Main Engine Water Cooling Failure Monitoring and Detection on Ships using Interface Modbus Communication

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Abstract

Main engine failure will damage engine systems, reduce navigation safety, and cause serious marine accidents. The cooling system is very important to prevent the engine's mechanical efficiency from deteriorating and engine failure due to overheating. Therefore, a monitoring and error detection system is needed. The system is based on the Modbus RS485 communication and interface. The collection equipment uses components from the 7S-50MC diesel engine. PLC is used as processing equipment and Logic Panel Autonics S070 is used as an interface. Through these tests, error detection in this study can provide an indication of an error when an abnormal situation occurs. In addition, data monitoring and system fault indication can be displayed on the interface. Testing of the system proved that it complies with the Indonesian Shipping Bureau (BKI) regulations on engine warning systems. The research developed can form the basis of more complex and reliable monitoring and fault detection system for applications on ships.

I. INTRODUCTION

Host failures are the most costly damage, accounting for 34.3% of total processing costs. The Swedish club noted that the average cost of such damage from 2005 to 2011 was almost 634 thousand dollars [1] [2] [3]. Damage to the engine system is not only costly but also affects navigation safety and causes serious marine accidents [4]. One of the reasons is the engine cooling system failure.

Combustion temperatures range from 600 ° C to 800 ° C, so a cooling system is essential to keep the ship's main engine running. If this temperature is not cooled each time the combustion process is completed,

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the mechanical efficiency of the engine will decrease and overheating can cause the engine to fail [5] [6]. So a monitoring and error detection system is required.

In addition to increasing maintenance restrictions, the system also regularly collects information from the machine. Process the received information to prevent accidental control operations and early restoration of backup systems that may adversely affect the plant [7]. Therefore, the safety and reliability of the ship become more effective.

Biro Klasifikasi Indonesia (BKI) has established automated system rule monitoring and failure detection rules. Mechanical alarm systems must provide visual and auditory signals to identify faults when an alert is issued. The alarm display is displayed as a word or symbol and the optical signal remains visible until the failure is resolved [8]. In addition, the system must also include various operating conditions, cycles, and operating functions.

There is a lot of research related to engine management in academic journals. Yemao et al. [9] will design the practical application of the marine engine room monitoring system. This paper shows the structure of the engine monitoring system with S7-200PLC and alarm card. Serial communication with RS232 and Ethernet sends data to the FameView application. Unfortunately, this paper focused only on the architectural design of the system and did not provide a clear explanation of the field equipment and fault detection algorithms.

Sanadhya et al. [10] provide a monitoring solution with dedicated field equipment for failure prediction, but the scope of interpretation is limited. They used an MPU6050 accelerometer and a piezoelectric microphone to obtain vibration and noise data from the fuel separator. They use peak factor calculations to predict failures based on data captured when signal pulses are detected. More extensive parameter monitoring has been investigated by Hu et al. [11] In the design of an integrated integrated integrated system for monitoring and diagnostics of marine diesel engines. The system consists of six monitoring subsystems.

This study uses the integration of research in [9] [10] [11] and the provisions of the machinery alarm system in [8]. The monitored parameter is different from previous studies, namely, the temperature of the main engine cooling water tank of the main engine of the ship. Fault detection serves as an early warning of abnormal conditions for each cylinder. The PLC's communication protocol Modbus RS485 sends field device data to the logic panel S070 as a man-machine interface. The created system can display data through the interface and detect errors.

II. METHODS

A. Basic Rules Requirement

The basic rule of this study is the mechanical alarm requirement for the cooling water temperature of the engine outlet cylinder. BKI sets alarms in the form of indicators and cap alarms [12]. The temperature reading comes from the thermocouple and the high limit alarm comes from the motor temperature switch. In addition, the monitoring and error detection system complies with the BKI rules. These rules are summarized as follows [8]:

- The mechanical alarm system should provide a visual and audible indication indicating an unacceptable deviation from the operating figure.
- The alarm delay must be kept within the time limit to prevent any danger to the observation system when the limit is exceeded.
- The meaning of individual indicators should be explained in words or symbols. In addition, the traffic lights should remain visible until the error disappears.
- Acknowledgment warnings should not prevent the emergence of new causes.
- Transient errors of non-interference self-correction should be saved and indicated by optical signals.

