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Development of a Simplified Performance Monitoring System for Small and Medium Sized Ships

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Abstract: Regulations on emissions from ships are being strengthened, and emission reduction systems and alternative technologies are being developed. In addition, the amount of emissions is closely related to the performance of the propulsion systems of the ship; however, performance measurement systems have mainly been developed for large commercial ships. For small and medium-sized ships, although the output of the propulsion system is rather low, the number of vessels sailing in the coast is very high. Therefore, a performance-monitoring system is required for small and medium-sized ships. However, for small and medium-sized ships, there are no suitable performance and emissions calculation systems. Conventional performance-measuring and analysis systems for large ships have difficulties in terms of their cost and installation when applied to small and medium-sized ships. In this study, a new system was developed that is able to calculate the speed, power, fuel consumption, carbon dioxide emission assumptions, and efficiency of a ship by receiving simple key data such as GPS, fuel flow, and rpm data rather than checking the ship's condition using massive forms of data. The system transmits data to the shore's remote-monitoring center in real-time through a communication network. Using these data, it is possible to estimate a ship's aging factor, engine performance, amount of exhaust gas, etc., and the accumulated data of all coastal ships in a country can be used as basic data for governments to use to support eco-friendly ship policies.

Keywords: emissions; performance measurement system; propulsion system; small and medium-sized ships; remote monitoring

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1. Introduction

1.1. Background

The Intergovernmental Panel on Climate Change (IPCC) announced that the average global temperature between 2021 and 2040 will increase by more than 1.5 °C compared to pre-industrial levels if current levels of greenhouse gas emissions are maintained [1]. Even now, the sea level is rising faster than expected due to global warming, and it has been confirmed that global warming is the cause of abnormal climatic phenomena, such as heat waves, drought, glacial collapse, large-scale hurricanes, and wildfires, occurring around the world. The seriousness of global warming has been recognized by the International Maritime Organization (IMO), and, as a solution to this problem in the maritime sector, regulations aiming to reduce greenhouse gas emissions from ships to net zero by 2050 compared to 2008 have been announced [2]. In the EU, maritime emissions have been included in the Emissions Trading Scheme (ETS), and as of 1 January 2018, GHG emission monitoring has been mandatory for large vessels of 5000 tons or more loading or unloading cargo or passengers at ports in the European Economic Area (EEA). More and more stringent ship emission regulations are being enforced. Regulations on emissions from large merchant ships navigating overseas areas accounts for a very large part of ocean environment, and a ship performance monitoring and analysis system is systematically equipped to respond to these regulations. By reflecting upon the results, it is possible to thoroughly manage and supervise the exhaust gas generated by ships. Vessels registered in the Republic of Korea can be divided into ocean-going vessels navigating abroad and coastal vessels navigating domestic coasts, and the number of coastal vessels (including fishing vessels) is 30 times greater than that of ocean-going vessels [3]. Although the total tonnage, size, and output of individual ships are smaller than those of ocean-going ships, it can be said that the total number of these ships is large, taking up a significant proportion of the total tonnage of ships. Therefore, it is crucial to utilize ship performance monitoring and analysis systems to monitor these coastal ships.

In addition, in the case of the project of retrofitting a conventional diesel propulsion system to an eco-friendly ship and a new building as an eco-friendly propulsion system, following the eco-friendly ship-supply policy in effect in Korea [4], the operating profile data of existing ships are absolutely required. The operation characteristic data refer to the ship's speed, engine output, fuel consumption, and power consumption, but most coastal ships are not equipped with a performance-monitoring system. Therefore, coastal vessels are designed in detail, without measuring the actual load profile, by referring to existing similar specifications, which can cause many problems when the actual vessel is built and operated.

However, most of the ship performance monitoring and analysis systems currently in use are limited to large merchant ships or to the engine manufacturers' own products, which do not provide ship owners with free access. In addition, since various sensors and software products are required, it is difficult to use them individually [5]. In particular, it is difficult to apply such a large system to a small coastal vessel. Accordingly, the development and application of a ship performance monitoring and analysis system that can be applied to small and medium-sized coastal ships will support the systematic accumulation of data according to ship type in the eco-friendly public ship conversion project of the Korean government [6]. In addition, in response to the Energy Efficiency Design Index (EEDI) and Energy Efficiency Existing Ship Index (EEXI) regulations limited to large merchant ships [7], if such a performance-monitoring and analysis system is developed and installed on coastal vessels, not only would it be possible to perform the EEXI management of coastal vessels, which account for a significant proportion of vessels, but the degree of aging of the vessel could be monitored from a remote center onshore. Additionally, based on the real-time ship data received from these ship performance monitoring and analysis systems, it is possible to transmit and receive various types of ship data from a remote center installed on land. It is also possible to incorporate digital twin technology based on these real-time data transmission and reception systems, and this could have a large impact on the prevention of accidents caused by ships through the continuous monitoring of coastal ships. Furthermore, it is possible to use this as the basis for the application of an autonomous navigation system. In this study, a ship-performance-monitoring system was configured and applied to an actual target ship. To develop the system, only the minimum number of sensors was selected, and the measuring data were converted to meaningful values for a performance evaluation, economic analysis, and an emissions evaluation. The software and portable hardware were developed using the UPS system. Based on the results, it was possible to monitor the operational status of the target ship based on the data that were measured and transmitted in real-time from the onshore remote center. A system was established on a test fishing boat to enable the operational status of the target vessel to be monitored at the onshore remote center.

