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Design and Implementation of Tank Level Monitoring System Using Internet of Things (IoT)

Mohammad Sapta Heriyawan [a,1,*], Tony Santiko [b,2], Erli Pujianto [c,3]

[a,c] Semarang Maritime Polytechnic, Jl. Singosari Raya No.2A, Wonodri, Semarang 50242, Indonesia
[b] Makassar Maritime Polytechnic, Jl. Tentara Pelajar No.171, Malimongan Tua, Makassar 90165, Indonesia
[1] hmsapta@pip-semarang.ac.id *; [2] toni.santiko34@gmail.com; [3] erli@pip-semarang.ac.id (9pt)
* corresponding author

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ABSTRACT

The goal of this project was to create, test, and evaluate an IoT-Based Tank Level Monitoring System that would be better than the manual sounding methods that are often used on ships because they are slow and prone to mistakes. Operational safety may be jeopardised by the time-consuming procedures and diminished data accuracy that frequently accompany manual measurement techniques. In order to overcome these constraints, the research team implemented the Blynk IoT platform, an HC-SR04 ultrasonic sensor, and an ESP32 microcontroller to develop an automated monitoring solution that can transmit real-time water level data to a mobile dashboard. Following the Waterfall Model, the system development process included the following stages: requirement analysis, system design, implementation, testing, and maintenance. The prototype maintained sustained Wi-Fi connectivity without data loss, demonstrating high measurement accuracy within the 2–400 cm range. The system demonstrated robust user acceptability by achieving an average usability rating of 3.8 on a 5-point Likert scale and 98.3% accuracy through iterative testing and expert validation. The real-time visualisation of water height and volume data by the Blynk interface was effective in facilitating both operational use and learning applications. The results corroborate that the proposed IoT-based monitoring system provides a scalable, cost-effective, and reliable alternative to manual measurement, thereby improving operational efficiency, safety assurance, and maritime technology education.

1. Introduction

The digital transformation of the maritime industry continues to accelerate alongside the growing demand for sea transportation in global trade. The integration of automation, sensors, and real-time data systems has become essential to ensure operational efficiency, safety, and sustainability. In this context, the implementation of Information and Communication Technology (ICT) plays a vital role, particularly in the monitoring of critical parameters such as water, oil, and fuel levels. Manual monitoring systems, which rely on sounding measurements, are often inefficient and require intensive labour input. These traditional approaches are also prone to human error, potentially leading to inaccurate data and operational delays. However, advancements in Internet of Things (IoT) technology have introduced new opportunities for improving shipboard monitoring systems. IoT enables automatic data acquisition, transmission, and visualization through interconnected sensors, microcontrollers, and cloud platforms. With this approach, liquid level monitoring can be performed remotely and in real time, significantly reducing manual effort and enhancing accuracy.

Previous studies have demonstrated the potential of IoT for environmental and industrial monitoring. For instance, applied the ESP32 microcontroller for data processing in real-time systems, emphasizing its cost efficiency and scalability [1]. Developed an IoT-based air quality monitoring system using ThingSpeak and Blynk, proving the feasibility of mobile-based visualization [2]. Similarly, Rao et al. [3] designed a water quality regulation system using ESP32, while Raagas et al. [4] created a smart water tank prototype employing Wi-Fi-enabled microcontrollers for building management. Singh et al. [5] further integrated IoT and industrial automation for tank management in buildings, highlighting energy efficiency and sustainability. These studies confirm that IoT-based sensing and visualization technologies are effective in improving monitoring accuracy, but they remain limited to controlled laboratory or land-based environments.

Despite these advancements, few studies have examined IoT implementation in maritime contexts, where unique environmental challenges such as vibration, humidity, electromagnetic interference, and unstable connectivity affect sensor reliability and data transmission. Moreover, most prior research lacks empirical validation from maritime experts or end-users, which is crucial to assess the system's practical suitability for ship operations. . The integration of ESP32 microcontroller, ultrasonic sensors, and Blynk-based interfaces presents a promising approach to overcome these challenges, offering both technical feasibility and operational practicality [1], [3]. These gaps indicate the need for an adaptive and validated IoT framework that is specifically designed for marine engineering applications.

Therefore, this research proposes an IoT-based Tank Level Monitoring System that integrates the ESP32 microcontroller, ultrasonic sensors, and the Blynk platform to automate real-time measurement and visualization of water levels in shipboard tanks. According to [4], [5], [6] [7], design and development activities involve translating analytical results into functional software packages. Turner [8] further defines design as the depiction, planning, and arrangement of system elements into a unified, functional whole. Meanwhile, [9] emphasizes that the development of information technology systems must be methodically controlled to meet users' information needs. Unlike earlier systems, this study emphasizes maritime adaptation, iterative testing under real ship conditions, and expert-based validation to ensure operational reliability and usability. The system aims to enhance measurement accuracy, minimize manual workload, and contribute to digital transformation in maritime technology education. Using a Research and Development (R&D) approach based on the Waterfall Model, the study encompasses stages of requirement analysis, system design, implementation, testing, and evaluation. The outcome is expected to provide a practical, cost-effective, and educationally valuable solution that advances both maritime operations and vocational learning in marine engineering.

