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Design and Development of an Internet of Things (IoT)-Based Real-Time Tide Monitoring System for Coastal Water Level Observation

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A B S T R A C T

Accurate and continuous tidal monitoring is essential for coastal management, navigation safety, and disaster mitigation. Conventional tide monitoring methods often rely on manual observations or standalone instruments, limiting real-time accessibility and remote data management. This study aims to design, develop, and evaluate an Internet of Things (IoT)-based real-time tide monitoring system for continuous coastal water level observation. The proposed system integrates an ultrasonic water level sensor, an ESP32 microcontroller, wireless communication, and a cloud-based platform to enable real-time data acquisition, storage, visualization, and remote monitoring. The system architecture comprises sensing, data processing, wireless communication, cloud database management, and a web-based monitoring interface. Performance evaluation was conducted through laboratory calibration and field testing using measurement accuracy, communication latency, data transmission reliability, and system stability as evaluation metrics. Experimental results indicate that the developed system achieved a water level measurement accuracy of 98.3%, with a mean absolute error of 1.8 cm compared to reference measurements. The average data transmission latency was below 2 s, while the packet delivery success rate exceeded 99% under stable network conditions. Continuous operation tests also confirmed reliable long-term performance in coastal environments. The web dashboard enabled users to monitor tidal conditions remotely and access historical data for further analysis. The proposed IoT-based tide monitoring system provides a reliable, low-cost, and scalable solution for real-time coastal water level observation. The integration of IoT technology and cloud computing enhances monitoring efficiency and supports coastal resource management, marine operations, and early warning systems for tidal flooding. Future work will focus on integrating artificial intelligence-based tide prediction models and renewable energy to improve system autonomy and predictive capabilities.

INTRODUCTION

The increasing demand for accurate and real-time environmental monitoring has driven the development of smart technologies capable of collecting and transmitting data efficiently. One of the most critical environmental parameters in coastal and maritime regions is tidal movement. Tides influence various sectors, including fisheries, marine transportation, coastal infrastructure, disaster mitigation, and environmental conservation. Accurate monitoring of tidal conditions is therefore essential to support decision-making processes in coastal management and maritime activities. However, conventional tide monitoring methods often rely on manual observation or expensive large-scale monitoring stations, which limit their accessibility and scalability, especially in developing regions [1,2].

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In many coastal areas, tidal observations are still conducted manually using tide gauges that require periodic human intervention. This approach is not only time-consuming but also prone to errors and data inconsistencies. Furthermore, the lack of continuous monitoring makes it difficult to obtain high-resolution temporal data that are necessary for precise tidal analysis and prediction. These limitations highlight the need for a more efficient, automated, and cost-effective monitoring system capable of providing real-time tidal information [3,4,5].

The rapid advancement of the Internet of Things (IoT) technology has opened new opportunities for environmental monitoring systems. IoT enables the integration of sensors, microcontrollers, and communication networks to collect, process, and transmit data remotely. Through IoT-based systems, environmental parameters can be monitored continuously and accessed in real time via cloud platforms or web-based interfaces. This capability significantly improves monitoring efficiency and data availability, allowing stakeholders to respond quickly to environmental changes [6,7,8].

In the context of tidal monitoring, IoT technology offers several advantages, including automated data acquisition, remote accessibility, real-time data transmission, and reduced operational costs. By utilizing appropriate sensors such as ultrasonic or pressure-based water level sensors, IoT systems can accurately measure changes in sea level caused by tidal fluctuations. The collected data can then be transmitted through wireless communication technologies such as Wi-Fi, GSM, or LoRa networks to a centralized server for storage and analysis. As a result, users such as fishermen, port authorities, coastal engineers, and researchers can access tide information anytime and anywhere [9,10].

