

Monitoring a vessel

TECHNICAL FIELD

- 5 The present disclosure relates to dynamically monitoring the cleanliness of a hull of a vessel during a journey of said vessel.

BACKGROUND

- 10 All surfaces submerged in seawater will experience fouling of organisms such as bacteria, diatoms, algae, mussels, tube worms and barnacles. Marine fouling is the undesirable accumulation of microorganisms, algae and animals on structures submerged in seawater. The fouling organisms can be divided into microfouling (bacterial and diatomic biofilms) and macrofouling (e.g. macroalgae, barnacles,
15 mussels, tubeworms, bryozoans) which live together forming a fouling community. In a simplistic overview of the fouling process, the first step is the development of a conditioning film where organic molecules adhere to the surface. This happens instantaneously when a surface is submerged in seawater. The primary colonizers, the bacteria and diatoms, will settle within a day. The secondary colonizers, spores of
20 macroalgae and protozoa, will settle within a week. Finally, the tertiary colonizers, the larvae of macrofouling, will settle within 2-3 weeks.

- The development of marine fouling is a known problem. Fouling of the underwater hull of a vessel will lead to increased drag resistance and increased fuel consumption or
25 reduced speed. Increased fuel consumption will lead to increased CO₂, NO_x and sulphur emissions. Heavy fouling can also lead to reduced manoeuvrability of the vessel. Many commercial vessels (e.g. container ships, bulk carriers, tankers, passenger ships) are trading worldwide. If the hull of a vessel is fouled the organisms will be transported from its original ecosystem to a different ecosystem. This is
30 problematic as new species can be introduced in sensitive ecosystems and eliminate indigenous species. A vessel can also be prohibited from entering a port if the hull is fouled.

- Different type of coating technologies are used to reduce the amount of fouling where
35 antifouling coatings containing biocides are the most efficient in preventing fouling.

SUMMARY

Commercial vessels often operate in different waters, in different trade, with different activity and idle periods. The risk of fouling is higher when objects are stationary or at low speed. Typical service intervals for commercial vessels are from 24 to 90 months. When the vessel is going into dry-dock for service and repair, the coating to be applied on the underwater hull is usually specified according to the planned trade for the next period. However, the trade of a vessel can be changed during the service interval. The inventors have identified that it is therefore difficult to design and specify a coating for the underwater hull that will be optimal for all possible situations.

If the trade of the vessel is changed the vessel can be fouled as the specified coating is not optimised for the new trade. This can lead to increased drag resistance and increased fuel consumption or reduced speed.

Therefore, a monitoring system is needed to be able to monitor a vessel and predict when there is a risk of loss of operational efficiency and thereby ensure that the correct actions are made before operational efficiency is lost.

Embodiments of the present disclosure, enable a ship operator (e.g. an owner of the vessel) to have real time monitoring over the operational efficiency of their fleet of one or more vessels.

According to another aspect of the present disclosure there is provided a computer implemented method of dynamically monitoring the cleanliness of a hull of a vessel during a journey of said vessel, the method performed on a computing device and comprising: retrieving environmental data from memory of the computing device, the environmental data associated with environment conditions of the vessel; determining a fouling protection value defining a tolerance to fouling associated with a surface of the vessel; and identifying a level of risk of fouling on the surface of the vessel based on the fouling protection value and the environment conditions.

In some implementations, the method comprises: determining a fouling value indicative of a level of fouling that the surface is exposed to based on at least the environmental

data; and identifying the level of risk of fouling on the surface of the vessel by determining a fouling risk value using the fouling protection value and the fouling value.

5 The environmental data may comprise a value associated with each of one or more environmental parameters.

The environmental data may relate to a geographical location of the vessel.

10 The environmental data may be sensed by at least one of: one or more sensors on the vessel; one or more sensors on a hull cleaning robot configured to clean the hull of the vessel; one or more sensors on a remotely operated underwater vehicle configured to inspect the hull of the vessel.

15 Environmental data relating to multiple geographical locations may be stored in the memory, and the environmental data relating to the geographical location of the vessel may be retrieved using the geographical location of the vessel.

20 Determining the fouling value may be further based on operational data associated with the vessel, the operational data comprising a value associated with each of one or more operational parameters, the one or more operational parameters comprising one or more of: (i) a parameter relating to speed over ground of the vessel; (ii) a parameter relating to an activity level of the vessel; (iii) a parameter relating to speed through water of the vessel; (iv) a parameter relating to a draught of the vessel; (v) a parameter relating to a heading of the vessel.

25 The fouling value may be an instantaneous fouling value indicative of a level of fouling that the surface is exposed to at a sampling time, the instantaneous fouling value determined by computing a weighted average of values of a plurality of risk parameters, the plurality of risk parameters comprising at least one environmental parameter defined in the environmental data.

30 The fouling risk value may be determined based on a plurality of instantaneous fouling risk values, each of the plurality of instantaneous fouling risk values identifying a level of risk of fouling on the surface of the vessel at a respective sampling time in a time period, and weighted with a weight defining the recency of the sampling time.

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The method may further comprise identifying high risk fouling conditions by determining that the fouling risk value exceeds a predetermined threshold, and in response outputting a control signal

- 5 The method may further comprise outputting the fouling risk value.

The method may further comprise outputting the fouling risk value to an output device of said computing device or outputting the fouling risk value to a remote computing device. The method may further comprise outputting a control signal in dependence on
10 receiving user confirmation that a control action is to be performed.

In some implementations, the method comprises determining a total duration of one or more idle periods of said vessel during a time period by querying an activity log associated with said vessel that is stored in memory; determining, from memory, an
15 age of the surface; determining from data prestored in memory an idle duration threshold based on the fouling protection value and the age of the surface; determining that the total duration exceeds the idle duration threshold, and in response identifying the level of risk of fouling on the surface of the vessel based on the environmental data.

20 Identifying the level of risk of fouling on the surface of the vessel may comprise comparing the environmental data to one or more predetermined thresholds. The method may comprise identifying high risk fouling conditions by determining that the environmental data exceeds the one or more predetermined thresholds, and in response outputting a control signal.

25 The method may further comprise: determining a fouling value indicative of a level of fouling that the surface is exposed to based on at least the environmental data; determining a fouling risk value using the fouling protection value and the fouling value; and identifying the level of risk of fouling on the surface of the vessel comprises
30 comparing the fouling risk value to a predetermined threshold.

The method may comprise identifying high risk fouling conditions by determining that the fouling risk value exceeds the predetermined threshold, and in response outputting a control signal.

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The environmental data may comprise a value associated with each of one or more environmental parameters.

The environmental data may relate to a geographical location of the vessel.

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The environmental data may be sensed by at least one of: one or more sensors on the vessel; and one or more sensors on a hull cleaning robot configured to clean the hull of the vessel; one or more sensors on a remotely operated underwater vehicle configured to inspect the hull of the vessel.

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Environmental data relating to multiple geographical locations may be stored in the memory, and the environmental data relating to the geographical location of the vessel may be retrieved using the geographical location of the vessel.

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In some implementations, the method comprises outputting the control signal to a remotely operated underwater vehicle or a hull cleaning robot configured to clean the hull of the vessel, to initiate inspection of the surface of the vessel.

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In some implementations, the method comprises outputting the control signal to an output device of the computing device or to a remote device on said vessel to alert a user to initiate inspection of the surface of the vessel.

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In some implementations, the method comprises outputting the control signal to a hull cleaning robot configured to clean the hull of the vessel, to initiate cleaning of the surface of the vessel.

In some implementations, the method comprises outputting the control signal to a vessel control system to control the vessel to take operational measures.

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The vessel or an on-shore monitoring station may comprise the computing device.

The computing device may be a hull cleaning robot configured to clean the hull of the vessel, and the method may comprise: outputting the control signal to a hull inspection device of the hull cleaning robot to initiate inspection of the surface of the vessel; or

outputting the control signal to a cleaning device of the hull cleaning robot to initiate cleaning of the surface of the vessel.

5 The outputting of said control signal may be further based on receiving user confirmation that a control action is to be performed.

The fouling protection value may be determined based on a value defining an attractiveness of the surface to fouling.

10 The value defining an attractiveness of the surface to fouling is determined based on one or more of (i) a surface energy of the surface, (ii) a topography of the surface, (iii) a porosity of the surface, (iv) an elasticity of the surface, and (v) a colour of the surface.

15 The fouling protection value may be determined based on a value defining an effect, on the surface, of water moving over said surface.

20 The value defining an effect, on the surface, of water moving over said surface may be determined using a speed over ground of the vessel or a speed through water of the vessel, and one or more of (i) a surface energy of the surface, (ii) a topography of the surface, and (iii) a porosity of the surface.

25 A coating providing said surface may be a polishing coating and the value defining an effect, on the surface, of water moving over said surface may be determined using a polishing rate associated with said coating.

A coating providing said surface may comprise a fouling control agent, and the fouling protection value may be determined based on a value defining an effect of the fouling control agent.

30 The one or more environmental parameters may comprise one or more of: (i) a parameter relating to a temperature of an aquatic environment of the vessel; (ii) a parameter relating to a water depth of the aquatic environment of the vessel; (iii) a parameter relating to a distance between the vessel and coastline; (iv) a parameter relating to a length of day; (v) a parameter relating to a light intensity in the aquatic environment; (vi) a parameter relating to an amount of chlorophyll in the aquatic

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environment; (vii) a parameter relating to a salinity level of the aquatic environment; (viii) a parameter relating to a pH level of the aquatic environment; (ix) a parameter relating to a nutrient level in the aquatic environment; (x) a parameter relating to an amount of carbon dioxide in the aquatic environment; and (xi) a parameter relating to an amount of gaseous oxygen dissolved in water in the aquatic environment.

The method may be performed periodically.

According to another aspect of the present disclosure there is provided a computer-readable storage medium comprising instructions which, when executed by a processor of a computing device, cause the processor to carry out the method of any preceding claim.

The instructions may be provided on a carrier such as a disk, CD- or DVD-ROM, programmed memory such as read-only memory (Firmware), or on a data carrier such as an optical or electrical signal carrier. Code (and/or data) to implement embodiments of the present disclosure may comprise source, object or executable code in a conventional programming language (interpreted or compiled) such as C, or assembly code, code for setting up or controlling an ASIC (Application Specific Integrated Circuit) or FPGA (Field Programmable Gate Array), or code for a hardware description language.

