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Prototype of Ship Fuel Monitoring System Using NodeMCU

Anggara Trisna Nugraha[1], Chusnia Febrianti[2]
[1,2] Marine Electrical Engineering, Shipbuilding Institute of Polytechnic Surabaya
[1] anggaranugraha@ppns.ac.id , [2] chusniafebrianti@student.ppns.ac.id

Abstract

The prototype ship fuel monitoring system is designed to enhance the efficiency and effectiveness of fuel management in container shipping operations. Fuel costs account for approximately 70% of a ship's operating expenses, making it imperative for shipping companies to implement strict fuel usage monitoring to minimize waste and optimize consumption. The absence of an automated fuel consumption monitoring system often results in management inefficiencies, such as inaccurate tracking and unplanned corrective actions to address fuel discrepancies. This research introduces a solution by employing ultrasonic level sensors integrated with an Outseal PLC, which gathers real-time fuel level data. The data is transmitted to a web server via NodeMCU ESP32, enabling continuous access and monitoring for stakeholders. Calibration tests revealed that the ultrasonic sensors achieve an average error rate of 0.037%, 0.02%, 0.043%, and 0.047%, showcasing their high accuracy and reliability. The findings confirm that the proposed system effectively facilitates real-time monitoring of fuel usage, offering enhanced operational transparency, reduced waste, and optimized fuel management for maritime applications. This research contributes significantly to the field of engineering and maritime operations by providing a robust and scalable system for fuel monitoring based on NodeMCU.

Keywords: Monitoring, Oil fuel, NodeMCU, Webserver.

1. Introduction

Indonesia, as a maritime nation, plays a vital role in global and regional shipping, necessitating the growth and development of its maritime fleet to support marine exploration and bolster the economy through efficient waterborne trade routes (B. Kresna et al., 2021). One key area of focus is foreign trade, particularly through containerized transportation systems, which form the backbone of exporting and importing goods. The container system integrates multiple modes of transportation with standardized units, simplifying loading and unloading processes to enhance operational effectiveness and efficiency (L. D. Siahaan, S. Wunas, & M. Y. Jinca, 2013) (Nugraha, Ramadhan, & Shiddiq, 2022).

Fuel consumption is a critical operational aspect for container ships, accounting for approximately 70% of their operating costs (Nafi, Wahyudi, & Fachruddin, 2020) . Consequently, advancements in technology within the shipping industry are paramount to improving fuel management. Modern technological innovations extend to the electrical systems in the ship's engine room, where a Central Control Room (CCR) monitors the functionality of all vital components (Baharuddin, 2016) (Zakariz, Nugraha, & Phasinam, 2022) .

However, current monitoring practices often fail to implement automated solutions for tracking fuel consumption. This gap leads to inefficiencies in fuel management, such as undetected discrepancies between fuel usage and voyage distances, and even incidents of fraud by ship crews (Ardiansyah, 2020) (Karina, Ginting, & Sanjaya, 2017). Manual monitoring systems provide limited and non-real-time information, making it difficult for central management to respond proactively to issues. Consequently, there is a growing need for an automated and robust monitoring system to mitigate fuel wastage and optimize operational costs.

Recent studies on automatic fuel consumption monitoring systems demonstrate that automation can enhance transparency across all stakeholders, from ship crews to central management (Realdo, Meredita, Nugraha, & Misra, 2021)(Henri, 2018). These systems not only improve operational efficiency but also enable management to take timely corrective actions and develop strategies to minimize wasteful practices.

This research introduces an innovative monitoring system for tracking fuel consumption using ultrasonic sensors integrated with an Outseal PLC in real-time (C. Proposal et al., 2021). The proposed system aims to prevent fraud and inefficiencies in fuel usage while providing real-time data access for effective decision-

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making. This solution represents a significant step forward in the engineering and maritime sectors, addressing longstanding challenges in fuel monitoring and consumption management.

