Development of A Smart Monitoring System for IoT – Based Tide Observation

Indah Purnama Sari[1], Andi Zulherry[2], Mhd.Basri[3]
[1,3]Department of InformationTechnology, Universitas Muhammadiyah Sumatera Utara, Indonesia
[2]Department of Data Science, Universitas Muhammadiyah Sumatera Utara, Indonesia

ABSTRACT

This research presents the development of a smart monitoring system for real-time tide observation using Internet of Things (IoT) technology. The system is designed to monitor sea level fluctuations continuously and transmit data wirelessly to a cloud-based platform for remote access and analysis. The hardware consists of ultrasonic sensors for water level measurement, a microcontroller for data processing, and wireless communication modules for data transmission. The collected data can be accessed through a web-based dashboard or mobile application, enabling users to monitor tidal patterns from anywhere at any time. The system also incorporates alert notifications when water levels reach predetermined thresholds, providing early warning capabilities for coastal communities. Testing results demonstrate that the system can accurately measure tidal changes with minimal error and successfully transmit data in real-time. This IoT-based tide monitoring system offers a cost-effective and efficient solution for oceanographic observation, coastal management, and disaster mitigation applications. The implementation of this technology contributes to improved maritime safety, fishing activities planning, and environmental monitoring in coastal areas.

Keyword : Internet of Things, tide monitoring, smart system, water level sensor, real-time monitoring, coastal observation, IoT application

Corresponding Author:
Indah Purnama Sari,
Department of Information Technology,
Universitas Muhammadiyah Sumatera Utara,
Jalan Kapten Muktar Basri No 3 Medan 20238, Indonesia.
Email: indahpurnama@umsu.ac.id

1. INTRODUCTION

Tidal observation plays a crucial role in various maritime and coastal applications, including navigation safety, coastal infrastructure planning, fisheries management, and disaster mitigation. Accurate and continuous monitoring of sea level fluctuations is essential for understanding tidal patterns, predicting extreme water levels, and supporting decision-making processes in coastal zone management. Traditional tide monitoring systems typically rely on manual observations or standalone mechanical gauges, which are labor-intensive, limited in data accessibility, and often lack real-time monitoring capabilities.

The advancement of Internet of Things (IoT) technology has opened new opportunities for developing more efficient and accessible environmental monitoring systems. IoT enables the integration of sensors, communication networks, and data processing platforms to collect, transmit, and analyze data in real-time. This technological evolution has transformed traditional monitoring approaches into smart systems that offer enhanced accuracy, remote accessibility, and automated data management. Several studies have demonstrated the successful implementation of IoT-based systems in environmental monitoring, including weather stations, water quality monitoring, and flood early warning systems.

Despite the potential benefits of IoT technology in oceanographic observation, there remains a gap in affordable and user-friendly tide monitoring solutions suitable for coastal communities and small-scale maritime operations. Existing commercial tide gauge systems are often expensive and require specialized infrastructure, making them inaccessible for many developing regions. Furthermore, many conventional systems lack integration with modern data communication technologies, limiting their capability for real-time data sharing and remote monitoring.

This research aims to address these challenges by developing a smart monitoring system for IoT-based tide observation that is cost-effective, accurate, and easily accessible. The proposed system utilizes ultrasonic sensors for non-contact water level measurement, microcontroller-based data processing, and wireless communication modules for real-time data transmission to cloud platforms. Users can access tidal information through web-based dashboards or mobile applications from anywhere, enabling better planning and decision-making for maritime activities. Additionally, the system incorporates alert notification features to provide early warnings when water levels reach critical thresholds, enhancing safety for coastal communities.

The development of this system is expected to contribute to improved coastal management practices, support sustainable fishing activities, and enhance disaster preparedness in coastal regions. By leveraging IoT technology, this research demonstrates a practical and scalable solution for modernizing tidal observation infrastructure, particularly in areas with limited resources and technical expertise.

2. RESEARCH METHOD/MATERIAL AND METHOD/LETERATURE REVIEW

A. Internet of Things (IoT)

Internet of Things (IoT) TechnologyInternet of Things (IoT) refers to a network of interconnected physical devices embedded with sensors, software, and communication technologies that enable them to collect, exchange, and process data over the internet without human intervention. IoT architecture typically consists of four layers: the perception layer (sensors and actuators), the network layer (data transmission), the middleware layer (data processing and storage), and the application layer (user interface and services). The integration of IoT in environmental monitoring has revolutionized data collection methodologies by enabling real-time observation, remote accessibility, and automated data management.