According to another aspect of the present disclosure there is provided a computing device for dynamically monitoring the cleanliness of a hull of a vessel during a journey of said vessel, the computing device comprising a processor configured to perform any of the methods described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the present disclosure and to show how embodiments may be put into effect, reference is made to the accompanying drawings in which:

Figure 1a illustrates a vessel and a robot;

Figure 1b illustrates a monitoring station in communication with a fleet of vessels;

Figure 2 is a schematic block diagram of the robot;

- Figure 3 is a schematic block diagram of a computing device;
- Figure 4 illustrates a method for dynamically monitoring the cleanliness of an underwater hull of a vessel in accordance with a first embodiment of the present disclosure;
- 5 Figures 5a and 5b illustrate methods of determining a fouling value;
- Figure 6a illustrates how values of environmental parameters may vary over time;
- Figure 6b illustrates how the fouling value may vary over time;
- Figure 6c illustrates the contribution of a speed over ground parameter to the fouling value;
- 10 Figure 6d illustrates the contribution of a sea surface water temperature parameter to the fouling value;
- Figure 6e illustrates the contribution of a distance to coastline parameter to the fouling value;
- Figure 7 illustrates a method for dynamically monitoring the cleanliness of an underwater hull of a vessel in accordance with a second embodiment of the present disclosure;
- 15 Figure 8a illustrates example control actions that may be performed in embodiments of the present disclosure in response to user confirmation that action is to be taken in response to the cleanliness of the hull of a vessel being monitored;
- 20 Figure 8b illustrates example control actions that may be performed in embodiments of the present disclosure automatically in response to the cleanliness of the hull of a vessel being monitored;
- Figure 8c illustrates example control actions that may be performed in embodiments of the present disclosure by a hull cleaning robot in response to user confirmation that action is to be taken in response to the cleanliness of the hull of a vessel being monitored;
- 25 Figure 8d illustrates example control actions that may be performed in embodiments of the present disclosure by a hull cleaning robot automatically in response to the cleanliness of the hull of a vessel being monitored; and
- 30 Figure 9 illustrates an example hull cleaning robot.

DETAILED DESCRIPTION

Embodiments will now be described by way of example only.

Figure 1a illustrates an aquatic vessel 100 for example a container ship, bulk carrier, tanker, or passenger ship. The aquatic vessel comprises a hull 101.

5 The vessel may comprise a robot station 104 (a docking station) which may be used to charge a hull cleaning robot 102. The robot station 104 may be positioned on the vessel above the sea level. The robot station 104 may allow for parking of the robot 102 when cleaning operations performed by the robot are paused. During cleaning of the surface of the hull 101, the robot 102 may traverse any surface of the hull 101 where marine fouling may form (e.g. a flat bottom or side bottom of the hull). Reference
10 to "cleaning" is used herein to refer to the removal of fouling organisms from the surface of the hull 101, such cleaning is sometimes referred to as "grooming". By performing the continual cleaning of the surface of the hull 101, the robot 102 typically performs removal of fouling at an early stage (e.g. primary colonizers) that has adhered to the surface of the hull 101. However, it will be appreciated that the cleaning
15 performed by the robot 102 may also involve removal of secondary colonizers and any subsequent colonizers.

As shown in Figure 1a, a computing device 106 may be provided on the vessel (e.g. in a deckhouse of the vessel) for communication with a remote device such as the robot
20 102 and/or a computing device 108 on shore e.g. at a monitoring station 110 as shown in Figure 1b.

Figure 1b illustrates such a monitoring station 110 comprising a computing device 110. The computing device 110 is in communication with one or more vessel via a
25 communication network 112.

In embodiments of the present disclosure, a computer implemented method for dynamically monitoring the cleanliness of an underwater hull of a vessel is performed during a journey of this vessel. As will be explained in more detail below, this method
30 may be performed on the robot 102, the computing device 106 on the vessel, or the on-shore computing device 108.

As shown in Figure 1b, in implementations where an on-shore computing device 108 performs the computer implemented method described herein, this enables a ship

operator to have real time monitoring over the operational efficiency of their fleet of vessels.

5 Embodiments of the present disclosure are not limited to dynamically monitoring the cleanliness of an underwater hull of a vessel which is equipped with a hull cleaning robot 102. As will be explained in more detail below, in response to detecting that such vessels are at high risk of fouling on the surface of the vessel, other actions not involving a hull cleaning robot can be taken in response to the detection.

10 Figure 2 is a schematic block diagram of the robot 102. As shown in Figure 2, the robot 102 is a computing device comprising a central processing unit ("CPU") 202. The CPU 202 is configured to control a cleaning device 208 (which may take the form of a rotary cylindrical brush) which is coupled to the CPU 202 and performs the removal of fouling organisms from the surface of the hull 101.

15 The CPU 202 may also comprise a hull fouling risk determination module 206 that is configured to dynamically monitor the cleanliness of an underwater hull of a vessel in accordance with embodiments of the present disclosure. It will be apparent from the below that whilst the robot 102 may comprise the hull fouling risk determination module 206, in alternative embodiments the hull fouling risk determination module 206 may be a component of computing device external to the robot 102.

20 The CPU 202 is coupled to a power source 214 (e.g. one or more battery). The power source 214 may be rechargeable e.g. using the robot station 104. The robot 102 also comprises a memory 210 for storing data as is known in the art.

25 As shown in Figure 2, the robot 102 may comprise one or more sensor 212 that are configured to output a sensor signal to the hull fouling risk determination module 206. Each of the sensors described herein may be a physical sensor (i.e. a physical measurement instrument) or a virtual sensor (i.e. software that combines sensed data from multiple physical sensors to compute a measurement).

30 The sensor(s) 212 may comprise one or more sensors configured to sense operational data associated with the vessel. In particular, the sensor(s) may comprise a speed sensor (e.g. a speed log) configured to output speed data indicating the speed of the

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- vessel 100. The speed sensor may be configured to perform 'Speed Over the Ground' and/or 'Speed Through Water' measurements. The speed sensor configured to perform a 'Speed Over the Ground' measurement may use information that is extracted from the navigation system of the vessel e.g. Global Positioning System (GPS), or other speed sensors on board (e.g. a GPS sensor in the docking station 104). The speed sensor configured to perform a 'Speed Through Water' may use one or more onboard sensors (typically Doppler-based or electromagnetic). It is also possible to use the robot 102 as a virtual sensor for 'Speed Through Water' measurements.
- 10 The sensor(s) 212 may comprise one or more sensors configured to sense other operational data associated with the vessel such as an activity level of the vessel, a draught of the vessel, a speed of the propeller of the vessel, and/or a heading of the vessel. The activity level of the vessel indicates how many hours the vessel has been moving during its journey, which may be defined as a value in hours or as a percentage of time spent moving during the journey. The vessel may be regarded as not moving when the speed over ground is less than a predetermined speed e.g. 6 knots. The draught is the depth of the keel of the vessel below the waterline at any point along the hull. The draught of a vessel can vary with the vessel loading state (e.g. if the vessel has a full cargo or not). The draught of a vessel can also vary for a given loading due to use of ballast water. The heading is the compass direction (angular distance relative to north) in which the vessel is pointing at any given moment.
- 20 The sensor(s) 212 may comprise one or more sensors configured to sense environmental data relating to the environment conditions of the vessel 100.
- 25 For example, the sensor(s) may comprise one or more of: (i) a chlorophyll sensor configured to sense an amount of chlorophyll in an aquatic environment of the vessel; (ii) a pH sensor configured to sense a pH level of the aquatic environment of the vessel; (iii) a nutrients sensor configured to sense a nutrient level in the aquatic environment of the vessel, the nutrients sensor may be configured to sense nutrients such as phosphate, nitrate etc.; (iv) a sunlight intensity sensor configured to sense a light intensity in the aquatic environment of the vessel; (v) a salinity sensor (e.g. a conductivity sensor) configured to sense a saline level of the aquatic environment of the vessel; (vi) a temperature sensor configured to sense a temperature of the aquatic environment of the vessel; (vii) a carbon dioxide sensor configured to sense an amount
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of carbon dioxide in the aquatic environment of the vessel; (viii) a location sensor (e.g. a GPS sensor) configured to sense a geographical location of the vessel; (ix) a dissolved oxygen sensor configured to sense an amount of gaseous oxygen dissolved in the water in the aquatic environment of the vessel; and (x) a depth sensor configured to sense a depth of the aquatic environment of the vessel. Such sensors are known to persons skilled in the art and are therefore not described in further detail herein.

The location sensor referred to above can be used to determine the distance between the vessel and nearby coastline.

Multiple sensors of the same type may be used in embodiments of the present disclosure. For example, multiple temperature sensors may be used to measure the temperature of the aquatic environment of the vessel at different depths. In embodiments, the readings from multiple sensors of the same type may be combined to provide a single value associated with the sensor type.

Whilst the sensor(s) referred to above have been described as being located on the robot 102, these sensors may be located on a remotely operated underwater vehicle configured to inspect the hull of the vessel, or these sensors may be located on the vessel 100.

The sensor(s) that are located on the vessel 100 may output the data directly to the hull fouling risk determination module 206 on the robot 102 via interface 216. Alternatively, the sensor(s) that are located on the vessel 100 may output data to the computing device 106 which relays the data to the robot 102 via interface 216.

The sensor(s) 212 may comprise a camera configured to output a camera signal comprising image data. The camera may output the camera signal to the computing device 106 and/or computing device 108. The camera enables the robot 102 to carry out a visual inspection of the hull of the vessel. The robot 102 may inspect the hull of the vessel without carrying out a visual inspection. Thus, in addition to or as an alternative to the camera, the robot 102 may comprise one or more other hull inspection device for carrying out an inspection of the hull such as electromagnetic device or ultrasound device.

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In some embodiments an interface 216 is provided to enable the robot 102 to receive and transmit data to the computing device 106 and the computing device 108. The interface 216 also enable the robot to receive data from sensors on the vessel. The interface 216 may comprise a wired and/or a wireless interface.

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The interface 216 also enables the robot 102 to download ship positioning data (e.g. Automatic Identification System (AIS) data) and/or satellite derived marine environment data. This information may be downloaded respectively, from an AIS data provider and a data centre storing satellite derived marine environment data such as a data centre associated with the Copernicus Marine Environment Monitoring Service (CMEMS). This information may be downloaded at least daily. Regarding the ship positioning data (e.g. AIS information), new data may be available for download every hour, in comparison with marine environmental data, which may only release one update per day or, in some exceptions, one update per week. The ship positioning data may also be downloaded from storage associated with a ship operator (e.g. reported position data or GPS data). Thus the ship operator may provide the ship positioning data e.g. for a vessel that has no AIS system installed.

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As noted above, in some embodiments the hull fouling risk determination module is a component of a computing device 106 on the vessel, or an on-shore computing device 108. Figure 3 illustrates such a computing device.

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As shown in Figure 3, the computing device 106,108 comprising a central processing unit ("CPU") 302. The CPU 302 is coupled to a memory 310 for storing data as is known in the art and an output device 312.

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The CPU 302 may also comprise a hull fouling risk determination module 306 that is configured to dynamically monitor the cleanliness of an underwater hull of a vessel in accordance with embodiments of the present disclosure.

The computing device 106,108 comprising an interface 316 to enable the computing device to receive and transmit data. The interface 316 enables the computing device 106,108 to receive data from the robot 102 (if one is present on the vessel), and/or receive data from sensors on the vessel. For example, the computing device may receive the operational data and/or the environmental data referred to above via the interface 316. The interface 316 also enables the computing device to communicate

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with the robot 102, a remotely operated underwater vehicle on the vessel, and/or a vessel control system of the vessel, whereby the vessel control system controls the direction and speed of the vessel.

- 5 The interface 316 also enables the computing device 106,108 to download ship positioning data (e.g. AIS data) and/or satellite derived marine environment data. This information may be downloaded respectively, from an AIS data provider and a data centre storing satellite derived marine environment data such as a data centre associated with the Copernicus Marine Environment Monitoring Service (CMEMS).
- 10 This information may be downloaded at least daily. Regarding the ship positioning data (e.g. AIS information), new data may be available for download every hour, in comparison with marine environmental data, which may only release one update per day or, in some exceptions, one update per week. The ship positioning data may also be downloaded from storage associated with a ship operator (e.g. reported position
- 15 data or GPS data. Thus the ship operator may provide the ship positioning data e.g. for a vessel that have no AIS system installed.