2. Method

This study utilized the Waterfall Model as the methodological framework to design, build, and assess an IoT-Based Tank Level Monitoring System specifically for maritime engineering applications. The Waterfall Model was selected for its methodical and linear characteristics, enabling the researcher to advance through each development phase in an organized and verifiable way [10]. This paradigm guarantees that the development process, from requirement analysis to system maintenance, remains consistent, disciplined, and purpose driven. Initially, a requirement analysis was performed to ascertain the primary issues and demands associated with liquid-level monitoring on vessels. By observing and interviewing ship engineers and crew, the researcher acquired both factual and experiential insights regarding the constraints of the current manual sounding approach. These discoveries established the foundation for delineating system specifications, including the requirements for automation, precision, and real-time monitoring capabilities. The subsequent phase, system design, converted these needs into a concrete technological concept. Hardware and software components were meticulously designed, using an ESP32 microcontroller as the primary processing unit, an ultrasonic sensor for distance measurement, and the Blynk IoT platform for real-time data presentation.

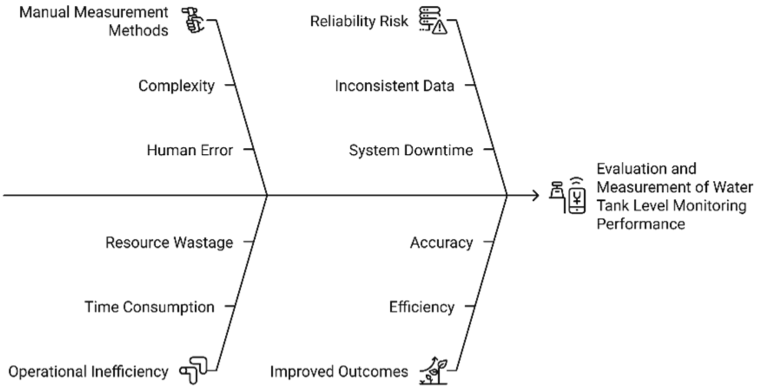

Fig. 1. Data Design of Evaluation and Measurement of Water Tank Level Monitoring Performance Framework

The design method included developing a mathematical model for volume computation and constructing a logical flowchart to illustrate the measurement algorithm. This phase was essential in connecting theoretical planning with real execution. The implementation phase entailed the construction of the prototype system and the development of firmware to facilitate sensor data gathering, signal processing, and cloud connection. The ESP32 microcontroller was designed to compute water volume using distance measurements from the ultrasonic sensor and relay the findings to the Blynk dashboard. At this point, the hardware and software subsystems were combined, verified for connectivity, and optimized to ensure synchronization between the sensor readings and the IoT interface.