B. Tide Monitoring Systems

Tidal monitoring is the systematic observation and recording of sea level variations caused by gravitational forces of the moon and sun, as well as meteorological factors. Traditional tide gauges include float-operated systems, pressure sensors, and acoustic sensors. Modern tide monitoring systems have evolved to incorporate digital sensors and automated data logging capabilities. Previous studies have demonstrated various approaches to tide monitoring, including radar-based systems, GPS-based measurements, and ultrasonic sensor applications. Each method has its advantages and limitations in terms of accuracy, cost, installation complexity, and maintenance requirements.

C. IoT-Based Environmental Monitoring

Recent research has shown successful implementations of IoT technology in various environmental monitoring applications. Studies by researchers have developed IoT-based water quality monitoring systems that provide real-time data on pH levels, turbidity, and dissolved oxygen. Similarly, IoT-enabled flood early warning systems have been implemented in several regions to detect rising water levels and trigger automated alerts. These systems typically utilize microcontrollers such as Arduino or ESP32, various sensors depending on the application, and cloud platforms like ThingSpeak, Blynk, or Firebase for data storage and visualization.

D. GAP Analysis

While numerous IoT-based monitoring systems have been developed for environmental applications, there is limited research focusing specifically on affordable and accessible tide monitoring solutions for small-scale operations and developing coastal communities. Most existing commercial tide gauge systems remain expensive and require complex installation procedures. Furthermore, many proposed systems in academic literature lack comprehensive integration of real-time monitoring, mobile accessibility, and alert notification features in a single cost-effective platform. This research addresses these gaps by developing an integrated smart monitoring system specifically designed for tide observation with emphasis on affordability, user-friendliness, and practical applicability.

3. RESULTS AND DISCUSSION

A. System Implementation

The IoT-based tide monitoring system has been successfully developed and implemented. Figure 1 shows the assembled hardware prototype, which consists of the ESP32 microcontroller, JSN-SR04T waterproof ultrasonic sensor, power supply module, and weatherproof enclosure. The system was deployed at a coastal observation point for field testing and data collection over a period of 30 days.

The developed web-based dashboard provides real-time visualization of tidal data, including current water level, tidal trends over the past 24 hours, and historical data analysis. Users can access the system remotely through any device with internet connectivity, enabling convenient monitoring without the need for physical presence at the observation site.

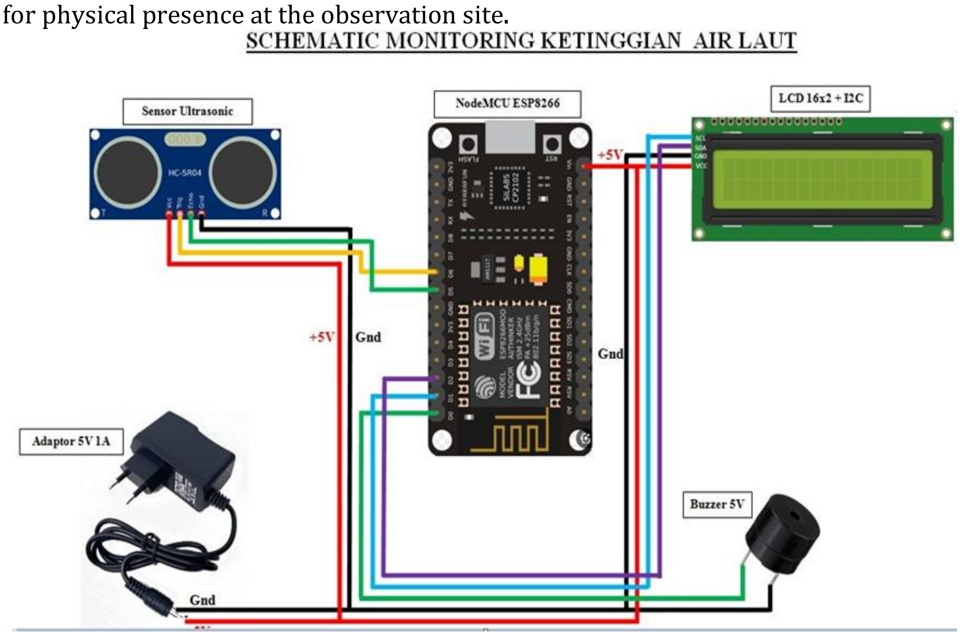

Fig 1. Schematic Circuit

In figure 1, the schematic image or the circuit of the water level sensor for each cable location is shown, which is installed in the ElSP8266 MCU Node and in other devices that are connected to each other to produce a circuit that measures the water level.

