Published in the USA
Biogeosystem Technique
Issued since 2014.
E-ISSN: 2413-7316
2024. 11(2): 115-123

DOI: 10.13187/bgt.2024.2.115
https://bgt.cherkasgu.press

Features of the Study of Biofouling on Ship Hulls Using Modern Possibilities of Artificial Intelligence

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Paper Review Summary:
Received: 2024, November 29
Received in revised form: 2024, December 18
Acceptance: 2024, December 26

Abstract

The study of biofouling on ship hulls has emerged as a critical area of research due to its significant impact on maritime operations and vessel longevity. This article presents a comprehensive overview of the current state of biofouling, emphasizing its detrimental effects on corrosion processes affecting ship structures. Biofouling not only accelerates corrosion but also increases fuel consumption, thereby raising operational costs and contributing to environmental concerns. The article delves into the intricate structure of biofouling, exploring the various organisms involved and their interactions with the hull materials.

Furthermore, the application of artificial intelligence (AI) in underwater drones for biofouling removal is discussed in detail. A classification of underwater drones specifically designed for this purpose is provided, alongside a schematic representation of their construction. This section highlights the technological advancements that enable drones to autonomously detect and mitigate biofouling, showcasing the integration of AI algorithms for enhanced performance.

Additionally, the article describes the design of a cleaning device attached to the drone, detailing its operational mechanisms and effectiveness in biofouling removal. A brief overview of the drone's control system is also included, illustrating how AI facilitates precise navigation and task execution. This research underscores the potential of modern AI technologies in revolutionizing the management of biofouling, ultimately contributing to more sustainable maritime practices and improved vessel maintenance strategies.

Keywords: biofouling, speed, plant, drones, artificial intelligence

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1. Introduction

In order to solve the issues of intensification of sea freight and passenger transportation in recent times, especially with the increasing role of shipping along the Northern Sea Route, there is an increasing need to take into account many factors that have not been given due attention before (Orlova, Rodionov, 2020; Zvyagintsev, 2005). They require non-standard approaches, construction of complex models, and conducting various studies that often lie at the junction of many different sciences (Zvyagintsev, Moshchenko, 2002). One of such tasks seems to us to be the study of the problem of biofouling on the surface of ships. Problems that previously, in principle, used different approaches (Ovchinnikov et al., 1974; Schansker et al., 2003). However, it was not possible to build a complete picture of the model of formation of these formations on the hulls of ships, at a time when such reasons lead to the emergence of problems with the loss of speed of ships (Bixler, Bhushan, 2012; Lenbaum et al., 2015).

If we consider the chain of problems, the formation of biofouling for a vessel leads to a decrease in its shipping characteristics and, first of all, to a decrease in its so-called cruising speed. When a vessel's speed drops, it becomes necessary to increase its operating costs, which means an increase in engine power and fuel costs and an increase in the financial costs of ship operators (Orlova, Rodionov, 2020).

2. Results and discussion

Status of the issue

Work on attempts to solve this problem has been going on for quite some time (Lazar, Schansker, 2009; Schansker et al., 2003; Joliot P., Joliot A., 2005). They are trying to develop new and new approaches and technologies to reduce biofouling, new methods to remove these growths from the surface of a vessel (Miyake et al., 2005). However, solving these issues opens up new and new questions, including environmental ones, because uncontrolled removal of bio-growths can bring to us microorganisms and algae that have migrated from other world regions. Which in turn can significantly reformat the biodiversity of domestic waters (Albitar et al., 2013; 2014; 2016; Aldrich, Qi, 2005).

Thus, the main objective of the study was to work out issues related to the mechanisms of biofouling formation, to study methods of diagnostics and combating this phenomenon, to understand which issues remain less studied and what can be done in this direction using the methods and techniques at the disposal of researchers (Asbeck et al., 2006; Balashov et al., 2011). The tasks for the study were literary studies of issues related to the emergence and development of biofouling of ships, the study of their biological composition, the processes of modeling their formation, methods of counteraction, the use of modern digital methods and techniques (Bax et al., 2003; Bixler, Bhushan, 2012).