- The output device 312 is configured to output information to a user of the computing device 106,108. For example the output device 312 may comprise a display to visually
- 20 output information. Additionally or alternatively, the output device 312 may comprise a speaker to audibly output information.

- The use of the operational data and the environmental data referred to above is not limited to any particular embodiment described herein, and may be used in all
- 25 embodiments.

In embodiments of the present disclosure, the cleanliness of an underwater hull of a vessel is dynamically monitored during a journey of this vessel.

- 30 The underwater hull of a vessel is typically coated. The coating present on the hull of the vessel may comprise a single layer, several layers of the same coating or may be a multi-layered coating, i.e. a coating system. In a multi-layered coating, the first coat (sometimes referred to as the primer coating) is often an anticorrosive layer. The primer coating is optionally over coated by a link coat or tie-coat followed by one or
- 35 more final coats or topcoats, with or without fouling protection properties. In another

type of multi-layered coating, the first (primer) coat may simply be over coated with a last coat or topcoat.

5 The underwater hull of the vessel may be coated with a single coating or coating system across the entire hull. Alternatively, the hull of the vessel may comprise of a number of sections of different coatings, or coating systems, on different parts of the hull (e.g. flat bottom, side bottom, vessel fore parts, vessel aft parts, waterline, parts prone to damages, propellers and rudders). The different coatings or coating systems present in different parts of the hull might be different types and/or different
10 thicknesses.

The coatings applied on the vessel can be divided in classes depending on if the coatings are polishing or non-polishing. A polishing coating is a coating that decreases in film thickness during the life-time of the coating. The reduction in film thickness may
15 be due to chemical reactions or erosion or a combination thereof. A non-polishing coating is a coating that does not decrease in film thickness during the life-time of the coating.

Polishing coatings are typically based on binder systems with various mechanisms for degradation. Self-polishing coating is another term commonly used. Most often the degradation is hydrolysis of bonds in the binder system resulting in increased water solubility and polishing of the coating. The hydrolysis can either be hydrolysis of pendant groups or side chains on the polymer backbone in the binder or hydrolysis of groups in the polymer backbone in the binder.
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25 The binder present in a polishing coating may, for example, comprise silyl (meth)acrylate copolymer, rosin based binder, (meth)acrylate binder, backbone degradable (meth)acrylate copolymer, metal (meth)acrylate binder, hybrids of silyl (meth)acrylate binder, (meth)acrylic hemiacetal ester copolymers, polyanhydride
30 binder, polyoxalate binder, non-aqueous dispersion binder, zwitterionic binder, polyester binder, poly(ester-siloxane) binder, poly(ester-ether-siloxane) binder, or mixtures thereof.

Typical silyl (meth)acrylate copolymers and coatings comprising these are described in
35 GB2558739, GB2559454, WO2019096926, GB2576431, WO2010071180,

WO2013073580, WO2012026237, WO2005005516, WO2013000476, WO2012048712, WO2011118526, WO0077102, WO2019198706, WO03070832 and WO2019216413.

- 5 Typical silyl (meth)acrylate copolymers with siloxane moieties are described in WO2011046087. Typical rosin based binders and coatings comprising these are described in WO2019096928, DE102018128725, DE102018128727 and WO9744401.

- 10 Typical (meth)acrylate binders and coatings comprising these are described in DE102018128725A1, DE102018128727A1, WO2019096928, WO2018086670 and WO9744401. Typical metal (meth)acrylate binders are described in WO2019081495 and WO2011046086. Typical hybrids of silyl (meth)acrylate binders are described in KR20140117986, WO2016063789, EP1323745, EP0714957, WO2017065172, JPH10168350A and WO2016066567. Typical polyanhydride binders are described in
15 WO2004/096927. Typical polyoxalate binders are described in WO2019081495 and WO2015114091. Typical non-aqueous dispersion binders are described in WO2019081495. Typical zwitterionic binders are described in WO2004018533 and WO2016066567. Typical polyester binders are described in WO2019081495, EP1072625, WO2010073995 and US20150141562. Typical poly(ester-siloxane) and
20 poly(ester-ether-siloxane) binders are described in WO2017009297, WO2018134291 and WO2015082397. Typical (meth)acrylate hemiacetal ester copolymer binders are described in WO2019179917, WO2016167360, EP0714957 and WO2017065172. Typical backbone degradable (meth)acrylate copolymer binders are described in WO2015010390, WO2018188488, WO2018196401 and WO2018196542.

- 25 Non-polishing coatings are typically cross linked and often containing low amount of VOC (volatile organic compounds). The binder present in a non-polishing coating may, for example, comprise polysiloxane, a siloxane copolymer, silicone binders, an epoxy-based binder, epoxysiloxane, polyurethanes or mixtures thereof.

- 30 Typical polysiloxane binders and coatings comprising these are described in WO2019101912, WO2011076856, WO2014117786, WO2016088694 and WO2013024106. Typical siloxane copolymer binders are described in WO2012130861 and WO2013000479. Typical epoxy-based binders and coatings comprising these are
35 described in WO2018046702, WO2018210861, WO2009019296, WO2009141438,

EP3431560 and WO2017140610. Typical epoxysiloxane binders are described in US2009281207, WO2019205078 and EP1086974. Other types of silicone binders are silicone resins typically denoted as MQ, DT, MDT, MTQ or QDT resins. The coating may be a riblet structured curable polysiloxane binder, as described in
 5 WO2019189412. The coating may be a dimple structured coating as described in US20180229808. Such coatings may be applied as a coating or as an adhesive foil. The coating may be a riblet structured adhesive foil with a fouling release topcoat, for example, as described in WO2018100108.

10 The coating applied on the vessel may also be divided in classes depending on if the coating contains a fouling control agent. Fouling control agents can be organic, organometallic or inorganic compounds that influences, repels or acts hazardously towards fouling organisms.

15 One group of fouling control agents are biocides which are substances intended to destroy, deter, render harmless, prevent action of or exert a controlling effect towards fouling organisms by chemical or biological means. The terms biocides, antifouling agents, antifoulants, active compounds, toxicants are used in the industry to describe known compounds that act to prevent marine fouling on a surface. The biocides may
 20 be inorganic, organometallic or organic.

Commonly used biocides are copper(I)oxide, copper thiocyanate, zinc pyrithione, copper pyrithione, zinc ethylenebis(dithiocarbamate) [zineb], 2-(tert-butylamino)-4-(cyclopropylamino)-6-(methylthio)-1,3,5-triazine [cubutryne], 4,5-dichloro-2-n-octyl-4-
 25 isothiazolin-3-one [DCOIT], N-dichlorofluoromethylthio-N',N'-dimethyl-N-phenylsulfamide [dichlorofluanid], N-dichlorofluoromethylthio-N',N'-dimethyl-N-p-tolylsulfamide [tolylfluand], triphenylborane pyridine [TPBP] and 4-bromo-2-(4-chlorophenyl)-5-(trifluoromethyl)-1H-pyrrole-3-carbonitrile [tralopyril] and 4-[1-(2,3-dimethylphenyl)ethyl]-1H-imidazole [medetomidine].

30 One group of fouling control agents that prevents or reduces attachment of fouling organisms by a physical mode of action are silicone oils, hydrophilic modified silicone oils and hydrophobic modified silicone oils. Typical silicone oils are described in WO2018/134291.

35

Both polishing and non-polishing coatings can contain fouling control agents such as biocides and silicone oils or mixtures thereof or be without a fouling control agent.

5 Embodiments of the present disclosure can be used to dynamically monitor the cleanliness of a coated hull (i.e. the cleanliness of a surface of a coating applied to the hull) or an uncoated hull of a vessel throughout the vessel's journey.

10 We now describe a first embodiment of the present disclosure with reference to Figure 4. Figure 4 illustrates a flowchart of a process 400 for dynamically monitoring the cleanliness of an underwater hull of a vessel performed by the hull fouling risk determination module 206,306. Thus, the process 400 is performed by a computing device. For example, the process 400 may be performed on the robot 102, the computing device 106 on the vessel, or the on-shore computing device 108.

15 The first embodiment aims to predict the fouling risk that a vessel might be exposed to during its service, which reflects on the degree of fouling that can develop or be present on the vessel's hull. In particular, the level of risk of fouling on an underwater surface of the vessel is identified by determining a fouling risk value using a fouling protection value and a fouling value. As explained below, this fouling risk value can be
20 considered in a normalized scale from 0 (low) to 1 (high).

At step S402, the fouling value is determined. The fouling value reflects how the conditions of the environment (marine and atmospheric) of the vessel can influence the development and growth of marine biofouling on a vessel's hull.

25 In order to determine the fouling value, the hull fouling risk determination module requires environmental data relating to the environment conditions of the vessel 100, examples of which have been provided above. The environmental data comprises a value associated with each of one or more environmental parameters.

30 The hull fouling risk determination module may identify the environmental data relating to the environment conditions of the vessel 100 in a number of different ways.

35 As shown in Figure 5a, in a process 500 at step S502 the hull fouling risk determination module retrieves environmental data from memory (e.g. local memory of the computing

device or in memory of a remote computing device that is accessible by the computing device). If the retrieved environmental data relates to the environment conditions of the vessel 100 (e.g. the environmental data has been sensed by sensors on the robot 102 or sensors on the vessel), the retrieved environmental data can be used at step S402 to determine the fouling value.

As shown in Figure 5a, in the process 500 if the retrieved environmental data includes but does not specifically relate to the environment conditions of the vessel 100, e.g. the retrieved environmental data is satellite derived marine environment data relating to environment conditions around the globe, at step S504 the hull fouling risk determination module obtains the geographical location of the vessel. The hull fouling risk determination module uses the geographical location of the vessel together with the retrieved environmental data to determine environmental data relating to the environment conditions of the vessel 100 which is then used at step S402 to determine the fouling value. In this example the geographical location of the vessel may have been sensed by a location sensor on the robot 102 or a location sensor on the vessel, or the geographical location of the vessel may be determined using ship positioning data (e.g. AIS data) downloaded respectively from an AIS data provider.

As shown in Figure 5b, in embodiments where an on-shore computer device 108 performs the process 400, in a process 550 the hull fouling risk determination module 306 retrieves environmental data at step S502 to determine a global fouling map at step S506. The global fouling map identifies the marine fouling conditions of multiple locations around the world and may change over time.

The environmental data retrieved at step S502 used to determine the global fouling map may comprise satellite derived marine environment data relating to environment conditions around the globe.

Additionally, or alternatively, the environmental data retrieved at step S502 used to determine the global fouling map may comprise, for each of one or more vessels, environmental data relating to the environment conditions of the vessel (e.g. the environmental data has been sensed by sensors on a robot on the vessel, or sensors on the vessel) and the geographical location of the vessel. In this example the geographical location of the vessel may have been sensed by a location sensor on a

robot on the vessel or a location sensor on the vessel, or the geographical location of the vessel may be determined using ship positioning data (e.g. AIS data) downloaded respectively from an AIS data provider.