B. System Architecture

This system consists of inputs, processes, and outputs. The input consists of an analog signal and a digital signal. The analog signal comes from the thermocouple and the digital signal comes from the temperature switch. The voltage change data from the thermocouple corresponds to the temperature change. The

thermocouple sends the voltage change to the temperature controller. Since there are only four thermocouple channels in the device, two temperature controls are used in this study. Figure 1 shows a block diagram of a thermocouple input measurement.

The digital signal depends on the state of the temperature switch. The principle of this switch is to change the contacts by expanding the bimetal strip. These changes provide digital data to the programmable logic control (PLC) for failure detection. There is also a button to let the engineer know that the alarm condition is recognized and a confirmation button. Figure 2 shows the architecture for reading digital inputs.

The PLC processes all inputs. Unlike digital inputs, the temperature controller sends temperature readings from thermocouples via RS485 Modbus communication. The Modbus communication protocol is a standard communication protocol used to transmit signals from the control unit to the controller or data acquisition system. Figure 3 shows the communication architecture between devices. The output of the system is a buzzer, and the buzzer interface is an alarm display with sound and light alarms. At the same time, interface monitoring displays abnormal data and warnings through Logic Panel Autonics S070. Figure 4 shows the hardware architecture.
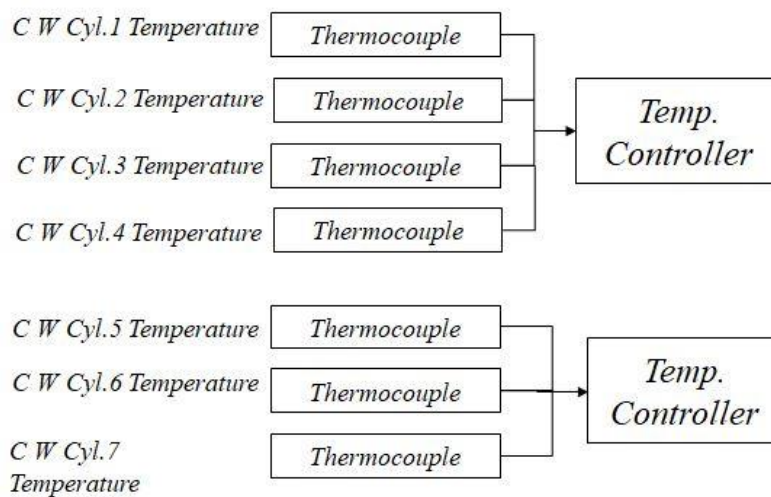

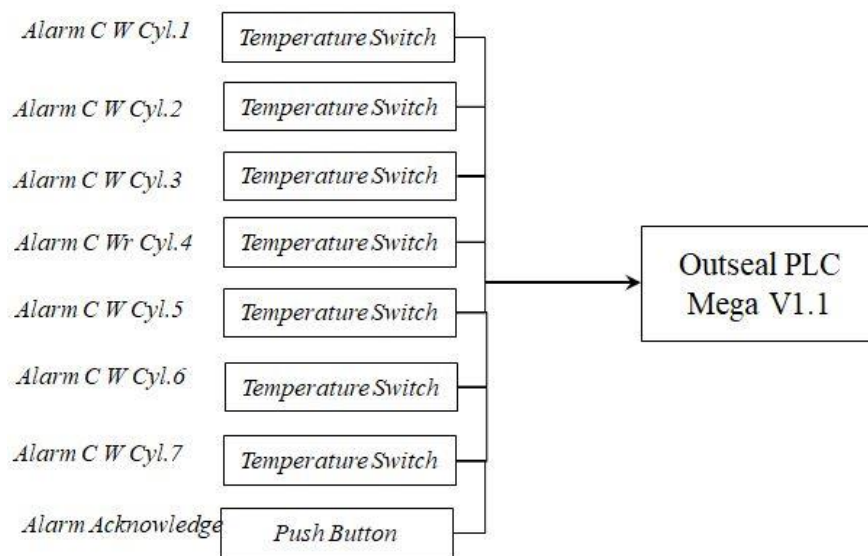**Figure 1.** Block Diagram of The Analog Input
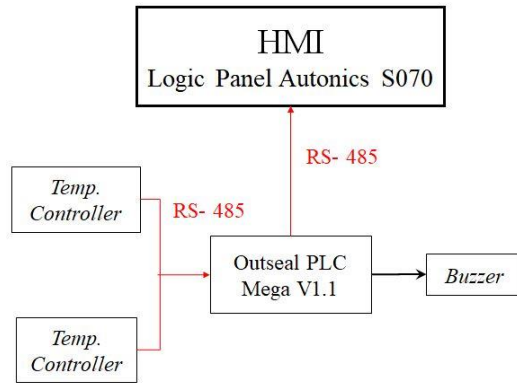