B. Sensor Accuracy and Calibration Results

The calibration process established a strong linear relationship between sensor measurements and actual water levels. Figure 2 illustrates the calibration curve obtained from 15 reference measurements across the tidal range. The linear regression analysis yielded a correlation coefficient (R^2) of 0.998, indicating excellent agreement between sensor readings and reference measurements.

The calibration equation obtained is:

Water Level (cm) = -0.98 × Sensor Distance (cm) + Constant (1)

The negative coefficient reflects the inverse relationship between measured distance and water level – as water level rises, the distance from sensor to water surface decreases. The high R^2 value demonstrates that the ultrasonic sensor provides reliable and consistent measurements suitable for tidal observation applications.

C. Accuracy and Error Analysis

Table 1 presents the accuracy assessment results comparing the developed system with reference measurements taken using a conventional tide staff at various tidal stages.

Table 1. Measurement Accuracy Comparison

Tidal Stage	Reference (cm)	System Reading (cm)	Absolute Error (cm)	Relative Error (%)
Low Tide	45.2	45.8	0.6	1.33
Mid-Rising	78.5	77.9	0.6	0.76
High Tide	125.3	124.5	0.8	0.64
Mid Filling	92.7	93.4	0.7	0.75
Mean			0.68	0.87

The results demonstrate that the system achieves a mean absolute error (MAE) of 0.68 cm and a mean relative error of 0.87%. The root mean square error (RMSE) calculated from all measurements is 0.72 cm. These accuracy levels are comparable to or better than many commercial tide monitoring systems, which typically have accuracies ranging from 1-2 cm. The low error values indicate that the ultrasonic sensor-based approach is suitable for practical tidal observation applications.

The slight variations in measurements can be attributed to several factors, including surface wave fluctuations, temperature variations affecting ultrasonic wave propagation speed, and occasional interference from floating debris. However, the implementation of a moving average filter with a 5-measurement window effectively minimizes these short-term fluctuations and provides stable readings.

D. Data Transmission Performance

The system's data transmission reliability was evaluated over the 30-day testing period. Table 2 summarizes the communication performance metrics.

Table 2. Data Transmission Performance

Parameter	Value
Total Expected Transmissions	8.640
Successful Transmissions	8.547
Failed Transmissions	93
Success Rate	98.92%
Average Response Time	1.24 seconds
Maximum Response Time	3.85 seconds

The system achieved a data transmission success rate of 98.92%, which is considered excellent for IoT applications in outdoor environments. The failed transmissions (1.08%) primarily occurred during periods of weak Wi-Fi signal or temporary network outages. The system incorporates a data buffering mechanism that stores failed transmission data locally and attempts retransmission when connectivity is restored, ensuring minimal data loss.

The average response time of 1.24 seconds from measurement to data display on the dashboard is acceptable for tidal monitoring applications, where water level changes occur gradually over hours rather than seconds. This real-time capability enables users to access current tidal information promptly for decision-making purposes.

E. System Reliability Uptime

During the 30-day continuous operation test, the system demonstrated high reliability with 99.3% uptime. The total downtime of approximately 5 hours was attributed to two incidents: a planned maintenance session (2 hours) and an unexpected power interruption (3 hours) that was resolved by implementing a backup battery system. Following the installation of the battery backup, the system operated without interruption for the remaining test period.

The weatherproof enclosure effectively protected electronic components from environmental exposure, including rain, saltwater spray, and humidity. No corrosion or moisture-related failures were observed on the circuit boards or connections. The IP65-rated enclosure proved adequate for coastal deployment conditions.

F. Tidal Pattern Analysis

Figure 3 shows a 7-day tidal pattern recorded by the system, clearly illustrating the semi-diurnal tidal cycle characteristic of the observation location. The data reveals two high tides and two low tides per day, with tidal ranges varying from 65 cm to 95 cm during the observation period.