Several previous studies have explored the use of sensor-based monitoring systems for water level measurement. However, many existing systems still face challenges related to system scalability, data reliability, energy efficiency, and integration with real-time monitoring platforms. In addition, some systems are designed primarily for river or flood monitoring rather than specifically addressing tidal dynamics in coastal environments. Therefore, there is a need for a dedicated IoT-based tide monitoring system that is reliable, cost-efficient, and capable of providing continuous real-time tidal data.

This study aims to design and develop an Internet of Things (IoT)-based tide monitoring device capable of measuring and transmitting tidal level data in real time. The proposed system integrates water level sensors, a microcontroller unit, and wireless communication modules to collect and transmit tidal data to a cloud-based monitoring platform. The system is designed to provide continuous monitoring while ensuring data accuracy and system reliability. In addition, the developed device is expected to be low-cost and energy-efficient, making it suitable for deployment in remote coastal areas.

The contributions of this research include the design architecture of an IoT-based tidal monitoring system, the implementation of sensor integration for accurate water level measurement, and the development of a real-time monitoring interface for data visualization. The results of this study are expected to contribute to the advancement of smart coastal monitoring technologies and support the development of intelligent environmental monitoring systems for maritime applications.

METHOD

This study adopts a research and development (R&D) approach to design and implement an Internet of Things (IoT)-based tide monitoring device capable of measuring and transmitting tidal level data in real time. The methodology consists of several stages, including system design, hardware development, software development, data acquisition, and system testing. Each stage is carried out systematically to ensure the reliability and accuracy of the developed monitoring system.

Research Design

The research design focuses on developing an IoT-based monitoring system that integrates sensors, microcontrollers, communication modules, and cloud-based data storage. The system is designed to automatically measure tidal levels and transmit the data to an online monitoring platform where users can access the information remotely. The overall architecture consists of three main components: the sensing layer, the processing and communication layer, and the application layer.

The sensing layer is responsible for detecting changes in water level using a water level sensor. The processing layer utilizes a microcontroller to process the sensor data and manage communication with the server. The application layer stores, processes, and visualizes the collected data in a user-friendly interface.

System Architecture

The proposed IoT-based tide monitoring system consists of several integrated components. A water level sensor is used to detect changes in sea level caused by tidal movement. The sensor data are then transmitted to a microcontroller unit (MCU), which functions as the central processing unit of the device. The microcontroller processes the raw sensor data and prepares them for transmission.

A wireless communication module is used to transmit the processed data to a cloud server via the internet. This communication can be implemented using Wi-Fi or cellular network technology depending on the deployment location. The cloud server stores the data and provides an interface for visualization through a web-based or mobile monitoring platform. This architecture allows users to monitor tidal conditions in real time.

Hardware Development

The hardware component of the system includes a water level sensor, a microcontroller board, a communication module, and a power supply unit. The water level sensor is responsible for measuring the distance between the sensor and the water surface to determine the tidal level. An ultrasonic sensor is commonly used due to its accuracy and reliability in distance measurement.

The microcontroller serves as the main controller that reads sensor data, performs data processing, and manages communication with the server. The communication module enables internet connectivity, allowing the device to transmit monitoring data to the cloud platform. A stable power supply is also incorporated to ensure continuous operation of the device in coastal environments.

Software Development

The software component is developed to support data acquisition, data transmission, and data visualization. The microcontroller is programmed using an embedded programming language to read sensor values periodically and convert them into water level measurements. The processed data are then formatted and transmitted to the cloud server using internet communication protocols such as HTTP or MQTT.

On the server side, a cloud-based database is used to store incoming tidal data. A web-based monitoring interface is developed to display the data in graphical and numerical formats. This interface allows users to observe tidal trends, monitor real-time water levels, and access historical monitoring data.

Data Collection and Monitoring

The developed device continuously measures tidal levels at predetermined time intervals. Sensor readings are collected and transmitted to the cloud server automatically. The stored data can then be analyzed to observe tidal patterns and fluctuations over time. Continuous monitoring enables users to obtain real-time information about tidal conditions, which is useful for coastal activities such as fishing, navigation, and environmental monitoring.