1.2. Literature Review

Regarding ships' performance-monitoring systems, research and development are mainly focused on large propulsion engines, which account for the most important part of ships' condition monitoring. For the real-time monitoring and efficient maintenance of ships, large merchant ships are often equipped with performance-monitoring and analysis systems provided by individual equipment manufacturers. Representatively, MAN Energy Solutions company, which occupy a large portion of the large propulsion engines of ships, applied a system that continuously monitors the combustion status of a ship's main engine using equipment such as the Pressure Mean Indicator (PMI) and the Computer-Controlled Surveillance Engine Diagnostics System (CoCoS-EDS), which are capable of diagnostic functions, and preventive maintenance information is applied to large ships [8]. In addition, KYMA [9] and HBM [10] have developed a system that increases fuel consumption efficiency via measuring load through installing a torque sensor on the shaft and thus optimizing the engine performance of the ship; this system is being applied to many large merchant ships.

To analyze the propulsion and navigation performance of ships, an engine-monitoring system using Principal Component Analysis (PCA) was applied to suggest the area used for the operation of a ship's engine [11]. A study was conducted on the change in the detection level of the performance-monitoring system in the case of sensor failure through a sensor fault detection model installed in a ship's main engine [12]. In addition, an empirical study comparing a ship model and a target ship was conducted to measure the performance of a ship that mainly sailed in the Arctic Ocean. By applying the monitoring system installed on the ship, the actual ship data and the data output from the model were compared to estimate the fuel consumption of the ship, and research on the suitability of the Arctic Ocean navigation plan was conducted [13]. In addition, research on a system that can predict a ship's output through machine learning was conducted by assembling a dataset that synchronizes the Automatic Identification System (AIS) equipment used for navigation and weather prediction information [14]. A study was conducted to establish a statistical model through an accurate analysis of data collected from sensors and devices installed for effective ship operation in large ships [15]. Through this approach, a step-by-step method of ship operation and performance analysis was presented [16]. Additionally, a project was carried out to monitor ship performance and find ways of reducing fuel consumption. To achieve this result, key data were collected, and a preliminary analysis was conducted; additionally, a study was conducted to select performance indicators and derive items for ship performance management [17]. In addition to these studies, a ship-performance-monitoring system was applied as a method of comparatively analyzing the effects of paints newly applied to ships' hulls and as a way of verifying the performance of products such as various ship sensors [18–20]. Rather than analyzing the performance of a ship, many studies have been conducted on the performance analysis system to highlight the differences that occur when a newly built ship or new types of equipment are applied and when a newly developed product is applied. However, there is insufficient research with which to analyze the data by installing such a ship-performance-monitoring system on small and medium-sized coastal vessels that are actually operating and to apply the results for the construction and operation of an eco-friendly ship conversion. Therefore, in this study, a ship-performance-monitoring system that can be applied to small and medium-sized coastal vessels (including fishing vessels) was developed. Through this, real-time measurements of operational data such as fuel flow, engine rpm, and GPS data of the target ship were carried out, and the load profile of the ship, fuel consumption, engine load, etc., were derived as a result of analyzing the measured data. Through the load profile derived as a result of this analysis, it is possible to select a optimal propulsion system for an eco-friendly ship and thus replace conventional vessels with eco-friendly vessels and to obtain technical data that can lay the foundation for operating existing vessels in as an eco-friendly a manner as possible. Therefore, this study can be said to be a very important step in the eco-friendly ship construction project.

2. Methodology

Numerous data on the systems in a ship are collected and transmitted. However, if all these data are used for evaluating performance and environmental effects, the monitoring system becomes a complicated system, making it difficult to apply to small and medium-sized ships due to the cost and installation area. Therefore, a minimum number of crucial data should be selected and transmitted to a system to calculate performance, efficiency, capital expenditures (CAPEX), Operating Expenditure (OPEX), and environmental effects. When developing the proposed simplified performance-monitoring system for small and medium-sized ships, as shown in Figure 1, the first step was to choose the desired result value, which can be measured or calculated by collecting values such as Specific Fuel Oil Consumption (SFOC), fuel consumption, ship's velocity, emissions assumptions, etc. In step II, only minimum sensors related to performance were selected, like rpm sensors, fuel flow sensors, etc. Also, using a conventional Global Positioning System (GPS) sensor, it is possible to check the position and speed of a ship according to the time, and the slip of the ship can also be calculated by comparing it with the output of the engine. The output of the engine has traditionally been calculated using the torque meter of the engine shaft or the mean effective pressure value of the cylinder. However, in the case of the proposed performance-monitoring system, fuel consumption, the output and efficiency of the engine, and SFOC can be estimated using only the fuel flow meter by employing the fuel index conversion value and rpm information. In addition, the calculated fuel consumption level can be converted into carbon dioxide emissions and fuel costs.

Figure 1. Methodology for designing a simplified performance-monitoring system.