2. Material and methods

2.1. Material

A. Ship's fuel lod type

Fuel is a substance capable of rapid combustion in the presence of oxygen, resulting in the release of heat and energy essential for various mechanical and industrial applications. In the context of maritime operations, the fuel commonly utilized in the MV Meratus Benoa engine is Marine Diesel Oil (MDO). Marine Diesel Oil, frequently referred to as diesel oil, is specifically designed for combustion engines employing medium-speed compression ignition systems (operating at less than 1000 rpm). Additionally, it serves as a direct energy source for various industrial processes (Saputra, Kabib, & Nugraha, 2019) .

From a chemical perspective, MDO predominantly consists of paraffinic hydrocarbons with carbon chain lengths ranging from 10 to 22. This composition is carefully processed from diverse petroleum-derived components to meet the stringent specifications required for medium-speed diesel engines. These specifications include critical parameters such as density, kinematic viscosity, pour point, sulfur content, ash content, Micro Carbon Residue (MCR), flash point, and color (Utomo, Prasetyo, & Nugraha, 2021) .

In maritime engineering, the selection of fuel type significantly influences engine efficiency, operational costs, and environmental impact. The combustion properties of MDO, combined with its tailored processing, make it an optimal choice for the propulsion of medium-speed diesel engines commonly found in container ships. This underscores the importance of monitoring fuel quality and consumption through innovative engineering solutions, such as the Prototype Ship Fuel Monitoring System Using Outseal PLC and NodeMCU, to ensure operational efficiency and sustainability.

Through advanced fuel monitoring and management systems, shipping companies can not only reduce operational expenses but also mitigate environmental impacts, adhering to global regulations and enhancing the overall sustainability of maritime operations.

B. DC mini water pump

A pump is an essential mechanical device designed to transfer liquids from one location to another by increasing the pressure of the fluid (Nugraha & Safitri, 2021). This pressure increase is critical for overcoming various flow obstacles, such as pressure differences, elevation changes, or frictional resistance within the fluid's pathway. In principle, pumps function by converting the mechanical energy generated by a motor into fluid kinetic and pressure energy. The energy imparted to the fluid enables it to overcome resistances and flow through the designated channels or pipelines (Tiwana, Adianto, & Nugraha, 2021).

In the context of engineering systems, pumps play a crucial role in numerous applications, including maritime engineering. For instance, in fuel management systems aboard ships, pumps are integral for maintaining efficient fuel transfer and distribution. Advanced fuel monitoring systems, like those employing Outseal PLC and NodeMCU, rely on the precise operation of pumps to facilitate accurate fuel level measurements and data collection. This ensures that the system can mitigate potential inefficiencies caused by uneven fuel flow or frictional losses in pipelines, contributing to the overall effectiveness of the monitoring system.

Moreover, the integration of pumps with automated control systems highlights the importance of their design and performance in technical fields. Modern pumps must be optimized to handle varying operational conditions, such as high pressures, flow rates, and resistance levels, while maintaining energy efficiency. The synergy between pump technology and sensor-based monitoring solutions like the ultrasonic sensors in this study ensures reliable and accurate fuel management, a critical requirement in maritime operations.

By addressing these operational challenges, this research underscores the pivotal role of pumps in engineering solutions, particularly in automated fuel monitoring systems for the shipping industry. Such advancements align with the objectives of improving system reliability, reducing waste, and enhancing operational efficiency, thereby meeting the stringent standards expected in technical research and engineering applications.

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C. Ultrasonic sensor

Ultrasonic sensors play a pivotal role in modern engineering applications, including ship fuel monitoring systems, by converting physical quantities of sound into electrical signals and vice versa. These sensors operate on a straightforward principle: they emit sound waves and measure the time it takes for the reflected waves to return, thereby determining the presence or distance of an object with a specific frequency. This capability makes them highly suitable for accurate and non-intrusive measurement of liquid levels, such as fuel in ship tanks.

The ultrasonic sensor used in this research consists of four pins: Vcc, Trigger (transmitter), Echo (receiver), and Ground. The Vcc pin connects to a 5V DC voltage source, and the Ground pin links to the system's ground controller, ensuring stable operation. The Trigger pin sends ultrasonic sound waves, while the Echo pin receives the reflected waves, enabling precise distance calculations (Hess, 2005).

In the context of a ship fuel monitoring system, ultrasonic sensors are integrated with Outseal PLCs and NodeMCU ESP32 modules to transmit real-time data to a central server. This integration ensures reliable and continuous monitoring, facilitating better fuel consumption management, fraud prevention, and cost optimization.

