for each distance, namely 0 meters, 50 meters, 100 meters, 150 meters, 200 meters, and 250 meters. The data delay was calculated as the period between the beginning of data transmission by the NRF24L01 transmitter and the receipt of the data by the NRF24L01 receiver (in seconds). There was a delay in each data transmission test where each distance was tested twenty times. At the testing distance of 0 meters, there was no delay in any of the twenty tests, giving the average delay of 0 seconds. At the testing distance of 50 meters, two data transmissions had a delay of 0.010 seconds, specifically the 9th and 15th tests, giving the average delay of 0.001 seconds. At the testing distance of 100 meters, three tests had the delay of 0.010 seconds, specifically the 5th, 9th, and 18th tests, giving the average delay of 0.002 seconds. At the testing distance of 150 meters, six data transmissions had delays, with three data sets experiencing the delay of 0.010 seconds and three data sets experiencing the delay of 0.100 seconds. There was also one data set that was not sent. At the testing distance of 200 meters, the majority of data sets experienced the delay of 0.100 seconds, while two data sets were not sent. Meanwhile, at the test distance of 250 meters, there was no delay because all the data sent were lost. These data suggest that the greater the distance, the greater the delay. Based on the data in Table 1, the best distance with the minimal delay for the use of NRF24L01 wireless communication is 0 meters to 100 meters.

The SRF05 sensor was placed at the bottom of the box to facilitate water level reading. The water level test data from the SRF05 sensor are shown in Table 2. The reading method was in accordance with Equations [1] and [2] in cm, while the results of the SRF05 data analysis with a ruler: 0 cm, 60 cm, 120 cm, 240 cm, 300 cm are shown in Table 3.

SRF05 Data	Ruler Level (cm)											
	0	30	60	90	120	150	180	210	240	270	300	330
1	0.20	29.83	59.74	89.54	119.35	149.30	179.29	209.32	238.88	268.51	298.43	327.99
2	0.20	29.96	59.75	89.54	119.35	149.47	179.29	209.24	238.75	268.55	298.43	328.14
3	0.30	29.83	59.72	89.54	119.60	149.30	179.17	209.22	239.02	268.67	298.43	328.29
4	0.00	29.83	59.92	89.71	119.45	149.47	179.29	208.94	238.88	268.65	298.49	328.29
5	0.40	29.83	59.92	89.54	119.45	149.21	179.17	209.22	238.75	268.65	298.43	328.14
6	0.30	29.96	59.94	89.54	119.35	149.57	179.04	209.24	239.02	268.71	298.33	327.80
7	0.20	30.01	59.75	89.71	119.44	149.47	179.04	209.32	239.02	268.71	298.49	327.92
8	0.20	29.83	59.74	89.60	119.44	149.31	179.11	208.74	238.95	268.62	298.65	328.00
9	0.00	29.83	59.75	89.71	119.57	149.00	179.11	208.24	239.02	268.75	298.43	328.14
10	0.00	29.96	59.74	89.71	119.37	149.57	179.11	209.24	238.88	268.75	298.63	328.00
11	0.40	30.01	59.94	89.71	119.57	149.30	179.29	208.06	238.75	268.62	298.43	328.05
12	0.30	30.02	59.74	89.71	119.55	149.47	179.21	209.24	238.75	268.55	298.37	328.14
13	0.30	29.83	59.75	89.71	119.55	149.00	179.29	209.24	238.85	268.67	298.65	327.89
14	0.30	29.96	59.92	89.54	119.50	149.21	179.29	209.24	238.88	268.55	298.65	327.92
15	0.60	29.83	59.92	89.54	119.60	149.21	179.29	209.32	238.75	268.67	298.33	327.99
16	0.00	29.83	59.75	89.71	119.50	149.30	179.17	209.24	238.75	268.55	298.43	327.99
17	0.00	30.01	59.94	89.54	119.35	149.57	179.29	209.32	238.85	268.77	298.33	327.80
18	0.40	29.96	59.75	89.54	119.45	149.30	179.17	208.94	238.88	268.62	298.33	328.05
19	0.20	30.01	59.74	89.71	119.50	149.30	179.11	209.32	238.75	268.77	298.37	328.14
20	0.00	29.83	59.75	89.71	119.60	149.30	179.29	208.24	238.75	268.75	298.37	328.29
$\bar{x}$	0.22	29.91	59.81	89.63	119.48	149.33	179.20	209.04	238.86	268.65	298.45	328.05
Error (%)	-	0.307	0.319	0.413	0.436	0.446	0.444	0.455	0.476	0.498	0.517	0.591

