

DESCRIPTION

FOULING IMPACT ASSESSMENT DEVICE AND PROGRAM

5 Technical Field

[0001] The present invention relates to a technology for assessing an impact of hull fouling.

Background Art

10 [0002] Technologies for assessing fouling of a hull of a ship are known (e.g., Patent Literature 1).

Citation List

Patent Literature

15 [0003] Patent Literature 1: JP 2018-27740A

Summary of Invention

Technical Problem

[0004] To assess an impact of hull fouling, one method involves carrying out
20 performance analysis of a ship based on a speed and horsepower of the ship. However, since degradation in performance of the ship identified by this performance analysis is caused not only by an impact of hull fouling but by other factors also, and thus it is not possible to accurately assess an impact of hull fouling using this method. Another method involves use of UWI (Under
25 Water Inspection) reports that include images captured of a bow, midsection, and stern of a hull, and a state of fouling determined using these images, to assess an impact of hull fouling based on information in the UWI reports. However, since the information included in the UWI reports shows only a partial fouling state of the hull, an impact of fouling of the entire surface of
30 the hull cannot be assessed using this method.

[0005] An object of the present invention is to accurately assess an impact of fouling of an entire surface of a hull of a ship.

Solution to Problem

5 [0006] One aspect of the present invention provides a fouling impact assessment device including: acquisition means for acquiring fouling levels of a plurality of regions of a surface of a hull of a ship; and calculation means for calculating a frictional resistance of an entirety of the hull, using coefficients of frictional resistance corresponding to the fouling levels of the plurality of
10 regions.

[0007] The acquisition means may further acquire position information indicating positions of the plurality of regions on the hull, and the calculation means may calculate, for each of the plurality of regions, a frictional resistance of a region, using a flow speed at a position indicated by the
15 position information of the region and a coefficient of frictional resistance corresponding to a fouling level of the region, and calculates the frictional resistance of the entirety of the hull by summing frictional resistances of the plurality of regions.

[0008] The fouling impact assessment device may further include reception
20 means for receiving images of the plurality of regions captured by an underwater moving body; determination means for determining the fouling levels of the plurality of regions using the images; and mapping means for associating, for each of the plurality of regions, position information indicating a position of a region with a fouling level of the region.

25 [0009] The underwater moving body may capture the images along a weld line of the hull, and the mapping means may specify positions of the plurality of regions on the hull, based on the weld line included in the images.

[0010] The mapping means may specify positions of the plurality of regions on the hull, based on a position of the underwater moving body measured
30 using an acoustic lighthouse.

[0011] The mapping means may specify positions of the plurality of regions on the hull, based on a position of the underwater moving body measured using an inertial navigation device.

5 [0012] The plurality of regions on the surface of the hull may be provided with marks indicating positions of the plurality of regions on the hull, and the mapping means may use the marks included in the images to specify the positions of the plurality of regions on the hull.

10 [0013] The fouling impact assessment device may further include reception means for receiving images of the plurality of regions captured by an underwater moving body that includes an arm and a camera, using the camera together with a fouling sample plate held alongside the surface of the hull by the arm; and determination means for determining the fouling levels of the plurality of regions, based on a similarity between fouling samples of the fouling sample plate included in the images and each of the plurality of
15 regions.

[0014] The fouling impact assessment device may further include storage means for storing a history of the frictional resistance of the entirety of the hull or fuel consumption calculated from the frictional resistance, and a period in which maintenance work for reducing the frictional resistance of the
20 hull is performed; and analysis means for performing trend analysis for predicting future change in fuel consumption in a case where the maintenance work is performed at a predetermined time interval, based on the history and the period.

[0015] The fouling impact assessment device may further include reception
25 means for receiving input of an image, captured together with a fouling sample plate by image capture means, of a target region between a first waterline in a first draft state of the hull and a second waterline in a second draft state different from the first draft state; and determination means for determining a fouling level of the target region, based on a similarity between
30 the target region and fouling samples of the fouling sample plate included in

the image, and the calculation means may calculate the frictional resistance of the entirety of the hull, further using a coefficient of frictional resistance corresponding to the fouling level of the target region.

[0016] The calculation means may calculate an increase in frictional resistance of the target region caused by fouling, based on a difference in required horsepower between the first draft state and the second draft state.

[0017] Another aspect of the present invention provides a program for causing a computer to execute: a step of acquiring fouling levels of a plurality of regions of a surface of a hull of a ship; and a step of calculating a frictional resistance of an entirety of the hull, using coefficients of frictional resistance corresponding to the fouling levels of the plurality of regions.

Advantageous Effects of Invention

[0018] According to an aspect of the present invention, the impact of fouling of an entire surface of a hull of a ship can be accurately assessed.

Brief Description of Drawings

[0019] FIG. 1 shows an example of an assessment system according to an embodiment.

FIG. 2 illustrates an image captured by an underwater drone.

FIG. 3 shows an example configuration of a server device.

FIG. 4 is a flowchart illustrating processing for quantitatively assessing an impact of fouling.

FIG. 5 illustrates mapping data.

FIG. 6 illustrates the results of trend analysis of an increase in fuel consumption caused by an impact of fouling of the entirety of a hull.

FIG. 7 shows an example of a submerged region of the hull.

FIG. 8 shows an example of correlation information indicating a relationship between ship speed and horsepower of a main engine.

FIG. 9 shows another example of correlation information indicating a

relationship between ship speed and horsepower of a main engine.

Description of Embodiments

1. Configuration

5 [0020] FIG. 1 shows an example of assessment system 1 according to an embodiment. Assessment system 1 uses images of the hull of a ship captured by underwater drone 20 to assess an impact of hull fouling, and provides information to assist in determining whether to implement maintenance work on the hull. It is of note that “hull” used herein refers to
10 the main body of ship 10, excluding cargo and accessories, and does not include the propeller.

[0021] Assessment system 1 includes underwater drone 20, control device 30, and server device 40. Underwater drone 20 is communicably connected to control device 30 via communication cable 2. Control device 30 is connected
15 to server device 40 via network 3 such as the Internet. Also, server device 40 is communicably connected to a terminal device (not shown) installed in ship 10 via network 3 and communication satellite 4. Server device 40 is thus able to acquire output of various sensors installed in ship 10.

[0022] Underwater drone 20 dives while ship 10 is moored, and moves
20 underwater along a predetermined route and captures images of a plurality of regions of the hull. More specifically, underwater drone 20 captures images of a plurality of regions of the hull while moving along weld lines of the hull. Underwater drone 20 is an example of an underwater moving body according to an aspect of the present invention. Underwater drone 20
25 includes arm 21, camera 22, and communication IF (interface) 23.

[0023] Arm 21 holds a fouling sample plate such as a Rubert gauge alongside the surface of the hull. More specifically, arm 21 presses the fouling sample plate against the surface of the hull using a spring or other pressing unit. This is because when using an image of the hull captured to determine a
30 fouling level of the hull, the hull included in the image is compared with the

fouling sample plate. Thus by keeping a distance of camera 22 to the hull as close as possible to the distance of camera 22 to the fouling sample plate, determination of the accuracy of a fouling level is increased.

[0024] Camera 22 captures images of a plurality of regions of the hull together with the fouling sample plate. The images captured by camera 22 are, for example, moving images. However, the images captured by camera 22 are not limited to moving images, and may, for example, be still images captured at predetermined time intervals. To capture images of the hull as comprehensively as possible, the images are preferably horizontal panoramic images. Images of the hull are captured together with the fouling sample plate so that when determining a fouling level of the hull using the images captured of the hull, the hull captured in these images can be compared with the fouling sample plate. Thus, by capturing images of the hull together with the fouling sample plate, comparison can be made that is unaffected by underwater variables such as variability in intensity of light underwater, angle of light, and color and turbidity of the water.