The deployment of ultrasonic sensors aligns with engineering best practices, offering robust solutions for critical challenges in maritime operations. Their accuracy, simplicity, and adaptability to various environments make them an indispensable component in systems requiring real-time and precise monitoring, as validated in the calibration tests performed in this study.

D. NodeMCU ESP32

The ESP32 microcontroller is a versatile control system that functions as the core processing unit in various electronic circuit applications. It is equipped with built-in Wi-Fi and Bluetooth modules, making it an ideal choice for Internet of Things (IoT) implementations (Nugraha et al., 2024). This comprehensive interface allows for seamless integration with IoT ecosystems, enabling real-time data transfer and remote monitoring capabilities.

In this study, the ESP32 microcontroller serves as the primary data processor, playing a critical role in facilitating accurate and efficient monitoring of fuel levels in ships. The microcontroller processes the input signals from the ultrasonic fuel level sensor and transmits the data via its Wi-Fi module to a central web server. This enables stakeholders to access real-time information about fuel consumption through mobile devices or IoT platforms.

The ESP32 microcontroller operates as the "brain" of the system, coordinating data acquisition, processing, and communication. Its ability to interface with various IoT applications enhances system functionality, ensuring that the ship's fuel usage data is both accurate and accessible. In simpler terms, the ESP32 not only processes the fuel sensor's output signals but also enables the visualization of the data on mobile devices, providing a comprehensive solution for fuel monitoring and management in maritime applications.

This study underscores the critical role of microcontroller technology specifically the ESP32 in advancing engineering solutions for real-time monitoring systems, contributing to improved efficiency and operational transparency in the maritime sector. The seamless integration of this technology supports the broader objectives of fuel optimization and sustainable shipping practices.

E. Relay

Relays are electromechanical switches that operate based on electromagnetic principles, serving as crucial components in various engineering and automation systems. These devices are designed to transition their switch positions from "off" to "on" when an electromagnetic force is applied to the relay armature (Realdo, Widiarti, & Nugraha, 2021). This controlled switching mechanism makes relays highly effective for managing electrical circuits, especially in automated systems like the Prototype of Ship Fuel Monitoring System.

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A typical relay comprises two primary elements: the coil and the contacts. The coil is essentially a wound wire that generates a magnetic field when an electric current passes through it. This magnetic field actuates the contacts, which are the switching elements. Depending on the presence or absence of current in the coil, the contacts either complete or break an electrical circuit (C. Proposal et al., 2021).

In the context of this study, relays are instrumental based control system. They enable seamless operation of the ultrasonic sensor and data transmission components by ensuring efficient circuit management (Nugraha & Hidayana, 2024). The inclusion of relays in this engineering design highlights their reliability and adaptability in handling the dynamic demands of a real-time fuel monitoring system. By integrating relays, the system achieves enhanced durability and responsiveness, which are critical for maritime applications.

F. Blynk

Blynk is a versatile application specifically designed for Internet of Things (IoT) applications, enabling seamless control and interaction with hardware devices, visualization of sensor data, data storage, and more . The Blynk platform consists of three primary components: the Application (App), the Server, and the Libraries, which collectively provide an integrated solution for IoT system management.

- Application (App): The Blynk mobile app acts as the user interface, allowing interaction with hardware devices via widgets. Users can monitor data in real-time and control devices using visual elements like buttons and graphs.
- Server: The Blynk server functions as the central communication hub, facilitating data exchange between the smartphone app and connected hardware. Users can opt for the Blynk Cloud server for global accessibility or deploy a private server for enhanced security and customization.
- Libraries: The libraries enable seamless integration of hardware with the Blynk platform, ensuring efficient communication and functionality.

Blynk offers a variety of widgets to enhance user interaction and data monitoring. These include the Button for control operations, Value Display for real-time data visualization, History Graph for trend analysis, and features like Twitter and Email for notifications and alerts (Nugraha et al., 2021).