Figure 2. Block Diagram of The Digital Input
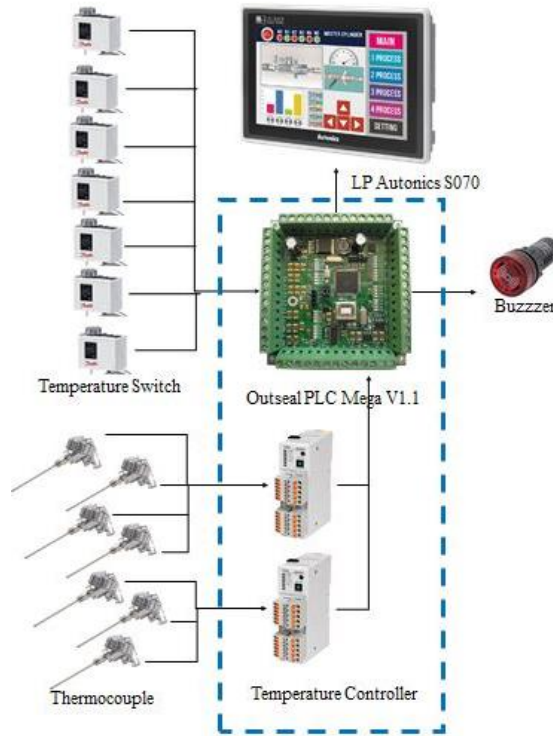
Figure 3. Devices Connection Diagram

Figure 4. Hardware Architecture

C. *System* Concept

Figure 5 shows the operating sequence of the monitoring and fault detection system. PLC reads the cooling water temperature data in real-time. The logic board reads and displays the temperature value, and the digital signal becomes fault detection.

When the cooling water temperature exceeds the set temperature of 80 °C, a fault is detected [13] [14] [15]. When the PLC receives the failure data, a processing failure is started and the buzzer is activated. A failure message was sent to Logic Panel S070 to notify the engineer. The logic panel also provides clear alarm information with the displayed alarm list. The interlock function displays the optical signal of the failure status until the failure is confirmed. If another error is displayed, the alarm will be activated again

and the alarm list will show the new error that occurred. The alarm list disappears only when the engineer recognizes a failure.
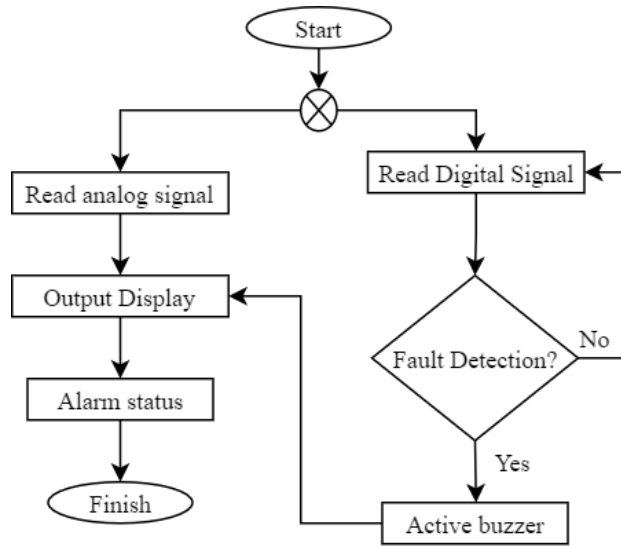