[0025] FIG. 2 illustrates image 220 captured by camera 22. Image 220 includes region 221, which is a region of the surface of the hull, and fouling sample plate 222. Fouling sample plate 222 includes a plurality of fouling samples 223 that have different levels of fouling. As mentioned above, underwater drone 20 captures images while moving along weld lines 224 of the hull, and thus image 220 includes weld lines 224 present on the surface of the hull.

[0026] Communication IF 23 transmits the images captured by camera 22 to control device 30 via communication cable 2. The images can include additional information such as a date and time of capture. It is of note that as used herein, the term “images” means digital images.

[0027] Control device 30 is installed on a pier and controls operation of underwater drone 20 in accordance with operations made by an operator. Control device 30 transfers images received from underwater drone 20 to

server device 40 via network 3.

[0028] Server device 40 is installed on land and is managed and operated by a shipping company. Server device 40 performs processing for assessing an impact of hull fouling of ship 10, based on the images captured by underwater drone 20 and provides information for determining whether to implement maintenance work on ship 10. Server device 40 is an example of a fouling impact assessment device according to an aspect of the present invention.

[0029] FIG. 3 shows an example configuration of server device 40. Server device 40 includes processor 41, memory 42, storage 43, communication IF 44, input unit 45, and display unit 46. Memory 42, storage 43, communication IF 44, input unit 45, and display unit 46 are each connected to processor 41 via a bus.

[0030] Processor 41 performs control of the various units of server device 40 and various computations by executing programs. Examples of processor 41 include one or more CPUs (Central Processing Units). Memory 42 is a computer-readable storage medium that is used as a work area of processor 41. Memory 42 stores data and programs that are executed by processor 41. Examples of memory 42 include a ROM (Read Only Memory) and a RAM (Random Access Memory). Storage 43 is a computer-readable storage medium that stores various types of data that are used by processor 41. Examples of storage 43 include an HDD (Hard Disk Drive) and an SSD (Solid State Drive). Memory 42 or storage 43 is an example of storage means according to an aspect of the present invention. Communication IF 44 is connected to network 3 and performs data communication with other devices via network 3 in accordance with a predetermined communication standard. Input unit 45 inputs to processor 41 signals generated by operations made by the user. Examples of input unit 45 include a keyboard and a mouse. Display unit 46 displays various types of information under control of processor 41. Examples of display unit 46 include a liquid crystal display.

[0031] Processor 41 functions as reception means 411, acquisition means 412,

determination means 413, mapping means 414, calculation means 415, creation means 416, and analysis means 417, by executing programs stored in memory 42. Reception means 411, acquisition means 412, determination means 413, mapping means 414, calculation means 415, creation means 416, and analysis means 417 are software modules that are realized by software cooperating with hardware resources.

[0032] Reception means 411 receives images of a plurality of regions of the hull captured by underwater drone 20. More specifically, when captured images of a plurality of regions of the hull are transmitted from underwater drone 20, reception means 411 receives the images via control device 30.

[0033] Acquisition means 412 acquires fouling levels of the plurality of regions of the surface of the hull along with position information indicating positions of the plurality of regions on the hull, using the images received by reception means 411. Acquisition means 412 includes determination means 413 and mapping means 414.

[0034] Determination means 413 determines the fouling level of each of a plurality of meshes obtained by dividing the surface of the hull, using the images received by reception means 411. More specifically, determination means 413 divides the surface of the hull into a plurality of meshes, with a region of the surface of the hull included in one image as one mesh. The number of meshes depends on the size of the hull, and may range from 100 to 1000 meshes, for example. It is of note that in a case where the image is a moving image, each frame constituting the moving image can be treated as one image. Determination means 413 determines a fouling level of each mesh, based on a similarity of a region of the surface of the hull included in the image with each fouling sample of the fouling sample plate. The fouling levels can be represented by letters representing grades such as "A" to "F," or by expressions representing qualitative assessments such as "Good," or by numerical values.

[0035] Mapping means 414 creates, for each of the plurality of meshes of the

hull, mapping data that maps position information indicating the position of the mesh on the hull to the fouling level of the mesh determined by determination means 413. More specifically, mapping means 414 specifies respective positions of the meshes on the hull, by comparing the weld lines included in the images received by reception means 411 with a steel plate layout diagram of the hull stored in storage 43. Next, mapping means 414 associates, for each of the plurality of meshes of the hull, the position information indicating the position of the mesh with the fouling level of the mesh. In this way, mapping data is created. Mapping means 414 stores the created mapping data in storage 43.

[0036] Calculation means 415 calculates the frictional resistance of the entirety of the hull, based on the mapping data stored in storage 43. More specifically, calculation means 415 first calculates, for each of the plurality of meshes of the hull, the frictional resistance of the mesh, using the flow speed at the position indicated by the position information of the mesh included in the mapping data, the area of the mesh, and a coefficient of frictional resistance corresponding to the fouling level of the mesh. The correspondence between the fouling level and the coefficient of frictional resistance is obtained by measuring the coefficient of frictional resistance of a plurality of fouling samples of fouling levels and is stored in advance in storage 43 as a correspondence table. The coefficient of frictional resistance increases as the fouling level increases. It is of note that the correspondence table may be modified, as appropriate, in accordance with a correspondence between measurement of a fouling level of an actual ship and the coefficient of frictional resistance. Next, calculation means 415 calculates the frictional resistance of the entirety of the hull, by summing the frictional resistances of the plurality of meshes of the hull. Calculation means 415 then stores the calculated frictional resistance of the entirety of the hull in a ship database stored in storage 43. The frictional resistance of the entirety of the hull indicates the impact of fouling of the entire surface of the hull. An amount

of fuel required to travel at a same speed increases as the frictional resistance of the entirety of the hull increases. Thus it is preferable to perform maintenance work such as hull cleaning to reduce the frictional resistance of the hull and obviate an impact of fouling.

5 [0037] Creation means 416 creates profitability information, based on the frictional resistance of the entirety of the hull stored in storage 43. More specifically, creation means 416 calculates a payback period for maintenance work based on an increase in fuel consumption caused by the impact of hull fouling calculated from the frictional resistance of the entirety of the hull, and
10 creates a profitability information report that includes the payback period. It is of note that as used herein, fuel consumption means fuel consumption rate, and, more specifically, means a distance that ship 10 can travel with a unit of fuel.

[0038] Analysis means 417 performs trend analysis based on the history of
15 the frictional resistance of the entirety of the hull stored in storage 43 or fuel consumption that is calculated from the frictional resistance. More specifically, analysis means 417 performs trend analysis for predicting future changes in fuel consumption in the case where maintenance work on the hull is performed at a predetermined time interval, based on the history of the
20 frictional resistance of the entirety of the hull or fuel consumption, and the history of maintenance work on the hull.

2. Operations

2.1 Quantitative Assessment of Impact of Fouling

25 [0039] FIG. 4 is a flowchart illustrating processing for quantitatively assessing the impact of fouling. Whenever ship 10 is moored at a pier and being loaded/unloaded, fouling is monitored during loading/unloading. Monitoring of fouling need not, however, necessarily be carried out each time ship 10 is moored at a pier and being loaded/unloaded. For example,
30 monitoring may be carried out only when ship 10 is moored at a pier that is

equipped to monitor fouling; or each time loading/unloading is carried out a predetermined number of times; or when anchored offshore; or when unanchored offshore with the engines stopped.

[0040] During fouling monitoring, underwater drone 20 moves back and forth along each of a plurality of vertically extending weld lines (hereinafter referred to as "vertical weld lines"), while moving between the plurality of vertical weld lines in a sequence starting, for example, from the bow. Thus, underwater drone 20 first moves along the vertical weld line closest to the bow, and travels successively along the upper starboard side, the lower starboard side, the bottom portion of the hull, the lower port side, and the upper port side, in that order. Next, underwater drone 20 moves to a vertical weld line next closest to the bow and travels in a reverse direction along this vertical weld line. Alternatively, underwater drone 20 moves back and forth along each of a plurality of horizontally extending weld lines (hereinafter referred to as "horizontal weld lines"), and travels successively between the plurality of horizontal weld lines along the upper starboard side, the lower starboard side, the bottom portion of the hull, the lower port side, and the upper port side, in that order. Thus, for example, underwater drone 20 first moves underwater along the horizontal weld lines closest to the upper starboard side in a direction from the bow toward the stern, and then moves to the horizontal weld line next closest to the upper starboard side and travels in a reverse direction along this horizontal weld line.