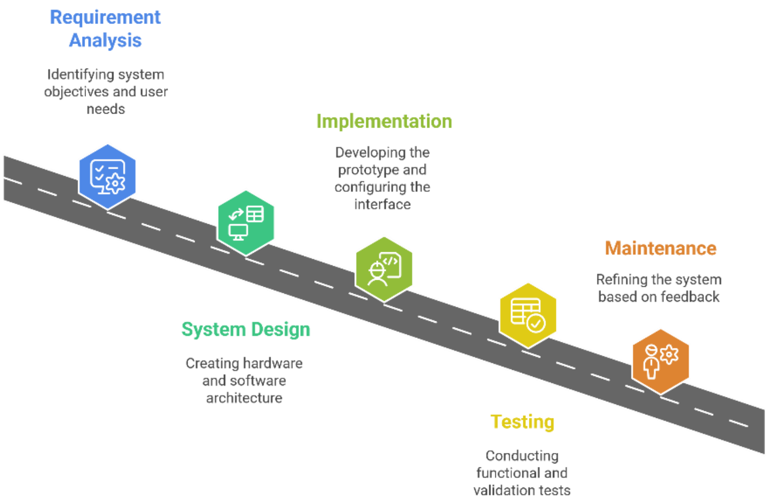

Fig. 2. IoT Based Tank Level Monitoring System Development

The testing phase was conducted to assess the functionality, correctness, and reliability of the developed system. Multiple test scenarios were conducted by juxtaposing the system's automatic readings with manual sounding results to evaluate accuracy under varying liquid-level situations. The evaluation also included measuring the system's response time, signal stability, and data consistency. Expert validation was performed to confirm that the system achieved the desired goals of feasibility and usability in marine contexts. The concluding phase of the Waterfall process, maintenance, focused on system enhancement and optimization. Following the testing outcomes and expert evaluations, modifications were implemented in the sensor calibration, code optimization, and data presentation format of the Blynk application. This iterative improvement approach guaranteed that the prototype attained operational stability and dependability prior to its ultimate deployment. This research utilized the Waterfall Model, offering a linear and regulated framework for the development of a technological innovation that is both functional and educationally significant. Each phase incrementally contributed to the subsequent one, establishing continuity among conceptual analysis, technical implementation, and system evaluation. This interpretative process resulted in a functional IoT-based monitoring prototype and illustrated how a systematic development methodology may improve technological proficiency and practical learning in maritime engineering.

The research was conducted onboard *Ship Pacific Bulk* a vessel operated by PT. Deli Pratama Angkutan Laut. The study subjects comprised 72 participants, including cadets undergoing sea practice (taruna praktek laut), the Fourth Engineer, and ship engineers (masinis) responsible for Tank Level calculations.

To determine an appropriate sample size for quantitative analysis, the Slovin formula was applied:

$$n = \frac{1 + N(e)}{2N}$$

n = number of samples,
N = total population (72), and
e = allowable error rate (0.1 or 10%).

Based on this calculation:

$$n = \frac{72}{1+72\ (0{,}1)^2} = \frac{72}{1+72\ (0{,}01)} = \frac{72}{1+0{,}72} = \frac{72}{1{,}72} = 41{,}86\ (42)$$

The study utilized a sequential exploratory mixed-methods design, commencing with qualitative data gathering to investigate field circumstances, subsequently followed by quantitative data collecting to rigorously validate the results [11]. This method was used to achieve a through comprehension of the operational reality of shipboard tank level measurement while concurrently validating the empirical reliability of the created IoT-based monitoring system. During the qualitative phase, data were gathered via in-depth interviews, direct observation, and document analysis. Semi-structured interviews were executed with the Fourth Engineer and many crew members with direct experience in conducting manual Tank Level measurements. The interviews sought to provide comprehensive insights on procedural procedures, utilized instruments, and persistent operational difficulties. Furthermore, direct observation was conducted to record real-time actions during the sounding process, encompassing the utilization of sounding tapes, sounding tables, and manual calculations with calculators. Document analysis corroborated these findings by scrutinizing operating reports, calculation records, and technical manuals pertinent to tank management methods. The interview with axial coding included diverse elements such as measuring techniques, supporting equipment, correction variables, and efficiency concerns, so facilitating a thorough comprehension of the manual approach and its constraints.

The quantitative stage was carried out to evaluate user opinions of the newly built system after the exploratory phase. Using Slovin's technique, 42 respondents were chosen from a total population of 72 maritime cadets and ship crew members to complete a likert scale questionnaire. User comments about the viability, effectiveness, and efficiency of the Blynk-based Tank Level monitoring application were evaluated using a questionnaire with 15 elements. This tool was thought to be appropriate for gathering quantitative information on user attitudes, opinions, and perceptions in a systematic way [12]. Three experts in information technology and marine engineering participated in an expert validation process to determine the generated prototype's technical integrity. The experts evaluated the system's operational suitability for maritime applications, hardware integration, sensor calibration, and interface design. Their suggestions to significant improvements, including adjustments to sensor calibration settings, improvements in data processing speed, and interface optimization inside the Blynk software. The study successfully verified that the IoT based Tank Level Monitoring System was both technically sound and operationally efficient, while also satisfying real user requirements and the practical realities of maritime settings, by combining qualitative research, quantitative validation, and expert evaluation.

The qualitative findings show that operator skills, a series of procedural stages, and a variety of manual equipment such sounding tapes, tables, and calculators continue to be crucial components of the manual Tank Level measurement procedure on board ships. Workflow that is laborious and prone to human mistake is produced by this reliance. The Fourth Engineer and the cadets were among the participants who underlined how delicate manual measurement accuracy is, as even slight instability during sounding or incorrect table reading can lead to significant differences. Inefficiency is further exacerbated by manual reporting systems, which rely on handwritten records and delayed transfer of information to the operational office or bridge, according to the analysis. Together, these results demonstrate the drawbacks of manual processes, which include operational delays, cognitive overload, and error susceptibility.