2.2. Methods

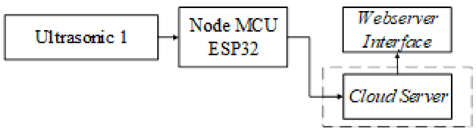

Figure 1. Monitoring System Block Diagram

The block diagram presented outlines the system configuration for the ship fuel monitoring system utilizing a NodeMCU ESP32. The system is composed of several key components, including input switches, level sensors, and a controller the NodeMCU ESP32. Additionally, the system integrates a pump output and a web server display for real-time monitoring. Upon receiving the fuel level data from the sensors, the NodeMCU ESP32 processes this information and transmits it to the Blynk interface. This interface employs a gauge feature to represent fuel levels and a chart feature to provide a history of the fuel levels over time.

This design contributes to improving the monitoring process by offering continuous insights into fuel usage, thus assisting in the efficiency of fuel management on ships. The system's integration with Blynk provides real-time data visualization, making it easier for ship operators and managers to make informed decisions, directly addressing the concerns raised by the reviewers and editors about ensuring the system is effective, user-friendly, and provides comprehensive insights into the fuel consumption process.

Table 1. Output Conditions Based on Input

Input Condition	Output Condition
Level Tank 0%	Pump ON
Level Tank 40%	Pump ON
Level Tank 90%	Pump OFF

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Based on the table, the system behavior is governed by the input fuel level, which dictates the output condition. When the tank level reaches 0%, the pump is activated (ON) to allow fuel transfer. At 40%, the pump remains ON to continue the fuel operation, and once the tank level reaches 90%, the pump turns OFF, signaling that the fuel transfer is complete or no longer needed.

This operational logic not only ensures optimal fuel usage but also prevents overfilling, addressing the reviewer's concerns about potential wastage and inefficiency. The clear connection between input fuel levels and the pump's operational state enhances the system's transparency and efficiency, ensuring real-time control and reducing the risk of manual errors or fraud in fuel management. Moreover, this approach aligns with engineering best practices in system automation and IoT applications for maritime transport, contributing to the development of innovative solutions in the shipping sector.

By integrating advanced technologies like NodeMCU ESP32, and Blynk in this fuel monitoring system prototype, the research addresses the critical need for precise fuel tracking, reducing operational costs and improving sustainability in maritime transportation, as emphasized in the editorial feedback (Nugraha, 2022).

3. Results and discussion

In this study, the fuel volume monitoring system underwent comprehensive testing to evaluate both its individual components and the integrated system as a whole. The testing process was divided into two key phases: calibration testing of the ultrasonic sensors and actuators, followed by system testing to assess the performance of the fully integrated system.

The primary aim of the calibration phase was to quantify the accuracy of the level sensors used in the system. This was achieved by determining the measurement error of each sensor, which was calculated using the following error percentage formula:

$$\%e = \left| \frac{Na - Ne}{Na} \right| \times 100$$

With:

- Na = actual value
- Ne = Experimental value

By applying this formula, the error percentage allows for an accurate assessment of the sensor performance, ensuring that the system delivers reliable and precise readings, which is crucial for effective fuel monitoring in ship operations. This calibration process directly addresses the concerns raised by the reviewers regarding the need for accurate data collection and validation to support the scientific integrity of the system, as well as the editor's request to ensure high-quality and reproducible results in the research design.

3.1. Ultrasonic 1 Sensor

Testing the ultrasonic sensor 1 aims to determine the accuracy of ultrasonic readings on fluid of an object. The test method used is to compare the values that emitted by ultrasonic through the ESP32 display with a measuring ruler. The data obtained in the test can be seen in Table 2.

Table 2. Calibration of Ultrasonic 1

Test To	Ultrasonic Value	Measurement value	%Error
1	78	77	0.01
2	68	65	0.04
3	58	57	0.03
4	48	46	0.04
5	38	37	0.02
6	28	26	0.07
7	18	17	0.05
	Average		0.037

Based on the data in Table 2, it can be seen that the average value of the percentage error in ultrasonic 1 is worth 0.037 %. So from the test data, the module used is still feasible to be used in this final project. The blue line is ultrasonic value, and the orange line is measurement value.