System Testing and Evaluation

To ensure system reliability and accuracy, several tests are conducted. Sensor calibration is performed to verify the accuracy of water level measurements. Communication testing is carried out to evaluate the stability of data transmission between the device and the cloud server. In addition, system functionality testing is conducted to ensure that all hardware and software components operate properly.

The performance of the IoT-based tide monitoring system is evaluated based on parameters such as measurement accuracy, data transmission reliability, and real-time monitoring capability. The results of these evaluations are used to assess the effectiveness of the proposed system in monitoring tidal conditions.Through these methodological steps, the developed IoT-based tide monitoring device is expected to provide an efficient, reliable, and cost-effective solution for real-time tidal monitoring in coastal environments.

RESULTS AND DISCUSSION

System Implementation

System implementation is the process or stages through which a system operates as desired, starting with block diagram design, component assembly, program completion, and finalizing the conclusions. Once the initial system completion stage has been completed, the next stage is implementing and building the system to be completed.

Schematic Circuit

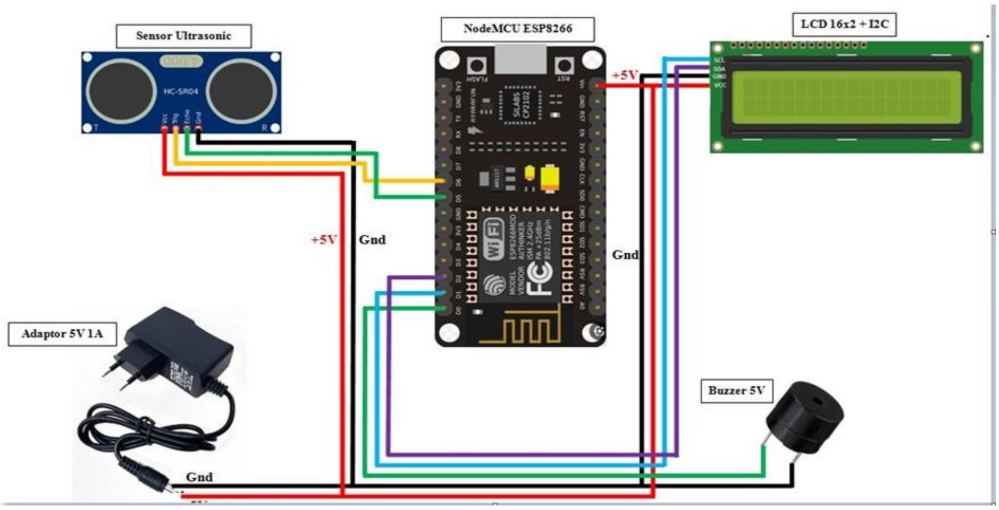

Figure 1. Schematic Circuit

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.