5 At step S504, the hull fouling risk determination module 306 obtains the geographical location of the vessel that is to be monitored and uses the geographical location of the vessel and the global fouling map to determine environmental data relating to the environment conditions specific to the vessel 100 being monitored which is then used at step S402 to determine the fouling value. In this example the geographical location
10 of the vessel may have been sensed by a location sensor on the robot 102 or a location sensor on the vessel, or the geographical location of the vessel may be determined using ship positioning data (e.g. AIS data) downloaded respectively from an AIS data provider.

15 In addition, operational characteristics of the vessel, in combination with environment parameters, can also be used to define the fouling value at step S402. The operational data comprising a value associated with each of one or more operational parameters. Examples of these operational characteristics include the speed over ground of the vessel, the speed through water of the vessel, the activity level of the vessel, the draught of the vessel, and a heading of the vessel.
20

One or more environmental parameters are used to determine the fouling value at step S402. Additionally, one or more operational parameters may be used to determine the fouling value at step S402.

25 As one example, expressions may be stored in memory which model the approximate risk/contribution that each parameter provides to the overall fouling value.

Such expressions may be empirically derived. To determine the marine biofouling pressure that a vessel might be exposed to at any point in time (defined by the fouling value), an amount of environment conditions (for example, surface seawater temperature, light availability, concentration of nutrients, concentration of chlorophyll a, surface seawater salinity, distance to coastline, water depth), and how they may influence the condition on the vessel's hull, were studied and analysed by the inventors
30 of the present disclosure for several port locations and vessels' routes. Empirical
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results from permanent test rafts, test patches on hulls, vessels' in docking conditions and inspection reports, were compared against marine and atmospheric environment conditions gathered for the ports or vessel's routes in question. Based on this study, empirical derived expressions were developed to model the approximate risk/contribution that each environment parameter provides to the overall fouling value.

Considering the example parameters provided below:

	$Speed_{risk} = S(t) \in [0,1]$	<i>Speed over ground of the vessel (in knots)</i>
	$Temperature_{risk} = T(t) \in [0,1]$	<i>Seawater surface temperature (in degrees Celsius)</i>
10	$Depth_{risk} = De(t) \in [0,1]$	<i>Water depth (in meters)</i>
	$Distance_{risk} = Di(t) \in [0,1]$	<i>Distance to coastline (in kilometres)</i>
	$Light_{risk} = L(t) \in [0,1]$	<i>Length of day (sunrise to sunset in hours)</i>
	$Chlorophyll_{risk} = C(t) \in [0,1]$	<i>Concentration of chlorophyll a (in mg.m⁻³)</i>
15	$Salinity_{risk} = Sa(t) \in [0,1]$	<i>Seawater surface salinity (in psu or g/kg)</i>

Where the Speed over ground of the vessel is an example operational parameter and the remaining parameters are environmental parameters, and t is a unit of time, normally in hours or days. The length of day parameter could be replaced by solar irradiance or by a combination of these two parameters.

Example expressions derived and implemented for each of the parameters is shown below.

$$Speed(S(t)) = 1 - \frac{1}{1 + e^{-c_1(S(t) - c_2)}} \quad (1)$$

where c_1 and c_2 are constants.

$$Temperature(T(t)) = \frac{1}{1 + e^{-c_3(T(t) - c_4)}} \quad (2)$$

where c_3 and c_4 are constants.

$$Depth(De(t)) = \begin{cases} c_5 De(t) + c_6 & \text{if } 0 < De(t) \leq 250m \\ 0.1 & \text{if } De(t) > 250m \end{cases} \quad (3)$$

where c_5 and c_6 are constants.

22

$$Distance(Di(t)) = \begin{cases} 1 & \text{if } Di(t) \leq 1.852km \\ \frac{c_7}{Di(t)} & \text{if } Di(t) > 1.852km \end{cases} \quad (4)$$

where c_7 is a constant.

$$Light(L(t)) = \begin{cases} 0 & \text{if } L(t) < 6h \\ c_8 L(t) - c_9 & \text{if } 6h \leq L(t) < 11h \\ 1 & \text{if } L(t) \geq 11h \end{cases} \quad (5)$$

5 where c_8 and c_9 are constants.

$$Chlorophyll(C(t)) = \frac{1}{1 + e^{-c_{10}(C(t) - c_{11})}} \quad (6)$$

where c_{10} and c_{11} are constants.

$$10 \quad Salinity(Sa(t)) = \begin{cases} 0 & \text{if } Sa(t) < 1 \text{ psu} \\ 0.5 & \text{if } 1 < Sa(t) < 10 \text{ psu} \\ 1 & \text{if } Sa(t) \geq 10 \text{ psu} \end{cases} \quad (7)$$

Similar expressions can be derived for other environmental parameters referred to herein.

15

Figure 6a illustrates how values of three example environmental parameters (solar irradiance, sea surface water temperature, and day length) vary over time in Sandefjord Norway over a 1 year period. In particular, curve 602 shows how the solar irradiance varies over the 1 year period, curve 604 shows how the day length varies over the 1 year period, and curve 606 shows how the temperature varies over the 1 year period,

20

Figure 6b illustrates how the fouling value may vary over time on a normalized scale. In particular, curve 608 shows how the fouling value varies over the 1 year period when it is based on two parameters, the sea surface water temperature and day length. Curve 610 shows how the fouling value varies over the 1 year period when it is based on two parameters, the sea surface water temperature and solar irradiance. Curve 612 shows how the fouling value varies over the 1 year period when it is based on all three of the example parameters (solar irradiance, sea surface water temperature, and day length).

25

30

It will be apparent that these expressions are intended to model the contribution of each individual parameter, in a scale from 0 (low) to 1 (high), to a total level of marine fouling that the surface of the vessel's hull is exposed to, which is defined by the fouling value in a normalized scale from 0 (low) to 1 (high).

5

With reference to Figure 6c, it can be seen that the contribution of the speed over ground parameter to the fouling value is maximum (i.e. equal to 1) when the vessel has a speed over ground of 0 kn, which means that the risk/contribution of fouling attachment/development on a vessel is maximum at that point in time. However, if this vessel is moving at approximately 4 kn the contribution drops to 40% (a value of 0.4 in the speed factor figure). The risk/contribution of the speed parameter is close to zero if the vessel is moving at 6 kn.

Regarding the contribution of the sea surface water temperature parameter to the fouling value, as shown in Figure 6d it can be seen that the contribution of fouling development increases with temperature but not in a linear way. At low and high temperature ranges, the degree of increase is lower than at median values.

As shown in Figure 6e, distance to coastline is a parameter whose risk/contribution of fouling attachment and development is high close to the shore but abruptly decreases as the vessel moves away from the coastline. The derived curve indicates that at 20 km from the coastline the contribution to the fouling value is approximately 10% (0.1 in the distance to coastline figure).

It will be apparent that the expressions provided above are merely examples. If expressions, such as those provided above, are used to model the approximate risk/contribution that each parameter provides to the overall fouling value, then the expressions may vary over time and may be improved through continuous analysis of empirical data gathered over time. Furthermore, one or more of the expressions to be used in determining the fouling value may vary in dependence on vessel type, vessel trade or trade areas.

If some parameters are considered more important for the determination of the fouling value at step S402, weights may be applied to each parameter.

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Thus, referring to the example parameters provided above, the total instantaneous fouling value is then, a weighted average of the different parameter risk factors, as shown in equation (8), where K is a constant and represents the weight given to each factor.

5

$$Fouling\ Value(t) = \frac{1}{\sum K} Speed(t)(K_T Temperature(t) + K_{De} Depth(t) + K_{Di} Distance(t) + K_C Chlorophyll(t) + K_{Sa} Salinity(t) + K_L Light(t)) \tag{8}$$

Table 1 shows example weights which may be applied for each individual parameter.

10

Coefficient K	Weight
Temperature K_T	3
Water Depth K_{De}	2
Distance to coastline K_{Di}	3
Chlorophyll K_C	3
Salinity K_{Sa}	1
Light K_L	3

Table 1.

Whilst methods to determine a fouling value have been described above with reference to the embodiment shown in Figure 4, the methods to determine a fouling value can also be applied in other embodiments of the present disclosure described herein, for example in the process shown in Figure 7.

15

Referring back to Figure 4, at step S404 a fouling protection value is determined. The fouling protection value defines the surface tolerance to marine biofouling associated with a surface of the vessel e.g. the protection given by a coating to the vessel's hull. As noted above, the hull of the vessel may be coated and in these scenarios the fouling protection value defines a tolerance to marine fouling associated with a surface of the coating i.e. the protection given by the coating to the vessel's hull. Alternatively, the hull of the vessel may not be coated and in these scenarios the fouling protection value defines a tolerance to fouling associated with a surface of the hull of the vessel.

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The fouling protection value may be prestored in memory. For example, the fouling protection value may be prestored in the local memory of the computing device or in memory of a remote computing device that is accessible by the computing device. In

these implementations, the fouling protection value has been precalculated and the hull fouling risk determination module determines the fouling protection value by retrieving it from memory. Thus, the hull fouling risk determination module may not perform the calculation of the fouling protection value itself.

5

In other implementations, the hull fouling risk determination module determines the fouling protection value by calculating the fouling protection value itself.

We describe in more detail later how the fouling protection value may be calculated.

10

The fouling protection value may be calculated in a normalized scale from 0 (low protection) to 1 (high protection).

At step S405, a fouling risk value is determined using the fouling value (determined at step S402) and the fouling protection value (determined at step S404). The fouling risk value defines a level of risk of fouling on the surface of the vessel.

15

For each point in time (depending on sampling period, which may for example be 1 hour) a fouling value and fouling protection value are determined. Expression (9) provided below gives an example of how the fouling risk value may be calculated as a function of the fouling value and fouling protection value.

20

Instantaneous Fouling Risk Value (time: x) =
$$\frac{\text{Fouling value (time: x)}}{\text{Fouling value (time: x)} + \text{Fouling protection value (time: x)}}$$

(9)

It will be appreciated that other expressions to calculate the fouling risk value as a function of the fouling value and fouling protection value may also be used.

The fouling risk value may be calculated in a normalized scale from 0 (low risk) to 1 (high risk). Table 2 shows an example of the application of expression (9).

25

Fouling risk value	Fouling protection value										
	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Fouling value	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.1	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.13	0.11	0.10
	0.2	1.00	0.67	0.50	0.40	0.33	0.29	0.25	0.22	0.20	0.18
	0.3	1.00	0.75	0.60	0.50	0.43	0.38	0.33	0.30	0.27	0.25
	0.4	1.00	0.80	0.67	0.57	0.50	0.44	0.40	0.36	0.33	0.31
	0.5	1.00	0.83	0.71	0.63	0.56	0.50	0.45	0.42	0.38	0.36
	0.6	1.00	0.86	0.75	0.67	0.60	0.55	0.50	0.46	0.43	0.40
	0.7	1.00	0.88	0.78	0.70	0.64	0.58	0.54	0.50	0.47	0.44
	0.8	1.00	0.89	0.80	0.73	0.67	0.62	0.57	0.53	0.50	0.47
	0.9	1.00	0.90	0.82	0.75	0.69	0.64	0.60	0.56	0.53	0.50
	1	1.00	0.91	0.83	0.77	0.71	0.67	0.63	0.59	0.56	0.53

Table 2.