After calculating the constant value c at the maximum engine output in Equation (1), the fuel index at each load is multiplied by the rpm and *c* value to determine the specific engine output value. The fuel index is calculated based on a comparison of the measured fuel consumption level for each load with the fuel consumption level at the maximum engine output.

$$Output[kW] = c \times RPM \times Fuel\ Index \quad (1)$$

$$SFOC[{}^{g}/_{kWh}] = \frac{Fuel\ oil\ consumption}{Engine\ output \times hour} \quad (2)$$

$$SC[{}^{g}/_{kWh}] = \frac{CO_2\ emission}{Engine\ output \times hour} \quad (3)$$

$$Fuel\ cost\ [USD] = fuel\ consumption[g] \times fuel\ price[USD/g] \quad (4)$$

To obtain the data and perform calculations, proper software and hardware should be developed, as in step III. In this research, specific software for the selected items and the data that were to be calculated was implemented using the LabView program and NI equipment. For the long-distance data transmission of the system, real-time shore communication via a Long-Term Evolution (LTE) communication network was applied using a portable system. After the installation of the system on the ship, the collected data should be checked and calculated so that they are rendered effective values for the performance and emissions evaluation in step V.

3. Results

3.1. The Desired Values

The results selected to analyze the ship's performance and emissions included the ship's position, the ship's speed, engine rpm, engine output [%, kW], fuel consumption, SFOC [g/kWh], Specific Carbon Dioxide (SC) [g/kWh], carbon dioxide emissions, and fuel cost. To calculate these parameters, GPS data, engine rpm, and fuel flow information were measured in real-time using the data measurement system, and the data were stored in the developed system and analyzed to derive the desired result.

3.2. Minimum Sensor Selection for the Desired Results

To convert the result values presented in Section 3.1 above, GPS, flowmeter, and RPM measurement sensors were selected. The Global Positioning System (GPS) receiver selected to recognize the ship's speed and position is an MTK 66 channel that uses a DGPS function to reduce errors, and it is manufactured at a tiny size so that it is easy to mount on an actual fishing boat. It applies the NMEA 0183 communication protocol and outputs date, time, location, operating profile, and speed data through this receiver, transmitting these data to the data collection and analysis device. GPS data are sent to the system through the RS232-to-USB converter via the NMEA 0183 communication protocol. The receiver sets the time to Korean time and collects three latitude/longitude/velocity signals every second. According to the NMEA protocol, all collected GPS signals are stored in the data collection and analysis system. The movement information of the ship's position according to time is converted into speed. This can be converted into [km/h] onshore and [knot] units at sea. To ensure data reliability, all Recommended Minimum Specific GNSS Data (GPRMC) signals and Global Positioning System Fix Data (GPGGA) are stored, and the GPRMC maintains a unique version of the essential position, velocity, and time data in the NMEA communication protocol. An essential element of analyzing a fishing boat's economic and environmental characteristics is a flow meter that measures fuel consumption. Due to the limited installation work on fishing boats, it was difficult to remove the fuel pipe and install an additional flow meter, so a digital non-contact flow meter was applied. The load was calculated according to the flow rate and engine rpm. The speed within 2000 [rpm] was output as a voltage signal of 0~1 [V] through the reflective tape installed on the rotating shaft with the non-contact rotation-speed-measuring device, and the data were transmitted to the data collection device.

3.3. Design and Construction of a Performance-Monitoring System

In the case of a conventional ship, the data collection and performance and emission analysis systems are complicated. The communication data are massive to ensure that they can handle all information about the pressure and temperature in the engine room and the ship's position, speed, engine rpm, power, and fuel oil consumption. However, in the case of a fishing ship, the ship's structure is too narrow, and the data transimited by a small propulsion engine is limited. Therefore, to evaluate fishing ships' economic and environmental characteristics, it is necessary to derive meaningful results with scarce information.

In this study, the system shown in Figure 2 was implemented so that speed, engine output, fuel consumption, efficiency, and carbon dioxide emissions could be checked by referencing GPS, engine rpm, and flow meter data.

