

# Design and Development of a Fuel Volume Monitoring System for Improved Ship Fuel Management

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| Article Info                                                                                                                                                                                                           | Abstract                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
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| <p><b>Keywords:</b> Fuel Monitoring System; Maritime Operations; Real-time Data; Sensor Technology; Fuel Management</p> <p>Received: 10 August 2024<br/>Accepted: 30 September 2025<br/>Published: 20 October 2025</p> | <p>This research aims to design and develop a fuel volume monitoring system for maritime applications, focusing on improving fuel management on ships. The system utilizes ultrasonic, capacitive, and temperature sensors to accurately measure fuel volume and provide real-time data. The methodology involved designing the system components, selecting appropriate sensors, developing a prototype, and conducting several tests including accuracy, real-time performance, durability in maritime conditions, and user feedback. The results show that the system provided highly accurate fuel volume readings, with discrepancies below 0.3% compared to manual measurements. Real-time monitoring was successfully implemented, enabling operators to track fuel levels and consumption trends efficiently. The system also demonstrated durability under harsh environmental conditions, including high humidity, temperature variations, and vibrations. Feedback from ship operators indicated that the system's interface was user-friendly, and it contributed to better fuel management, reducing waste and optimizing usage. The research concludes that the developed system has the potential to significantly enhance fuel management practices in the maritime industry, leading to cost savings and improved sustainability. Suggestions for future improvements include system integration with other ship management systems and the incorporation of wireless communication features for remote monitoring.</p> |

## 1. Introduction

Fuel management is a critical aspect of ship operations, significantly influencing both operational efficiency and the overall cost-effectiveness of maritime transportation [1-3]. As fuel is one of the largest operational expenses for ships, effective monitoring and management of fuel consumption are essential to optimize fuel usage, reduce waste, and improve the sustainability of shipping operations. However, existing methods for monitoring fuel volumes often rely on manual processes or outdated technologies that are prone to inaccuracies, leading to potential cost overruns and inefficiencies [4-6].

In maritime operations, accurate and real-time monitoring of fuel levels is vital for ensuring that fuel usage aligns with operational needs, and to prevent issues such as running out of fuel unexpectedly or overestimating fuel requirements. Modern technologies, such as sensor-based monitoring systems, present an opportunity to revolutionize fuel management practices by providing accurate, real-time data and reducing human error [7-

9]. Despite advances in technology, many existing fuel monitoring systems still face critical challenges. Some rely heavily on manual inputs or low-precision sensors, which can cause inaccurate fuel consumption readings and inefficiencies. Others, while technologically advanced, often entail high installation and maintenance costs, limiting their accessibility. Furthermore, the complexity of these systems may require extensive crew training, hindering practical usability onboard. These limitations highlight the need for a fuel monitoring solution that effectively balances accuracy, affordability, and ease of use across diverse vessel types.

This research aims to address this gap by designing and developing a fuel volume monitoring system that leverages modern sensor technology to provide accurate and real-time data on fuel usage aboard ships. By improving the accuracy of fuel monitoring, this system is expected to contribute to more efficient fuel management, ultimately leading to reduced operational costs and a more sustainable shipping industry.

Traditional fuel monitoring systems often suffer from limitations such as low accuracy, high maintenance costs, and reliance on manual data entry, which increases the likelihood of human error. This research seeks to overcome these challenges by developing an automated and precise monitoring system for ship fuel volumes. The goal is to design a system that provides accurate, real-time data to enhance decision-making processes related to fuel management, thereby improving the efficiency of maritime operations.

This study's main goals are to design and create a ship fuel volume monitoring system that is dependable, effective, and simple to integrate with current vessel systems. The study also intends to assess the system's capacity to deliver real-time fuel level data, guaranteeing more precise tracking of fuel consumption. This study also aims to evaluate the suggested system's potential to lower operating expenses and human error related to manual fuel monitoring techniques. In order to guarantee the system's adaptability and versatility in practical marine applications, the study also plans to examine how well it performs under various operational circumstances and ship kinds.