In practical terms, an instantaneous fouling risk value may not always accurately reflect the actual total risk of a vessel being fouled. An example is the case when a vessel has several relatively long stops with almost no activity between these. It will be apparent that the total fouling risk during a certain stop will be higher than the risk in earlier stops.

Considering this, the fouling risk value can be computed as a weighted average of the instantaneous fouling risk values over a certain period of time.

$$Fouling\ risk\ value(time: x) = \sum_{time: x - window size}^{time: x} \left[\frac{\text{Instantaneous fouling risk (time: x)}}{(time: x)} \cdot w \right] \quad (10)$$

where, window size is the number of days considered in the evaluation of the fouling risk value (e.g. three months) and w is a weight factor. Higher weight is given to recent instantaneous values and lower weight to older instantaneous values. Weight factors range between 0 and 1, and the fouling risk value should range also between 0 and 1.

Thus in some embodiments, the fouling risk value is determined based on a plurality of instantaneous fouling risk values, each of the plurality of instantaneous fouling risk values identifying a level of risk of fouling on the surface of the vessel at a respective sampling time in a time period, each of the plurality of instantaneous fouling risk values weighted with a weight defining the recency of the sampling time.

Once the fouling risk value has been determined at step S405, the process 400 may proceed to step S407. At step S407 the hull fouling risk determination module outputs the fouling risk value.

5 In embodiments where the robot 102 comprises the hull fouling risk determination module 206, at step S407 the hull fouling risk determination module 206 outputs the fouling risk value to a remote computing device such as the computing device 106 on the vessel, or the on-shore computing device 108, for output to a user. This enables the user to view the fouling risk value and determine whether a control action should be
10 taken.

In embodiments where the computing device 106 on the vessel comprises the hull fouling risk determination module 306, at step S407 the hull fouling risk determination module 306 may output the fouling risk value to a remote computing device such as the
15 on-shore computing device 108, for output to a user. This enables the user to view the fouling risk value and determine whether a control action should be taken. Additionally or alternatively, at step S407 the hull fouling risk determination module 306 may output the fouling risk value via the output device 312 of the computing device 106.

20 In embodiments where the on-shore computing device 108 comprises the hull fouling risk determination module 306, at step S407 the hull fouling risk determination module 306 may output the fouling risk value via the output device 312 of the computing device 108.

25 Once the fouling risk value has been determined at step S405, the process 400 may alternatively proceed to step S406. At step S406 the hull fouling risk determination module identifies whether there is high risk fouling conditions by determining whether the fouling risk value exceeds a predetermined threshold. If the fouling risk value is below the predetermined threshold, this indicates that there is low risk fouling
30 conditions and the process 400 loops back to the start where it waits for the next sampling time (i.e. waits for the sampling period to elapse).

If the fouling risk value is above the predetermined threshold, this indicates that there is high risk fouling conditions and the process 400 proceeds to step S408 where the hull

fouling risk determination module outputs a control signal. This is described in further detail later.

We now describe a second embodiment of the present disclosure with reference to Figure 7. Figure 7 illustrates a flowchart of a process 700 for dynamically monitoring the cleanliness of a surface an underwater hull of a vessel performed by the hull fouling risk determination module 206,306. Thus, the process 700 is performed by a computing device. For example, the process 700 may be performed on the robot 102, the computing device 106 on the vessel, or the on-shore computing device 108.

At step S702 a fouling protection value is determined. The fouling protection value defines a tolerance to fouling associated with the surface of the hull. As noted above, the hull of the vessel may be coated and in these scenarios the fouling protection value defines a tolerance to marine fouling associated with a surface of the coating i.e. the protection given by the coating to the vessel's hull. Alternatively, the hull of the vessel may not be coated and in these scenarios the fouling protection value defines a tolerance to fouling associated with a surface of the hull of the vessel.

The fouling protection value may be prestored in memory. For example, the fouling protection value may be prestored in the local memory of the computing device or in memory of a remote computing device that is accessible by the computing device. In these implementations, the fouling protection value has been precalculated and the hull fouling risk determination module determines the fouling protection value by retrieving it from memory. Thus, the hull fouling risk determination module may not perform the calculation of the fouling protection value itself.

In other implementations, the hull fouling risk determination module determines the fouling protection value by calculating the fouling protection value itself.

We describe in more detail later how the fouling protection value may be calculated. The fouling protection value may be calculated in a normalized scale from 0 (low protection) to 1 (high protection).

At step S704, the hull fouling risk determination module determines a total duration of one or more idle periods of said vessel. Step S704 may be performed using the number of idle days that the vessel has been idle during the time period by querying an

activity log associated with the vessel that is stored in memory. The number of idle days may be a cumulative figure or may define a number of consecutive idle days. The vessel may be considered idle if the speed over ground of the vessel is less than a predetermined threshold (e.g. <6kn). For example, a vessel may be considered idle when the vessel is in lay-up, detainment, remaining at or shifting within a place, drifting, at anchorage and/or berth, or sailing at low speed. An idle day can be defined as a day where the speed over ground of the vessel has been less than a predetermined threshold for over a predetermined threshold percentage (e.g. > 60%) of the day. The activity log may be stored in the local memory of the computing device or in memory of a remote computing device that is accessible by the computing device.

At step S706, the hull fouling risk determination module determines an age of the surface. The age of the surface may be prestored in memory. For example, the age of the surface may be prestored in the local memory of the computing device or in memory of a remote computing device that is accessible by the computing device.

For coated hulls, at step S706 the hull fouling risk determination module determines an age of the coating providing the surface. The age of the coating may be defined by the number of years since dry docking of the vessel when the coating was applied. If the vessel has been cleaned since the coating was applied, the age of the coating may be defined by the time (e.g. in days) that has passed since the vessel was cleaned.

For an uncoated hull of a vessel, at step S706 the hull fouling risk determination module determines an age of the uncoated hull. The age of the uncoated hull may be defined by the time (e.g. in days) that has passed since the vessel was cleaned.

At step S708, the hull fouling risk determination module determines an idle duration threshold based on the fouling protection value and the age of the surface. The idle duration threshold defines a maximum idle time that is allowed during the time period referred to above. The idle duration threshold may define a maximum number of idle days allowed during the time period referred to above.

The idle duration threshold may be determined at S708 based on how the idle periods e.g. idle days, are distributed during the time period. For example if the time period is 30 days, an idle duration threshold based on a cumulative number of idle days can be

set to 15 days. In contrast, the idle duration threshold may be different for a vessel that alternates each day between sailing and being idle.

5 Data defining the idle duration threshold (e.g. in days) based on the fouling protection value of the surface and the age of the surface may be prestored in the local memory of the computing device or in memory of a remote computing device that is accessible by the computing device. Table 3 provides an example to illustrate the concept.

Fouling protection value (x)	Year 1	Year 2	Year 3	Year 4
$A \leq x \leq B$	40	40	40	30
$B < x \leq C$	30	30	30	25
$C < x \leq D$	25	25	20	20
$D < x \leq E$	20	20	15	10
$E < x \leq F$	30	30	30	25

Table 3.

10 As shown in Table 3, the idle duration threshold may be obtained based on the fouling protection value and the age of the surface. For example, as shown in Table 3 a coating that is less than 1 year old having a fouling protection value (x) within the range $B < x \leq C$ may be associated with an idle duration threshold of 30 days.

15 At step S710, the hull fouling risk determination module determines whether the total idle duration determined at step S704 exceeds the idle duration threshold determined at step S708.

20 If the total idle duration is below the idle duration threshold the process 700 loops back to the start where it waits for the next sampling time (i.e. waits for the sampling period to elapse).
If the total idle duration is above the idle duration threshold the process 700 proceeds to step S712.

25

At step S712 retrieves environmental data relating to the environment conditions of the vessel 100, examples of which have been provided above. The environmental data comprises a value associated with each of one or more environmental parameters.

5 The hull fouling risk determination module may identify the environmental data relating to the environment conditions of the vessel 100 in a number of different ways as described above

10 At step S714 the hull fouling risk determination module determines whether there is high risk fouling conditions using the environmental data relating to the environment conditions of the vessel 100.

15 If the hull fouling risk determination module determines at step S714 that there is low risk fouling conditions then the process 700 loops back to the start where it waits for the next sampling time (i.e. waits for the sampling period to elapse).

20 If the hull fouling risk determination module determines at step S714 that there is high risk fouling conditions then the process 700 proceeds to step S716 where the hull fouling risk determination module outputs a control signal. This is described in further detail later.

25 At step S714, the hull fouling risk determination module may compare the environmental data to one or more predetermined thresholds, and if one or more of the predetermined thresholds are exceeded the hull fouling risk determination module determines at step S714 that there is high risk fouling conditions and the process proceeds to step S716 referred to above.

30 Alternatively in order to make the determination step S714, the hull fouling risk determination module may determine a fouling value as described above with reference to step S402, determine a fouling risk value as described above with reference to step S405, and identify whether there is high risk fouling conditions by determining whether the fouling risk value exceeds a predetermined threshold. If the fouling risk value exceeds the predetermined threshold the hull fouling risk determination module determines at step S714 that there is high risk fouling conditions and the process proceeds to step S716 referred to above.

35

We now describe how the fouling protection value may be calculated. As noted previously the hull fouling risk determination module may calculate the fouling protection value itself or it may retrieve the fouling protection value that has been precalculated (e.g. by another computing device).

5

The fouling protection value defines a tolerance to marine fouling associated with a surface of the vessel. That is, the fouling protection value defines the surface's ability to prevent marine fouling from attaching and eventually grow onto/into an underwater area and more specifically into a vessel's underwater hull.

10

Effective fouling protection is mainly achieved today by, but not restricted to, applying coatings on a vessel's underwater hull. The properties of the surface and the composition of the surface material influence the fouling protection capacity. However as noted above embodiments are not limited to monitoring the cleanliness of coated surfaces and can also be used to monitoring the cleanliness of uncoated surfaces of a hull of a vessel.

15

The fouling protection value may be calculated based on a value defining an attractiveness of the surface to fouling. Fouling organisms have a tendency to prefer certain types of surfaces for settlement and colonization. This is related to biological and physical factors. Thus, these characteristics and how these affect the attractiveness of a surface can be considered and modelled. Considering surface attractiveness (P_c) is of particular importance when it comes to periods when a vessel is in standstill position. The surface attractiveness (P_c) describes the tendency of marine organisms to attach to the underwater surface of the hull. Fouling organisms have the tendency to prefer dark, rough and porous surfaces.

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The surface attractiveness (P_c) of the surface may be determined based on one or more of (i) a surface energy of the surface, (ii) a topography of the surface (e.g. the roughness and/or texture of the surface) , (iii) a porosity of the surface, (iv) an elasticity of the surface, and (iv) a colour of the surface (e.g. how dark the colour of the surface is).

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If some parameters are considered more important for the determination of the surface attractiveness, weights may be applied to each parameter.

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Persons skilled in the art are aware of techniques to determine the above characteristics of a surface. For example, porosity can be determined by combining image analysis and microscopy (light or scanning electron) to map voids on the surface. It may also be determined according to ASTM D6583. Surface energy can be calculated based on contact angles determined by using a goniometer and different solvents. Surface roughness can be calculated based on x, y and z coordinates determined with confocal, weight light or laser microscopes or a tactile profilometer. Elasticity may be determined by Dynamic mechanical testing (DMA) or a Universal Test Machine. Dark colours are colours with low reflectance of visible light. In an RGB colour model, the darkness of a colour can be approximated by the sum of its red, green and blue values.