Table 1. Axial Coding (Linking causes, conditions, and consequences)

Category / Phenomenon	Causal Conditions	Context / Intervening Conditions	Action / Interaction Strategies	Consequences / Outcomes
Manual Operational Procedure	Ship routine requires manual measurement (sounding tape, manual table)	Traditional working culture, limited technology access	Follow SOP using manual tools and calculations	Time-consuming, dependent on human skill
Complexity of Manual Method	Many steps and correction factors (trim, SG)	Lack of integrated digital tools	Use multiple aids (tape, calculator, table)	High workload and potential error
Human Error and Accuracy Issues	Misreading table or incorrect SG	Fatigue, multitasking, environmental conditions (vibration, humidity)	Cross-check with others or remeasure	Decreased accuracy, inconsistent data
Operational Inefficiency	Manual reporting and repetitive process	High ship activity, limited manpower	Submit report after manual input	Delayed reporting, slow decision-making
Reliability Risk	Data inaccuracy due to manual method	Limited supervision and data traceability	Manual correction post-measurement	Reduced trust in manual data
Need for Digital Transformation	Accumulated inefficiency and inaccuracy	Awareness of IoT/automation possibilities	Adoption of digital system	Faster, more accurate, transparent process
User Readiness for Innovation	Experience-based recognition of inefficiency	Younger generation (cadets) are tech-oriented	Acceptance of IoT solution	Improved motivation and learning engagement
Expected Benefits of IoT System	Integration of sensors, microcontroller, and Blynk	Real-time monitoring environment	Automate measurement and data transfer	Efficiency, accuracy, usability, learning support

Tank level measurement processes on ships that rely on manual methods are technically difficult, highly dependent on operator competence, and prone to human error. Under the time-sensitive and high-pressure conditions of ship operations, these conditions produce operational inefficiencies and hazards to data dependability. Cadets and seasoned engineers alike are becoming more cognisant of these difficulties, which is leading to a joint preparedness for technological advancement. An approach to overcome operational issues is to use Internet of Things (IoT) technology, which includes an ESP32 microcontroller, ultrasonic sensors, and the Blynk platform, to automate, accurately, and monitor in real-time. Aligning with the goals of marine digitalisation and modern engineering education, this shift from manual to digital measurement signifies not just a technology revolution but also a paradigm shift in the way we learn.

Table 2. Conceptual Model Summary

Dimension	Description
Causal Condition	Manual complexity, frequent human error, and slow reporting motivate innovation.
Context	Shipboard environment (vibration, humidity, tight schedule) demands efficiency and accuracy.
Intervening Condition	User experience, technological familiarity, and institutional readiness influence adoption.
Action Strategy	Design and implementation of IoT-based monitoring system (ESP32 + Blynk).
Outcome	Increased operational efficiency, improved data accuracy, reduced human error, and strengthened learning integration.

These limitations, as shown by axial coding synthesis, constitute the causative factors that necessitate the digital revolution of marine surveillance systems. Given the potential advantages of an Internet of Things-based system that could carry out real-time measurements, automated volume calculations, and wireless data reporting via mobile devices, the participants clearly voiced an anticipation for automation. This kind of innovation is seen as a way to improve accuracy, efficiency, and dependability while simultaneously addressing persistent problems in shipboard operations. The shift from manual, labour-intensive processes to an IoT-driven monitoring paradigm that symbolises the larger agenda of marine digital transformation is thus the central phenomenon that emerges from this qualitative investigation. This synthesis emphasises how implementing IoT technology in tank level monitoring meets both practical and educational purposes, enhancing operational performance and acting as a teaching tool to help maritime engineering students become more technologically proficient.

The research indicates that manual tank level measurement processes on vessels are intricate, reliant on the operator, and prone to human error. These techniques, comprising several stages utilising sounding recordings, correction tables, and manual computations, reveal considerable vulnerabilities in time-sensitive and high-pressure situations, including fatigue, multitasking, and environmental instability. These elements lead to postponed reporting, diminished data precision, and general ineffectiveness in maritime operations. The results of axial coding indicate that these operational constraints necessitate digital change in maritime monitoring. The research illustrates how automation and real-time monitoring can effectively overcome the shortcomings of manual techniques, leading to greater operational efficiency, higher data reliability, reduced human error, and heightened incentive for technology-driven learning. The shift from manual to IoT-based monitoring signifies a fundamental change in maritime engineering, connecting operational excellence with competency-driven learning.

The qualitative findings are further supported by the quantitative validation results, which confirm the technical reliability and educational significance of the IoT-Based Tank Level Monitoring System. The system received an overall feasibility score of 91.6% (Very Feasible) based on evaluations from three experts in marine engineering, information technology, and educational technology. This outcome empirically validates the previously identified qualitative themes, specifically the inefficiency, complexity, and human error associated with manual measuring processes, with the pronounced user preparedness and anticipation for automation. The peak validation scores were noted for data correctness (94%) and innovation and practical value (94%), consistent with the qualitative insights that highlighted the necessity for real-time precision and technical advancement in shipboard operations. Similarly, the experts assessed the educational relevance at 92%, confirming the system's efficacy as a project-based learning instrument that integrates theory with practical application in maritime engineering education.