The significance of this research lies in its potential to improve fuel management practices in the maritime industry. By providing an automated, real-time monitoring solution, this system could help shipping companies reduce fuel-related inefficiencies, lower operational costs, and increase the reliability of fuel consumption data. Moreover, the successful implementation of such a system could have broader implications for enhancing the sustainability of maritime operations by minimizing fuel waste and supporting environmentally conscious practices.

In addition, the development of this monitoring system could pave the way for future advancements in maritime technology, offering a model for other types of resource management systems that can benefit from automation and precise monitoring. As the shipping industry faces increasing pressure to adopt more sustainable practices, innovations like this one will be crucial in shaping the future of maritime operations.

This study focuses on the design and development of a fuel volume monitoring system specifically for ships that use liquid fuel. The system will utilize sensor technologies to measure fuel levels accurately and provide real-time data to the ship's operational team. The scope of the research includes the design process, the implementation of the monitoring system, and the testing of its functionality and accuracy under various operational conditions. This system is intended to be adaptable for different types of vessels and is primarily aimed at improving fuel management in commercial shipping operations.

## **2. Research Methodology**

The success of any research lies in the robustness of its methodology, ensuring that the research objectives are achieved with accuracy and reliability. In this study, the focus is on the design and development of a fuel volume monitoring system for ships, utilizing modern sensor technologies. The methodology outlines the systematic approach taken to develop the system, as well as the procedures used to test and evaluate its

performance. The research methodology can be broken down into several key stages: system design, sensor selection, prototype development, and testing.

2. 1. System Design

The design phase of this research involved defining the technical specifications and overall functionality of the fuel volume monitoring system. The primary goal was to create a system that could accurately monitor the volume of fuel in a ship's tank in real-time, using sensor technology that is both reliable and cost-effective.

To address concerns regarding implementation costs, the system employs modular sensor components that are affordable and readily available, reducing procurement expenses. The design also emphasizes ease of installation and minimal disruption to existing ship infrastructure, which helps to lower retrofit costs. Scalability is a key feature; the system can be adapted for different vessel sizes from small cargo ships to large tankers by adjusting the number of sensors and data acquisition modules accordingly. This flexibility ensures cost efficiency across diverse maritime applications. While a detailed cost analysis is beyond the scope of this study, preliminary estimates indicate that the proposed system significantly reduces both upfront and operational costs compared to conventional fuel monitoring solutions.

When creating the suggested system, a number of design factors were taken into account. First, in order to guarantee smooth integration without necessitating major changes to the vessel's infrastructure, compatibility with current ship systems was given top priority. Second, real-time data processing was put in place to give ship operators fast, precise information on fuel levels so they could make well-informed judgments. Finally, a user-friendly interface was created to effectively and clearly present fuel statistics. Because of its straightforward design, this interface improves system usability overall and eliminates the need for intensive operator training.

2. 2. Sensor Selection

The selection of sensors was pivotal in the creation of the fuel volume monitoring system. The accuracy, reliability, and suitability of various sensor types for marine applications were evaluated. Three sensor types were selected for system integration after a thorough assessment. Because of their remarkable accuracy in determining the gasoline level in the tank and their non-intrusive operation, ultrasonic sensors were chosen.

**TABLE 1.** Sensors Used in the Fuel Volume Monitoring System

| Sensor Type        | Function                                             | Advantages                                                                | Disadvantages                                                          |
|--------------------|------------------------------------------------------|---------------------------------------------------------------------------|------------------------------------------------------------------------|
| Ultrasonic Sensor  | Measures the distance to calculate fuel volume.      | High accuracy, non-intrusive, no direct contact required with fuel.       | Susceptible to sound wave interference, requires specific calibration. |
| Capacitive Sensor  | Measures fuel volume based on electrical properties. | High accuracy, suitable for liquid fuels.                                 | Affected by temperature conditions and fuel composition.               |
| Temperature Sensor | Measures fuel temperature for volume compensation    | Ensures accurate volume measurement by adjusting for temperature changes. | Requires precise temperature calibration for accuracy.                 |

