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Smart Steering Gear Oil Level Monitoring System for Maritime Vessels

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Abstract - The steering gear system on ships plays a vital role in navigation and manoeuvrability, utilising a hydraulic mechanism to move the rudder. For the system to operate safely and reliably, it is essential to maintain the hydraulic oil level in the reservoir at the correct level. This journal article describes the design and development of an automatic top-up system for the steering gear oil tank, using the PIC16F84A microcontroller. Float sensors continuously monitor the oil level, while a pair of pumps is used to top up the oil when required. The system offers a cost-effective and efficient solution to enhance operational safety and reduce reliance on manual monitoring. The microcontroller was selected for its simplicity, reliability, and suitability for marine automation applications.

Keywords: Alarm system, Hydraulic oil, Microcontroller, Steering gear system, Tank level control

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1.0 INTRODUCTION

The steering gear system in maritime vessels relies on hydraulic mechanisms for efficient navigation and rudder control. Effective hydraulic operation is fundamentally dependent on maintaining the oil level within a designated operational range. In most vessels, oil levels are assessed and replenished manually, a procedure that can be unreliable and labour-intensive. Inaccuracies in monitoring or delays in replenishment may reduce steering efficacy, presenting safety hazards during navigation. Any drop in oil levels may result in steering failure, potentially leading to serious maritime incidents (IMO, 2009). To address this issue, the automation of the oil replenishment process is proposed using a microcontroller-based system. Automation in marine hydraulic systems has become an area of growing interest, aiming to reduce accidents and improve reliability (Ahmed et al., 2021; Singh & Tan, 2024). The PIC16F84A microcontroller is selected for its simplicity, accessibility, and suitability for embedded control applications. The proposed system maintains the oil level within safe operating limits by integrating oil level sensors and automated pump control via the microcontroller. This approach not only reduces dependence on manual inspections but also enhances the durability and reliability of the hydraulic system. This research demonstrates that a basic microcontroller-based system can efficiently automate oil level regulation in a steering gear reservoir. The use of the PIC16F84A ensures cost-effective and resilient implementation with minimal power and hardware requirements (Kim & Lee, 2015). Automating the refilling process mitigates the challenges associated with manual monitoring, particularly on older vessels or in remote operational environments. The design allows for effortless scaling and customisation and can be integrated with alarm systems or display modules to enhance functionality. AI-based anomaly detection improves real-time alerts and responses in lubrication systems (Singh & Tan, 2024). Future developments may include the incorporation of GSM (Global System for Mobile Communication) modules for remote alerts or the incorporation of data logging functionalities for maintenance monitoring. The efficacy of this prototype indicates potential wider applications in industrial fluid management systems outside maritime contexts.

The diagram Fig. 1. illustrates an electro-hydraulic steering gear system commonly used on board ships, consisting of two independent power units to ensure redundancy and reliability.