Biofouling and corrosion

So, it is worth recognizing that biofouling is a very interesting form of biological symbiosis of plant and animal life forms - a set of attached and mobile forms of organisms inhabiting anthropogenic surfaces in operation (Zvyagintsev, 2005; Zvyagintsev, Moshchenko, 2002). The importance of the issue is also determined by the fact that these same reasons lead to the loss of functionality of not only ships, but also parts of locks and port facilities (Caduff, 1990). These reasons sooner or later lead to corrosion (Chambers et al., 2006).

A study of the literature has made it possible to understand that, depending on the operating conditions and the state of the anti-corrosion protection means, the corrosion rate of the underwater part of the ship's hull, generally speaking, can vary within wide limits (Chen et al., 2010; 2012; 2017; Courson, Shelburne, 2001). In known cases of hull electro corrosion under the influence of stray currents, corrosion damage can develop at a rate of up to 5 mm/year. In the underwater part of the hull, the most intense corrosion damage can usually be observed in the area of the bow and stern counter as a result of the action of strong water jets causing mechanical destruction of the protective coating and the ship's hull, and on the hull, rudders and sternpost under the influence of the galvanic pair - hull – propeller (Cioanta, McGhin, 2017; Daltorio et al., 2005). As a result, it is necessary to frequently repair the nozzle or use means of its protection that exclude the use of paint and varnish coatings (Davidson et al., 2008). On the outside, the nozzle is painted with abrasion-resistant, non-swelling paints, on which an antifouling paint is also applied on top (Drake, Lodge, 2007).

Various types of fairings located in the underwater part of the hull are used in conditions typical for the part of the hull where they are located. The frontal areas of the fairing surface experience a more significant effect of water (Erneland, 2014). Therefore, the destruction of the protective coating, fouling and corrosion are most intense here (Ferreira et al., 2013). On ships sailing in the seas, freshwater basins and rivers of the tropics throughout the year, in the rest – in the warm season, fouling – various types of animals and algae settle on the underwater part of the hull, fairings, nozzles, rudders, mortars, brackets, as well as in the area of variable waterline (Floerl et al., 2010). Having settled and quickly multiplied, they not only make the underwater part rough, which reduces the speed of the vessel, but also destroy the protective coating. Inspection of the underwater part of the hull of operating ships and all structures located on it is possible when the vessel is docked or with the help of a diver (Holappa et al., 2013). A diver cannot always detect paint defects, correctly assess the danger of emerging signs of biofouling or corrosion damage and promptly eliminate them. Therefore, when defects in the protective coating and accompanying corrosion damage are detected, the vessel must be brought into the dock, which is associated with large material costs (Godwin, 2003). As a result, special attention must be paid to the quality of preparatory work, the choice of impact schemes and control technology.

The mechanism of fouling on marine or freshwater vessels and structures is based on biofilms that form on such structures, which are the link between marine or aquatic organisms and the structure itself (Holappa et al., 2013). Biofilms form and fouling organisms attach to all subsurface structures such as propellers, rudders, inlets and outlets, sonar housings and protective grilles, as shown in the Figure 1 the most common methods used to remove biofouling (Bixler, Bhushan, 2012) are dry dock cleaning, antifouling paint and periodic underwater cleaning. It was noted that a good method for removing biofouling is the use of high-pressure abrasives in dry docks. In the dry dock cleaning method, ship owners accept increased sailing costs and wait for the complete cleaning and repainting of the hull in the dock. The method requires the ship to enter the dock and completely leave the water, and then clean the surface of the vessel with high-intensity labor (Hopkins et al., 2009). Dry dock cleaning apparently has its drawbacks in the form of long work cycles, high labor intensity and high cleaning costs. In the antifouling paint method, the hulls of ships are coated with a soft antifouling paint that can effectively kill or inhibit the growth of organisms.