Figure 5. Flowchart Process

D.   System *Design*

GP Editor is an interface design application. The presentation contains two pages. Figure 6 (a) shows the engine cooling water and Figure 6 (b) shows the alarm monitoring. The temperature change of the cooling water is dynamically shown graphically in the bar graph in Figure 6 (a). For ease of observation, each cylinder image uses CW x as the name of the thermocouple position at the outlet of cylinder x. In addition, temperature display settings are an intuitive format with unsigned data types that can be adapted to source values. Accuracy and read-only values are required to determine the temperature value. Each value specifies a unit of temperature, followed by a unit of Celsius.

The second display is the alarm monitor in Figure 6 (b). This indicator is important for warning of engine failures: the alarm and safety list and the warning section. The alarm and safety list section records errors and displays its interface according to the date and time of occurrence. When something goes wrong, the flash button will signal the technician. When an error is detected, the text "WARNING" will also emit a red warning signal. You can use the left and right arrow keys at the bottom right of the screen to change the position from the first part to the second part.

(a)   (b)

Figure 6. Main Engine and Alarm Monitoring Display

III.   RESULTS AND DISCUSSIONS

A.   Results

   The PLC is programmed and tested in Outseal Studio to define digital input, digital output response, and communication with the S070 logic board. The digital input test uses the (NO) switch to run the PLC's internal memory. At the same time, the digital output test is designed to understand the status of the PLC relay.
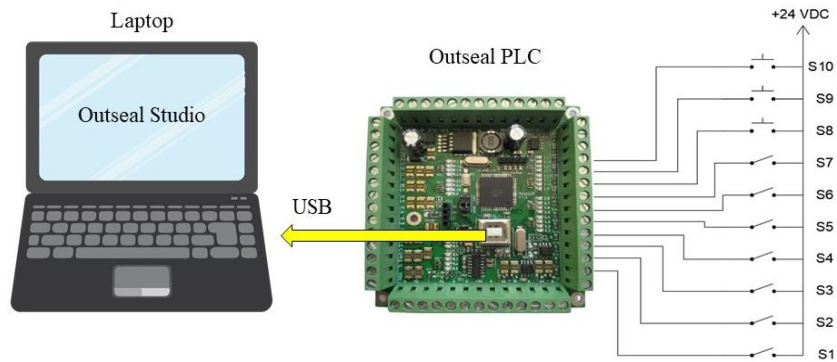

Figure 7. Wiring Diagram Digital Input Test

   The digital input test is shown in Figure 7. This study uses only S1 to S7 toggle switches. All switches connect to the PLC's digital input port. The response of the PLC input port is displayed on the PC through Outseal Studio and can be monitored. The test results are shown in Table 1.

   Figure 8 shows a digital output test. The switch connects the PLC digital input and the relay connects the PLC digital output. Each relay responds to all states of the switch. When the switch is on, the relay works, and also the opposite. For example, when the switch (S1) is off, Outseal Studios S1dan R1 contacts do not emit green light. As a result, the relay does not work. As the digital input test, the digital output test uses Outseal Studio to monitor the relay response. Table 2 shows the results of the digital output test.
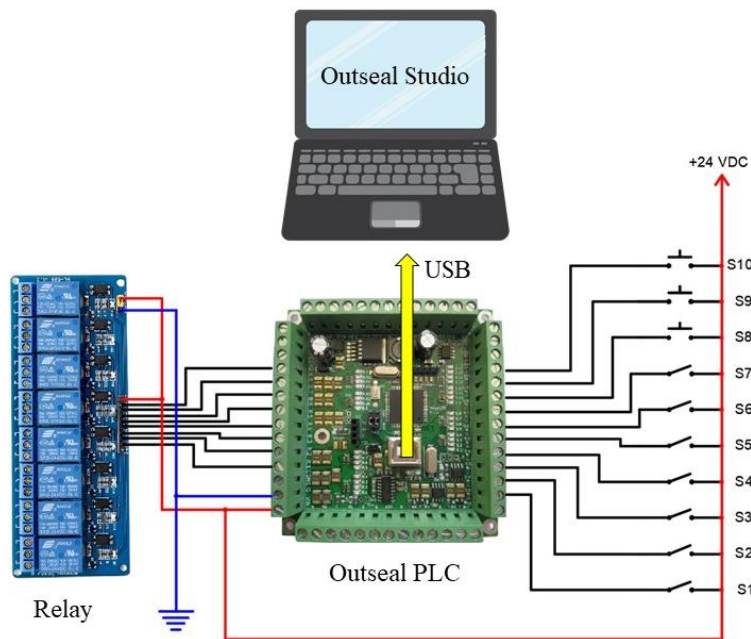