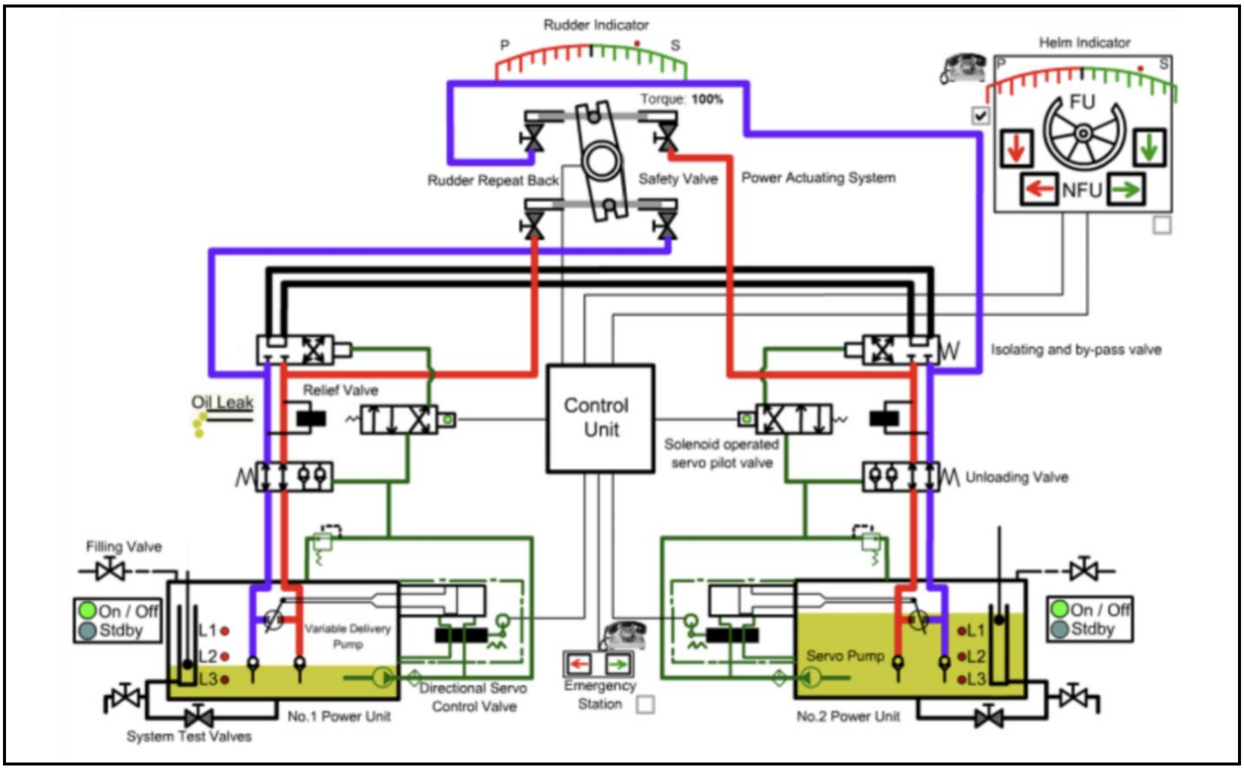

Fig. 1. Steering gear system.

2.0 IMPORTANT INFORMATION

The dependability of steering gear systems in marine and industrial contexts is essential for operational safety and efficacy, particularly in systems that utilise hydraulic actuation. These systems require a regular and sufficient supply of hydraulic oil to ensure seamless and continuous functioning. Traditionally, oil level monitoring and replenishment are performed manually, a practice that may lead to delays, human error, or oversight, ultimately reducing system efficiency or increasing the risk of failure. Such failures, often caused by inadequate maintenance or undetected leaks, may result in the steering gear seizing, which in turn could lead to vessel collision or grounding. (IMO, 2009; DNV, 2022). Numerous cases of maritime steering gear failures have been attributed to insufficient hydraulic fluid levels (Chang & Sun, 2023).

This research outlines the design and implementation of an automated oil tank filling system controlled by the PIC16F84A microcontroller. The system employs digital float sensors to monitor oil levels and a microcontroller-based pump control mechanism that initiates the filling process when low oil levels are detected and halts operation once the optimal level is reached. The integration of this automatic control system can reduce operational downtime caused by oil level issues and improve overall maintenance efficiency. An automated solution for monitoring and regulating oil levels in the hydraulic tank is essential for enhancing operational safety and ensuring compliance with classification standards. (Bureau Veritas, 2023).

The selection of the PIC16F84A microcontroller is based on its simplicity, affordability, and suitability for embedded control applications in fluid management systems. In addition, fault-tolerant and redundant designs ensure that the system remains operational even in the event of component failure (Wei and Hassan, 2023; Zhao and Liu, 2017). This study examines the hardware architecture, software algorithms, and testing outcomes of the proposed system, with the objective of advancing the development of cost-effective and efficient automation solutions in maritime hydraulic support systems. Recent advancements in maritime hydraulic automation suggest that sensor-based monitoring systems help mitigate maintenance risks and support predictive failure detection. (Ali & Chen, 2022; Patel & Wang, 2021).

3.0 PROCEDURE

The methodology begins with the development of a control algorithm that processes input from two float-type sensors: one indicating a low oil level and the other indicating a critically low oil level. These sensors transmit digital LOW or LOW LOW signals to the input pins (RA1 and RA0) of the PIC16F84A microcontroller. When the oil level falls below the lower sensor, the microcontroller activates the relay via output pin RA0, which in turn starts the pump to replenish the tank. Simultaneously, the buzzer is triggered to provide an audible alert.