[0041] While moving in this manner, underwater drone 20 holds fouling sample plate 222 alongside the hull surface using arm 21, and uses camera 22 to capture images of a plurality of regions of the hull together with fouling sample plate 222. Underwater drone 20 uses communication IF 23 to transmit the images captured by camera 22 to control device 30. The processing of step S11 is started when control device 30 transfers these images to server device 40.

[0042] At step S11, reception means 411 receives the images transmitted by

underwater drone 20 via control device 30 and stores the received images in storage 43.

[0043] At step S12, determination means 413 determines the fouling level of each mesh of the hull, based on the images acquired at step S11. In the example shown in FIG. 2, determination means 413 calculates a similarity between region 221 of the surface of the hull included in the image and each fouling sample 223 using image analysis. For example, if the fouling sample 223 with the highest similarity indicates a fouling level "E," determination means 413 determines that fouling level "E" is the fouling level of that mesh.

[0044] At step S13, mapping means 414 maps, for each of the plurality of meshes of the hull, the position information indicating the position of the mesh to the fouling level of the mesh determined at step S12. More specifically, mapping means 414 specifies respective positions of the meshes on the hull, by comparing the weld lines included in the images acquired at step S11 with the steel plate layout diagram of the hull stored in storage 43. For example, in a case where the 10th vertical weld line counted from the stern on the starboard side of the hull intersects the 50th horizontal weld line counted from the bottom portion of the hull in image 220 shown in FIG. 2, the position where these weld lines 224 intersect in the steel plate layout diagram is specified as the position of the mesh captured in that image.

[0045] Also, in a case where a mark is painted on the hull in the image acquired at step S11, mapping means 414 may take this mark into account in specifying a position of the mesh on the hull. For example, in a case where the image includes the characters "FPT" indicating a location of a tank, mapping means 414 may specify the location where these characters are painted on the hull as the position of the mesh. It is of note that marks for specifying positions of corresponding meshes may be provided in advance at all intersections of the weld lines on the hull. When positions of all the meshes are specified in this way, mapping means 414 creates, for each of the plurality of meshes of the hull, mapping data associating position information

of a mesh with a fouling level of the mesh, and stores the mapping data in storage 43.

[0046] FIG. 5 illustrates mapping data 500. Mapping data 500 may be in the form of a three-dimensional diagram or a two-dimensional diagram, representing the starboard and port sides. In mapping data 500, the meshes are arranged to correspond to their positions on the surface of the hull. Each mesh is indicated using a color that corresponds to a fouling level. In FIG. 5, different types of hatching are used to indicate different colors. It is of note that mapping data 500 is not limited to the example shown in FIG. 5, and may be a developed view of the hull or a table associating position information of each mesh with a fouling level of the mesh.

[0047] In a case where the images captured by underwater drone 20 do not cover the entirety of the hull, meshes whose fouling level has been determined are discretely distributed. In such a case, mapping means 414 may interpolate between those meshes using a known method such as spline interpolation.

[0048] Returning to FIG. 4, at step S14, calculation means 415 calculates the frictional resistance of the entirety of the hull, based on the mapping data created at step S13. First, calculation means 415 calculates a frictional resistance D_f of each mesh of the hull, by equation (1) below.

$$D_f = 1/2\rho V^2 S \times C_f \quad (1)$$

[0049] Here, ρ is the specific gravity of water, V is the flow speed at the mesh, S is the area of the mesh, and C_f is the coefficient of frictional resistance of the mesh. The specific gravity ρ of water is a constant. Flow speed V is estimated by CFD (Computational Fluid Dynamics). Alternatively, flow speed V may be estimated from the wear rate of the coating of the actual ship. Flow speed V differs depending on the position on the hull. Thus, the flow speed at the position indicated by the position information of a target mesh is used for flow speed V . In a case where the mesh has a rectangular shape of 1 meter in length and 5 meters in width, for example, area S will be

$1 \text{ m} \times 5 \text{ m} = 5 \text{ m}^2$. In a case where the fouling level of the target mesh is "E," for example, the coefficient of frictional resistance associated with fouling level "E" in the correspondence table stored in storage 43 is used for coefficient of frictional resistance C_f .

5 [0050] Note that, in a case where meshes whose frictional resistance D_f has been calculated are discretely distributed, due to the images captured by underwater drone 20 not covering the entirety of the hull, calculation means 415 may interpolate between those meshes using a known method such as spline interpolation.

10 [0051] Next, calculation means 415 calculates the frictional resistance of the entirety of the hull, by summing the frictional resistances D_f of all the meshes of the hull. In a case where the hull is divided into 1000 meshes, for example, calculation means 415 calculates the frictional resistance of the entirety of the hull, by summing the frictional resistances D_f of those meshes.

15 [0052] Furthermore, calculation means 415 may calculate an impact of an increase in frictional resistance of the propeller, by subtracting an increase in horsepower required to maintain the same ship speed due to an increase in frictional resistance of the entirety of the hull from the increase in horsepower required to maintain the same ship speed due to the increase in frictional resistance of the entirety of ship 10, including the hull and propeller. The
20 frictional resistance of the entirety of ship 10 may be calculated using a known method that uses ship speed and horsepower, for example.

[0053] At step S15, calculation means 415 calculates an increase in fuel consumption caused by an impact of hull fouling, by equation (2) below, using
25 the frictional resistance calculated at step S14.

$$\begin{aligned} \text{Fuel increase caused by hull fouling impact} &= \text{horsepower increase} \\ &\text{required to maintain same ship speed due to hull fouling impact} \times \text{fuel} \\ &\text{consumption rate} = \text{frictional resistance increase caused by hull} \\ &\text{fouling impact} \times \text{ship speed} \times \text{combustion consumption rate} \end{aligned} \quad (2)$$

30 [0054] Here, the combustion consumption rate is fuel consumption per unit

of horsepower, where the unit is g/kwh, for example. The increase in frictional resistance caused by the impact of hull fouling is obtained by calculating the difference between the frictional resistance of the entirety of the ship calculated at step S14 and a reference value such as an initial value.

5 The ship speed is the planned speed of ship 10 or the actual observed speed of ship 10. The ship speed may be input through operation of input unit 45 by the operator, or may be acquired from a sensor installed in ship 10.

[0055] Calculation means 415 may calculate the increase in fuel consumption caused by the impact of propeller fouling, by using the increase
10 in frictional resistance of the propeller, instead of the increase in frictional resistance caused by the impact of hull fouling in equation (2) above.

[0056] At step S16, calculation means 415 stores the frictional resistance of the entirety of the hull calculated at step S14 and the increase in fuel consumption caused by the impact of hull fouling calculated at step S15 in
15 the ship database stored in storage 43. In the ship database, the frictional resistance of the entirety of the hull and the increase in fuel consumption caused by the impact of hull fouling may be stored in association with identification information of ship 10 and the date and time of implementation of fouling monitoring. The date and time of image capture added to the
20 image captured of the hull may be used as the date and time of implementation of fouling monitoring.

[0057] The frictional resistance of the entirety of the hull and the increase in fuel consumption caused by the impact of hull fouling are calculated each time ship 10 is loaded/unloaded, and the histories of the frictional resistance of the
25 entirety of the hull and the increase in fuel consumption caused by the impact of hull fouling that indicate the impact of hull fouling are accumulated in time series, and are stored in the ship database. The history of maintenance work input by operation of input unit 45 by the operator is also stored in the ship database. This history of maintenance work includes the type of
30 maintenance work and the period in which the maintenance work is

performed.