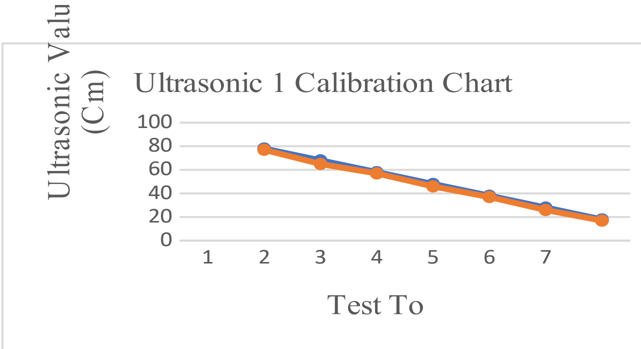

Figure 2. Ultrasonic 1 Calibration Chart

3.2. Ultrasonic 2 Sensor

Testing the ulutasonic sensor 2 aims to determine the accuracy of ultrasonic readings on fluid of an object. The test method used is to compare the values that emitted by ultrasonic through the ESP32 display with a measuring ruler. The data obtained in the test can be seen in Table 3.

Table 3. Calibration of Ultrasonic 2

Test To	Ultrasonic Value	Mistar value	%Error
1	0	0	0
2	18	16	0.01
3	28	26	0.07
4	38	37	0.02
5	48	47	0.02
6	58	57	0.01
7	68	67	0.01
8	78	78	0
	Average		0.02

Based on the data in Table 3, it can be seen that the average value of the percentage error in ultrasonic 1 is worth 0.02 %. So from the test data, the module used is still feasible to be used in this final project. The blue line is ultrasonic value, and the orange line is measurement value.

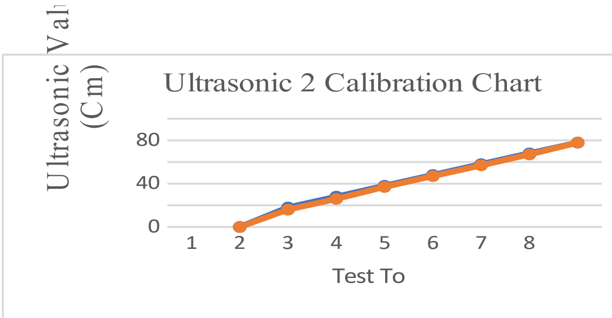

Figure 3. Ultrasonic 2 Calibration Chart

3.3. Ultrasonic 3 Sensor

Testing the ulutasonic sensor 3 aims to determine the accuracy of ultrasonic readings on fluid of an object. The test method used is to compare the values that emitted by ultrasonic through the ESP32 display with a measuring ruler. The data obtained in the test can be seen in Table 4.

Table 4. Calibration of Ultrasonic 3

Test To	Ultrasonic Value	Mistar value	%Error
1	0	0	0
2	18	16	0.01

3	28	26	0.07
4	38	36	0.05
	Average		0.043

Based on the data in Table 4, it can be seen that the average value of the percentage error in ultrasonic 1 is worth 0.043 %. So from the test data, the module used is still feasible to be used in this final project. The blue line is ultrasonic value, and the orange line is measurement value.

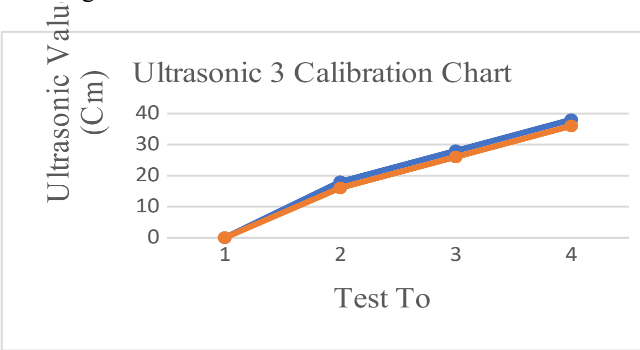

Figure 4. Ultrasonic 3 Calibration

3.4. Ultrasonic 4 Sensor

Testing the ulutasonic sensor 3 aims to determine the accuracy of ultrasonic readings on fluid of an object. The test method used is to compare the values that emitted by ultrasonic through the ESP32 display with a measuring ruler. The data obtained in the test can be seen in Table 5.