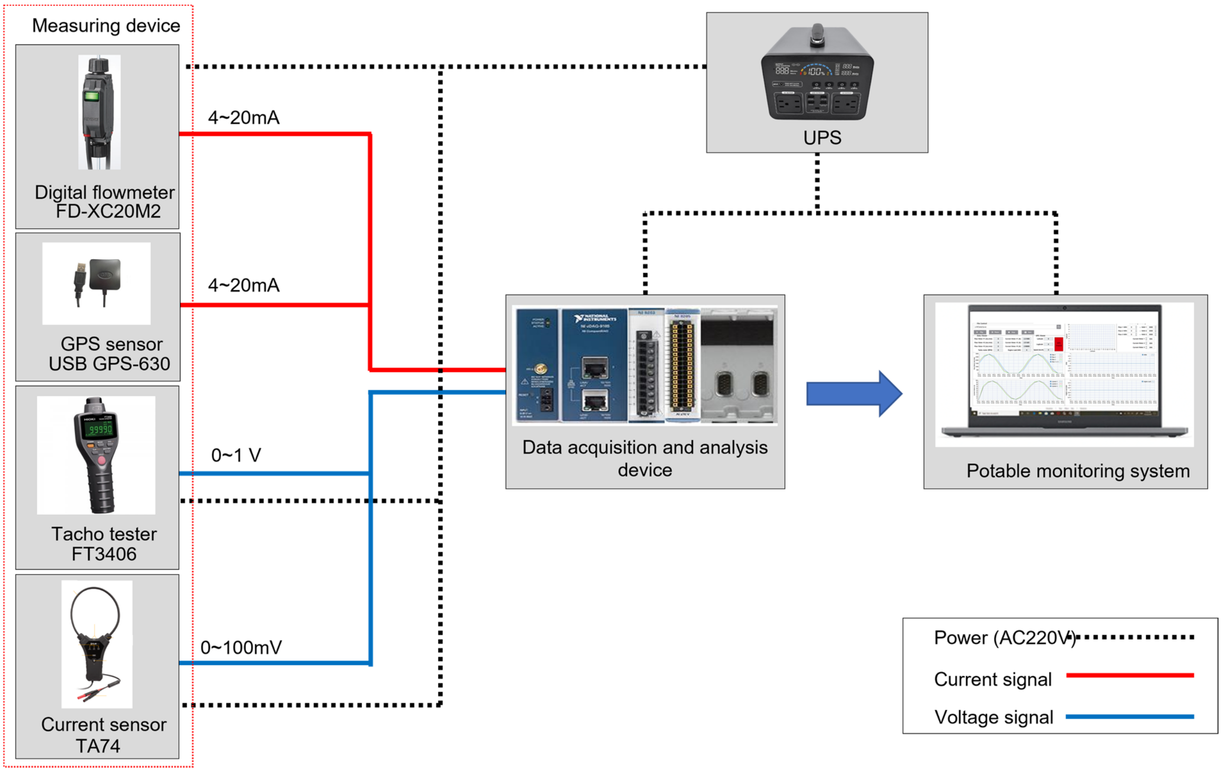

Figure 2. Configuration of data acquisition and analysis system.

The measurement system proposed in this study makes it possible to determine data including the operating profile, engine operation characteristics and efficiency, fuel consumption, fuel cost, and carbon dioxide emissions of a fishing ship. Although it is simpler than the conventional system, it has a significant advantage in its ability to intensively calculate the essential elements for analyzing the economic and environmental characteristics of a ship.

The proposed system is designed to be portable and can be quickly installed and dismantled on various types of small and medium-sized ships. The generator's output can also be calculated using the current-measuring device of a ship's generator. Data from the flowmeter and rotation-speed-measuring device are received through NI cDAQ. The NI cDAQ-8184 is an ethernet-based data acquisition device that acquires data via connecting to a PC. The NI 9203 is a current input module that receives the current output signal from the flowmeter, converts it into a flow rate, and stores it. It is designed for use in high-performance control and monitoring applications. It features a 200 kS/s, ±20 mA, 8-channel C Series current input module with a programmable input range and variable connection options. The NI-9203 includes channel-to-ground double ground isolation (250 Vrms isolation) for safety and noise immunity to protect against signal transients. The NI 9205 is a voltage input module that receives the voltage from the high-current-measuring device, converts it, and saves it. The NI 9205 accepts either single-ended or differential analog inputs, each of which are assigned four programmable input ranges. It features ±10 V, 250 kS/s, 16-bit, 32-channel C Series voltage input modules with a choice of four programmable input ranges. The NI 9205 includes up to 60 V overvoltage protection between input channels and COM to protect the system from signal transients and provides channel–ground double ground isolation for safety, noise immunity, and high common-mode voltage ranges. The NI 9401 is a digital input module that converts the pulse output from the tachometer into a digital count, converts it to RPM, and stores it. Each device receives 1000 samples per second and outputs one piece of data per second as an average value. In the case of the rotation-speed-measuring device, the system was configured to measure rotation speed by multiplying the data obtained as an average value by 60. The program proceeds as shown in Figure 3. All signals verify the validity of the GPS signal at the start to synchronize it with the GPS signal and start data collection after verifying the GPS signal. All data are corrected according to the sensor's calibration value, as specified by the user, and the flow rate regression is also converted to calculate the total flow rate. All data are precisely synchronized and stored as data. The program is designed to reconnect within five seconds if the connection is disconnected when a fishing ship is experiencing unstable power supply conditions.

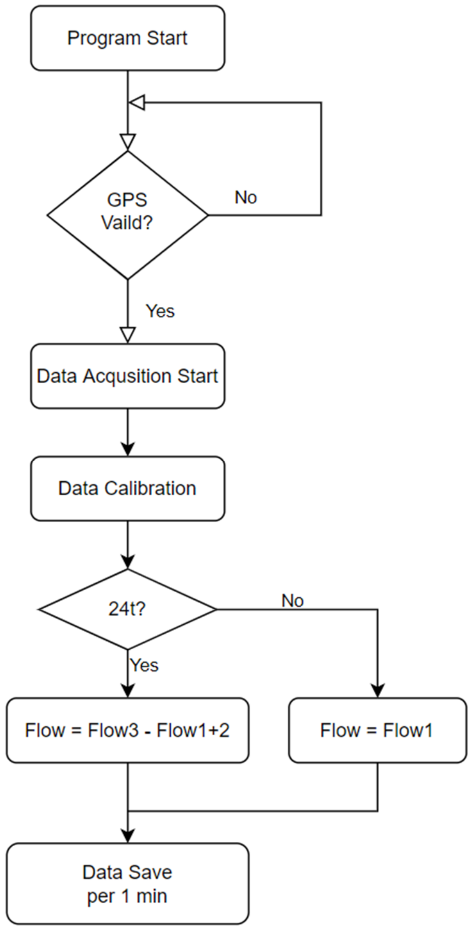

Figure 3. Flow chart of data acquisition.

In addition, since the instability and quality deterioration of the power supplied by fishing boats may affect the operation of installed equipment or sensors, a UPS power supply was established for the stable operation of devices and sensors. The measuring device is powered by the output of the battery pack. The battery pack for the power supply is a lithium–iron–phosphate battery with a total capacity of 2200 W. The data analysis system can be operated without a separate power supply for one week.