Figure 8. Wiring Diagram Digital Output Test

Table 1. Result of The Digital Input Test

No.	Digital Input	Switch State	Internal Memory Response
1.	S1	0	0
		1	1
2.	S2	0	0
		1	1
3.	S3	0	0
		1	1
4.	S4	0	0
		1	1
5.	S5	0	0
		1	1
6.	S6	0	0
		1	1
7.	S7	0	0
		1	1

Table 2. Result of The Digital Output Test

No.	Digital Input	Switch State	Output Response	Digital Output
1.	S1	0	0	R1
		1	1	
2.	S2	0	0	R2
		1	1	
3.	S3	0	0	R3
		1	1	
4.	S4	0	0	R4
		1	1	
5.	S5	0	0	R5
		1	1	
6.	S6	0	0	R6
		1	1	
7.	S7	0	0	R7
		1	1	

The communication test is to test the Modbus communication between the temperature controller, PLC, and logic board. The thermocouple sends the temperature value to the temperature controller. The PLC then receives this value and sends it to the logic board. Figure 8 shows the testing process. Figure 9(a) shows the circuit, Figure 9(b) shows the test process, and Figure 9(c) shows the temperature of the thermocouple. Table 3 shows the results of the digital output test.
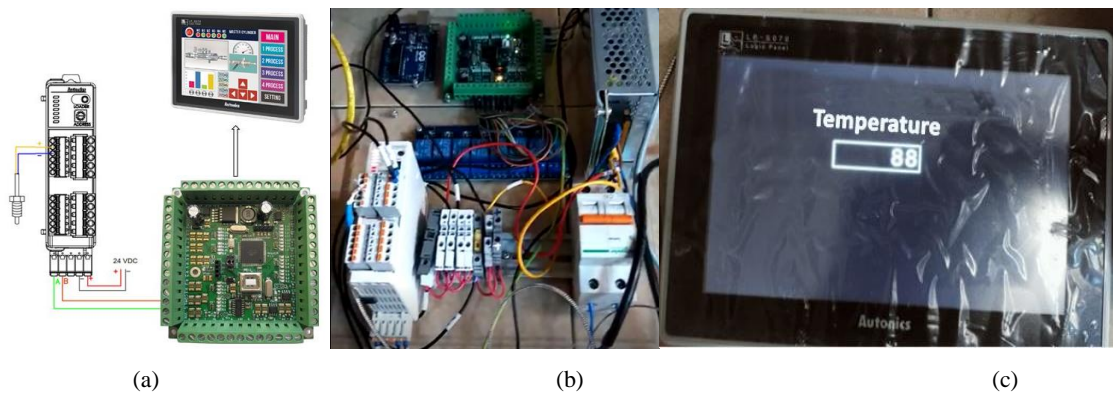

(a)   (b)   (c)

Figure 9. Communication Test

Table 3. Communication Test Result

Data Order	Temperature(°C)
1	27
2	30
3	36
4	40
5	42
6	48
7	53
8	59
9	66
10	71
11	79
12	83
13	85
14	88
15	90

Experiments onboard were also carried out by connecting an onboard data collection system to the prototype. Seven existing 7S-50MC diesel temperature switches connect the Outseal PLC digital input. The system switch is in the (NC) state. Therefore, the buzzer as an audio signal is not activated. However, if the switch state changes from NC to NO, an error will occur. Table 4 shows the results of a standard engine condition test.