The value for the surface attractiveness (P_c) may be normalized and vary between 0 and 1.

One example of how the surface attractiveness P_c can be calculated is shown below:

$$P_c = [w_s * 1 / \text{normalized surface energy}] + [w_r * 1 / \text{normalized roughness}] + [\text{aging effect factor}] \quad (11)$$

where normalized surface energy is the ratio of the coating surface energy to a reference surface energy, for example of an epoxy coating, and normalized roughness is the ratio of the coating surface roughness to a reference roughness value.

Surface attractiveness factor may also be considered time dependent and will therefore, be affected by the age of the surface. The age of the surface may be factored in using an aging effect factor as shown above, which may vary between 0 and 1.

w_s and w_r are the weight factors for normalized surface energy and normalized surface roughness.

Persons skilled in the art will appreciate that there are different classes of fouling organisms and that the surface attractiveness value P_c can be calculated considering all classes of fouling organisms or just specific types of fouling organisms.

Additionally or alternatively, the fouling protection value may be calculated based on a value defining an effect, on a surface of the vessel, of water moving over the surface.

5 A strategy from preventing settlement/growth of fouling is the removal of such organisms via the mechanical forces that develop while a vessel is sailing. This strategy can be divided into two different approaches. One approach is to make the surface as smooth and slippery as possible so that when the vessel is moving, the shear forces applied remove any organism attached into a vessel's hull. The other approach is to develop self-renewing surfaces which contribute to the removal of
10 fouling settlement through film erosion and polishing.

The value (P_b) defining an effect, on the surface, of water moving over the surface may be determined using a speed over ground of the vessel or a speed through water of the vessel, and one or more of (i) a surface energy of the surface, (ii) a topography
15 of the surface (e.g. the roughness and/or texture of the surface), and (iii) a porosity of the surface.

The value (P_b) defining an effect, on the surface, of water moving over the surface may be normalized and vary between 0 and 1.

20 In scenarios where embodiments of the present disclosure are used to monitor the cleanliness of a surface of coating applied to the hull of a vessel, the value (P_b) defining an effect, on the surface, of water moving over the surface would depend on the characteristics of the coating.

25 As noted above, the coatings applied on the vessel can be divided in classes depending on if the coatings are polishing or non-polishing.

For polishing coatings, the value P_b may be modelled as a function of polishing rate and surface characteristics.

30
$$P_b(\text{time: } x) = \text{Polishing rate (time: } x) + \text{surface characteristics factor} \quad (12)$$

The polishing rate defines the rate at which the thickness of the coating reduces over time. The polishing rate is typically specified by the manufacturer of the coating, and is typically expressed in terms of an annual polishing rate.

The polishing rate of a polishing coating can be determined in accordance with the test method "Real life dynamic testing" described in GB2558739 where the coatings are applied and tested on vessels. The polishing rate can also be determined in laboratory test in accordance with the test method "Determination of the polishing rates of antifouling coating films on rotating disc in seawater" described in WO2019096926. Laboratory testing can be made using seawater with different temperature to determine the temperatures effect on the polishing rate. It will be appreciated that the above are provided as mere examples of how the polishing rate of a coating may be calculated, and alternative test conditions (in a laboratory or at sea, different speeds, different sea water temperatures may be used).

The polishing rate may be normalized to a reference polishing rate, which may be technology and/or coating specific. The reference polishing rate would reflect the theoretical annual polishing rate for which the balance between diffusion of fouling control agents and leach layer thickness is maintained at an acceptable level. The leached layer is the area towards the surface where the composition has changed due to loss of water-soluble materials. The leach layer thickness can be determined with the methods described above for polishing rate.

The surface characteristics factor may be determined using one or more of (i) a surface energy of the surface, (ii) a topography of the surface (e.g. the roughness and/or texture of the surface), and (iii) a porosity of the surface.

It will be appreciated by persons skilled in the art that the surface characteristics factor will depend on the coating age and surface exposure history. By surface exposure history we refer to the cumulative amount of time in a certain period when fouling could eventually attach to the surface. This is typically referring to periods when the vessel stays still. Normally, surface exposure would be balanced by surface renewal (vessel will stop for a short period of time, then sail (for a decent amount of time) and will follow this pattern throughout the whole dry-docking period. Surface renewal can refer to either polishing for polishing coatings, or simply forces (e.g. water moving over the surface) acting on the hull when vessel moves.

One example of how the surface characteristics factor can be calculated is shown below:

$$\text{Surface characteristic factor} = v_f * [w_1 * (1/\text{normalized surface energy}) + w_2 * (1/\text{normalized roughness}) + \text{age factor}] \quad (13)$$

5 where normalized surface energy is the ratio of the coating surface energy to a reference surface energy, for example of an epoxy coating, and normalized roughness is the ratio of the coating surface roughness to a reference roughness value.

10 v_f , w_1 and w_2 are the weight factors for vessel speed, normalized surface energy and normalized surface roughness.

The age of the surface may be factored in using an age effect factor as shown above.

15 For non-polishing coatings, P_b can be modelled as function of vessel speed (e.g. a speed over ground of the vessel or a speed through water of the vessel) and surface characteristics (e.g. a surface characteristics factor).

The surface characteristics factor may be determined using one or more of (i) a surface energy of the surface, (ii) a topography of the surface (e.g. the roughness and/or texture of the surface), and (iii) a porosity of the surface.

20 For example, value (P_b) defining an effect, on the surface, of water moving over the surface can be considered maximum when the speed is above a certain threshold and minimum when speed is zero. The speed threshold can be determined experimentally as the speed at which all types of fouling can be removed from the hull surface. The speed threshold is species dependent and different methods can be used to determine it, e.g. ASTM D5618 for barnacles. When it comes to the dependency of P_b on surface characteristics, the latter will have an impact on the net shear forces applied to the surface.

30 In addition to the above, in scenarios where embodiments of the present disclosure are used to monitor the cleanliness of a surface of coating applied to the hull of a vessel, and the coating contains fouling control agents, the fouling protection value may be calculated based on a value defining the effect of fouling control agents on the surface (e.g. biocides) to marine biofouling.

Fouling control agents can be any form of organic or non-organic substances, which influence, repel or act as hazardous towards fouling organisms making it difficult or even impossible to settle or survive on the surface.

5 The effect of the fouling control agent on marine biofouling is described by the diffusion of the latter from the coating to the surface. In broad terms, the effect of the fouling control agent (P_a) is modelled as function of (i) vessel speed (e.g. a speed over ground of the vessel or a speed through water of the vessel), (ii) surface exposure history, and (iii) the age of the coating.

10

The value (P_a) defining the effect of the fouling control agent (P_a) may be normalized and vary between 0 and 1.

15

When the vessel sails, fouling control agents are continuously being transported from the coating to the surface. However, because of the water flow along the hull, these in a simplistic model are considered washed out almost immediately and not offering much protection against marine organisms. When the vessel decelerates and eventually comes into a standstill position, diffusion of the fouling control agent does not stop and, since water velocity relative to the hull decreases, concentration of the fouling control agent starts increasing.

20

With regards to the surface exposure history, if surface exposure is not balanced by surface renewal then this will have an impact on the effect of fouling control agents (diffusion of fouling control agents is being inhibited). An example is a biocidal self-polishing surface which needs to maintain the leach layer thickness within acceptable levels so that biocides can effectively diffuse to the surface and protect the latter. If surface exposure history is unfavorable (vessel had a very long stop or many stops relatively recently, or if the amount of time sailing between ports has been relatively low), then the above-mentioned balance is perturbed. The balance between surface renewal and surface exposure can be also seen from a long-term perspective. A certain technology might have a better control over this balance, ensuring a more stable diffusion of the fouling control agents to the surface throughout the lifetime of the coating.

30

One possible way to model the effect of fouling control agents is described by the following formula:

$$P_a(\text{time: } x) = P_a(\text{time: } x-1) + \left[\frac{1}{\text{leach layer factor}(\text{time: } x)} \right] * (\text{mean release rate}) - (\text{removal agent factor}) \quad (14)$$

Where:

- $P_a(\text{time: } x)$ is the concentration of the fouling control agent at time x ;
- $P_a(\text{time: } x-1)$ is the concentration of fouling control agent at time $x-1$;
- leach layer factor($\text{time: } x$) is a factor accounting for the thickness of the leach layer, the leach layer factor can be dependent on the age of the coating and coating technology;
- mean release rate is the average change in fouling control agent concentration per unit of time, the mean release rate may be estimated on the polishing rate and/or knowledge of the coating technology of the coating, alternatively the release rate may be experimentally determined using known methods (e.g. ISO10890:2010, ASTM D6442-99, ISO 15181-2, ISO 15181-3, ISO 15181-6) ; and
- removal agent factor is a factor accounting for the diffusion of fouling control agent in the sea water, the removal agent factor may be dependent on the temperature, viscosity of the sea water and water speed over the surface (approximated by vessel speed).

As exemplified earlier, ideally, there should be a balance between the release of fouling control agents and surface renewal. This balance ensures minimal changes in the leach layer thickness and, therefore, easier diffusion of the fouling control agents to the surface. To account for the changes in leach layer thickness, the following formula can be used:

$$\text{Leach layer factor}(\text{time: } x) = \text{leach layer factor}(\text{time: } x-1) + \delta \quad (15)$$

where δ is a correction factor accounting for surface renewal through polishing. For polishing surfaces δ is modelled as a function of vessel speed e.g. a speed over ground of the vessel or a speed through water of the vessel. When vessel speed is higher than a certain threshold, δ is expected to be negative. On the contrary, when vessel speed is below the same threshold, this correction factor is positive, meaning that over longer periods of low activity/inactivity, leach layer thickness will increase with time. The threshold used would depend on coating technology and will reflect the

minimum speed at which polishing starts. For non-polishing coatings, delta is positive and constant throughout the lifetime of the coating.

5 As fouling control agents reach the coating surface, these will naturally diffuse further into the sea water. To account for this, a "removal agent" factor may be used. The removal agent is a function of vessel speed (e.g. a speed over ground of the vessel or a speed through water of the vessel), so that when the vessel speed is lower than a certain threshold (e.g. 3kn), the removal agent factor is small, but never zero. This is because water velocity relative to vessel hull is small. On the other hand, when vessel
10 speed is beyond the same threshold, the removal agent factor is greater.

The effect of fouling control agent is also dependent on the agent itself. Not all fouling control agents that diffuse to the coating surface have the same protection effect. Furthermore, a coating might have several fouling control agents, and these might be
15 effective against different fouling organisms.

To correct the fouling control agent parameter computed by the above formula, an effectiveness of the agent factor can be used which may vary between 0 and 1. Thus a final value (P_a) defining the effect of the fouling control agent at any point in time can
20 be defined as:

$$P_a = \text{agent_effectiveness_factor} * P_a(\text{time: } x) \quad (16)$$

An example equation for calculating the fouling protection value is shown below:

$$\text{Fouling protection value} = [w_a * P_a] + [w_b * P_b] + [w_c * P_c] \quad (17)$$

25 where P_a accounts for the effect of the fouling control agent, P_b accounts for the effect of shear forces applied on the surface and P_c accounts for the effect of surface attractiveness, and w_a, w_b and w_c are weight factors.