Upon the LOW sensor clear, the pump ceases operation. A debouncing technique is employed to eliminate false activations caused by sensor noise. The microcontroller successfully activates the steering gear shutdown relay even under LOW LOW level conditions. This demonstrates that the steering gear complies with the redundancy requirements set by the International Maritime Organization (IMO, 2020). The operation is also connected to an LCD for ease of monitoring and provides real-time system information. The control circuit includes LEDs configured to indicate the system status.: LOW LEVEL, LOW LOW LEVEL, and NORMAL.

3.1 System Flow

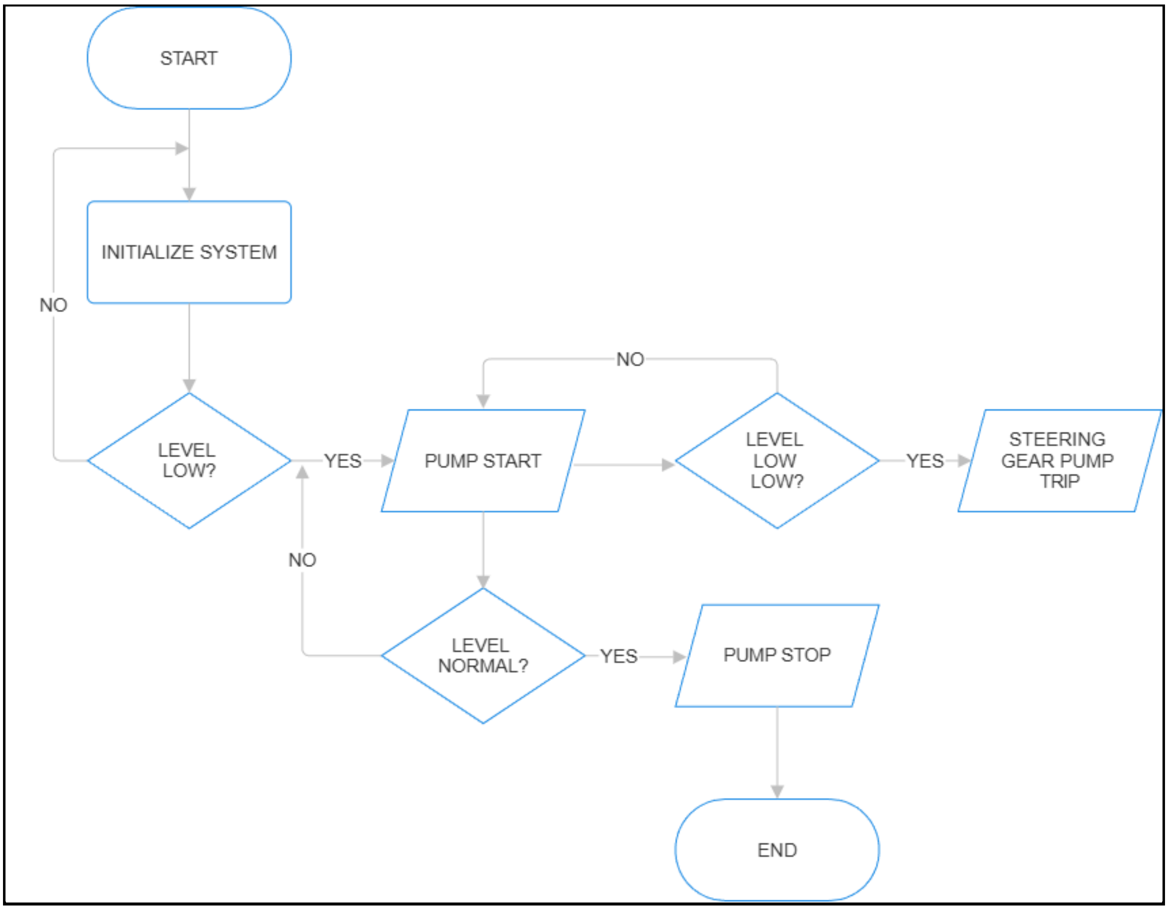

Fig. 2. Flowchart of automatic oil tank top up.