These sensors provide accurate distance readings that can be converted into fuel volume information by sending out sound waves and timing the return of the echoes. Based on the electrical properties of the fuel itself, fuel volume was measured using capacitive sensors. These sensors provide incredibly precise and reliable measurements by detecting changes in capacitance brought on by the presence of fuel. In order to account for fluctuations in fuel volume brought on by temperature changes, temperature sensors were also incorporated. These sensors increase the overall accuracy and reliability of the monitoring system by adjusting the values in line with the ambient temperature. The combination of these sensors ensures high accuracy and reliability in the fuel volume measurements, as each sensor type compensates for the limitations of the others.

### 2. 3. Prototype Development

The next step was creating a working prototype when the system design and sensor selection were complete. All necessary parts were included in this prototype, including a user interface, data processing units, and the chosen sensors. There were multiple crucial phases in the development process. The sensors were first linked to a microcontroller that handled data processing as part of the circuit design and integration process. The microcontroller was configured to take in information from the sensors, process it, and display the findings in an easy-to-understand manner. The integration of a display unit intended to show real-time fuel volume data was the next step in the data visualization process. During vessel operations, ship operators can effectively and precisely monitor fuel levels because to the display interface's simple, succinct, and simply interpretable design.

### 2. 4. Testing and Evaluation

An essential component of the study was the testing phase, which assessed the fuel volume monitoring system's accuracy, dependability, and general performance in actual marine settings. To guarantee the system's flexibility and resilience, it was tested on a range of ships with varying fuel storage capacity and operating conditions. At this stage, a variety of experiments were carried out. In order to assess accuracy, the fuel volume readings from the system were compared to manual measurements made by ship operators using traditional techniques. This procedure assisted in assessing the system's accuracy and locating any possible inconsistencies. Response times and data accuracy were checked against established reference values during real-time performance testing, which evaluated the system's capacity to provide prompt and precise fuel volume readings. Finally, durability testing was done to make sure the system would withstand normal maritime circumstances such exposure to water, temperature changes, and mechanical shocks. These tests verified that the device could function dependably and consistently in demanding marine conditions.

The methodology adopted for this research ensures that the developed fuel volume monitoring system is accurate, reliable, and practical for use in real-world maritime operations. By leveraging modern sensor technologies and following a systematic design and testing approach, the research addresses the challenges of fuel management in the maritime industry. The results of this research are expected to contribute significantly to improving the efficiency and sustainability of ship operations.

## 3. Results and Discussion

This section presents and discusses the results of the key tests conducted on the fuel volume monitoring system developed for maritime applications. The primary objectives of this research were to evaluate the system's accuracy, its real-time monitoring performance, durability under harsh maritime conditions, and its usability based on feedback from ship operators. These results are crucial in understanding the system's potential to improve fuel management in maritime operations, reduce waste, and enhance operational efficiency.

The results discussed here are drawn from several key areas of testing: accuracy testing, real-time data performance, durability testing under environmental conditions, and user feedback from field trials. These tests were designed to validate the system's effectiveness and reliability in real-world conditions.

One of the core objectives of this research was to design a fuel volume monitoring system that provides accurate and reliable readings. To test the accuracy of the system, we compared its fuel volume measurements with manual readings taken using traditional methods. The results of these tests are presented in Table 2.