Table 4. Normal Engine Safety Test Result

No.	Switch Fault	Input Switch	Output Response	Fault Indication
1	Alarm C.W Cyl.1	1	0	Normal
2	Alarm C.W Cyl.2	1	0	Normal
3	Alarm C.W Cyl.3	1	0	Normal
4	Alarm C.W Cyl.4	1	0	Normal
5	Alarm C.W Cyl.5	1	0	Normal
6	Alarm C.W Cyl.6	1	0	Normal
7	Alarm C.W Cyl.7	1	0	Normal

Determine the fault condition by disconnecting the temperature switch cable from the digital input PLC. Therefore, the contact state changes from (NO) to (NC). An active buzzer indicates that the detection of faults is triggered, and there is an alarm indication on the interface. Table 5 shows the failure condition test. See Table 6 for thermocouple simulation data. When the main engine is not running, the average temperature of the cooling water leaving the cylinder is 72.2 ° C. Figure 10 shows the process of obtaining temperature data from one of the main cooling water tanks of the engine.

Table 5. Engine Performance Check Result Error

No.	Switch Fault	Input Switch	Output Response	Logic Panel Fault Indication
1	Alarm C.W Cyl.1	0	1	Warning
2	Alarm C.W Cyl.2	0	1	Warning
3	Alarm C.W Cyl.3	0	1	Warning
4	Alarm C.W Cyl.4	0	1	Warning
5	Alarm C.W Cyl.5	0	1	Warning
6	Alarm C.W Cyl.6	0	1	Warning
7	Alarm C.W Cyl.7	0	1	Warning

Table 6. Cooling Water Temperature Test Result

No.	Thermocouple Location	Cooling Water Temperature(°C)
1	Cylinder 1 Outlet	72.3
2	Cylinder 2 Outlet	72.3
3	Cylinder 3 Outlet	72.1
4	Cylinder 4 Outlet	72.2
5	Cylinder 5 Outlet	72.3
6	Cylinder 6 Outlet	72.1
7	Cylinder 7 Outlet	72.0

Figure 10. Main Engine Cooling Water Test

B.   *Discussions*

A clear explanation of a system is the system architecture, hardware architecture, system concepts, system interface design, and system testing process. From system architecture to hardware architecture, clear communication between devices is ensured. System concepts provide a directed workflow for the system. Moreover, and most importantly, an informative and accurate interface for monitoring the status of the main engine is also provided.

The digital input test proves that the internal memory changes according to the switching conditions. With an input voltage of +24 VDC, the PLC can read the input signal and transfer it to internal memory according to its pins. The digital output test gives a relay response that matches the switching conditions and the input voltage. The results of this test confirm that the Outseal PLC can operate according to the generated program.

Communication test results on the thermostat, PLC and logic panel show that the thermostat can send and process data to the PLC. In addition, the data received in the logic panel is displayed graphically.

In addition, tests were performed on a 7S-50MC diesel engine by connecting the temperature switch and temperature controller for each cylinder to the PLC. Since the engine is not running, this test produces data about the normal condition of the engine. Failure conditions range from opening the switch to the PLC input to changing the normally closed (NC) contact to normally open (NO). From a testing point of view, the failure detection in this investigation can indicate an error when an unusual situation occurs.

The test results show that the average temperature of the cooling water at the hot freshwater outlet is 72.2°C. Analog data is used only for temperature monitoring and does not detect errors to avoid errors when the temperature values cannot be read based on the actual values due to thermocouple damage.

IV. CONCLUSIONS

This study provides a 7S-50MC cooling water monitoring and fault detection system. During the test, the engine state was not active. The created system is based on RS485 Modbus communication and interface. Unlike previous studies, the capture device uses existing components of the main engine.

This study discusses system architecture, hardware architecture, system concepts with well-defined workflows, interface design, and fulfillment of BKI alarm requirements under test. First, the system can display optical and audible signals via an interface and buzzer. Second, the alarm delay is in the range of 1-2 seconds after the anomaly occurs. Third, signs of failure can be displayed via the safety list section of the interface. Fourth, checking for an error does not block the new fault signal. Fifth, the alarm list function remembers the alarm status until the engineer confirms the status.