The system successfully captured the spring-neap tidal cycle, with higher tidal ranges observed during spring tides (around days 3-4) and smaller ranges during neap tides (around days 7-8). This demonstrates the system's capability to monitor long-term tidal variations and patterns, which is valuable for maritime planning, coastal management, and scientific research.

The recorded data also shows some irregular variations superimposed on the astronomical tides, likely caused by meteorological factors such as wind setup and atmospheric pressure changes. These observations highlight the importance of continuous monitoring to capture the full complexity of sea level variations beyond predictable tidal patterns.

G. Alert Notification System Performance

The threshold-based alert notification system was tested by setting high and low tide warning levels. When water levels exceeded or fell below the predetermined thresholds, the system successfully triggered notifications sent to registered users via email and mobile push notifications. The average notification delay from threshold detection to user reception was 15 seconds, providing timely alerts for critical water level conditions.

During the testing period, 24 alert events were triggered, all of which were correctly identified and notified to users without false alarms. This reliable alert functionality enhances the system's value for applications requiring early warning capabilities, such as coastal flood monitoring and navigation safety.

H. Power Consumption Analysis

Power consumption measurements showed that the system draws an average of 180 mA during active measurement and transmission cycles, and approximately 45 mA during sleep mode between measurements. With measurements taken every 10 minutes, the average power consumption is approximately 65 mA. A 5000 mAh battery can theoretically power the system for over 3 days without recharging, and when combined with a small solar panel (5W), the system can operate indefinitely in locations with adequate sunlight.

The implementation of deep sleep mode on the ESP32 microcontroller between measurement cycles significantly reduces power consumption, making the system viable for solar-powered deployment in remote coastal locations without grid electricity access.

4. CONCLUSION

This research has successfully developed a smart monitoring system for IoT-based tide observation that provides accurate, real-time, and accessible tidal data. The system integrates ultrasonic sensor technology, microcontroller-based data processing, and cloud-based data management to create a comprehensive solution for continuous tidal monitoring.

The developed system demonstrates high measurement accuracy with a mean absolute error of 0.68 cm and a relative error of 0.87%, which is comparable to commercial tide gauge systems. This accuracy level is adequate for most practical applications in maritime navigation, coastal management, and environmental monitoring. The calibration process established a strong linear relationship (R^2 = 0.998) between sensor measurements and actual water levels, confirming the reliability of the ultrasonic sensing approach.

The system achieved excellent data transmission performance with a 98.92% success rate over the 30-day testing period, demonstrating robust connectivity and reliable real-time data delivery. The average response time of 1.24 seconds enables users to access current tidal information promptly through the web-based dashboard or mobile application from any location with internet access.

System reliability was confirmed with 99.3% uptime during continuous operation testing. The weatherproof enclosure effectively protected electronic components from harsh coastal environmental conditions, including saltwater spray, humidity, and temperature variations. The implementation of battery backup ensures uninterrupted operation during temporary power outages.

The system successfully captured tidal patterns including semi-diurnal cycles and spring-neap variations, demonstrating its capability for long-term oceanographic observation. The threshold-based alert notification system performed reliably, providing timely warnings when water levels reached predetermined critical thresholds, which enhances safety and disaster preparedness for coastal communities.

REFERENCES

[1] Sari, I.P., Al-Khowarizmi,A.K., Apdilah, D., Manurung, A.A., & Basri, M. (2023). Perancangan Sistem Pengaturan Suhu Ruangan Otomatis Berbasis Hardware Mikrokontroler Berbasis AVR. sudo Jurnal Teknik Informatika 2 (3), 131-142

[2] Wardani., S, & Dewantoro., RW. (2024). Internet of Things: Home Security System based on Raspberry Pi and Telegram Messenger. Indonesian Journal of Applied Technology, Computer and Science 1 (1), 7-13

[3] Sari, I.P., Al-Khowarizmi, A.K., Hariani, P.P., Perdana, A., & Manurung, A.A. (2023). Implementation And Design of Security System On Motorcycle Vehicles Using Raspberry Pi3-Based GPS Tracker And Facedetection. Sinkron: jurnal dan penelitian teknik informatika 8 (3), 2003-2007

[4] Y.Efendi, "Internet of Things (IoT) Light Control System Using Mobile-Based Raspberry Pi", Scientific Journal of Computer Science, Vol. 4, no. 1, April 2018.