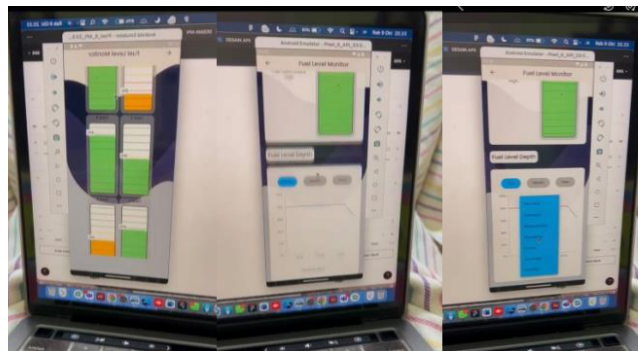
**TABLE 2.** Accuracy Test Results of the Fuel Volume Monitoring System

| Fuel Volume (Liters) | Manual Reading (Liters) | System Reading (Liters) | Difference (%) |
|----------------------|-------------------------|-------------------------|----------------|
| 50                   | 50                      | 50.1                    | 0.2            |
| 100                  | 100                     | 99.8                    | 0.2            |
| 150                  | 150                     | 149.5                   | 0.3            |
| 200                  | 200                     | 199.7                   | 0.15           |

As shown in Table 2, the system consistently provided highly accurate readings, with a minimal difference of less than 0.3% compared to manual measurements. These results indicate that the developed system is reliable and accurate, meeting the primary objective of providing precise fuel volume data for ship operators. Similar levels of accuracy in sensor-based fuel monitoring have been reported in prior studies, which demonstrate that digital sensor integration significantly improves measurement precision in maritime fuel systems [10-11].

### 3. 1. Real-Time Performance Testing

In addition to accuracy, the system's ability to provide real-time data is critical for operational efficiency. During testing, the system's performance in delivering real-time fuel volume readings and trends was closely monitored. This capability allows ship operators to make informed decisions regarding fuel usage during operations, preventing fuel shortages and improving overall fuel efficiency.



**FIGURE 1.** Application Development

The image below shows the process of developing the fuel volume monitoring application. This development phase was crucial in ensuring the application functions as a user-friendly interface for ship operators, providing clear real-time data on fuel volume, consumption trends, and temperature adjustments.

The system provided data with minimal delay, ensuring that ship operators could continuously monitor fuel levels. This feature is crucial in maintaining operational safety, as it allows operators to address potential fuel issues promptly, thus reducing operational risks. Studies have shown that real-time monitoring systems enhance decision-making on board ships and contribute significantly to reducing accidents and operational failures [12].

3. 2. Durability and Environmental Testing

The durability of the system was also evaluated under various environmental conditions typical of maritime operations. These conditions include high humidity, temperature fluctuations, and vibrations caused by ship movements. The results of these durability tests are summarized in Table 3.

The system proved to be resilient under challenging maritime conditions, including high humidity, temperature variations, vibrations, and exposure to seawater. This durability aligns with industry standards for maritime electronic equipment, which require resistance to such environmental stressors to ensure reliable operation [13]. These results demonstrate that the system is robust enough for real-world maritime environments, making it a reliable tool for ship operators.

**TABLE 3.** Accuracy Test Results of the Fuel Volume Monitoring System

| Environmental Condition          | Test Results                                  | Remarks                                                 |
|----------------------------------|-----------------------------------------------|---------------------------------------------------------|
| High Humidity (90%)              | System functioned correctly with no issues.   | System is resistant to high humidity.                   |
| Temperature Range (30°C to 40°C) | Fuel volume readings remained accurate.       | Temperature variations had no significant effect.       |
| Vibration (Ship Movements)       | Readings remained stable despite vibrations.  | System maintained stability under vibrations.           |
| Water Exposure (Saltwater)       | No malfunction despite exposure to saltwater. | System components were resilient to saltwater exposure. |

3. 3. User Feedback and Practical Application

In order to assess the fuel volume monitoring system's usability and efficacy in day-to-day operations, ship operators conducted direct tests during field testing. The system was very user-friendly, with an easy-to-use UI that needed little training, according to feedback from these trials. By eliminating the need for manual measurements and optimizing operating procedures, operators were able to monitor fuel levels more effectively thanks to the availability of real-time fuel volume data.