[0058] The shipping company can provide the information stored in the ship database to a management company that implements maintenance work of ship 10. Examples of this provision method include transmission to a terminal device of the management company and mailing of printed materials printed on a printer (not shown).

2.2 Provision of Profitability Information on Maintenance Work

[0059] Creation means 416 provides profitability information on maintenance work based on the ship database stored in storage 43, to assist personnel in charge in the management company in determining whether to implement maintenance work. More specifically, creation means 416 calculates the payback period by equation (3) below, using the increase in fuel consumption caused by the impact of hull fouling stored in the ship database.

$$\text{Payback period} = \text{maintenance work cost} / \text{fuel consumption increase caused by hull fouling impact} \quad (3)$$

[0060] Here, in the case where the unit of increase in fuel consumption caused by the impact of hull fouling is ton/day, the unit of the payback period will be day, and in the case where the unit of increase in fuel consumption caused by the impact of hull fouling is ton/year, the unit of the payback period will be year. The maintenance work cost is the cost required for maintenance work, and is determined in advance for each management company that implements maintenance work. The maintenance work cost may include opportunity costs that accompany maintenance work. Since an increase in fuel consumption caused by an impact of hull fouling is eliminated by implementing maintenance work, a period over which the maintenance work cost can be recovered is obtained by equation (3) above.

[0061] Creation means 416 creates a report that includes the payback period. Also, creation means 416 may determine whether maintenance work should be implemented by comparing the payback period with a threshold value, and

include the determination result in the report. The shipping company provides the report to the management company that performs maintenance work on ship 10. Examples of the provision method include transmission to a terminal device of the management company and mailing printed materials printed on a printer (not shown). By comparing the payback period included in the report with the threshold value set for each management company, the personnel in charge in the management company can determine whether to implement maintenance work. For example, the personnel in charge in the management company can determine that hull cleaning should be implemented when, for example, a payback period for recovery of a cost of hull cleaning is less than 1.5 years, with the cost recovery being realized as a reduction in increase in fuel consumption that would otherwise be caused by an impact of hull fouling.

2.3 Trend Analysis

[0062] Analysis means 417 performs trend analysis, based on the ship database stored in storage 43. More specifically, analysis means 417 predicts future changes in fuel consumption increase caused by an impact of hull fouling in a case where maintenance work on the hull is performed at a predetermined time interval, based on a prior change over time in fuel consumption increase caused by the impact of hull fouling, and on the periods in which maintenance work is performed and that are stored in the ship database. It is of note here that while prediction of a future increase in fuel consumption caused by an impact of hull fouling is provided as an example, future fuel consumption itself may be predicted.

[0063] FIGS. 6(a) to 6(c) illustrate results of trend analysis of an increase in fuel consumption caused by an impact of hull fouling where the impact indicated is of fouling of the entirety of the hull. In FIGS. 6(a) to 6(c), the horizontal axis shows time (in years), and the vertical axis shows the fuel consumption increase (%) caused by the impact of hull fouling. It is of note

that in the examples shown in FIGS. 6(a) to 6(c), the fuel consumption increase (%) caused by the impact of hull fouling is used. However, an increase in frictional resistance caused by the impact of hull fouling may be used instead of the fuel consumption increase (%).

[0064] In FIGS. 6(a) to 6(c), past changes in increase of fuel consumption caused by an impact of hull fouling are the same, but subsequent patterns of maintenance work are different. FIG. 6(a) shows a result of trend analysis in a case where pattern A, in which hull cleaning is implemented at intervals of 1 year, is subsequently employed. FIG. 6(b) shows a result of trend analysis in a case where pattern B, in which hull cleaning is implemented at intervals of 1.5 years, is subsequently employed. FIG. 6(c) shows a result of trend analysis in a case where pattern C, in which hull cleaning is implemented at intervals of 2 years, is subsequently employed.

[0065] The method of generating the results of trend analysis shown in FIGS.

6(a) to 6(c) will now be described in detail. A graph of the solid line portion of trendline L1, L2, or L3 is created from time series data of past fuel consumption increases (%) caused by an impact of hull fouling obtained from the ship database. More specifically, a graph of the solid line portion of trendline L1, L2, or L3 is created by connecting the points indicating fuel consumption increases (%) caused by the impact of hull fouling at a plurality of points in time represented by black dots in FIGS. 6(a) to 6(c). In this example, hull cleaning is performed in past periods P1 and P2. The fuel consumption increase (%) caused by the impact of hull fouling decreases when hull cleaning is performed. Thus, it is preferable to calculate an increase in fuel consumption caused by an impact of hull fouling by performing processing to quantitatively assess the fouling impact shown in FIG. 4 at least before and after these past hull cleanings. Points Q1 and Q2 indicating the fuel consumption increase (%) caused by the impact of hull fouling before and after the hull cleaning in period P1, and points Q3 and Q4 indicating the fuel consumption increase (%) caused by the impact of hull fouling before and after

the hull cleaning in period P2 are thereby obtained.

[0066] Trendline L11 is obtained by joining the points Q2 and Q4 indicating the fuel consumption increase (%) caused by the impact of hull fouling after the hull cleaning in periods P1 and P2 in the solid line portion of trendline L1, L2, or L3 to the origin by use of a method such as curve approximation. The lower limit value of the increase in fuel consumption caused by the impact of hull fouling after hull cleaning gradually increases over time, due to cumulative degradation such as unevenness in the steel plates of the hull that cannot be rectified despite hull cleaning. The trend of the fuel consumption increase (%) caused by an impact of hull fouling due to factors other than hull fouling is evident from trendline L11. Trendline L15 is obtained by joining the positive portions of the slope of the solid line portion of trendline L1, L2, or L3. The trend of the fuel consumption increase (%) caused by the impact of hull fouling due to hull fouling is evident from trendline L15.

[0067] By using trendline L11 and trendline L15, the trend of fuel consumption increase (%) caused by the impact of hull fouling in the case where hull cleaning is performed at a predetermined interval such as every 1 year, every 1.5 years, or every 2 years in the future can be predicted. In the case where hull cleaning is performed every 1 year, for example, the fuel consumption increase (%) caused by the impact of hull fouling indicated by the two-dot dashed line portion of trendline L1 in FIG. 6(a) is predicted. In the case where hull cleaning is performed every 1.5 years, the fuel consumption increase (%) caused by the impact of hull fouling indicated by the two-dot dashed line portion of trendline L2 in FIG. 6(b) is predicted. In the case where hull cleaning is performed every 2 years, the fuel consumption increase (%) caused by the impact of hull fouling indicated by the two-dot dashed line of trendline L3 in FIG. 6(c) is predicted.

[0068] For each of the trend analysis results shown in FIGS. 6(a) to 6(c), the frequency of hull cleaning can be determined, by calculating “cost reduction due to improved fuel consumption – cost increase due to hull cleaning” for the

remaining life of ship 10.

[0069] The two-dot dashed line portion of trendline L1 shown in FIG. 6(a) represents a change in an increase in fuel consumption caused by an impact of hull fouling predicted in the case where hull cleaning is subsequently performed at intervals of 1 year. In the example shown in FIG. 6(a), hull cleaning is scheduled to be performed in periods P3 to P5 at intervals of 1 year. The total increase in fuel consumption caused by the impact of hull fouling predicted in the case where hull cleaning is performed at intervals of 1 year is represented by the area of the figure enclosed by the two-dot dashed line portion of trendline L1 and the horizontal axis.

[0070] The two-dot dashed line portion of trendline L2 shown in FIG. 6(b) represents a change in an increase in fuel consumption caused by the impact of hull fouling predicted in the case where hull cleaning is subsequently performed at intervals of 1.5 years. In the example shown in FIG. 6(b), hull cleaning is scheduled to be performed in periods P6 and P7 at intervals of 1.5 years. The total increase in fuel consumption predicted in the case where hull cleaning is performed at intervals of 1.5 years is represented by the area of the figure enclosed by the two-dot dashed line portion of line L2 and the horizontal axis.