It will be appreciated that embodiments of the present disclosure are not limited to using a fouling protection value calculated using all of these parameters.

30 In embodiments where the fouling protection value is calculated using more than one of these parameters, as shown in equation (17) weight factors may be used.

Weight factors may be modelled as functions of vessel speed and/or coating technology and the sum of w_a , w_b and w_c is proposed to be 1. For example, in the case of a polishing coating, when the vessel is idling, w_a is expected to be higher than w_b and w_c is also of importance, while when vessel starts moving and speed increases, w_b is dominating. In the case of a non-polishing surface without fouling control agents, w_a would be zero, w_c - dominating when vessel stays still and w_b – dominating when vessel sails.

Each of the parameters of the equation (17) may be normalized and vary between 0 and 1.

It is important to note that the fouling protection value will be different for different types of marine organisms. P_a , P_b and P_c will vary because, for example, different species will react differently to different biocides, will be easier or harder to be removed from the surface and/or will have a different tendency to attach to the latter.

An example equation for calculating a generalized fouling protection value is shown below:

$$\text{Fouling protection value} = \sum_{i=1}^I (g_i \cdot P_i), \quad (18)$$

where i is the number of different species of marine organisms, P_i – species-specific fouling protection value and g_i is a weighting factor.

We now refer to Figures 8a-d which illustrate example control actions that may be performed in embodiments of the present disclosure in response to high risk fouling conditions being detected.

Figure 8a illustrates example control actions that may be performed in embodiments of the present disclosure where the computing device 106 on the vessel or the on-shore computing device 108 comprises the hull fouling risk determination module 306.

In particular, Figure 8a illustrates example control actions that may be performed in response to user confirmation that action is to be taken in response to the cleanliness of the hull of a vessel being monitored.

As shown, Figure 8a includes a step of the hull fouling risk determination module 306 outputting a control signal that there is high risk fouling conditions which corresponds to step S408 and S716 described above. In the embodiment shown in Figure 8a, this control signal is output to alert a user of the high risk fouling conditions. In particular,
5 the control signal controls an output device to alert the user of the high risk fouling conditions.

In embodiments where the computing device 106 on the vessel comprises the hull fouling risk determination module 306, at steps S408 and S716 the hull fouling risk determination module 306 may output the alert to a remote computing device such as
10 the on-shore computing device 108, for output to a user. This enables the user to determine whether a control action should be taken. Additionally or alternatively, at steps S408 and S716 the hull fouling risk determination module 306 may output the alert via the output device 312 of the computing device 106 for a user on the vessel to
15 respond to.

In embodiments where the on-shore computing device 108 comprises the hull fouling risk determination module 306, at steps S408 and S716 the hull fouling risk determination module 306 may output the alert via the output device 312 of the
20 computing device 108.

In response to the hull fouling risk determination module 306 outputting the fouling risk value at step S407, or outputting the control signal at step S408 or S716, at step S802 the hull fouling risk determination module 306 waits for receipt of user confirmation that
25 action is to be taken.

The hull fouling risk determination module 306 may receive user confirmation that action is to be taken in response to the user supplying an input via an input device of the computing device (not shown in Figure 3). If the control signal is output to a remote
30 computing device, the hull fouling risk determination module 306 may receive user confirmation that action is to be taken in response to receiving a confirmation message received via interface 316.

If the user does not confirm that action is to be taken, the process 400,700 loops back to the start where it waits for the next sampling time (i.e. waits for the sampling period to elapse).

- 5 If the user confirms that action is to be taken, the hull fouling risk determination module 306 outputs a further control signal so that an appropriate action is made before operational efficiency is lost. This can be implemented in various ways.

10 In one example, at step S804 the hull fouling risk determination module 306 outputs a control signal to initiate inspection of the hull of the vessel.

15 The hull fouling risk determination module 306 may output this control signal to a robot 102 on the vessel, or a remotely operated underwater vehicle on the vessel, to initiate inspection of the hull of the vessel. As will be understood, the robot 102 on the vessel or a remotely operated underwater vehicle can carry out inspection of the hull of the vessel by traversing the hull of the vessel and using a hull inspection device (e.g. a camera) to inspect the hull. Alternatively, the hull fouling risk determination module 306 may output this control signal to a remote computing device on the vessel to alert a user to manually launch the robot 102 or a remotely operated underwater vehicle (e.g. a swimming remotely operated underwater vehicle) to inspect the hull of the vessel. In 20 embodiments where the on-shore computing device 108 comprises the hull fouling risk determination module 306, the remote computing device may correspond to the computing device 106. In embodiments where the computing device 106 comprises the hull fouling risk determination module 306, the remote computing device may correspond to a further computing device on the vessel (e.g. a mobile computing device of a vessel worker).

30 In another example, at step S808 the hull fouling risk determination module 306 outputs a control signal to the robot 102 to initiate cleaning of the hull of the vessel. In embodiments where the on-shore computing device 108 comprises the hull fouling risk determination module 306, this control signal may be sent via the computing device 106 on the vessel. As will be understood, the robot 102 on the vessel carries out cleaning of the hull of the vessel by traversing the hull of the vessel whilst using the cleaning device 208.

35

Referring back to step S804, if based on the inspection of the hull it is confirmed at step S806 that the surface of the hull is fouled, then the process may proceed to step S808 described above. The confirmation that the surface of the hull is fouled performed at step S806 may be performed automatically by the inspection vehicle (e.g. the robot 102 or a remotely operated underwater vehicle) by processing data captured by a hull inspection device of the inspection vehicle. For example, in the case of a camera being used to inspect the hull, the captured image data may be processed to detect marine fouling. Alternatively, the confirmation that the surface of the hull is fouled performed at step S806 may comprise the inspection vehicle transmitting data captured by a hull inspection device of the inspection vehicle to the computing device 106,108. A user can then view the received data to confirm whether or not the surface of the hull is fouled. If the user does not confirm that the surface of the hull is fouled, the process 400,700 loops back to the start where it waits for the next sampling time (i.e. waits for the sampling period to elapse).

In another example, at step S810 the hull fouling risk determination module 306 outputs a control signal to a control system on the vessel to take operational measures in response to the detected fouling conditions. For example, the control signal may control the vessel control system to divert the vessel to a cleaning dock, increase the speed of the vessel, and/or change the vessel's course.

Figure 8b illustrates example control actions that may be performed in embodiments of the present disclosure where the computing device 106 on the vessel or the on-shore computing device 108 comprises the hull fouling risk determination module 306.

In particular, Figure 8b illustrates example control actions that may be performed automatically (with no user involvement) in response to the cleanliness of the hull of a vessel being monitored.

As shown in Figure 8b, in response to the hull fouling risk determination module 306 determining that there is high risk fouling conditions at step S406,S714, the hull fouling risk determination module 306 outputs a control signal output at step S408,S716 so that an appropriate action is made before operational efficiency is lost.

These control actions correspond to those described with reference to Figure 8a. Thus at steps S408, S716 the hull fouling risk determination module 306 may output a control signal to initiate inspection of the hull of the vessel, this is illustrated in Figure 8b as steps S408a and S716a. Alternatively, at steps S408, S716 the hull fouling risk determination module 306 may output a control signal to the robot 102 to initiate cleaning of the hull of the vessel, this is illustrated in Figure 8b as steps S408b and S716b. Alternatively, at steps S408, S716 the hull fouling risk determination module 306 may output a control signal to a control system on the vessel to take operational measures, this is illustrated in Figure 8b as steps S408c and S716c.

Figure 8c illustrates example control actions that may be performed in embodiments of the present disclosure where the robot 102 comprises the hull fouling risk determination module 206.

In particular Figure 8c illustrates example control actions that may be performed in response to user confirmation that action is to be taken in response to the cleanliness of the hull of a vessel being monitored.

As shown, Figure 8c includes a step of the hull fouling risk determination module 206 outputting a control signal that there is high risk fouling conditions which corresponds to step S408 and S716 described above. In the embodiment shown in Figure 8c, this control signal may be output to the computing device 106 on the vessel, or the on-shore computing device 108, to alert a user of the high risk fouling conditions. In particular, the control signal controls a remote device to alert the user of the high risk fouling conditions. This enables the user to determine whether a control action should be taken.

In response to the hull fouling risk determination module 206 outputting the fouling risk value at step S407, or outputting the control signal at step S408 or S716, at step S802 the hull fouling risk determination module 206 waits for receipt of user confirmation that action is to be taken e.g. by receiving a confirmation message received via interface 216.

If the user does not confirm that action is to be taken the process 400, 700 loops back to the start where it waits for the next sampling time (i.e. waits for the sampling period to elapse).

If the user confirms that action is to be taken, the hull fouling risk determination module 206 outputs a further control signal so that an appropriate action is made before operational efficiency is lost. This can be implemented in various ways.

5

In one example, at step S804 the hull fouling risk determination module 206 outputs a control signal to initiate inspection of the hull of the vessel. For example, the hull fouling risk determination module 206 outputs a control signal to activate a hull inspection device of the robot 102 and controls the robot 102 to travel to inspect the surface of the hull.

10

In another example, at step S808 the hull fouling risk determination module 206 outputs a control signal to initiate cleaning the hull of the vessel. For example, the hull fouling risk determination module 206 outputs a control signal to activate the cleaning device 208 of the robot 102 and controls the robot 102 to travel to clean the surface of the hull.

15

Referring back to step S804, if based on the inspection of the hull it is confirmed at step S806 that the surface of the hull is fouled, then the process may proceed to step S808 described above. The confirmation that the surface of the hull is fouled performed at step S806 may be performed automatically by the robot 102 by processing data captured by a hull inspection device of the inspection vehicle. For example, in the case of a camera being used to inspect the hull, the captured image data may be processed to detect marine fouling. Alternatively, the confirmation that the surface of the hull is fouled performed at step S806 may comprise the robot 102 transmitting data captured by a hull inspection device of the robot to the computing device 106,108. A user can then view the received data to confirm whether or not the surface of the hull is fouled. If the user does not confirm that the surface of the hull is fouled, the process 400,700 loops back to the start where it waits for the next sampling time (i.e. waits for the sampling period to elapse).

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Figure 8d illustrates example control actions that may be performed in embodiments of the present disclosure where the robot 102 comprises the hull fouling risk determination module 206.

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In particular Figure 8d illustrates example control actions that may be performed automatically in response to the cleanliness of the hull of a vessel being monitored.

5 As shown in Figure 8d, in response to the hull fouling risk determination module 206 determining that there is high risk fouling conditions at step S406,S714, the hull fouling risk determination module 206 outputs a control signal output at step S408,S716 so that an appropriate action is made before operational efficiency is lost.

10 These control actions correspond to those described with reference to Figure 8c. Thus at steps S408,S716 the hull fouling risk determination module 206 may output a control signal to initiate inspection of the hull of the vessel, this is illustrated in Figure 8d as steps S408a and S716a. Alternatively, at steps S408,S716 the hull fouling risk determination module 206 may output a control signal to initiate cleaning of the hull of the vessel, this is illustrated in Figure 8d as steps S408b and S716b.