The data collection device can be connected to a PC via Ethernet. It is possible to transmit the data collected from the ship to the shore data analysis device in real time through the LTE communication network. The data are saved every second, and the data come in the form of TDMS. LabVIEW's fastest data storage method is applied to ensure capacity and system stability during long-term measurement. It is easy to export data to Excel and link them to the monitoring program DIADEM. The data capacity can reach about 50 MB per day, and the device is designed to store voyage data for an average of one week or more.

As shown in Figure 4a, GPS data are transmitted to the system through the RS232-to-USB converter through the NMEA 0183 communication protocol. The system receives time zones for each region of the world, adjusts the time to Korean time, and collects three signals of latitude/longitude/velocity each second. All collected GPS signals are stored in the data collection/analysis system according to the NMEA protocol. To ensure data reliability, both Recommended Minimum Specific GNSS Data (GPRMC) and Global Positioning System Fix Data (GPGGA) signals are stored. GPRMC refers to a unique version of essential position, velocity, and time data in the NMEA communication protocol, and GPGGA refers to fixed data with a total of 17 field values. Collected and processed data are stored every second. The data are in the form of TDMS, and the lowest-volume and fastest data storage method provided by LabVIEW is applied to ensure high capacity and system stability during long-term measurement. It is easy to export the data to Excel and link them with the monitoring program 'DIADEM'. The current data capacity is up to about 50 MB per day, and it is possible to store more than a week of average voyage data, as shown in Figure 4b.

In addition, data such as fuel consumption, engine output, rotation speed, ship speed, and position stored in the data collection/analysis device can be checked in real-time through the mobile monitoring device. Data are saved in TDMS file format using the software for data confirmation, as presented in Figure 4c, and can be checked using 'DIADEM,' a commercial software provided by NI, and exported to an Excel file. The data of the flow meter and rpm measuring device are received through NI cDAQ. The data transmitted from each device receive 1000 samples per second and output 1 data point per second as an average value. In the case of the rpm-measuring device, the system was configured to measure rpm by multiplying the averaged data by 60. The data collected as current value from each device are converted into flow rate and RPM data through a conversion process and stored. The system is designed to try to reconnect within 5 s if the connection is lost in unstable power supply conditions. The data on the data acquisition/analysis device are saved in the TDMS file format and can be checked using 'DIADEM', a commercial software provided by NI. In addition, if necessary, they can be exported to Excel and used, and the monitoring screen is configured to set the data range, save files, and check trends through real-time figures and graphs, as shown in Figure 4d,e.