[0071] The two-dot dashed line portion of trendline L3 shown in FIG. 6(c) represents a change in an increase in fuel consumption caused by the impact of hull fouling predicted in the case where hull cleaning is performed at intervals of 2 years. In the example shown in FIG. 6(c), hull cleaning is scheduled to be performed in periods P8 and P9 at an interval of 2 years. The total increase in fuel consumption predicted in the case where hull cleaning is performed at intervals of 2 years is represented by the area of the figure enclosed by the two-dot dashed line portion of line L3 and the horizontal axis.

[0072] The relationship between the implementation frequency of maintenance work and the total increase in fuel consumption caused by the

impact of hull fouling in the lifecycle of ship 10 is evident from FIGS. 6(a) to 6(c). An increase in frequency of maintenance work results in a decrease in total increase of fuel consumption caused by an impact of hull fouling. Thus, whereas an increase in frequency of maintenance work results in an increase
5 in the cost of maintenance work, fuel costs decrease. Analysis means 417 calculates the total reducible cost, based on the cost of maintenance work and reduction in fuel cost when hull cleaning is implemented at intervals of 1 year, 1.5 years, and 2 years.

[0073] The shipping company provides the results of trend analysis shown in
10 FIGS. 6(a) to 6(c) to the management company that performs maintenance work on ship 10. The total reducible cost also may be provided to the management company along with the results of trend analysis. Examples of this provision method include transmission to a terminal device of the management company and mailing printed materials printed on a printer
15 (not shown). By comparing the results of trend analysis shown in FIGS. 6(a) to 6(c), the personnel in charge in the management company are able to formulate an optimal maintenance work plan. Accordingly, the personnel in charge in the management company can formulate a maintenance work plan for performing maintenance work at intervals of 1.5 years, in a case where
20 the total reducible cost is greatest in the trend analysis result shown in FIG. 6(b).

[0074] When large-scale repairs such as sandblasting are implemented, degradation that is not recovered by hull cleaning, such as unevenness of steel plates of the hull and exfoliation of coating is rectified, and as a result a
25 baseline of an increase in fuel consumption caused by the impact of hull fouling is lowered. For example, in a case where large-scale repairs are implemented together with hull cleaning, the lower limit value of the increase in fuel consumption caused by the impact of hull fouling decreases after implementation of repairs and hull cleaning. Therefore, trend analysis may
30 be performed taking into account rectification of degradation achieved by

implementing large-scale repairs, but not achieved by hull cleaning alone.

[0075] Furthermore, in the examples shown in FIGS. 6(a) to 6(c), only the results of trend analysis in the increase in fuel consumption due to the impact of hull fouling of the entirety of the hull are shown. However results of trend

5 analysis of an increase in fuel consumption caused by an impact of propeller fouling and results of trend analysis of an increase in fuel consumption caused by the impact of fouling of the entirety of the hull of ship 10 calculated using horsepower and ship speed may also be shown. Patterns of maintenance work are not limited to those in which only the implementation interval of hull cleaning differs, and patterns may be included in which implementation intervals of hull cleaning, propeller cleaning, large-scale repairs, or in which at least two of the foregoing differ, or patterns in which the implementation period of a next maintenance work differs, such that a next maintenance work is implemented immediately, or six months later, or one year later.

15 [0076] According to the exemplary embodiment described above, the frictional resistance of the hull is calculated based on the fouling level of the hull. Thus, compared to a case where performance analysis of ship 10 is carried out based only on ship speed and horsepower, the impact of hull fouling can be accurately assessed. Also, based on the images captured of

20 the plurality of regions of the hull, mapping data in which position information of these regions is mapped to fouling levels is created, and the frictional resistance of the entirety of the hull is calculated based on the mapping data, thus enabling an impact of fouling of the entire surface of the hull to be assessed. By calculating the frictional resistance of the entirety of

25 the hull in this way, the impact of fouling of the entire surface of the hull can be quantitatively assessed, thus enabling the personnel in charge in the management company to determine whether maintenance work should be implemented. Also, effectiveness of maintenance work is higher when maintenance work is implemented based on the frictional resistance of the
30 entirety of the hull calculated in this way. Satisfactory results resulting

from implementation of maintenance work are increased when effectiveness of maintenance work is high, and thus implementation of maintenance work can thus be made more effective.

[0077] Furthermore, the management company is provided with profitability information including the payback period, and thus the personnel in charge in the management company are able to determine whether to implement maintenance work based on profitability. Furthermore, the management company is provided with the results of trend analysis of the increase in fuel consumption caused by the impact of hull fouling, and thus the personnel in charge in the management company can determine a frequency of implementation of maintenance work to minimize total cost during the lifecycle of ship 10. The personnel in charge in the management company are therefore able to formulate a plan for optimizing maintenance work.

[0078] Furthermore, the frictional resistance of the entirety of the hull and the frictional resistance of the propeller can be calculated separately, and thus the cause of performance degradation of ship 10 can be separated into the impact of hull fouling and the impact of propeller fouling. Maintenance work optimized dependent on the cause of the performance degradation of ship 10 can thus be carried out such that hull cleaning is carried out when performance degradation of ship 10 is caused by the impact of hull fouling, and propeller cleaning is carried out when performance degradation of ship 10 is caused by the impact of propeller fouling.

3. Variations

[0079] The exemplary embodiment described above is an example of the present invention, and the present invention is not limited to this embodiment. The exemplary embodiment described above may be modified as shown in the following variations. Two or more of the following variations may be implemented in combination.

3.1 Variation 1

[0080] In the exemplary embodiment described above, mapping means 414 may specify the position of each mesh on the hull by a method using acoustic lighthouses. Acoustic lighthouses are installed in at least three places including a pier, seabed, and sea surface. Underwater drone 20 is provided with a receiver that receives acoustic signals emitted by the acoustic lighthouses and measures the three-dimensional position of underwater drone 20 by three-point positioning based on acoustic signals received from the three acoustic lighthouses. As another example, underwater drone 20 may measure the three-dimensional position of underwater drone 20 based on the acoustic signals and on depth gauge information received from two of the acoustic lighthouses, or an acoustic signal received from one of the acoustic lighthouses, and a reception angle thereof.

[0081] Underwater drone 20 measures the image capture direction of camera 22 and the image capture distance to the hull surface to be captured. Underwater drone 20 transmits the images captured by camera 22 together with position information indicating the three-dimensional position of underwater drone 20, the image capture direction, and the image capture distance as additional information. Mapping means 414 specifies the position of each mesh on the hull, based on the position information of underwater drone 20, the image capture direction, and the image capture distance included with the images. For example, mapping means 414 specifies a position that is the image capture distance from the position of underwater drone 20 in the image capture direction as the position of the corresponding mesh on the hull. By use of the method according to this variation, the position of each mesh on the hull can be determined.

[0082] Although ship 10 is moored, and its three-dimensional position does not change significantly, since there are changes in draft dependent on a cargo amount, changes in water level, slight changes in the bow-stern direction, and the like, the three-dimensional position of ship 10 can be measured. As a

result, the position of underwater drone 20 relative to ship 10 can be more accurately specified. It is of note that the three-dimensional position of ship 10 can be measured, for example, by using a method similar to that used for measuring the three-dimensional position of underwater drone 20.

5 [0083] In this variation, underwater drone 20 may measure the three-dimensional position of underwater drone 20 using a method of estimating a known position thereof, such as a method using an inertial navigation device, either alone or in combination with the method using the acoustic lighthouses described above.

10

3.2 Variation 2

[0084] In the exemplary embodiment described above, marks used to specify three-dimensional positions on the hull may be provided on a plurality of regions of the surface of the hull by application, for example of an uneven
15 coating. Marks indicating positions of those regions are provided on the surface of the hull, for example, at predetermined intervals along the weld lines. Mapping means 414 uses the marks included with captured images to specify positions of the meshes on the hull. According to this variation, the position of each mesh of the hull can be accurately determined.