Table 2. Water Level Test Data from the SRF05 Sensor

The mean of the test data was determined, yielding an average error of 0.446%, i.e. remarkable accuracy of 99.554%. As shown in Table 2, the standard deviation of the test data was also found to be relatively low (under 1), thereby indicating that the data obtained were more precise with the mean value. The sample variation was modest, and the data range was not excessively wide; the largest range was 0.6 cm at the 0 cm ruler level, which was situated at the farthest distance from the sensor. In conclusion, the overall performance of the SRF05 sensor was exceptional, as it was capable of detecting water levels up to 330 cm from the bottom of the tube.

3.2. Measuring Tool Performance Testing Results

The SRF05 sensor was placed at the bottom of the box to facilitate water level reading. The water level test data from the SRF05 sensor were shown in Table 2. The reading method was in accordance with Equations [1] and [2] in cm, and data analysis results are shown in Table 3.

The mean of the test data was determined, yielding an average error of 0.446%, i.e. remarkable accuracy of 99.554%. As shown in Table 2, the standard deviation of the test data was also found to be relatively low (under 1), thereby indicating that the data obtained were more precise with the mean value. The sample variation was modest, and the data range was not excessively wide; the largest range was 0.6 cm at the 0 cm ruler level, which was situated at the farthest distance from the sensor. In conclusion, the overall performance of the SRF05 sensor was exceptional, as it was capable of detecting water levels up to 330 cm from the bottom of the tube.

Ruler level (cm)	0	60	120	180	240	300
Mean	0.215	59.8085	119.477	179.201	238.8565	298.45
Standard error	0.03857665	0.0203169	0.02024976	0.02053111	0.02346638	0.02487865
Median	0.2	59.75	119.475	179.19	238.865	298.43
Mode	0	59.75	119.35	179.29	238.75	298.43
Standard Deviation	0.17252002	0.09085993	0.09055966	0.0918179	0.10494485	0.11126072
Sample variance	0.02976316	0.00825553	0.00820105	0.00843053	0.01101342	0.01237895
Kurtosis	-0.3941766	-1.6644618	-1.3149038	-1.3168791	-1.177451	-0.3296461
Skewness	0.22191455	0.67553997	-0.1238655	-0.3879047	0.44024197	0.91101825
Range	0.6	0.22	0.25	0.25	0.27	0.32
Minimum	0	59.72	119.35	179.04	238.75	298.33
Maximum	0.6	59.94	119.6	179.29	239.02	298.65
Sum	4.3	1196.17	2389.54	3584.02	4777.13	5969
Count	20	20	20	20	20	20
Confidence level (95.0%)	0.08074186	0.04252375	0.04238323	0.0429721	0.0491157	0.05207162

Table 3. SRF05 data analysis results at ruler level: 0 cm, 60 cm, 120 cm, 240 cm, 300 cm

3.3. Sea Level Monitoring Tool Performance Testing Results

The assessment of the tide monitoring tool integrated with Blynk was conducted at Nambangan (7°13'05.6"S 112°47'09.6"E), in the vicinity of Kenjeran beach tourism, Surabaya. The sensor module was positioned approximately 100 meters from the Nambangan shoreline, and the server module in the closest fisherman's house, approximately 150 meters from the server module.