Table 3. Expert Validation Results of IoT-Based Tank Level Monitoring System

Aspect Evaluated	Indicators	Expert 1 (Marine Eng.)	Expert 2 (IT Expert)	Expert 3 (EdTech Expert)	Mean Score	Feasibility (%)	Category
System Design	Hardware integration, sensor selection, circuit layout	4.6	4.4	4.5	4.5	90	Very Feasible
Functionality	Real-time data transmission, stability, response time	4.7	4.5	4.6	4.6	92	Very Feasible
Data Accuracy	Precision of ultrasonic sensor readings vs. manual sounding	4.7	4.6	4.7	4.7	94	Very Feasible
Interface and Usability	Blynk app visualization, ease of navigation	4.5	4.6	4.8	4.6	92	Very Feasible
Security and Connectivity	Wi-Fi stability, data transmission, system protection	4.3	4.5	4.4	4.4	88	Feasible
Educational Relevance	Support for learning, clarity of function, project-based use	4.5	4.4	4.8	4.6	92	Very Feasible
Innovation and Practical Value	Novelty, maritime applicability, industry readiness	4.6	4.7	4.8	4.7	94	Very Feasible
Average		4.56	4.53	4.65	4.58	91.6%	Very Feasible

Although the security and connectivity aspect received a relatively lower score (88%), it remains in the "feasible" category and reflects realistic concerns about the stability of wireless communication in maritime environments—a limitation that was also identified during the field observation and interview sessions. The integration of qualitative and quantitative data illustrates methodological complementarity: the qualitative phase yielded profound contextual insights into operational challenges and user expectations, whereas the quantitative validation supplied empirical evidence of the system's functionality and applicability. The results collectively demonstrate that the IoT-based monitoring system addresses the operational inefficiencies and human error risks identified in the qualitative phase while also reflecting the overarching goals of digital transformation in maritime technology and education. The IoT-Based Tank Level Monitoring System has been validated by three experts, achieving a feasibility rate of 91.6%, indicating its potential for real-time monitoring and practical implementation on ships. The highest-rated aspects were Data Accuracy (94%) and Innovation (94%), with minor concerns about security and connectivity (88%). The system meets technical feasibility and educational usability standards, supporting its implementation in maritime engineering training and shipboard operations. The consistency of expert scores reinforces the assessment's reliability.

The study combines qualitative and quantitative findings to highlight the need for digital transformation in maritime engineering. The manual Tank Level measurement process on ships is characterized by high procedural complexity, dependence on operator skill, and susceptibility to human error. These operational inefficiencies, combined with time delays and cognitive fatigue, led to the identification of the need for an IoT-based system that could improve speed, accuracy, and reliability in real-time monitoring. The quantitative validation results confirmed these themes, with an overall feasibility score of 91.6% (Very Feasible) obtained from three domain experts. The highest ratings were observed in aspects of data accuracy, innovation, and educational relevance, reflecting the core qualitative findings regarding precision and the system's value as a pedagogical tool. The system also addresses environmental challenges, such as unstable Wi-Fi signals and vibration affecting sensor stability. The study concludes that the IoT-Based Tank Level Monitoring System not only resolves operational inefficiencies and human error but also introduces an innovative instructional medium for maritime engineering education.

2.1. Pleminary Product Design

This talk elucidates the preliminary product design for his research, namely a water level monitoring system utilizing the Internet of Things as a developmental innovation to streamline and expedite monitoring, as well as serve as an educational instrument. Consequently, the author will endeavor to communicate the findings effectively to facilitate learning and future progress, thereby enabling industrial application. The author concluded from the research findings that manual monitoring is labor-intensive and necessitates improvements in efficiency and efficacy. Consequently, an innovative solution for water level monitoring is required to expedite the procedure. Consequently, a novel solution is required to facilitate and streamline water level computations [7], [13], [14]. A concise comprehension of Android applications, along with accessible data, facilitated the creation of a product development design that significantly aids in liquid level monitoring. The subsequent outlines the process for developing a product design with the ESP32 sensor and the Blynk application. The author concluded from the research findings that manual monitoring is labor-intensive and necessitates enhancements in efficiency and efficacy. Consequently, an innovative solution for water level monitoring is required to expedite the procedure. Consequently, a novel solution is required to facilitate and streamline water level computations. A product development concept was designed to significantly aid in liquid level monitoring, based on a fundamental understanding of Android applications and available data.The subsequent approach outlines the steps for developing a product design utilizing the ESP32 sensor and the Blynk application.