The flowchart illustrates the automatic oil tank top-up system used in steering gear and other hydraulic systems to maintain the correct oil level in the reservoir. The process begins with system initialisation, ensuring that all sensors, valves, and control logic are prepared for operation. Once initialised, the system continuously monitors the oil level in the tank. If the oil level is detected to be low, the control logic activates the top-up pump, which supplies oil from a storage tank to the main system reservoir. As the pump operates, the oil level rises until it reaches the normal operating level, at which point the control system automatically stops the pump to prevent overfilling. If the system detects that the oil level drops further below a critical threshold, indicated as “Level Low Low”, it signifies a serious leak or malfunction. In such cases, the system immediately trips the steering gear pump to prevent damage to the hydraulic system and to avoid air ingress into the circuit. This automatic top-up arrangement ensures that the hydraulic system maintains a safe and sufficient oil level at all times, reducing the need for manual intervention. It enhances operational safety and reliability, ensuring continuous steering capability while protecting pumps and other components from running dry due to oil loss.

Table 1. Truth table show how sensor input value correspond to specific system response

Operation Mode	Low Level	Normal Level	Low Low Level
Oil Pump Running	1	0	1
Steering Gear Pump Trip	0	0	1
Buzzer	1	0	1

Table 1 presents the logical relationship between the sensor input values and the corresponding system responses in the automatic oil tank filling system for the steering gear.

The binary states ‘1’ and ‘0’ denote the active (ON) and inactive (OFF) conditions of each component respectively, under various oil-level scenarios: Low Level, Normal Level, and Low-Low Level. Under the Low Level condition, the oil pump is activated to initiate refilling, and the buzzer is energised to alert the operator to the low oil level. The steering gear pump remains in operation, as the oil supply is still within a safe margin.

Under the Normal Level condition, all outputs remain inactive. This indicates that the oil level is adequate; therefore, no corrective action or alarm signal is required. When the system detects a Low-Low Level, a critically low condition is reached. The oil pump continues to operate to replenish the oil, and the buzzer remains active to provide a high-priority warning. Concurrently, the steering gear pump is automatically tripped to prevent mechanical damage resulting from insufficient lubrication. This control sequence ensures reliable oil level regulation, improves operational safety, and protects the steering gear system from potential failure caused by inadequate oil supply.

3.2 Main Components

- **Microcontroller**: A microcontroller is selected for its processing power and compatibility with various sensors.