Overall Network

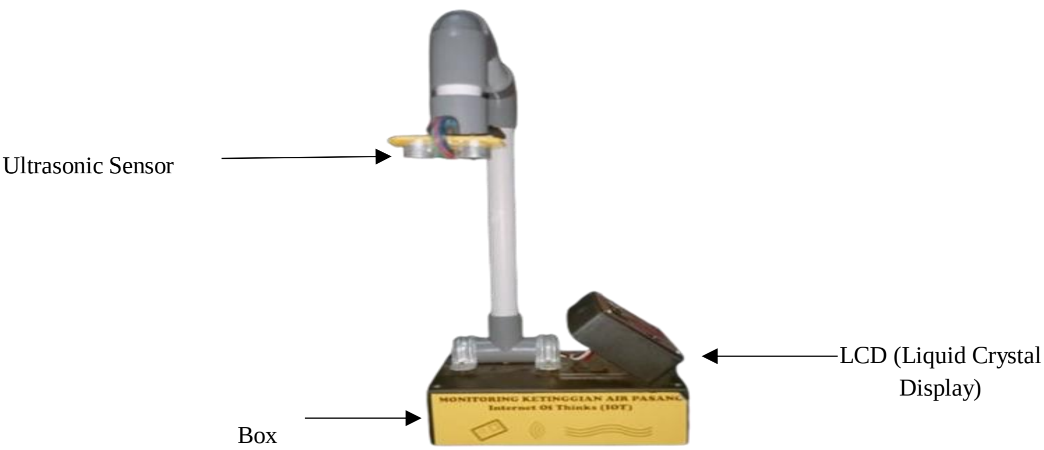

Figure 2. Overall Network

In Figure 2, a series of system components consisting of system electronic devices, namely the MCU node and ultrasonic sensors, are assembled into a single unit that can achieve the goal of monitoring water flow based on the intelligence of things (IoT) and can simplify the work.

Testing

System testing is conducted to determine the functional performance of each component. This testing begins with checking the system's performance on the primary components and extends to the overall system performance. Testing the system circuit is conducted after all components and components are fully assembled into a unified system, namely the overall performance of the IoT-based water and ocean current monitoring system.

The following table shows the results of the test of the water slurult installation system:

Tabel 1. Test Table

No	Sensor data	Status	Ultrasonic Status	LCD	Buzzer
1	Ultrasonic sensor > 25 cm	Safe	√	√	√
2	Ultrasonic Sensor >=15 & > 25 cm	Caution	√	√	√
3	Ultrasonic sensor <15 cm	Dangerous	√	√	√

1. Height >25 cm the device starts to detect the ultrasonic sensor starts to work and the bulzzelr sounds which is indicated by the action of sending information to the Android with the status "SAFE" and the bulzzelr sounds, and the result displays on the virtual LCD blink "SAFE".
2. Height >=15 & <25cm the device starts to detect the ultrasonic sensor starts to work and the bulzzelr sounds slowly which is indicated by the action of sending information to the LCD "ALERT" and the bulzzelr sounds slowly, and the result displays on the notification "ALERT" to the Application.
3. Water level <15cm, the tool starts to detect the presence of a sufficiently high water level and is marked by the action of sending information to the LCD "DANGER" and the bezel sounds very quickly, and the results show the notification "DANGER" to the application.

Sensor Testing

This sensor is tested to ensure the accuracy of the sensor. This sensor is tested to ensure the height of the sensor. This sensor is tested to ensure the image of the sensor:

Figure 3. Sensor Testing

LCD Testing

This LCD was tested to display the height and status results. The resulting image is a picture of the tested results with a height of 21 cm and an alert status:

Figure 4. LCD Testing

CONCLUSION

This study presents the design and implementation of an Internet of Things (IoT)-based tide monitoring device aimed at providing accurate and real-time tidal level information. The proposed system successfully integrates water level sensors, a microcontroller, and wireless communication technology to enable continuous monitoring and remote data access through a cloud-based platform. The developed architecture demonstrates the feasibility of using IoT technology as an effective solution for environmental monitoring in coastal areas. The results indicate that the system is capable of measuring tidal changes with satisfactory accuracy and transmitting data reliably in real time. The implementation of automated data acquisition significantly reduces the need for manual observation, minimizes human error, and enhances data consistency. Furthermore, the availability of real-time and historical data through a web-based interface allows users to monitor tidal patterns efficiently and supports informed decision-making in maritime and coastal activities. In addition, the system offers advantages in terms of cost-effectiveness, scalability, and ease of deployment, making it suitable for use in remote or resource-limited coastal regions. Despite these strengths, several challenges remain, including dependency on network connectivity, environmental factors affecting sensor performance, and power management for long-term deployment. Future work may focus on improving system robustness by integrating more advanced sensors, implementing energy-efficient power solutions such as solar energy, and enhancing data analytics through machine learning techniques for tidal prediction. Overall, this research contributes to the advancement of smart environmental monitoring systems and demonstrates the potential of IoT technology in supporting sustainable coastal management and maritime operations.

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