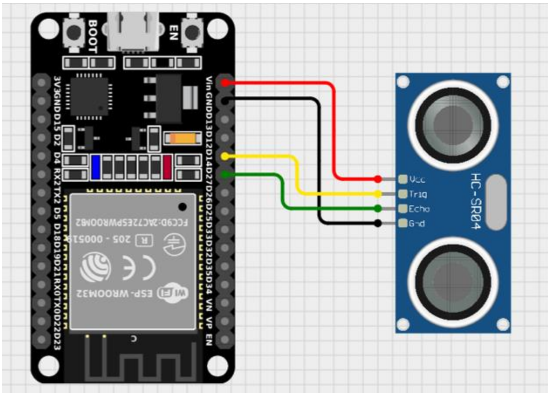

Fig. 3. Preliminary Product Design

Application design entails the systematic planning of software construction and implementation. This entails comprehensive analysis of the application's objective, user requirements, necessary functionalities, software architecture, workflow, and security measures. The design process generally encompasses problem identification, requirements analysis, design modelling, and assessment to guarantee that the application fulfills user expectations and achieves the intended objectives. Prior to developing an application, the developer must formulate a design or blueprint of the application's structure to streamline the creation of the intended application.

2.2. Developing an Application Design

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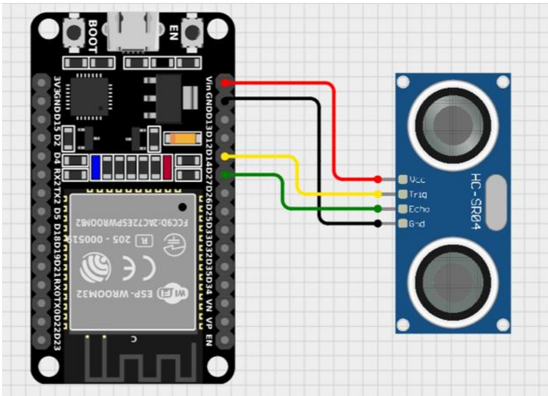

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2.3. Developing Automation

Effective water utilization and management aboard vessels is essential to avert waste and guarantee an adequate water supply. A prevalent issue is the challenge of real-time monitoring of water levels in tanks or containers, particularly in systems that depend on manual approaches. The Internet of Things (IoT) provides a more pragmatic and effective resolution to this issue. The ESP32, a microcontroller with an integrated Wi-Fi module, is extensively utilized in the construction of IoT systems. This project focuses on developing a water level monitoring system using the ESP32 microcontroller and an ultrasonic sensor. The system transmits data to an IoT platform, specifically Blynk, allowing for real-time monitoring of water levels for both domestic and commercial applications. The architecture includes the HC-SR04 sensor to measure water distance, with the ESP32 processing and sending this data to the Blynk server via Wi-Fi. Users can access an intuitive interface on the Blynk app to monitor water levels and volume, and the system can also activate a water pump or send alerts when certain levels are reached. This setup exemplifies a practical IoT solution for efficient water management without the need for direct supervision.

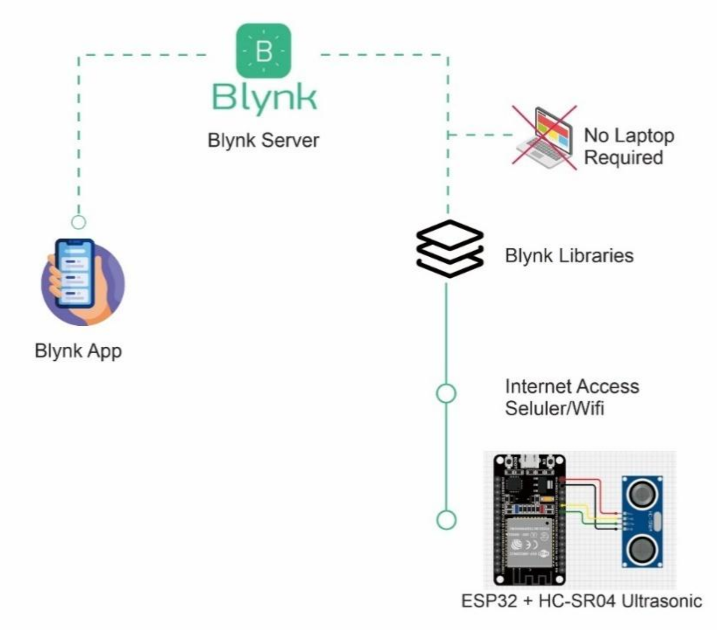

Fig. 5. IoT Project Topology

2.4. System Testing

Use either SI (MKS) or CGS as primary units. (SI units are encouraged.) English units may The testing phase was conducted to ensure the system operated according to design specifications, covering hardware and software performance:

- **Ultrasonic Sensor (HC-SR04):**
  - Tested to measure water surface distance at varying tank levels.
  - Achieved reliable accuracy within a range of **2–400 cm**.
- **Microcontroller (ESP32):**
  - Evaluated for Wi-Fi connectivity and real-time data transmission to the **Blynk** platform.
  - Successfully transmitted water-level data continuously without connection drops.
- **Blynk Software Interface:**
  - Tested for data display accuracy and synchronization.
  - Real-time readings of water height and volume were correctly visualized on label widgets.

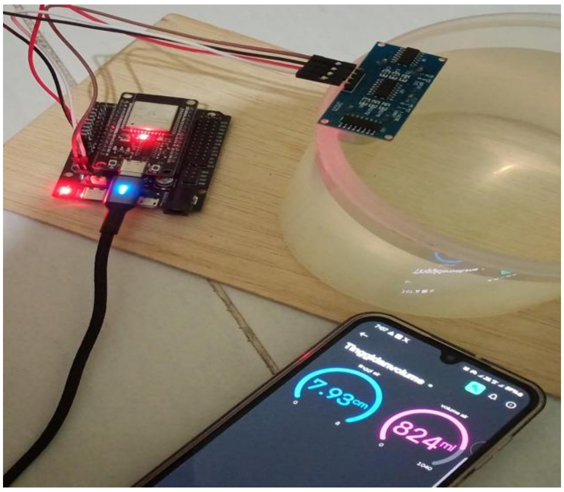

Fig. 6. IoT Response Dashboard and Blynk app data view

Several improvements were made after initial testing to enhance system performance:

- **Sensor Calibration Adjustment:** Volume calculations refined to match actual tank dimensions.
- **Constant Value Modification:** Updated base area parameter according to the cylinder area formula.
- **Program Stabilization:** Optimized delay () function to prevent duplicate or error readings.

The final implementation was carried out through the following steps:

- **Hardware Assembly:** ESP32, HC-SR04 sensor, and power circuit connected as per schematic design.
- **Program Uploading:** Firmware uploaded to ESP32 using Arduino IDE with appropriate configuration.
- **Blynk Configuration:** Datastreams (V0 for water height, V1 for water volume) configured and linked to the dashboard.
- **Field Testing:** System deployed on a **10 cm-high, 11.5 cm-diameter tank**, transmitting and monitoring data in real time through the Blynk application.

Visualizations of the implementation results can be seen on the Blynk dashboard and in the attached documentation. Overall, the system functioned as expected and can be used as an Internet of Things-based water tank monitoring solution.

3. Results and Discussion

The IoT-Based Tank Level Monitoring System's consistent high accuracy (average 98.3%) across a range of liquid levels and operational conditions is confirmed by the repeated validation trials. These findings indicate that the ESP32 microcontroller, ultrasonic sensor, and Blynk IoT platform are capable of accurately reproducing the results of manual sounding with minimal variation. The system's adaptability and technical maturity for real-time maritime monitoring applications are demonstrated by the reduction in latency from 2.5 seconds to 1.1 seconds following code optimisation. The qualitative findings that identified inefficiency, complexity, and human error as the primary challenges in manual tank measurement are further supported by this quantitative consistency. These operational constraints are directly addressed by the automation of data acquisition, volume calculation, and report visualisation, which provides quantifyable enhancements in data transparency, speed, and accuracy. Furthermore, the observed accuracy stability is consistent with the user perceptions collected through questionnaires (average scores 3.6–4.5), suggesting that the application that has been developed satisfies the practicality and reliability expectations of users in the context of daily ship operations.

In comparison, these results build upon previous researchm including that conducted by [6], [13] that established the validity of IoT liquid-level monitoring systems in static laboratory environments. In contrast to those studies, the present research validates system performance in a genuine maritime environment, taking into consideration dynamic variables such as humidity, vibration, and limited connectivity. The high feasibility ratings from three domain experts (average 91.6%) further substantiate that the system is both technically sound and pedagogically viable, supporting not only shipboard operations but also vocational education and training objectives.