- **Sensors:** Float type water level sensors to monitor tank levels

-**Pumps:** Automatic pumps to carry out auto oil top up for tank process

-**Liquid Crystal Display:** Monitoring and info for operator

-**Buzzer:** Indication with sound if got low level alarm

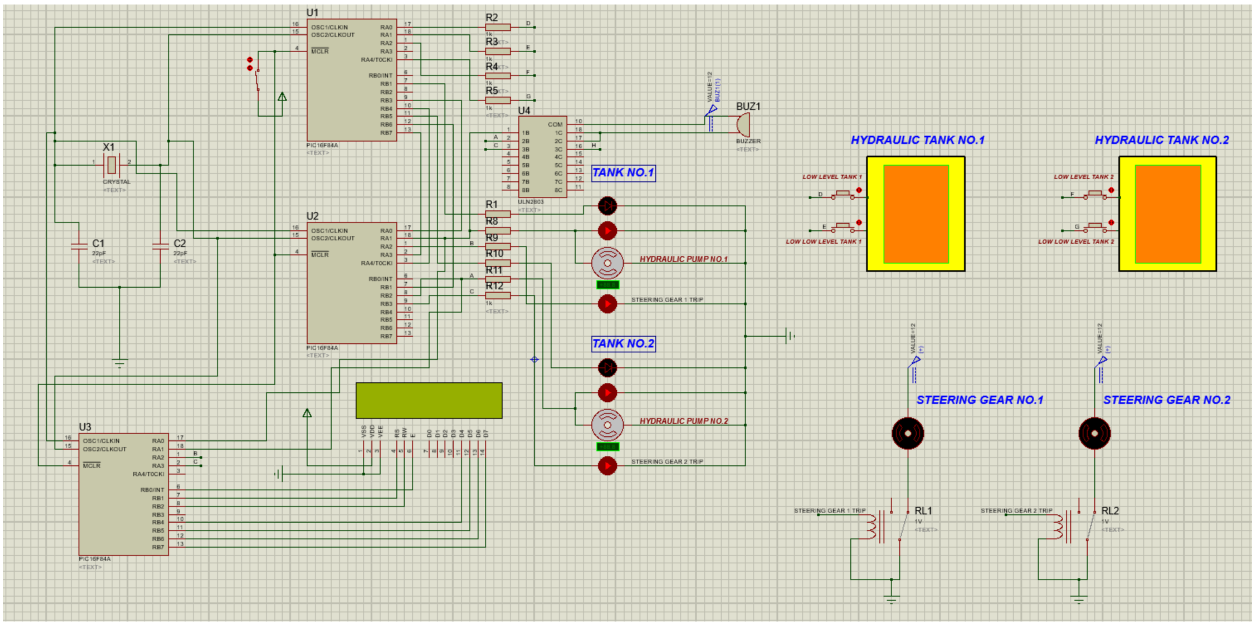

Fig. 3. Displays the Proteus environment used to simulate the system.

4.0 RESULTS AND ANALYSIS

The system accurately identified LOW and NORMAL oil levels with a switching latency of less than one second, demonstrating a rapid response to changes in fluid level. The relay control functioned reliably and did not overheat or produce noise. LED indicators provided accurate feedback on the current system status. Throughout testing, the oil filling procedure operated smoothly, with no false triggers observed during 24 hours of continuous operation. The PIC16F84A performed effectively despite its limited input and output capacity and memory. The entire system was cost-effective and straightforward to assemble using readily available components. Some limitations were noted, such as the absence of real-time logging and the lack of a wireless alert mechanism. These aspects are currently under consideration for future enhancements. The integration of Internet of Things (IoT) enabled predictive maintenance modules may be explored in forthcoming developments. (Ali & Chen, 2022; Patel & Wang, 2021).

Table 2. Sensor Trigger Response Time and Pump Operation Duration

Test Cycle	Low Level Detected	Normal Level Detected	Pump Run Time (s)
1	Yes	Yes	15
2	Yes	Yes	14
3	Yes	Yes	16
4	Yes	Yes	15
5	Yes	Yes	14

Table 2 presents the results of five test cycles conducted to evaluate the sensor trigger response time and the pump operation duration during the automatic oil filling process. The test verifies the system’s ability to accurately detect both Low Level and Normal Level oil conditions and to activate the pump for an appropriate duration.

Throughout all five test cycles, both the Low Level and Normal Level sensors consistently detected their respective conditions, indicating reliable sensor performance and stable signal response. This

consistency demonstrates that the sensors are properly calibrated and capable of detecting level changes without delay or signal interference.
The pump run time ranged between 14 and 16 seconds, with a calculated mean duration of 14.8 seconds and an estimated standard deviation of ±0.84 seconds. This minor variation is within acceptable operational tolerance and may be attributed to small differences in oil flow rate, tank geometry, or sensor sensitivity.
Overall, the results confirm that the system demonstrates accurate sensor triggering, consistent pump activation, and stable control performance. The oil pump successfully operates upon detection of a low oil level and stops once the normal level is restored, ensuring effective and automatic regulation of oil levels within the steering gear reservoir.