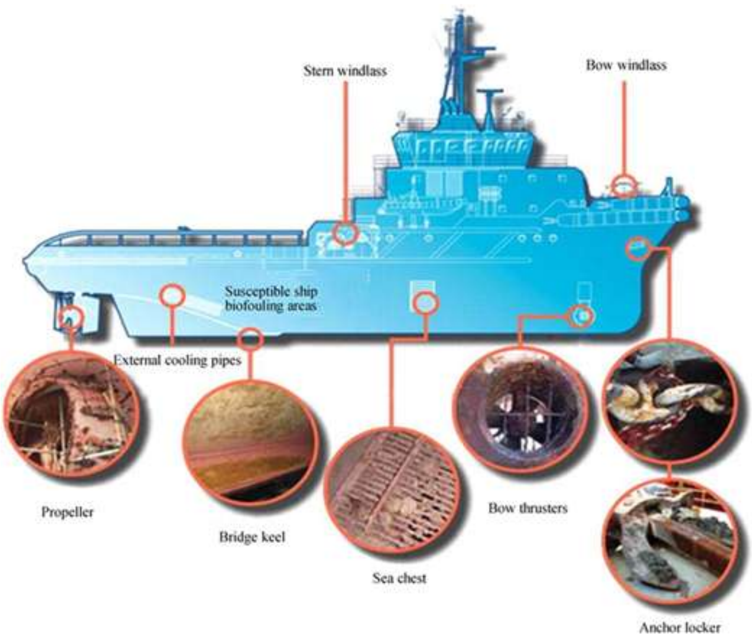

Fig. 1. Scheme of attachment of marine fouling organisms to the subsurface structures of the vessel

It is extremely important to know the structure of biofouling layers on a vessel, as can be seen from our research. At least in order to effectively combat biofouling. Moreover, in recent years, the most modern methods based on ultrasound and laser radiation have been effectively included in the number of methods (Hua et al., 2018; Huang et al., 2017). Therefore, it is important to develop the direction of biofouling diagnostics.

In general, it is accepted to consider that biofoulings are classified by the type of organisms, for example, simple organisms, which include algae and bacteria, as well as living organisms – mollusks, worms, small fish. Also interesting is the division by the degree of growth – biofilms and colonial organisms.

Study of the structure of biofouling

We attempted to study plants to understand the possibility of their identification in the same layer of biofouling material. We conducted such a study of photoluminescence on green plants and algae. In the experiment, it was found that plants, when excited by radiation with the excitation energies specified above, show bright red photoluminescence. The photoluminescence spectra for green plants in all cases are two closely spaced bands (Zvyagintsev, Moshchenko, 2002). It is important to note that the energies of both bands for different types of plants were almost the same (Orlova, Rodionov, 2020). We believe that modern technologies, such as underwater drones equipped with high-resolution cameras or mobile photoluminescence installations, provide unique opportunities for monitoring the condition of ship hulls in real time (Lenbaum et al., 2015). Using images obtained from such drones, deep learning algorithms are able to effectively process large arrays of visual data. These algorithms, based on neural networks, allow identifying and classifying different types of biofouling by learning from pre-labeled data (Kostenko et al., 2019). Transformational models such as convolutional neural networks (CNNs) show particularly high performance in visual classification tasks because they can extract meaningful features from images, making the identification process more accurate.

Involvement of artificial intelligence and the use of drones

One of the most promising areas of using artificial intelligence (AI) to classify biofouling is the use of real-time data transmission tools. Equipping underwater drones with an image transmission system allows monitoring the condition of the hull of ships or lock components directly during their operation. AI algorithms can be integrated into technical tools, analyzing incoming data and providing recommendations for necessary actions. Thus, ship owners can quickly respond to changes in the condition of the hull and carry out preventive or cleaning work in a timely manner, which in turn helps reduce operating costs and improves the efficiency of shipping.

However, for the successful implementation of such systems, it is important to consider a number of factors, such as the quality and availability of training data. The development of extensive and diverse datasets of biofouling images, as well as the implementation of data augmentation methods, can significantly improve the quality of classification (Kostenko et al., 2019). It is also important to consider the impact of different lighting conditions and underwater environments on the accuracy of the algorithms. Certification-based evaluation and testing systems can help assess the effectiveness of the developed solutions and ensure their reliability during operation.