The comparison of tide sensor data obtained by the tool with the tide data obtained in the conventional manner by the staff is illustrated in Figure 5. The evaluation covered a 24-hour period, from 10.00 a.m. on October 16, 2022 to 10.00 a.m. on the following day. As depicted in the table, the tide staff established that the error of the monitoring tool for height data for 0-43 cm was under 1%. Conversely, for height data exceeding 43 cm, the error range was between 1% and 2%. The highest error was observed at 1.00 am on the 17th, amounting to 2.5% (the difference of 3.93 cm). Various factors contributed to these errors, including sensor characteristics, wind and weather factors, and the precision of reading staff. Two data points had a 0% error, the first at 3.00 p.m. on the 16th, and the second at 8.00 a.m. on the 17th. The data collected had an overall error average of 1.43%, indicating that the monitoring tool performed effectively.

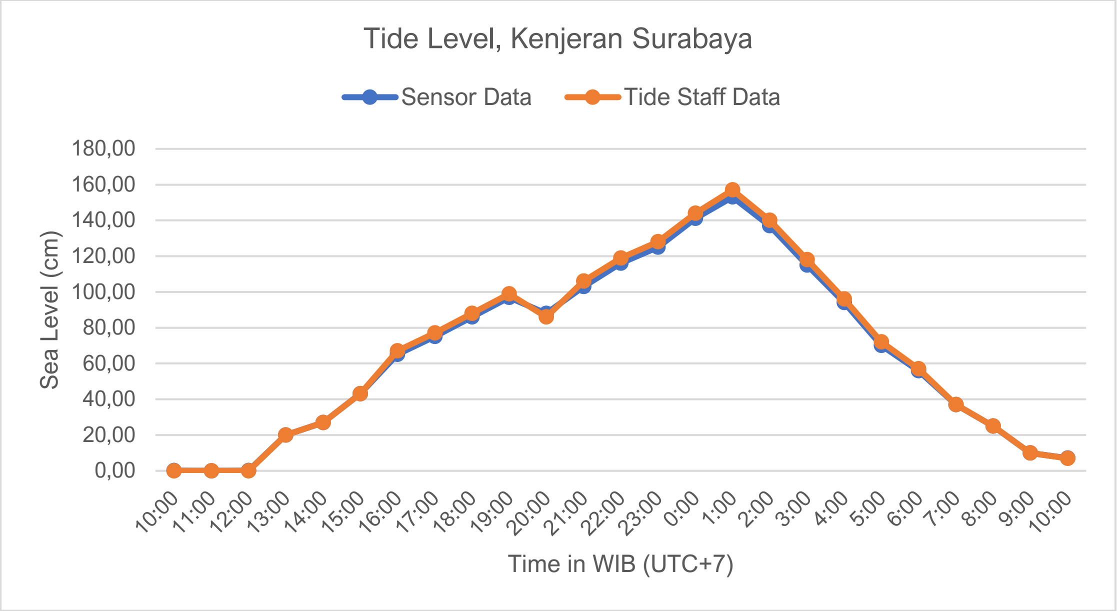

Figure 5. Comparison of tidal sensor data obtained by the tool with tidal data measured by conventional tide staff over a 24-hour period at Kenjeran, Surabaya

The data collection period started on October 16, 2022 at 10:00 a.m. and ended on October 17, 2022 at 10:00 a.m. (Figure 5). The tide staff used this 24-hour data set as a calibration tool for tide monitoring. Between 10:00 a.m. and12:00 p.m. (noon), both the monitoring equipment and tidal staff indicated that the water level had reached its lowest low tide. At 12:00-7:00 p.m., the data displayed a significant increase, with the highest level recorded by the equipment being 97.03 cm, and by the staff 99 cm. Between 7:00-8:00 p.m., the data for both the monitoring equipment and tide staff showed a decrease in height level, with readings of 88.04 cm and 86 cm, respectively. Between 8:00 p.m. and 01:00 a.m., the water level rose again, with the highest level of 153.07 cm measured by the monitoring equipment at 01:00 a.m., and 157 cm by the tide staff. Between 01:00 a.m. and 10:00 a.m., the water level dropped to its lowest point at 09:00 a.m., with the readings of 7.02 cm on the monitoring equipment and 7 cm by the tide staff. An examination of data discrepancies between the monitoring equipment and tide staff reveals that the greater the discrepancy, the higher the sea level. However, as noted in Table 6, the data were deemed satisfactory, with the average error of only 1.43% and the highest error of 2.5% occurring when the tide was at its highest.