V. REFERENCES

[1] The Swedish Club, "Main Engine Damage Study," 2015. [Online]. Available: https://www.swedishclub.com/media_upload/files/Publications/Loss%20Prevention/Main%20Engine%20damage%202015%20The%20Swedish%20Club.pdf. [Accessed 17 July 2021].

[2] J. A. Pagán Rubio, F. Vera-García, J. Hernandez Grau, J. Muñoz Cámara and D. Albaladejo Hernandez, "Marine diesel engine failure simulator based on thermodynamic model," *Applied Thermal Engineering,* vol. 144, no. 10.1016/J.APPLTHERMALENG.2018.08.096, pp. 982 - 995, 2018.

[3] R. Li, S. Li, and K. Xu, "Acoustic Diagnosis Method for Engine Failure," *IOP Conference Series: Materials Science and Engineering,* vol. 677, no. 3, p. 032058, 2019.

[4] X. X, Y. X, Y. K, Z. J, S. C and Y. C, "Review of Condition Monitoring and Fault Diagnosis for Marine Power System," *Transportation Safety and Environment,* vol. 3, no. 2, pp. 85-102, 2021.

[5] Y. Chen, W. Han and H. Jin, "Investigation of an ammonia-water combined power and cooling system driven by the jacket water and exhaust gas heat of an internal combustion engine," *International Journal of Refrigeration,* vol. 82, no. 10.1016/J.IJREFRIG.2017.06.018, pp. 174-188, 2017.

[6] C. Jiale, L. Tie, and Z. Xinyi, "A Study of Smart Thermal Insulation Coating on Improving Thermal Efficiency in a Marine Two-Stroke Low-Speed Diesel Engine," *Fuel,* vol. 304, 2021.

[7] Nugraha, Anggara Trisna, and Dadang Priyambodo. "Prototype Design of Carbon Monoxide Box Separator as a Form of Ar-Rum Verse 41 and To Support Sustainable Development Goals Number 13 (Climate Action)." Journal of Electronics, Electromedical Engineering, and Medical Informatics 3.2 (2021): 99-105.

[8] Biro Klasifikasi Indonesia, "Rules for Automation," *Rules for Classification and Construction,* vol. VII, pp. 1-2, 2018.

[9] M. Yemao, L. Monica and M. Scott N, "Managing Unruly Technologies in The Engine Control Room: from Problem Patching to an Architectural Thinking and Standardization," *WMU Journal of Maritime Affairs,* pp. 497-519, 2018.

[10] D. Sanadhya and R. Sharma, "Condition Monitoring of Marine Fuel Oil Separator System," *International Journal for Research in Applied Science & Engineering Technology (IJRASET),* vol. 8, no. 2, pp. 260-2264, 2020.

[11] Y. J., Y. Y., and H. N, "Design and Implementation of Integrated Monitoring and Diagnosis System for Marine Diesel Engine," *Engineering Asset Management - Systems, Professional Practices, and Certification,* pp. 647-659, 2015.

[12] Biro Klasifikasi Indonesia, "Rules for Machinery Installations," *Rules for Classification and Construction,* vol. III, pp. 2-26, 2019.

[13] G. Theotokatos, K. Sfakianakis, and D. Vassalos, "Investigation of Ship Cooling System Operation for Improving Energy Efficiency," *J Mar Sci Technol,* pp. 38-50, 2017.

[14] Nugraha, Anggara Trisna, Alwy Muhammad Ravi, and Mayda Zita Aliem Tiwana. "Penggunaan Algoritma Interferensi dan Observasi Untuk Sistem Pelacak Titik Daya Maksimum Pada Sel Surya Menggunakan Konverter DC-DC Photovoltaics." Jurnal Janitra Informatika dan Sistem Informasi 1.1 (2021): 8-18.

[15] E. S. Koenhardono, "Performance Improvement of Hopper Cooling System on Traditional Fishing Boats Due to Excessive Cooling," *Kapal: Jurnal Ilmu Pengetahuan dan Teknologi Kelautan,* vol. 17, no. 2, pp. 58-64, 2020.

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