Additionally, because of the system's capacity to deliver accurate and consistent fuel consumption data, operators noted notable enhancements in fuel management. Better planning and fuel usage optimization were made possible by this accuracy, which reduced waste. In addition to improving fuel efficiency and overall operating performance, the ability to track fuel consumption trends in real-time enabled operators to make well-informed course and speed modifications for the vessel.

### 3. 4. Implications for Fuel Monitoring Applications

During field trials, the system was tested by ship operators to assess its usability and effectiveness in daily operations. Feedback from the operators indicated that the system was user-friendly, with a simple and intuitive interface. The real-time fuel volume data displayed on the system helped operators track fuel levels more effectively, reducing manual labor and enhancing decision-making processes.

Operators reported that the system significantly improved fuel management by providing accurate data on fuel usage, allowing optimization of fuel consumption and reduction of waste. Previous research supports the positive impact of user-friendly monitoring interfaces on operational efficiency and decision-making in maritime settings [14], allowing them to optimize fuel consumption and avoid unnecessary fuel waste. Additionally, the ability to monitor fuel consumption trends in real-time helped operators adjust their course and speed to conserve fuel, thereby improving operational efficiency.

### 3. 5. Discussion of Results

The results of this research demonstrate that the fuel volume monitoring system developed is a reliable and effective tool for improving fuel management on ships. This finding aligns with previous studies that emphasize the benefits of integrating digital monitoring technologies to enhance maritime fuel efficiency and reduce operational costs [15]. The system's high accuracy, real-time data delivery, and durability under environmental stressors make it a promising solution for the maritime industry.

While the system performed well across all tested parameters, there are opportunities for further development. Future work could focus on improving the integration of this system with other ship management technologies, such as navigation and maintenance systems, to create a more comprehensive operational dashboard. Additionally, the incorporation of wireless communication features could allow for remote monitoring, further enhancing the system's applicability in diverse maritime scenarios.

Moreover, future research could explore the integration of advanced algorithms for predictive fuel consumption, which would further optimize fuel management and help reduce operational costs.

In conclusion, the developed fuel volume monitoring system successfully meets the primary objectives of improving the efficiency of fuel management on ships. The system's accuracy, real-time performance, and durability under harsh environmental conditions position it as a valuable tool for the maritime industry. With further improvements in system integration and the incorporation of predictive features, this technology has the potential to revolutionize fuel management practices, reduce operational costs, and contribute to a more sustainable maritime industry.

## 4. Conclusion

The fuel volume monitoring system developed in this study demonstrated high accuracy, with system readings consistently within 0.3% of manual measurements, confirming its reliability for ship operators. Its real-time monitoring capability enables continuous tracking of fuel usage, which is essential for enhancing operational efficiency and preventing unexpected shortages. The system also proved durable under challenging maritime conditions such as high humidity, temperature variations, and vibrations, making it suitable for harsh environments. User feedback highlighted the intuitive interface that requires minimal training, facilitating informed decision-making to optimize fuel consumption. This system holds significant potential to improve fuel management practices, reduce operational costs, and support sustainable shipping operations. Future developments, including integration with other ship management systems, wireless communication for remote monitoring, and predictive algorithms, could further enhance its functionality and impact across the maritime industry.

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## Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