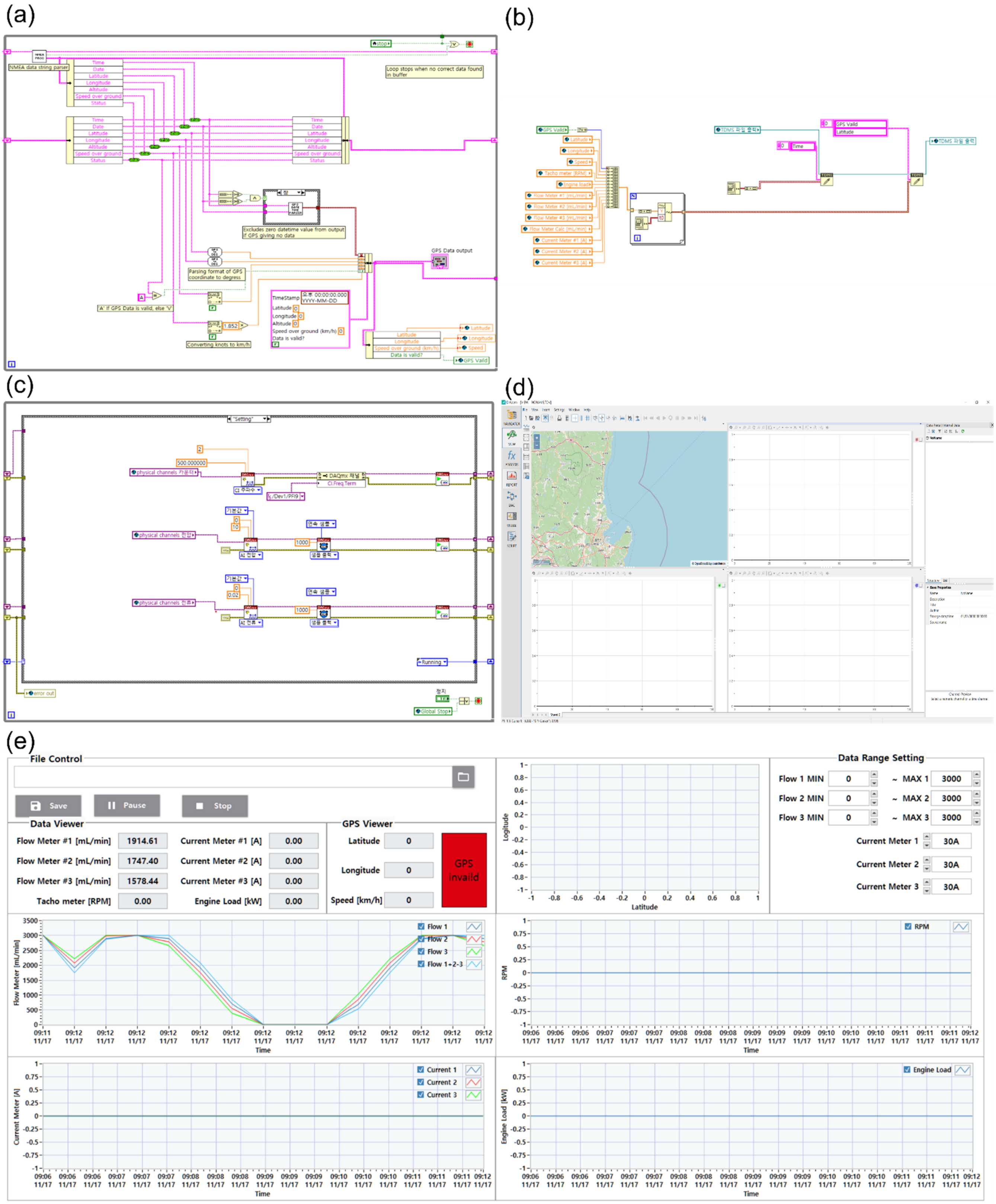

Figure 4. Data acquisition, analysis, and monitoring system; (**a**) software for GPS data, (**b**) software for data collection, (**c**) software for data storage, (**d**) software for data monitoring, and (**e**) data-monitoring system.

3.4. Installation and the Measurement of Performance

3.4.1. Select Reference Vessel

The vessel selected was a 4.99-ton boat, operating in the coastal combined fishery, that has a relatively short sailing time. The weather conditions on 7 December 2021, when the operation and analysis cycle of the ship were analyzed, were generally sunny, and the average wave height was 0.2~0.7 m. It operated in a relatively calm state. The operation cycle was analyzed and initiated. The ship sailed at an average speed of 8.2 knots during the operating cycle. During sailing, the engine was stopped, and according to the current pattern, a drifting type of operation cycle was observed in the area. It was operated on the same course at an average speed of 7.9 knots when returning to the berth.

3.4.2. Installation

For the 4.99-ton boat, the flowmeter, rpm detector, GPS, data collector, and UPS were installed on-site, as shown in Figure 5.

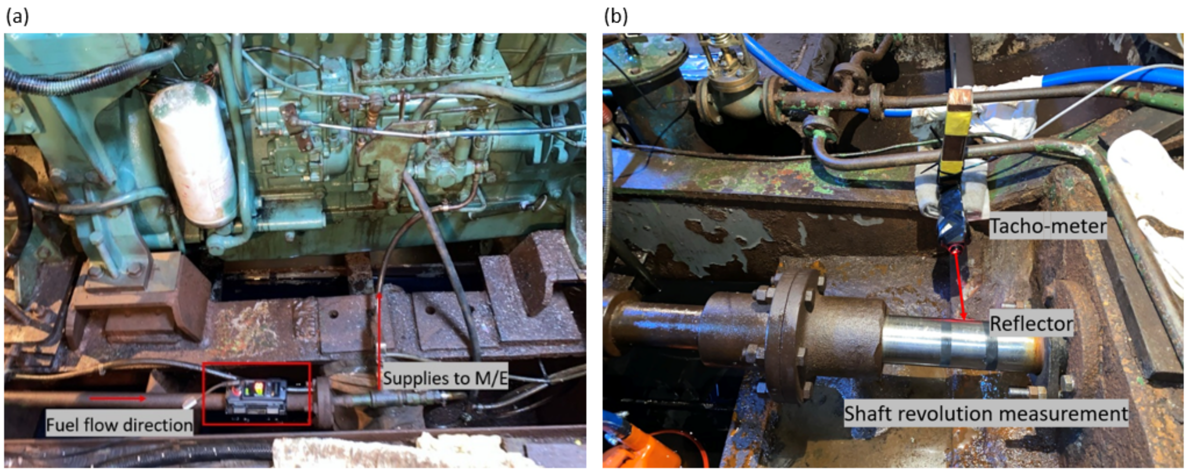

Figure 5. Installation position of sensors with respect to the engine: (**a**) digital non-contact flowmeter; (**b**) rpm sensor.

3.4.3. Performance Measurement

Location and Speed

The position of the ship is automatically recognized by the GPS signal, and the coordinate signal, synchronized with time, indicates the ship's speed, as shown in Figure 6.

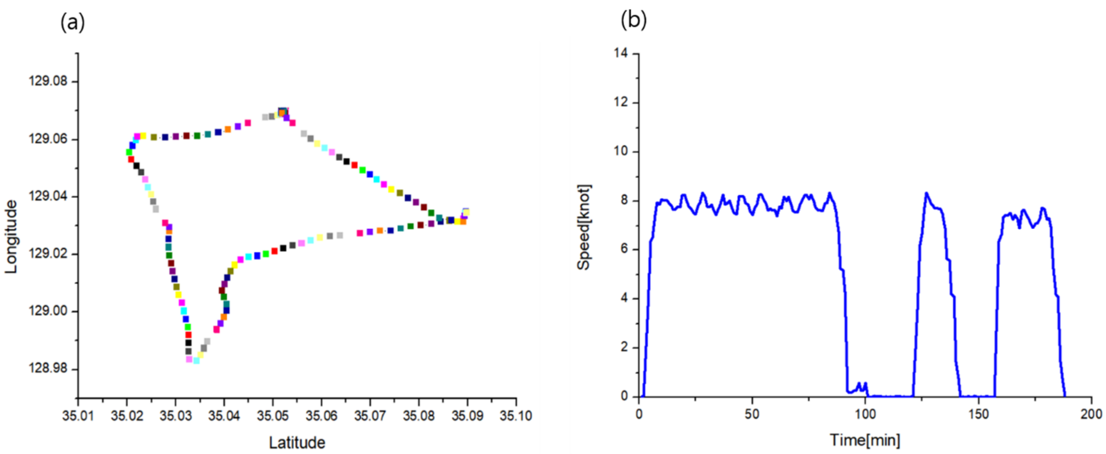

Figure 6. Position and speed of reference boat: (**a**) position; (**b**) speed.