20

3.3 Variation 3

[0085] In the exemplary embodiment described above, underwater drone 20 may be provided with travel wheels that travel over the surface of the hull. Underwater drone 20 may measure the travel distance and use the measured
25 travel distance to specify the position of underwater drone 20 relative to ship 10. For measurement of the travel distance, either a method of calculating the travel distance, based on a number of rotations of the wheels, or a method of measuring the travel distance using a laser rangefinder or the like may be employed. Underwater drone 20 transmits the measured travel distance as
30 additional information included with captured images. Mapping means 414

determines the positions of the meshes on the hull, based on the travel distance included with the captured images. For example, mapping means 414 specifies a position that is a travel distance away along a predetermined travel route from a position where underwater drone 20 starts to travel as a position of the corresponding mesh on the hull. By use of the method according to this variation, the position of each mesh on the hull can be determined.

3.4 Variation 4

[0086] In the exemplary embodiment described above, underwater drone 20 need not necessarily capture images of surface of the hull together with a fouling sample plate. For example, underwater drone 20 captures images using camera 22 of the surface of the hull. Storage 43 stores a fouling sample image showing a fouling sample plate. Mapping means 414 uses image analysis to calculate a similarity between each fouling sample included in the fouling sample image stored in storage 43 and a region of the surface of the hull included in the images captured by underwater drone 20, and determines the fouling level corresponding to the fouling sample with a highest similarity. Preferably the fouling sample image used to determine the fouling level shows a fouling sample plate for use in an underwater environment similar to the underwater environment of the hull. For example, a fouling sample plate with a similar image capture environment may be selected for use, based on information such as brightness during underwater image capture. By use of the method according to this variation, the fouling level of each mesh on the hull can be determined.

3.5 Variation 5

[0087] In the exemplary embodiment described above, calculation means 415 may calculate the frictional resistance of the propeller using the fouling level of the propeller. For example, underwater drone 20 uses camera 22 to

capture images of the propeller both before and after defouling. Determination means 413 determines the fouling level of the propeller by analyzing these images. For example, a large difference between the image before defouling of the propeller and the image after defouling indicates that the fouling level of the propeller is high. Calculation means 415 uses the fouling level of the propeller instead of the fouling level of the hull to calculate the frictional resistance of the propeller using equation (1) above. The coefficient of frictional resistance corresponding to the fouling level of the propeller is used as the coefficient of frictional resistance C_f of the mesh, instead of the coefficient of frictional resistance corresponding to the fouling level of the mesh of the hull. According to this variation, the frictional resistance of the propeller can be obtained with higher accuracy.

3.6 Variation 6

[0088] In the exemplary embodiment described above, underwater drone 20 need not necessarily capture images of the surface of the hull. For example, a diver may dive with a camera and capture images of the surface of the hull using the camera. The images captured by the camera are transmitted to server device 40. By use of the method according to this variation, images of the hull surface can be captured.

3.7 Variation 7

[0089] In the exemplary embodiment described above, the configurations of assessment system 1, ship 10, underwater drone 20, control device 30, and server device 40 are provided examples, but are not limited thereto. The functions of one device may be distributed among a plurality of devices, or the functions of a plurality of devices may be provided in one device. Also, the operations of assessment system 1, ship 10, underwater drone 20, control device 30, and server device 40 are provided as an example, only, and are not limited thereto. The order of processing procedures of assessment system 1,

ship 10, underwater drone 20, control device 30, and server device 40 may be interchanged, or one or more of the processing procedures may be omitted, as long as there are no inconsistencies.

5 3.8 Variation 8

[0090] Another mode of the present invention may provide a method using processing steps that are performed in assessment system 1, ship 10, underwater drone 20, control device 30, and server device 40. Yet another mode of the present invention may provide a program executed in underwater
10 drone 20, control device 30, or server device 40. The program may be provided by being stored on a computer-readable recording medium, or may be provided by being downloaded via the Internet or the like.

3.9 Variation 9

15 [0091] Fouling as referred to herein may include not only biological fouling but also deterioration of surface roughness such as unevenness of the steel plates of the hull and exfoliation of a coating. In this case, the fouling level referred to herein can include surface roughness. Server device 40 may calculate the frictional resistance of the entirety of the hull taking into
20 account deterioration of surface roughness such as unevenness of the steel plates of the hull and exfoliation of the coating, by determining a fouling level that reflects the deterioration of surface roughness such as unevenness of the steel plates of the hull and exfoliation of the coating, along with biological fouling using a method of machine learning of the images of the hull
25 captured by underwater drone 20.

3.10 Variation 10

[0092] In the exemplary embodiment described above, underwater drone 20 captures images of the portion of the hull that is immersed, and the impact of
30 hull fouling is assessed using the images captured of the hull. However, the

draft differs when ship 10 is loaded with cargo and when ship 10 is not loaded with cargo. Thus, a portion of the hull is above the water surface when ship 10 is lightly loaded but is submerged when ship 10 is fully loaded. The fully loaded state is a state in which ship 10 is carrying a maximum amount of cargo or ballast, and the waterline is deepest. The lightly loaded state, which is also known as a ballast state, is a state in which ship 10 is carrying little or no cargo and the waterline is relatively shallow. The fully loaded state and the lightly loaded state are examples respectively of a first draft state and a second draft state according to an aspect of the present invention. Such portions of the hull may also be fouled by biological adhesion, exfoliation of coating, and the like. Therefore, in this variation, the impact of fouling is also assessed for the portion of the hull that is located underwater in the fully loaded state and above the water surface in the lightly loaded state.

[0093] FIG. 7 shows an example of submerged region 100 of the hull.

Submerged region 100 is the region of the hull between fully loaded waterline 101 and waterline 102. Submerged region 100 is an example of a target region according to an aspect of the present invention. Fully loaded waterline 101 refers to a waterline that is immersed in the fully loaded state. Waterline 102 refers to the line where the water surface meets the portion where the hull is immersed in the lightly loaded state. Fully loaded waterline 101 and waterline 102 are examples respectively of a first waterline and a second waterline according to an aspect of the present invention. As shown in FIG. 7, submerged region 100 is immersed in the fully loaded state and above the water surface in the lightly loaded state.

[0094] Assessment system 1 has an image capture means that captures images of submerged region 100 together with a fouling sample plate. The image capture means is a camera, for example. A number of methods can be used for capturing images of submerged region 100 together with the fouling sample plate. In a first method, a person uses the image capture means to capture images of submerged region 100 from the pier. At this time, the

person holds the fouling sample plate within the capture range of the image capture means. The image capture means is thus able to capture images of submerged region 100 together with the fouling sample plate.

[0095] In a second method, an aerial drone equipped with the image capture means flies around ship 10 and captures images of submerged region 100 from the air using the image capture means. At this time, the fouling sample plate may be held within the capture range of the image capture means by using an arm of the aerial drone. Alternatively, the fouling sample plate may be held by a wheeled drone that travels over the surface of the hull, and is disposed in submerged region 100 within the capture range. The image capture means is therefore able to capture images of submerged region 100 together with the fouling sample plate.

[0096] In a third method, a boat-type drone equipped with an image capture means moves on the water surface around ship 10 and captures images of submerged region 100 from the water surface using the image capture means. At this time, the fouling sample plate may be held within the capture range of the image capture means using an arm of the boat-type drone. Alternatively, the fouling sample plate may be held by a wheeled drone that travels over the surface of the hull and is disposed in submerged region 100 within the image capture range. The image capture means is thus able to capture images of submerged region 100 together with the fouling sample plate.

[0097] Also, similarly to variation 4 described above, the image capture means need not necessarily capture images of submerged region 100 together with the fouling sample plate. For example, the image capture means may only capture images of submerged region 100. Storage 43 stores a fouling sample image showing a fouling sample plate. This fouling sample image may be captured in advance in an environment unrelated to submerged region 100, or may be captured at the image capture location of submerged region 100. In the latter case, the image of submerged region 100 and the

fouling sample image are captured in generally the same environment, and thus can be compared with each other without being impacted by sunlight or other environmental factors.