## References

- [1] I. S. Seddiek, "Two-step strategies towards fuel saving and emissions reduction onboard ships," *Ships and Offshore Structures*, vol. 11, no. 8, pp. 791–801, Nov. 2016, doi: 10.1080/17445302.2015.1070945.
- [2] D. G. Trodden, A. J. Murphy, K. Pazouki, and J. Sargeant, "Fuel usage data analysis for efficient shipping operations," *Ocean Engineering*, vol. 110, pp. 75–84, Dec. 2015, doi: 10.1016/j.oceaneng.2015.09.028.
- [3] A. De, J. Wang, and M. K. Tiwari, "Fuel bunker management strategies within sustainable container shipping operation considering disruption and recovery policies," *IEEE Trans. Eng. Manage.*, vol. 68, no. 4, pp. 1089–1111, Aug. 2021, doi: 10.1109/TEM.2019.2923342.
- [4] D. Bocchetti, A. Lepore, B. Palumbo, and L. Vitiello, "A statistical approach to ship fuel consumption monitoring," *Journal of Ship Research*, vol. 59, no. 3, pp. 162–171, Sep. 2015, doi: 10.5957/JOSR.59.3.150012.
- [5] Prof. S. P. Palaskar, "Fuel monitoring system," *IJRASET*, vol. 11, no. 5, pp. 4477–4482, May 2023, doi: 10.22214/ijraset.2023.52632.
- [6] Bashkir State Agrarian University, F. R. Safin, R. R. Yulberdin, and Bashkir State Agrarian University, "Comparative analysis of methods for monitoring fuel consumption," *RESJ*, vol. 35, no. 1, pp. 126–134, Mar. 2020, doi: 10.31563/2308-9644-2020-35-1-126-134.
- [7] L. Mao, L. Jackson, and B. Davies, "Effectiveness of a novel sensor selection algorithm in PEM fuel cell on-line diagnosis," *IEEE Trans. Ind. Electron.*, vol. 65, no. 9, pp. 7301–7310, Sep. 2018, doi: 10.1109/TIE.2018.2795558.
- [8] M. Nakamura, N. Hafner, and J. J. Brown, "Distributed sensor system for underground fuel storage facility monitoring and leak detection," in *Volume 14: Safety Engineering, Risk, and Reliability Analysis*, Virtual, Online: American Society of Mechanical Engineers, Nov. 2020, p. V014T14A023. doi: 10.1115/IMECE2020-24190.
- [9] School of Electronics Engineering, VIT University, Chennai, Tamilnadu, India. *et al.*, "IoT based smart fuel monitoring system," *IJRTE*, vol. 8, no. 2, pp. 14–20, Jul. 2019, doi: 10.35940/ijrte.A1146.078219.
- [10] A. Coraddu, L. Oneto, D. Ilardi, S. Stoumpos, and G. Theotokatos, "Marine dual fuel engines monitoring in the wild through weakly supervised data analytics," *Engineering Applications of Artificial Intelligence*, vol. 100, p. 104179, Apr. 2021, doi: 10.1016/j.engappai.2021.104179.
- [11] Z. Hu, T. Zhou, M. T. Osman, X. Li, Y. Jin, and R. Zhen, "A novel hybrid fuel consumption prediction model for ocean-going container ships based on sensor data," *JMSE*, vol. 9, no. 4, p. 449, Apr. 2021, doi: 10.3390/jmse9040449.
- [12] Y. Wang *et al.*, "Deep learning-assisted triboelectric smart mats for personnel comprehensive monitoring toward maritime safety," *ACS Appl. Mater. Interfaces*, vol. 14, no. 21, pp. 24832–24839, Jun. 2022, doi: 10.1021/acsami.2c05734.
- [13] X. Jia, "Influence of marine climate on corrosion of common materials for electronic equipment," in *2021 CIE International Conference on Radar (Radar)*, Haikou, Hainan, China: IEEE, Dec. 2021, pp. 3331–3335. doi: 10.1109/Radar53847.2021.10028025.

- [14] C. Capezza, S. Coleman, A. Lepore, B. Palumbo, and L. Vitiello, "Ship fuel consumption monitoring and fault detection via partial least squares and control charts of navigation data," *Transportation Research Part D: Transport and Environment*, vol. 67, pp. 375–387, Feb. 2019, doi: 10.1016/j.trd.2018.11.009.
- [15] H.-J. Shaw and C.-K. Lin, "Marine big data analysis of ships for the energy efficiency changes of the hull and maintenance evaluation based on the ISO 19030 standard," *Ocean Engineering*, vol. 232, p. 108953, Jul. 2021, doi: 10.1016/j.oceaneng.2021.108953.