Table 4. System Validation Test Results under Varying Water Levels

Trial No.	Water Level (cm)	Manual Reading (cm³)	IoT System Reading (cm³)	Accuracy (%)	Latency (sec)	Remarks
1	10	9.8	9.7	99.0	2.5	Initial test; minor delay in Blynk synchronization
2	20	19.9	19.5	98.0	2.2	Stable readings; small deviation due to sensor delay
3	30	29.8	29.1	97.7	1.8	Improved accuracy after calibration
4	40	39.9	39.2	98.2	1.3	Consistent performance under vibration conditions
5	40 (repeat)	39.9	39.4	98.7	1.1	Stable data; minimal latency post-optimization

Trial No.	Water Level (cm)	Manual Reading (cm^3)	IoT System Reading (cm^3)	Accuracy (%)	Latency (sec)	Remarks
Mean	—	—	—	98.3	1.78	Reliable and consistent system output

The findings, which combine both types of evidence, show that there has been a definite change from manual to digital monitoring in marine practice. The qualitative stage identified systemic inefficiencies, operator dependency, and the necessity for modernisation, while the quantitative substantiation provided empirical evidence of enhanced precision and system performance. This triangulation enhances the research's overall credibility by demonstrating that the proposed IoT-based system effectively connects educational enhancement, technological innovation, and operational reliability. This system's digital transformation has a practical impact on the following: increased efficiency (reduced workload and reporting time), enhanced safety (minimised human error and data misreporting), and expanded learning impact (hands-on IoT skill development for recruits). Collectively, these findings confirm that the prototype that has been developed is not merely an incremental enhancement; rather, it is a strategic technological advancement that is consistent with the global agenda of competency-based maritime education and smart maritime operations.

4. Conclusion

This study effectively developed, designed, and validated an IoT-based tank level monitoring system that was specifically designed for maritime engineering applications. The results indicate that the incorporation of the ESP32 microcontroller, ultrasonic sensors, and the Blynk platform successfully automates tank level measuring and reporting, supplanting the labour-intensive manual methods formerly employed aboard ships. The system achieved a steady average accuracy of 98.3% across various trials at different water levels, demonstrating robust real-time performance and a reduction in latency from 2.5 seconds to 1.1 seconds after calibration and firmware optimisation. The results, along with favourable user input (mean Likert scores of 3.6–4.5) and expert validation (91.6% feasibility), affirm that the created system is precise, reliable, and exceptionally useable in operational maritime settings. The Waterfall development paradigm offered a systematic and rigorous framework that guaranteed logical progression from requirement analysis to validation. Each phase problem identification, system design, implementation, testing, and maintenance was conducted consecutively, facilitating ongoing verification and enhancement of both hardware and software elements. This systematic approach enhanced the system's stability, reduced development errors, and streamlined the integration of conceptual design with technical implementation. The methodical structure of the Waterfall approach facilitated traceability, allowing for adjustments informed by expert comments and empirical testing results.

The research findings confirm that the developed IoT-based monitoring system is both technically viable and revolutionary in operational and educational contexts. It improves efficiency, precision, and data transparency while advancing the digitalisation initiative in marine education and operations. Future endeavours may concentrate on enhancing connection characteristics, augmenting data security, and incorporating machine learning for predictive maintenance, so reinforcing its significance in smart maritime technology ecosystems. The implementation of IoT-based monitoring systems in maritime operations presents a viable solution, exhibiting proven accuracy and stability. These technologies provide real-time data visualisation, expedited decision-making, improved operational safety, and diminished danger of human error. Broader implementation can enhance the efficiency of fuel, ballast, and freshwater management across diverse vessel categories. Maritime education and training institutes ought to incorporate these systems into their curricula, therefore augmenting students' comprehension of instrumentation, automation, and digital data processing. Future development must prioritise data security, networking, and predictive analytics, incorporating encryption protocols and cloud-based backup solutions. Machine learning techniques are advocated for predictive maintenance and anomaly detection, enhancing system adaptability to various shipboard conditions. Regulatory authorities and maritime academies ought to collaborate to formulate rules and standards for the implementation of IoT-based monitoring systems in shipboard operations. Collaboration between academia and industry may stimulate innovation and ensure IoT technologies correspond with practical realities and developing trends in maritime digitalisation.

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Author Contribution

Mohammad Sapta Heriyawan designed the study, developed the prototype, and drafted the manuscript. **Tony Santiko** contributed to the system analysis and validation process. Erli Pujianto supported the hardware design and calibration**. Andang Febriantoro** performed software integration and data analysis. **Agus Adi Wibowo** reviewed and refined the manuscript, ensuring technical and academic quality. All authors read and approved the final version of the manuscript.

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Conflict of Interest The authors declare no conflict of interest. All research, data collection, and analysis were conducted independently, without any commercial or financial relationships that could influence the results or interpretation of this study.

Data and Software Availability Statements

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.The developed IoT application code (ESP32 firmware and Blynk configuration files) supporting the findings of this study is available at the following repository: GitHub Repository: https://github.com/msh-heriyawan/IoT-Tank-Level-Monitoring.

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