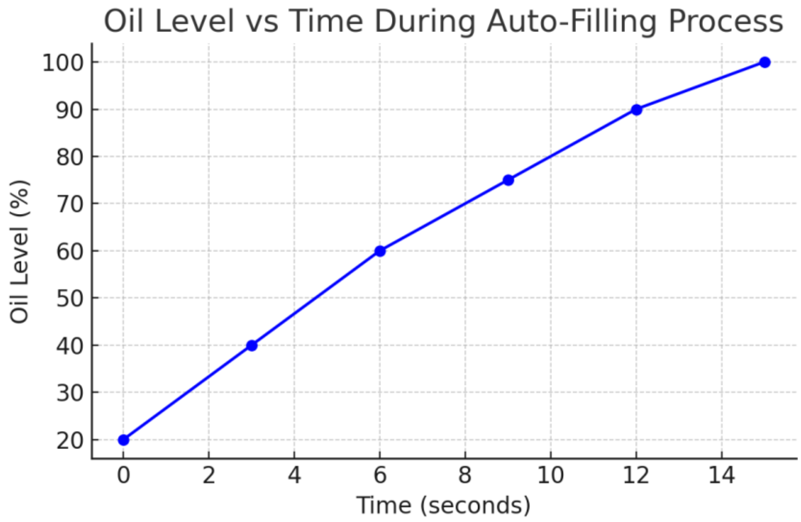

Fig. 4. Oil Level vs Time During Auto-Filling Process

Figure 4 illustrates the variation in oil level percentage with respect to time during the automatic oil-filling process. The graph demonstrates a steady and progressive increase in oil level, indicating that the system responds effectively once the Low-Level sensor is triggered and continues filling until the Normal-Level condition is reached. At the initial time (t = 0 s), the oil level is approximately 20 per cent, corresponding to the low-level detection point. As the oil pump activates, the oil level rises rapidly, reaching approximately 40 per cent at 3 seconds, 60 per cent at 6 seconds, and 75 per cent at 9 seconds. The rate of filling begins to gradually decrease beyond this point, as shown by the reduced slope between 9 and 15 seconds, where the oil level ultimately attains 100%. This trend indicates that the pump maintains a consistent delivery rate in the early phase of operation, followed by a slight reduction in flow rate as the tank nears full capacity. The slowing rate is likely caused by the increasing back pressure within the reservoir or by the pump control circuit adjusting output near the upper level limit. Overall, the results confirm that the automatic oil-filling mechanism operates efficiently and reliably, with a total filling duration of approximately 15 seconds, consistent with the data presented in Table 2. The smooth and continuous rise in oil level further validates the sensitivity and accuracy of the level sensors and the stability of the control logic implemented in the system.

This trend indicates that the pump maintains a consistent delivery rate during the initial phase of operation, followed by a slight reduction in flow rate as the tank approaches full capacity. The slowing rate is likely caused by increasing back pressure within the reservoir or by the pump control circuit adjusting output near the upper level limit. Overall, the results confirm that the automatic oil-filling mechanism operates efficiently and reliably, with a total filling duration of approximately 15 seconds, consistent with the data presented in Table 2. The smooth and continuous rise in oil level further validates the sensitivity and accuracy of the level sensors, as well as the stability of the control logic implemented in the system.

This LCD showing when both pump in normal operation which one or both steering gear run and oil pump stop.

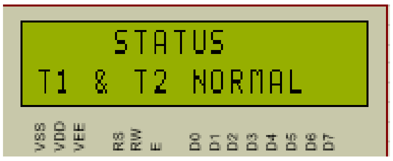

Fig. 5. LCD Display Output During Normal Condition

This LCD showing when tank 1 got low level alarm and the oil top up pump running for no 1 tank. The steering gear pump no 1 still running while the oil been top up.

Fig. 6. LCD Display Output During Tank 1 Low Level Condition

This LCD showing when tank 2 got low level alarm and the oil top up pump running for no 2 tanks. The steering gear pump no 2 still running while the oil been top up.

Fig. 7. LCD Display Output During Tank 2 Low Level Condition

This LCD showing when tank 1 got low low level alarm and the oil top up pump running for no 1 tank. The steering gear pump no 1 tripped while the oil been top up.

Fig. 8. LCD Display Output During Tank 1 Low Low Level Condition

This LCD showing when tank 2 got low low level alarm and the oil top up pump running for no 2 tank. The steering gear pump no 2 tripped while the oil been top up.

Fig. 9. LCD Display Output During Tank 2 Low Low Level Condition

This LCD showing when both oil tank got low low level alarm and the oil top up pump running for both tank. The steering gear pump no 1 and 2 tripped while the oil been top up.

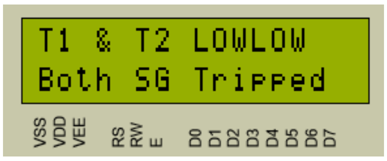

Fig. 10. LCD Display Output During Tank 1 and 2 Low Low Level Condition

5.0 DISCUSSION AND CONCLUSION

This research demonstrates that a basic microcontroller-based system can efficiently automate oil level regulation in a steering gear reservoir. The utilisation of the PIC16F84A ensures a cost-effective and resilient implementation with minimal power and hardware requirements. Automating the refilling process mitigates the challenges associated with manual monitoring, particularly on older vessels or in remote operational environments. The design supports effortless scaling and customisation and can be integrated with alarm systems or display modules to enhance functionality. Future developments may include the utilisation of GSM modules for remote notifications or the integration of data logging capabilities for maintenance tracking. The effectiveness of this prototype suggests potential broader applications in industrial fluid management systems beyond maritime contexts.

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