15 The process 400 and 700 described above is performed multiple time during the vessel's journey. That is, the process 400 and 700 may be performed periodically e.g. at fixed time intervals defining a sampling period or at varying time intervals.

20 The hull of a vessel can be divided into different regions and each region can be assessed differently using the process 400 or process 700 described above. A propeller of the vessel may be regarded to be part of the hull. For the propeller the speed of the propeller can be used in the process 400 or process 700. A rudder of the vessel may be regarded as part of the hull.

25 The results of inspections on the hull referred to above can be used to develop the expressions and coefficients used in one or more of steps S402, S404, and S406 in the process 400.

30 The results of inspections on the hull referred to above can also be used in the process 700. For example this feedback can also be used to modify the data the defining the idle duration threshold based on the fouling protection value of the coating and the age of the surface (e.g. the fouling protection value shown in Table 3) used at step S708. This feedback can also be used to improve the classification of high risk fouling conditions at step S714.

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Figure 9 illustrates an example robot 102 for cleaning the hulls of marine vessels. The wheels 4 of the robot are magnetic, in order to adhere to ferrous hulls. The robot 102 is driven by the wheels 4, and the wheels 4 are driven by electric motors (not shown). In Figure 9, the robot 102 is shown fully assembled in a perspective view. The chassis 2 of the robot 1 is a perimeter frame that holds a sealed container 3 that encloses a power supply (e.g. batteries) and may include one or more of the electrical components shown in Figure 2. The container 3 is waterproof and sealed to prevent water ingress. Two beam “axles” 5 are fixed to the chassis 2 and these beams 5 support the wheels 4 as well as associated elements of the suspension arrangement and steering mechanisms for the wheels 4. The robot 102 includes the cleaning device 208, which may take the form of a rotary cylindrical brush, and this is also fixed to the chassis 2. It will be appreciated that Figure 9 shows just one example form that the robot 102 may take and other examples are possible.

Generally, any of the functions described herein can be implemented using software, firmware, hardware (e.g., fixed logic circuitry), or a combination of these implementations. The terms “functionality” and “module” as used herein generally represent software, firmware, hardware, or a combination thereof. In the case of a software implementation, the functionality or module represents program code that performs specified tasks when executed on a processor (e.g. CPU or CPUs). The program code can be stored in one or more computer readable memory device (e.g. memory 210 or memory 310). The features of the techniques described below are platform-independent, meaning that the techniques may be implemented on a variety of commercial computing platforms having a variety of processors.

While the present disclosure has been particularly shown and described with reference to preferred embodiments, it will be understood to those skilled in the art that various changes in form and detail may be made without departing from the scope of the present disclosure as defined by the appendant claims.

CLAIMS

1. A computer implemented method of dynamically monitoring the cleanliness of a hull of a vessel during a journey of said vessel, the method performed on a computing device and comprising:
- 5 retrieving environmental data from memory of the computing device, the environmental data associated with environment conditions of the vessel;
- determining a fouling protection value defining a tolerance to fouling associated with a surface of the vessel; and
- 10 identifying a level of risk of fouling on the surface of the vessel based on the fouling protection value and the environment conditions.
2. The method of claim 1, further comprising:
- determining a fouling value indicative of a level of fouling that the surface is
- 15 exposed to based on at least the environmental data; and
- identifying the level of risk of fouling on the surface of the vessel by determining a fouling risk value using the fouling protection value and the fouling value.
3. The method of claim 2, wherein the environmental data comprises a value
- 20 associated with each of one or more environmental parameters.
4. The method of claim 3, wherein the environmental data relates to a geographical location of the vessel.
- 25 5. The method of claim 2 or 4, wherein the environmental data is sensed by at least one of:
- one or more sensors on the vessel;
- one or more sensors on a hull cleaning robot configured to clean the hull of the vessel;
- 30 one or more sensors on a remotely operated underwater vehicle configured to inspect the hull of the vessel.
6. The method of claim 4, wherein environmental data relating to multiple geographical locations is stored in the memory, and the environmental data relating to

the geographical location of the vessel is retrieved using the geographical location of the vessel.

7. The method of any of claims 2 to 6, wherein determining the fouling value is further based on operational data associated with the vessel, the operational data comprising a value associated with each of one or more operational parameters, the one or more operational parameters comprising one or more of: (i) a parameter relating to speed over ground of the vessel; (ii) a parameter relating to an activity level of the vessel; (iii) a parameter relating to speed through water of the vessel; (iv) a parameter relating to a draught of the vessel; (v) a parameter relating to a heading of the vessel.

8. The method of any of claims 2 to 7, where the fouling value is an instantaneous fouling value indicative of a level of fouling that the surface is exposed to at a sampling time, the instantaneous fouling value determined by computing a weighted average of values of a plurality of risk parameters, the plurality of risk parameters comprising at least one environmental parameter defined in the environmental data.

9. The method of any of claims 2 to 7, where the fouling risk value is determined based on: (i) a plurality of instantaneous fouling risk values, each of the plurality of instantaneous fouling risk values identifying a level of risk of fouling on the surface of the vessel at a respective sampling time in a time period, (ii) a time factor relating to said time period, and (iii) activity of the vessel during said time period.

10. The method of any of claims 2 to 9 further comprising identifying high risk fouling conditions by determining that the fouling risk value exceeds a predetermined threshold, and in response outputting a control signal

11. The method of any of claims 2 to 10, further comprising outputting the fouling risk value.

12. The method of claim 11, further comprising outputting the fouling risk value to an output device of said computing device or outputting the fouling risk value to a remote computing device.

13. The method of claim 12, further comprising outputting a control signal in dependence on receiving user confirmation that a control action is to be performed.

14. The method of claim 1, further comprising:

5 determining a total duration of one or more idle periods of said vessel during a time period by querying an activity log associated with said vessel that is stored in memory;

determining, from memory, an age of the surface;

10 determining from data prestored in memory an idle duration threshold based on the fouling protection value and the age of the surface; and

determining that the total duration exceeds the idle duration threshold, and in response identifying the level of risk of fouling on the surface of the vessel based on the environmental data.

15 15. The method of claim 14, wherein identifying the level of risk of fouling on the surface of the vessel comprises comparing the environmental data to one or more predetermined thresholds.

20 16. The method of claim 15, further comprising identifying high risk fouling conditions by determining that the environmental data exceeds the one or more predetermined thresholds, and in response outputting a control signal.

17. The method of claim 14, further comprising:

25 determining a fouling value indicative of a level of fouling that the surface is exposed to based on at least the environmental data;

determining a fouling risk value using the fouling protection value and the fouling value; and

identifying the level of risk of fouling on the surface of the vessel comprises comparing the fouling risk value to a predetermined threshold.

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18. The method of claim 17, further comprising identifying high risk fouling conditions by determining that the fouling risk value exceeds the predetermined threshold, and in response outputting a control signal.

19. The method of any of claims 14 to 18, wherein the environmental data comprises a value associated with each of one or more environmental parameters.
20. The method of claim 19, wherein the environmental data relates to a geographical location of the vessel.
21. The method of claim 20, wherein the environmental data is sensed by at least one of:
- one or more sensors on the vessel; and
 - one or more sensors on a hull cleaning robot configured to clean the hull of the vessel;
 - one or more sensors on a remotely operated underwater vehicle configured to inspect the hull of the vessel.
22. The method of claim 20, wherein environmental data relating to multiple geographical locations is stored in the memory, and the environmental data relating to the geographical location of the vessel is retrieved using the geographical location of the vessel.
23. The method of claim 10, 13, 16 or 18, wherein the method comprises outputting the control signal to a remotely operated underwater vehicle or a hull cleaning robot configured to clean the hull of the vessel, to initiate inspection of the surface of the vessel.
24. The method of claim 10, 13, 16 or 18, wherein the method comprises outputting the control signal to an output device of the computing device or to a remote device on said vessel to alert a user to initiate inspection of the surface of the vessel.
25. The method of claim 10, 13, 16 or 18, wherein the method comprises outputting the control signal to a hull cleaning robot configured to clean the hull of the vessel, to initiate cleaning of the surface of the vessel.
26. The method of claim 10, 13, 16 or 18, wherein the method comprises outputting the control signal to a vessel control system to control the vessel to take operational measures.

27. The method of any of claims 23 to 26, wherein the vessel or an on-shore monitoring station comprises the computing device.

28. The method of claim 10, 13, 16 or 18, wherein the computing device is a hull cleaning robot configured to clean the hull of the vessel, and method comprises:

outputting the control signal to a hull inspection device of the hull cleaning robot to initiate inspection of the surface of the vessel; or

outputting the control signal to a cleaning device of the hull cleaning robot to initiate cleaning of the surface of the vessel.

29. The method of any of claims 23 to 28, wherein the outputting of said control signal is further based on receiving user confirmation that a control action is to be performed.

30. The method of any preceding claim, wherein the fouling protection value is determined based on a value defining an attractiveness of the surface to fouling.

31. The method of claim 30, wherein the value defining an attractiveness of the surface to fouling is determined based on one or more of (i) a surface energy of the surface, (ii) a topography of the surface, (iii) a porosity of the surface, (iv) an elasticity of the surface, and (v) a colour of the surface.

32. The method of any preceding claim, wherein the fouling protection value is determined based on a value defining an effect, on the surface, of water moving over said surface.

33. The method of claim 32, wherein the value defining an effect, on the surface, of water moving over said surface is determined using a speed over ground of the vessel or a speed through water of the vessel, and one or more of (i) a surface energy of the surface, (ii) a topography of the surface, and (iii) a porosity of the surface.

34. The method of claim 32 or 33, wherein a coating providing said surface is a polishing coating and the value defining an effect, on the surface, of water moving over said surface is determined using a polishing rate associated with said coating.

35. The method of any of claims 29 to 33, wherein a coating providing said surface comprises a fouling control agent, and the fouling protection value is determined based on a value defining an effect of the fouling control agent.

5 36. The method of claim 3 or 19, wherein the one or more environmental parameters comprise one or more of: (i) a parameter relating to a temperature of an aquatic environment of the vessel; (ii) a parameter relating to a water depth of the aquatic environment of the vessel; (iii) a parameter relating to a distance between the vessel and coastline; (iv) a parameter relating to a length of day; (v) a parameter
10 relating to a light intensity in the aquatic environment; (vi) a parameter relating to an amount of chlorophyll in the aquatic environment; (vii) a parameter relating to a salinity level of the aquatic environment; (viii) a parameter relating to a pH level of the aquatic environment; (ix) a parameter relating to a nutrient level in the aquatic environment; (x)
15 a parameter relating to an amount of carbon dioxide in the aquatic environment; and (xi) a parameter relating to an amount of gaseous oxygen dissolved in water in the aquatic environment.

37. The method of any preceding claim, wherein the method is performed periodically.

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38. A computer-readable storage medium comprising instructions which, when executed by a processor of a computing device, cause the processor to carry out the method of any preceding claim.

25 39. A computing device for dynamically monitoring the cleanliness of a hull of a vessel during a journey of said vessel, the computing device comprising a processor configured to:

retrieve environmental data from memory of the computing device, the environmental data associated with environment conditions of the vessel;

30 determine a fouling protection value defining a tolerance to fouling associated with a surface of the vessel; and

identify a level of risk of fouling on the surface of the vessel based on the fouling protection value and the environment conditions.