[0098] The images captured by the image capture means in this way are input to server device 40 using an operation by a person or via network 3.

Reception means 411 receives input of the images. Reception means 411 is an example of a reception means according to an aspect of the present invention. Determination means 413 determines the fouling level of

submerged region 100 of the hull, based on the similarity between submerged region 100 of the hull included in the input images and the respective fouling samples of the fouling sample plate, similarly to the exemplary embodiment described above. Mapping means 414 maps the position information indicating the position of submerged region 100 of the hull to the fouling level of submerged region 100 determined by the determination means 413, using

a method similar to the exemplary embodiment or variations described above.

Photogrammetry (image joining technology) may also be used in this mapping.

[0099] Calculation means 415 may calculate the frictional resistance D_f of submerged region 100 by equation (1) above, using coefficient of frictional resistance C_f corresponding to the fouling level of submerged region 100, and

calculates the frictional resistance of the entirety of the hull by summing the frictional resistances D_f of all the meshes of the hull and the frictional resistance D_f of submerged region 100. According to this configuration, the fouling impact can be assessed by including not only the region located underwater in the lightly loaded state but also the submerged region 100 that appears above the water surface in the lightly loaded state.

[0100] Also, in this variation, correlation analysis of the impact of fouling may be carried out based on the fouling level of submerged region 100 and the difference in required horsepower between the fully loaded state and the lightly loaded state caused by fouling of submerged region 100. The required

horsepower is a horsepower required to maintain a certain speed.

Calculation means 415 calculates the increase in frictional resistance of submerged region 100 caused by fouling, in accordance with the difference in the required horsepower between the fully loaded state and the lightly loaded state. It is of note that the difference in the required horsepower used in correlation analysis of the fouling impact is not limited to the difference in the required horsepower between the fully loaded state and the lightly loaded state. For example, the difference in required horsepower between the fully or lightly loaded state and a draft state other than the fully or lightly loaded state, or the difference in required horsepower between two draft states other than the fully and lightly loaded states may be used.

[0101] FIG. 8 shows an example of correlation information indicating the relationship between ship speed and horsepower of the main engine. In FIG. 8, the horizontal axis is ship speed (kts) and the vertical axis is horsepower (kw) of the main engine. The correlation information is stored in storage 43 of server device 40. This correlation information includes speed-horsepower curves C1 to C4. Speed-horsepower curve C1 indicates the relationship between ship speed and horsepower of the main engine in a fully loaded state with fouling. Speed-horsepower curve C2 indicates the relationship between ship speed and horsepower of the main engine in a fully loaded state without fouling. Speed-horsepower curve C3 indicates the relationship between ship speed and horsepower of the main engine in a lightly loaded state with fouling. Speed-horsepower curve C4 indicates the relationship between ship speed and horsepower of the main engine in a lightly loaded state without fouling. The relationship between ship speed and horsepower of the main engine may, for example, be derived from measurement values of ship speed and horsepower of the main engine in tank tests, or may be derived from actual measurement values acquired from sensors installed in ship 10. “With fouling” as referred to here indicates the presence of fouling at a fouling level determined by determination means 413, for example.

[0102] Focusing on speed-horsepower curve C1 and speed-horsepower curve

C3, a difference in required horsepower $\Delta BHP_{\text{fouling/draft impact}}$ between the horsepower of speed-horsepower curve C1 and the horsepower of speed-horsepower curve C3 in the case where the ship speed is 15 kts includes the impact of fouling of submerged region 100 in addition to the impact of the change in draft. The difference in required horsepower $\Delta BHP_{\text{fouling/draft impact}}$ increases as the fouling level of submerged region 100 increases.

[0103] Calculation means 415 calculates a difference in required horsepower $\Delta BHP_{\text{fouling/draft impact}}$ between the fully loaded state and the lightly loaded state by equation (4) below. The difference in required horsepower $\Delta BHP_{\text{fouling/draft impact}}$ indicates the difference in performance of ship 10 between the lightly loaded state and the fully loaded state due to fouling of submerged region 100. The difference in required horsepower $\Delta BHP_{\text{fouling/draft impact}}$ includes the impact of draft change and fouling of submerged region 100.

$$\Delta BHP_{\text{fouling/draft impact}} = BHP_{C1} - BHP_{C3} \quad (4)$$

Here, BHP_{C1} is the required horsepower of speed-horsepower curve C1, and BHP_{C3} is the required horsepower of speed-horsepower curve C3.

[0104] The relationship between horsepower BHP of the main engine, frictional resistance R_f , and ship speed V is shown by equation (5) below.

$$BHP \times \eta = EHP = R \times V = (R_f + R_w) \times V \quad (5)$$

Here, EHP is effective horsepower, η is the propulsion coefficient, and R_w is wave drag. Effective horsepower EHP indicates the amount of axial work of the propeller. Wave drag R_w can be estimated by use of a known estimation equation.

[0105] Propulsion coefficient η is derived by equation (6) below.

$$\eta = \eta_0 \times \eta_{\text{hull}} \times \eta_R \quad (6)$$

Here, η_0 is propeller efficiency, η_{hull} is hull efficiency, and η_R is behind efficiency. Propeller efficiency η_0 , hull efficiency η_{hull} , and behind efficiency η_R can each be estimated by known estimation equations.

[0106] Calculation means 415 is able to calculate the increase in frictional resistance ΔR_f of submerged region 100 caused by draft change and fouling,

by using a difference in required horsepower $\Delta\text{BHP}_{\text{fouling/draft impact}}$ instead of horsepower BHP of the main engine in equation (5) above.

[0107] The relationship between frictional resistance R_f and coefficient of frictional resistance C_f is indicated by equation (7) below.

$$5 \quad R_f = 1/2\rho C_f S V^2 \quad (7)$$

Here, ρ is the specific gravity of water, S is the area of submerged region 100, and V is the flow speed in submerged region 100.

[0108] Calculation means 415 is able to calculate an increase in coefficient of frictional resistance ΔC_f of submerged region 100 caused by draft and fouling, by using increase in frictional resistance ΔR_f instead of frictional resistance R_f in equation (7) above. Also, calculation means 415 is able to obtain a coefficient of frictional resistance C_f by adding an increase in coefficient of frictional resistance ΔC_f to a predetermined reference coefficient of frictional resistance in a state without fouling. A more reliable coefficient of frictional resistance C_f corresponding to the fouling level of submerged region 100 is thereby evident. According to this configuration, the impact of fouling of submerged region 100 can be more accurately assessed.

[0109] Also, server device 40 may include a correction unit that corrects coefficient of frictional resistance C_f used by calculation means 415 in the exemplary embodiment described above, using coefficient of frictional resistance C_f obtained in this variation. The correction unit may use coefficient of frictional resistance C_f obtained in this variation to correct not only coefficient of frictional resistance C_f but also the frictional resistance of the entirety of the hull, and the increase in frictional resistance caused by the impact of hull fouling. According to this configuration, accuracy of assessing the impact of hull fouling is improved.

[0110] As another example of fouling impact correlation analysis, calculation means 415 may use a difference in required horsepower $\Delta\text{BHP}_{\text{fouling impact}}$ that does not include the impact of draft change, instead of a difference in required horsepower $\Delta\text{BHP}_{\text{fouling/draft impact}}$ calculated by equation (4) above.

[0111] FIG. 9 shows another example of correlation information indicating the relationship between ship speed and horsepower of the main engine. In FIG. 9, the horizontal axis is ship speed (kts), and the vertical axis is horsepower (kw) of the main engine. This correlation information is stored in storage 43 of server device 40, and includes speed-horsepower curves C1 to C4, similarly to FIG. 8.