The Sea Level Monitoring application, used in conjunction with the Blynk application on a user's smartphone, delivers a visual display that facilitates real-time monitoring of water levels from a remote location. The application features a graph that displays the water level data in an easily readable format, as well as a variety of widgets that function as real-time clocks, email and notification alerts, and water level indicators. Additionally, the Blynk app allows for the delivery of hourly notification pop-ups and water level email alerts, providing the user with up-to-date information on the status of the water levels being monitored.

3.4. Result of the Seven-Day Sea Level Monitoring in Kenjeran, Surabaya

Sea level monitoring data were gathered over a seven-day period, from 9:00 a.m. on October 16, 2022 to 5:00 p.m. on October 23, 2022, as shown in Figure 6. On October 17, a high tide was observed, followed by a slight drop, a subsequent return of the tide, and finally, the lowest low tide. Similarly, on October 18, a high tide was observed, followed by the lowest low tide. On the 19th and 20th, a pattern of high tide, followed by a 10-20 centimeter drop, a high tide, but not as high as the first, and finally the lowest low tide was observed. This pattern continued on the 21st, 22nd, and 23rd, with high tides, followed by a 80-100 centimeter drop, and then high tides again, but not as high as the first, and finally the lowest low tide. The tide monitoring tool revealed that there were two high tides and two low tides over a 24-hour period in Nambangan, Kenjeran Tourism Beach Surabaya.

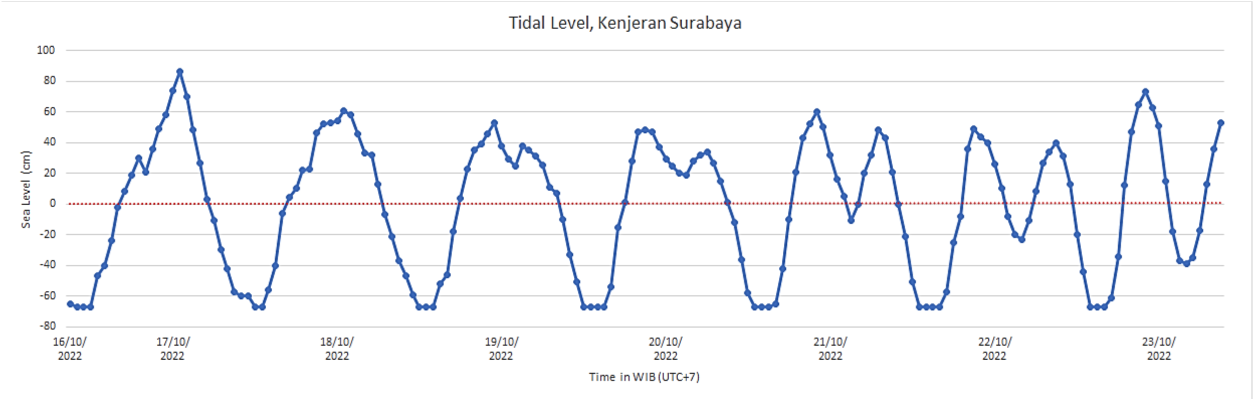

Figure 6. Sea level monitoring data collected over a seven-day period in Kenjeran Tourism Coast Area, Surabaya

4. DISCUSSION

4.1. The Advantages of This Tide monitoring Tool as a Novelty Introduced by This Research

With regard to real-time tide measurement tools, the current state-of-the-art technology still relies on an SMS gateway for real-time functionality, which is heavily dependent on signal providers. The tide gauge used in this study had the error rate of 1.833%. However, this study utilized the Internet of Things (IoT) principle and the Blynk application as a tide monitor, allowing for real-time monitoring to be conducted from anywhere at any time. The error rate of the monitoring tool in this study was 1.43%, which is 0.403% lower than in the study conducted by Fadly & Dewi (2019).