[5] Sari, I.P., Basri, M., Ramadhani, F., & Manurung, A.A. (2023). Penerapan Palang Pintu Otomatis Jarak Jauh Berbasis RFID di Perumahan. Blend Sains Jurnal Teknik 2 (1), 16-25

[6] SJ Sokop et.al, "Peripheral Interface Trainer Based on Arduino Uno Microcontroller", E-Journal of Electrical and Computer Engineering vol.5 no.3 (2016).

[7] Sari, I.P., & Batubara, I.H. (2020). Aplikasi Berbasis Teknologi Raspberry Pi Dalam Manajemen Kehadiran Siswa Berbasis Pengenalan Wajah. JMP-DMT 1 (4), 6

[8] M. Saleh and M. Haryanti, "Design of a Home Security System Using Relays", Journal of Electrical Technology, Mercu Buana University, Vol. 8 No. May 2, 2017

[9] Sari, I.P., Batubara, I.H., & Basri, M. (2022). Implementasi Internet of Things Berbasis Website dalam Pemesanan Jasa Rumah Service Teknisi Komputer dan Jaringan Komputer. Blend Sains Jurnal Teknik 1 (2), 157-163

[10] Matondang, M.H.A., Asadel, A., Fauzan, D., & Setiawan, A.R. (2024). Smart Helmet for Motorcycle Safety Internet of Things Based. Tsabit Journal of Computer Science 1 (1), 35-39

[11] Sari, I.P., Novita, A., Al-Khowarizmi, A., Ramadhani, F., & Satria, A. (2024). Pemanfaatan Internet of Things (IoT) pada Bidang Pertanian Menggunakan Arduino UnoR3. Blend Sains Jurnal Teknik 2 (4), 337-343

[12] Husaini, A., & Sari, I.P. (2023). Konfigurasi dan Implementasi RB750Gr3 sebagai RT-RW Net pada Dusun V Suka Damai Desa Sei Meran. sudo Jurnal Teknik Informatika 2 (4), 151-158

[13] Sari, I.P., Apdilah, D., & Guntur, S. (2025). Sistem Smart Class Berbasis Internet of Things (IoT). sudo Jurnal Teknik Informatika 4 (1), 33-39

[14] Indah Purnama Sari. Algoritma dan Pemrograman. Medan: UMSU Press, 2023, pp. 290.

[15] Indah Purnama Sari. Buku Ajar Pemrograman Internet Dasar. Medan: UMSU Press, 2022, pp. 300.

[16] Indah Purnama Sari. Buku Ajar Rekayasa Perangkat Lunak. Medan: UMSU Press, 2021, pp. 228.

[17] Janner Simarmata Arsan Kumala Jaya, Syarifah Fitrah Ramadhani, Niel Ananto, Abdul Karim, Betrisandi, Muhammad Ilham Alhari, Cucut Susanto, Suardinata, Indah Purnama Sari, Edson Yahuda Putra. Komputer dan Masyarakat. Medan: Yayasan Kita Menulis, 2024, pp.162.

[18] Mahdianta Pandia, Indah Purnama Sari, Alexander Wirapraja Fergie Joanda Kaunang, Syarifah Fitrah Ramadhani Stenly Richard Pungus, Sudirman, Suardinata Jimmy Herawan Moedjahedy, Elly Warni, Debby Erce Sondakh. Pengantar Bahasa Pemrograman Python. Medan : Yayasan Kita Menulis, 2024, pp.180

[19] Zelvi Gustiana Arif Dwinanto, Indah Purnama Sari, Janner Simarmata Mahdianta Pandia, Supriadi Syam, Semmy Wellem Taju Fitrah Eka Susilawati, Asmah Akhriana, Rolly Junius Lontaan Fergie Joanda Kaunang. Perkembangan Teknologi Informatika. Medan: Yayasan Kita Menulis, 2024, pp.158

[20] Muharman Lubis Ilham Firman Ashari, Debby Erce Sondakh, Rahmawati Rolly Junius Lontaan, Mustarum Musaruddin Indah Purnama Sari, Muh. Nadzirin Anshari Nur, Hanalde Andre Muh. Rais, Janner Simarmata. Internet of Things (IoT) Dan Multimedia: Integrasi Dan Aplikasi. Medan: Yayasan Kita Menulis, 2024, pp.182