[0112] Focusing on speed-horsepower curve C1 and speed-horsepower curve C2, a difference in required horsepower $\Delta BHP_{\text{fully loaded state}}$ between the horsepower of speed-horsepower curve C1 and the horsepower of speed-horsepower curve C2 when the ship speed is 15 kts includes the impact of fouling of submerged region 100 and regions other than submerged region 100 that are located underwater in the fully loaded state. On the other hand, focusing on speed-horsepower curve C3 and speed-horsepower curve C4, the difference in required horsepower $\Delta BHP_{\text{lightly loaded state}}$ between the horsepower of speed-horsepower curve C3 and the horsepower of speed-horsepower curve C4 when the ship speed is 15 kts includes the impact of fouling of regions other than submerged region 100 that are located underwater in the lightly loaded state, but does not include the impact of fouling of submerged region 100 that is located above the water surface in the lightly loaded state. Accordingly, a difference in required horsepower $\Delta BHP_{\text{fouling impact}}$ caused by fouling of submerged region 100 can be obtained, by taking the difference between the difference in required horsepower $\Delta BHP_{\text{fully loaded state}}$ and the difference in required horsepower $\Delta BHP_{\text{lightly loaded state}}$. This difference in required horsepower $\Delta BHP_{\text{fouling impact}}$ includes the impact of fouling but does not include the impact of draft. The difference in required horsepower $\Delta BHP_{\text{fouling impact}}$ increases as the fouling level of submerged region 100 increases.

[0113] Calculation means 415 calculates a difference in required horsepower $\Delta BHP_{\text{fouling impact}}$ by the following equations (8) to (10).

$$\Delta BHP_{\text{fully loaded state}} = BHP_{C1} - BHP_{C2} \quad (8)$$

$$\Delta BHP_{\text{lightly loaded state}} = BHP_{C3} - BHP_{C4} \quad (9)$$

$$\Delta BHP_{\text{fouling impact}} = \Delta BHP_{\text{fully loaded state}} - \Delta BHP_{\text{lightly loaded state}} \quad (10)$$

Here, $\Delta BHP_{\text{fully loaded state}}$ is the difference in required horsepower between fouled and unfouled in the fully loaded state, BHP_{C1} is the required horsepower of speed-horsepower curve C1, BHP_{C2} is the required horsepower of speed-horsepower curve C2, $\Delta BHP_{\text{lightly loaded state}}$ is the difference in required horsepower between fouled and unfouled in the lightly loaded state, BHP_{C3} is the required horsepower of speed-horsepower curve C3, and BHP_{C4} is the required horsepower of speed-horsepower curve C4. Difference in required horsepower $\Delta BHP_{\text{fully loaded state}}$ indicates the impact of fouling of submerged region 100 and regions other than submerged region 100 that are located underwater in the fully loaded state. On the other hand, difference in required horsepower $\Delta BHP_{\text{lightly loaded state}}$ indicates the impact of fouling of regions other than submerged region 100 that are located underwater in the lightly loaded state. Difference in required horsepower $\Delta BHP_{\text{fouling impact}}$ indicates the impact of fouling of submerged region 100. Difference in required horsepower $\Delta BHP_{\text{fouling impact}}$ does not include the impact of draft.

[0114] By using difference in required horsepower $\Delta BHP_{\text{fouling impact}}$ calculated in this way, calculation means 415 is able to calculate an increase in frictional resistance ΔR_f caused by fouling of submerged region 100, an increase in coefficient of frictional resistance ΔC_f , and coefficient of frictional resistance C_f by equations (5) to (7) above. Also, as described above, the correction unit of server device 40 may use coefficient of frictional resistance C_f obtained in this variation to correct a coefficient of frictional resistance C_f , the frictional resistance of the entirety of the hull, and the increase in frictional resistance caused by the impact of hull fouling used by calculation means 415 in the above exemplary embodiment. According to this configuration, the impact of fouling of submerged region 100 can be assessed more accurately.

Reference Signs List

[0115]

- 1 ... Assessment system, 10 ... Ship, 20 ... Underwater drone, 21 ... Arm, 22 ... Camera, 23 ... Communication IF, 30 ... Control device, 40 ... Server device,
- 5 41 ... Processor, 42 ... Memory, 43 ... Storage, 44 ... Communication IF, 45 ... Input unit, 46 ... Display unit, 411 ... Reception means, 412 ... Acquisition means, 413 ... Determination means, 414 ... Mapping means, 415 ... Calculation means, 416 ... Creation means, 417 ... Analysis means

CLAIMS

Claim 1. A fouling impact assessment device comprising:

5 acquisition means for acquiring fouling levels of a plurality of regions of a surface of a hull of a ship; and

calculation means for calculating a frictional resistance of an entirety of the hull, using coefficients of frictional resistance corresponding to the fouling levels of the plurality of regions.

10 Claim 2. The fouling impact assessment device according to claim 1,

wherein the acquisition means further acquires position information indicating positions of the plurality of regions on the hull, and

the calculation means calculates, for each of the plurality of regions, a frictional resistance of a region, using a flow speed at a position indicated
15 by the position information of the region and a coefficient of frictional resistance corresponding to a fouling level of the region, and calculates the frictional resistance of the entirety of the hull by summing frictional resistances of the plurality of regions.

20 Claim 3. The fouling impact assessment device according to claim 1, further comprising:

reception means for receiving images of the plurality of regions captured by an underwater moving body;

determination means for determining the fouling levels of the
25 plurality of regions using the images; and

mapping means for associating, for each of the plurality of regions, position information indicating a position of a region with a fouling level of the region.

30 Claim 4. The fouling impact assessment device according to claim 3,

wherein the underwater moving body captures the images along a weld line of the hull, and

the mapping means specifies positions of the plurality of regions on the hull, based on the weld line included in the images.

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Claim 5. The fouling impact assessment device according to claim 3,

wherein the mapping means specifies positions of the plurality of regions on the hull, based on a position of the underwater moving body measured using an acoustic lighthouse.

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Claim 6. The fouling impact assessment device according to claim 3,

wherein the mapping means specifies positions of the plurality of regions on the hull, based on a position of the underwater moving body measured using an inertial navigation device.

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Claim 7. The fouling impact assessment device according to claim 3 or 4,

wherein the plurality of regions on the surface of the hull are provided with marks indicating positions of the plurality of regions on the hull, and

the mapping means uses the marks included in the images to specify the positions of the plurality of regions on the hull.

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Claim 8. The fouling impact assessment device according to claim 1, further comprising:

reception means for receiving images of the plurality of regions captured by an underwater moving body that includes an arm and a camera, using the camera together with a fouling sample plate held alongside the surface of the hull by the arm; and

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determination means for determining the fouling levels of the plurality of regions, based on a similarity between fouling samples of the fouling sample plate included in the images and each of the plurality of

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regions.

Claim 9. The fouling impact assessment device according to claim 1, further comprising:

- 5 storage means for storing a history of the frictional resistance of the entirety of the hull or fuel consumption calculated from the frictional resistance, and a period in which maintenance work for reducing the frictional resistance of the hull is performed; and
- analysis means for performing trend analysis for predicting future
- 10 change in fuel consumption in a case where the maintenance work is performed at a predetermined time interval, based on the history and the period.

Claim 10. The fouling impact assessment device according to claim 1, further comprising:

- reception means for receiving input of an image, captured together with a fouling sample plate by image capture means, of a target region between a first waterline in a first draft state of the hull and a second waterline in a second draft state different from the first draft state; and
- 20 determination means for determining a fouling level of the target region, based on a similarity between the target region and fouling samples of the fouling sample plate included in the image, and
- wherein the calculation means calculates the frictional resistance of the entirety of the hull, further using a coefficient of frictional resistance
- 25 corresponding to the fouling level of the target region.

Claim 11. The fouling impact assessment device according to claim 10,

- wherein the calculation means calculates an increase in frictional resistance of the target region caused by fouling, based on a difference in
- 30 required horsepower between the first draft state and the second draft state.

Claim 12. A program for causing a computer to execute:

a step of acquiring fouling levels of a plurality of regions of a surface of a hull of a ship; and

5 a step of calculating a frictional resistance of an entirety of the hull, using coefficients of frictional resistance corresponding to the fouling levels of the plurality of regions.