Engine Rpm

Since the relative ratio of the reduction gear is different when the propeller rpm and the engine rpm are measured, as shown in Figure 7, the propeller rpm is converted into engine rpm, reflecting the reduction ratio.

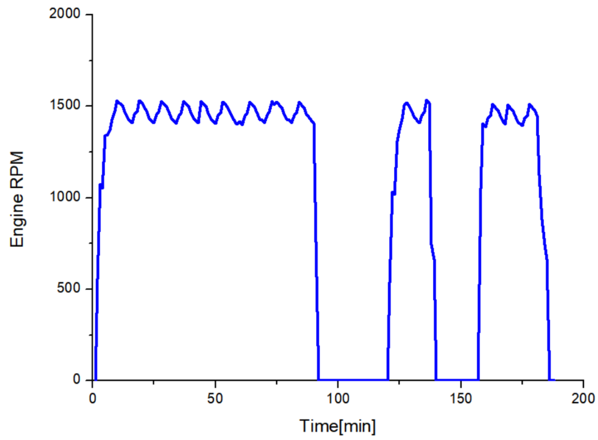

Figure 7. rpm of the reference fishing boat.

Engine Output and Fuel Index

As the ship was old, the fuel index was relatively high and was always maximal when the ship was sailing so that the maximum ship speed could be achieved, as shown in Figure 8. As a result, the efficiency of the fishing ship was reduced, and the carbon dioxide emissions increased due to the age of the ship.

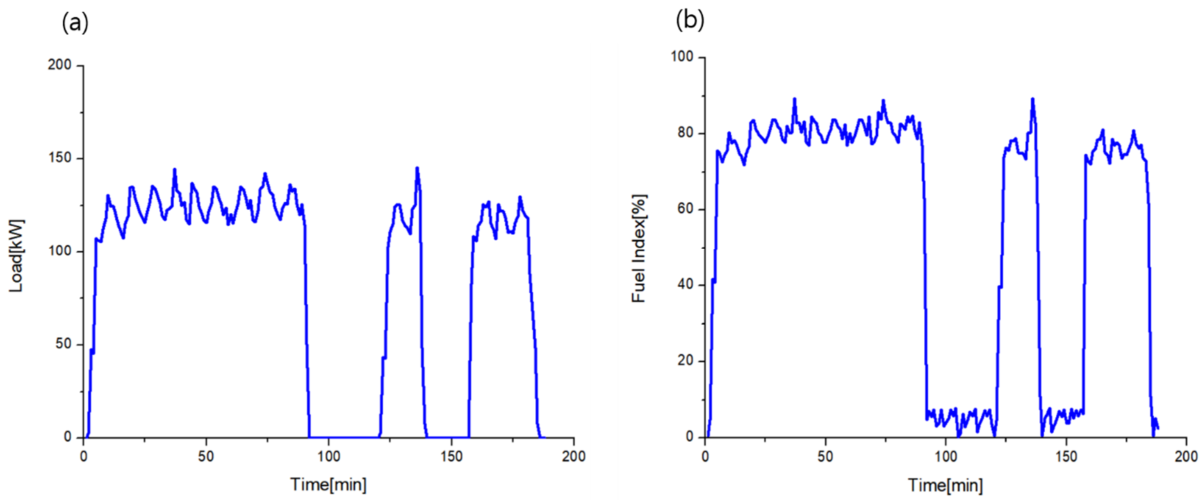

Figure 8. Output and fuel index of reference fishing boat: (**a**) engine output; (**b**) fuel index.

Specific Fuel Oil Consumption (SFOC) and Efficiency

Based on the fuel consumption per unit time and the output at a given time, the fuel consumption per unit time can be calculated, as shown in Figure 9. This indicates an efficient operation section of the engine and generally exhibits excellent efficiency in a high-load region. In addition, in the case of the selected fishing ship, it can be confirmed that the existing SFOC curve deviates from the entire area, as shown in the load–SFOC curve, due to the old age of the propulsion system. This can be used to predict an increase in carbon dioxide emissions through increased fuel consumption. In addition, idling operations in the low-load area adversely affect the ship's overall environmental performance.