Compared to prior research, such as Quraish et al. (2019) which used a PING sensor to create a web-based tide measuring instrument, this study's sensor had a significantly smaller error. The largest difference between the sensor results and tide staff data compared in this study was only 3.93 cm, whereas the previous study reported a difference of up to 60 cm.

In a recent study conducted by Supriyadi et al. (2021), the focus was on Arduino-based tide monitoring. The data collected were stored exclusively on an SD card, offline. However, this research also implemented a unique approach by storing the sensor detection data not only on a micro SD card, but also on the Blynk cloud and sending it as an hourly backup to the user's email.

On the other hand, JuniarkoPrananda, et al. (2021) utilized ThingSpeakTM as their monitoring website. While their research successfully displayed measurement data through the website, it did not extend to a flexible monitoring system via an android application. By contrast, the Blynk application used in this study allowed for direct monitoring of measurement data on a smartphone (android or iOS) without the need for prior website setup. Additionally, the development of the IoT system on Blynk was streamlined, requiring no laptop setup, as it was designed directly on the Blynk application and connected to field devices or measurement modules.

Agustin, et al. (2022) investigated the use of NodeMCU and HC-SR04 for tide monitoring. Their findings involved simulated observations of water levels in a tub with the maximum height of 50 cm. The study successfully demonstrated laboratory-scale simulations that could detect heights of up to 330 cm above water surface, with the average error of 0.5%. Furthermore, the research was also tested on a field scale at the Kenjeran beach tourist area in Surabaya, resulting in the average error of 1.43%.

5. CONCLUSIONS

The tide monitoring tool based on the Internet of Things (IoT) consisting of a sensor module and a server module was designed and constructed. The sensor module incorporated an ultrasonic sensor component, SRF05, as an altitude sensor, while the server module included NRF24L01 components for wireless communication, an Arduino Nano as a controller, RTC DS3231SN as a real-time clock, LCD i2c as data interface, micro SD as storage media, and NodeMCU ESP8266 as a microcontroller, as well as a Wi-Fi module that effectively sent data to the Blynk cloud, resulting in a user-friendly sea level monitoring application that functions both in real-time and remotely.

The testing demonstrated that the maximum distance between the sensor module and the server was 150 meters, at which point data transmission occurred optimally without experiencing any lost connections or delays. This distance was determined to be the maximum distance between the sensor placement near the sea and the server placement on the beach. Overall, the monitoring tool was efficient, as proven by laboratory scale testing, with the achieved accuracy of 99.554%.

The implementation of Blynk in the construction of a tide monitoring system offers the benefit of real-time and remote monitoring, as demonstrated by a trial conducted in Nambangan, Kenjeran beach tourist area in Surabaya. The error rate for data obtained from the tide monitoring device integrated with the Blynk application was found to be 1.43%, which is lower than the data obtained by manual monitoring. The monitoring device is capable of storing data both offline and online, using MicroSD and Blynk cloud respectively. Additionally, the Blynk application on the device allows for notifications and hourly sea level updates to be sent via email. Observations conducted over a period of seven days revealed that the tidal patterns in Kenjeran Tourism Beach Surabaya, consist of two high tides and two low tides within a 24-hour period.

ACKNOWLEDGEMENTS

The authors are grateful for the research grant for the Master’s Thesis Research Schema entitled “Design and Construction of a Sea Water Tide Monitoring Tool Based on the Internet of Things and Implemented in the Kenjeran Beach Tourism Area, Surabaya / Design of Sea Level Monitoring Tool Based on the Internet of Things and Applied in Kenjeran Tourism Coast Area, Surabaya“ received from the Ministry of Education, Culture, Research and Technology, Indonesia (Kusuma, et al., 2023). Grand number: 159/E5/P6.02.00.PT/2022, 10 Mei 2022. We thank the Rector of the University of Hang Tuah Surabaya.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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