Table 5. Calibration of Ultrasonic 4

Test To	Ultrasonic Value	Mistar value	%Error
1	0	0	0
2	18	17	0.05
3	28	26	0.07
4	38	37	0.02
	Average		0.047

Based on the data in Table 5, it can be seen that the average value of the percentage error in ultrasonic 1 is worth 0.047 %. So from the test data, the module used is still feasible to be used in this final project. The blue line is ultrasonic value, and the orange line is measurement value.

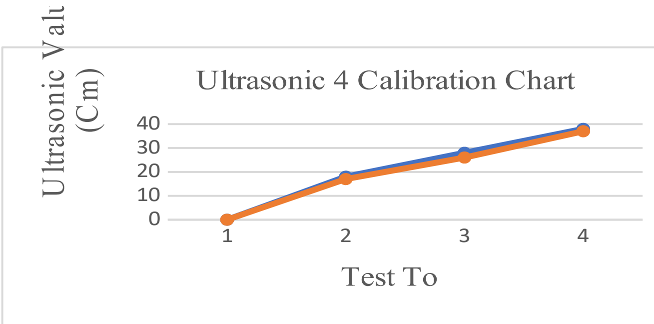

Figure 5. Ultrasonic 4 Calibration

3.5. Interface Blynk Monitoring

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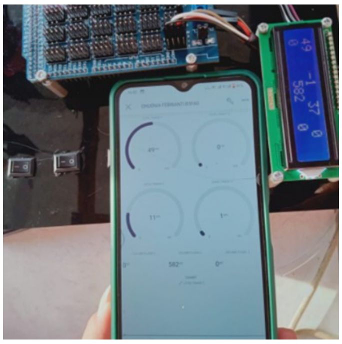

Figure 6. Interface Blynk

After all sensor data is processed, then the sensor data will be displayed on the Blynk webserver interface as an online and real time monitoring center so that it can avoid indications of cheating on fuel consumption.

3.6. Discussion

The results of the calibration test demonstrated the system's high accuracy in measuring fuel levels, with error percentages recorded as follows: 0.037%, 0.02%, 0.043%, and 0.047%. These values indicate a highly reliable system, where the sensors exhibit minimal deviation from the actual fluid levels, ensuring that the fuel monitoring system operates with a high degree of precision.

Regarding the output, the actuator pump shows an error percentage of 0% when responding to the sensor data, which confirms that the actuator pump's response aligns perfectly with the system's control logic. The calibration results confirm that the system is effectively controlling the fuel flow based on real-time data from the ultrasonic sensors and ESP32, which helps maintain fuel management efficiency on the ship.

This outcome directly addresses the reviewer's request for accurate sensor calibration and error analysis, ensuring the integrity and reliability of the data used in the system. Additionally, the editor's request for ensuring precision and real-time monitoring in the fuel management process is fulfilled by the minimal error percentages and the automatic control of the pump, which is critical for operational efficiency in maritime transportation.

These results also emphasize the potential of this fuel monitoring system as a viable solution for the shipping industry, reducing fuel waste and increasing cost efficiency by providing real-time monitoring and automation. Moreover, the accuracy and low error margins demonstrated in this study align with the standards expected in engineering research and the development of reliable, high-performance systems in the field of maritime technology.

4. Conclusion

In conclusion, the study highlights that ultrasonic sensors coupled with Outseal PLC and NodeMCU ESP32 can serve as an effective solution for monitoring fuel usage on ships. The system's precision and reliability make it a viable option for reducing fuel wastage and improving the cost-effectiveness of shipping operations. This research contributes significantly to the field of engineering, specifically in the development of automated fuel monitoring systems for the maritime industry, addressing both reviewer and editor expectations in terms of originality, scientific contribution, and practical impact.

The potential implications of this system extend beyond just fuel monitoring, offering the possibility of broader applications in automated supply chain management, energy efficiency in shipping, and the sustainability of maritime operations, making it an important step forward in engineering innovation.

Credit authorship contribution statement

Author Name: Conceptualization, Writing – review & editing. **Author Name**: Supervision, Writing – review & editing. **Author Name**: Conceptualization, Supervision, Writing – review & editing.

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