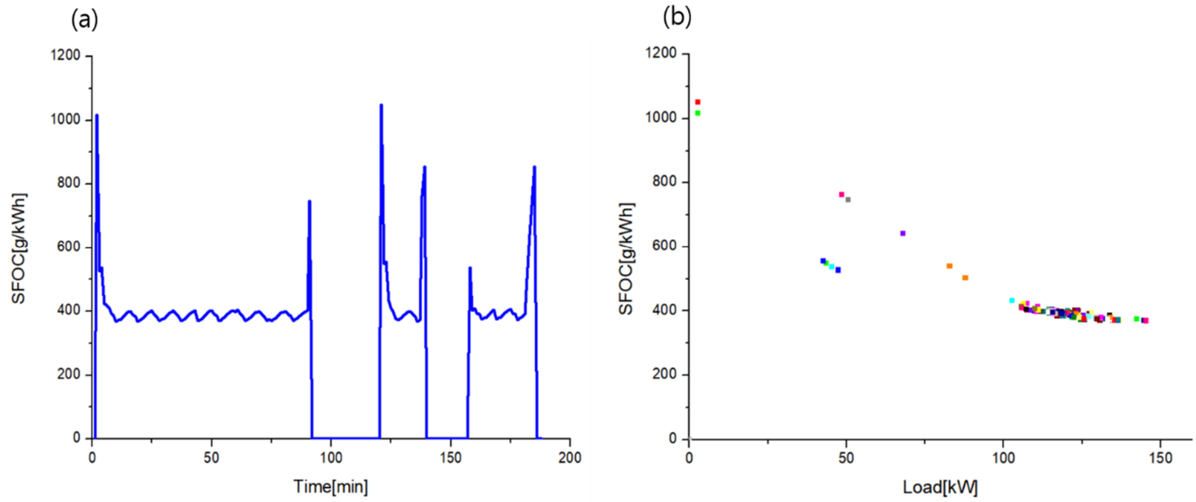

Figure 9. SFOC of reference ship: (**a**) SFOC–time; (**b**) SFOC–curve load.

Fuel Oil Consumption, Fuel Cost, and CO_2 Emissions

As shown in Table 1, it is possible to calculate the accumulated fuel consumption value using the flowmeter. The fuel cost calculation was based on Hongkong USD 948/mt as of 2022, and to estimate carbon dioxide emissions, a CF value of 3.206 at ISO 8217 grade was used.

Table 1. Fuel oil consumption, fuel cost, and CO_2 emissions of the reference ship.

Item	Unit	Amount
Fuel oil consumption	[kg]	106.1
Fuel cost	[USD]	100.6
CO_2 emissions	[kg]	340.2

4. Discussion

4.1. Novelty

Previous research on ship performance and emissions focused on large merchant ships, and, in the case of small and medium-sized ships, the construction of facilities is limited due to the relatively low cost of shipbuilding and the narrow hull structures. However, in efforts to reduce emissions from ships, the total carbon dioxide emissions of ships on the coast can become as high as those of ocean-going merchant ships. Accordingly, government policy is being strengthened for coastal ships due to the high number of coastal ships. In this study, using only a fuel flow meter, an rpm sensor, and a GPS sensor, a ship performance and emissions analysis could be achieved for small and medium-sized ships. Measured fuel consumption data can be converted to fuel consumption and engine output data, which can be compared to shop test data. This will show the aging trend and efficiency of a ship. Furthermore, fuel consumption data can be transformed into fuel costs and CO_2 emission amount estimations. By using a fuel flow sensor, the total CO_2 emission amount not only for one ship but also for a whole country's CO_2 emissions from coastal ships can be estimated using this portable performance system. Through this approach, the performance and CO_2 emissions of ships and engines can be evaluated.

4.2. Future Study

In the case of coastal ships, since they use various types of fuels, the emission effects according to the fuel properties should be reviewed. As electric power is used in ships, the power consumption of the generator should be reviewed to consider the total operation efficiency of the ship by calculating the electricity used for special functions.

5. Conclusions

This study developed a ship performance and CO_2 emissions assumption system for small and medium-sized ships. Comparing the technical developments of performance-monitoring systems in large merchant ships and small-medium-sized ships, it was difficult to find effective systems for small-medium-sized ships. However, the environmental effect of coastal ships on the ocean is a crucial issue. To evaluate the emissions of a conventional ship, measuring sensors are installed in the ships' funnel or on the engine side. It usually requires a complicated system which causes expensive investment. However, the monitoring system proposed in this study was intended to make a simple performance and emissions gas-monitoring system using limited sensors and a developed system. Using this approach, data were collected using the collection device and software, and additional data were collected using a pre-entered formula. This enabled the user to check real-time data, which were also transmitted from the shore. It was possible to verify the ship's position and speed over time, engine output, engine SFOC, fuel consumption, fuel cost, and estimated carbon dioxide emissions. Considering the space of a small coastal ship, the system was implemented as a portable system, and a UPS was installed to prepare for a blackout situation on the ship. The type of sensor was selected according to its capacity so that it could be applied to various small and medium-sized ships, and a non-contact method was applied so that the conventional system was not modified. The correction factor and fuel data should be further adjusted according to the type of ship and fuel used. Lastly, one of our research shortcomings in this study is that the correction factor for the power calculation, should be verified using an additional torque meter or other power meter. Also, the emission amount verification by the CO_2 sensor is required to reduce our research gap.

Using this system, the user and government can ascertain a ship's aging trend and its effect on fuel cost and CO_2 emissions. These load profile data also will give source data to design an eco-friendly propulsion system for small and medium-sized ships, and it will be possible for policymakers to calculate the expected environmental benefits when converting to an eco-friendly propulsion system.

Author Contributions: H.K.: investigation, formal analysis, resources, conceptualization. H.J.: funding acquisition, project administration, software, writing—review and editing, supervision. S.K.: data curation, methodology, validation, visualization, writing—original draft. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

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