In recent years, with the rapid development of robotics and artificial intelligence, hull cleaning robots have gradually become the focus of attention in this field – Figure 2 (Lee et al., 2022; Mazue et al., 2021). They can effectively and safely complete cleaning tasks in various water conditions, and have great economic and social value (Legg et al., 2015).

The underwater hull cleaning robot mainly consists of surface equipment and underwater equipment (Kalumuck et al., 1997). The surface equipment includes control, casting and retrieving units, and the underwater equipment includes slave industrial computer, adsorption mechanism, drive mechanism, cleaning mechanism, position sensors, orientation sensor, underwater camera, etc (Longo, Muscato, 2006; Mazue et al., 2011). The diagram of the underwater hull cleaning robot is shown in Figure 3.

The movement of the robot on the outside of the body is carried out by the motor, and its deviation is carried out by the difference in the angular velocity of the two motors. It uses a permanent magnet in adsorption. The brushes work during the movement along the specified route. The cleaning equipment consists of brushes, an actuator module of the drive and a support. The two motors that drive the two brushes rotate in opposite directions. The robot cleans while moving until the cleaning is completed (Menon et al., 2004).

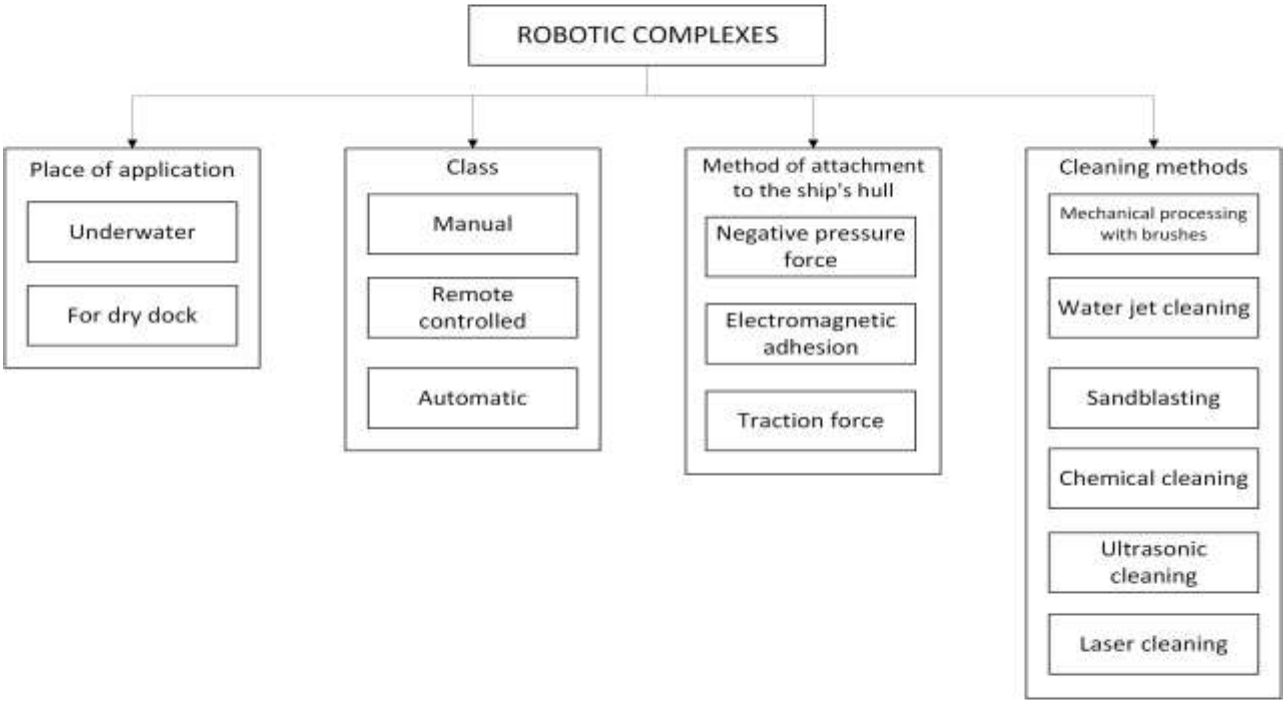

Fig. 2. Classification of robotic systems used for cleaning ship hulls from biofouling

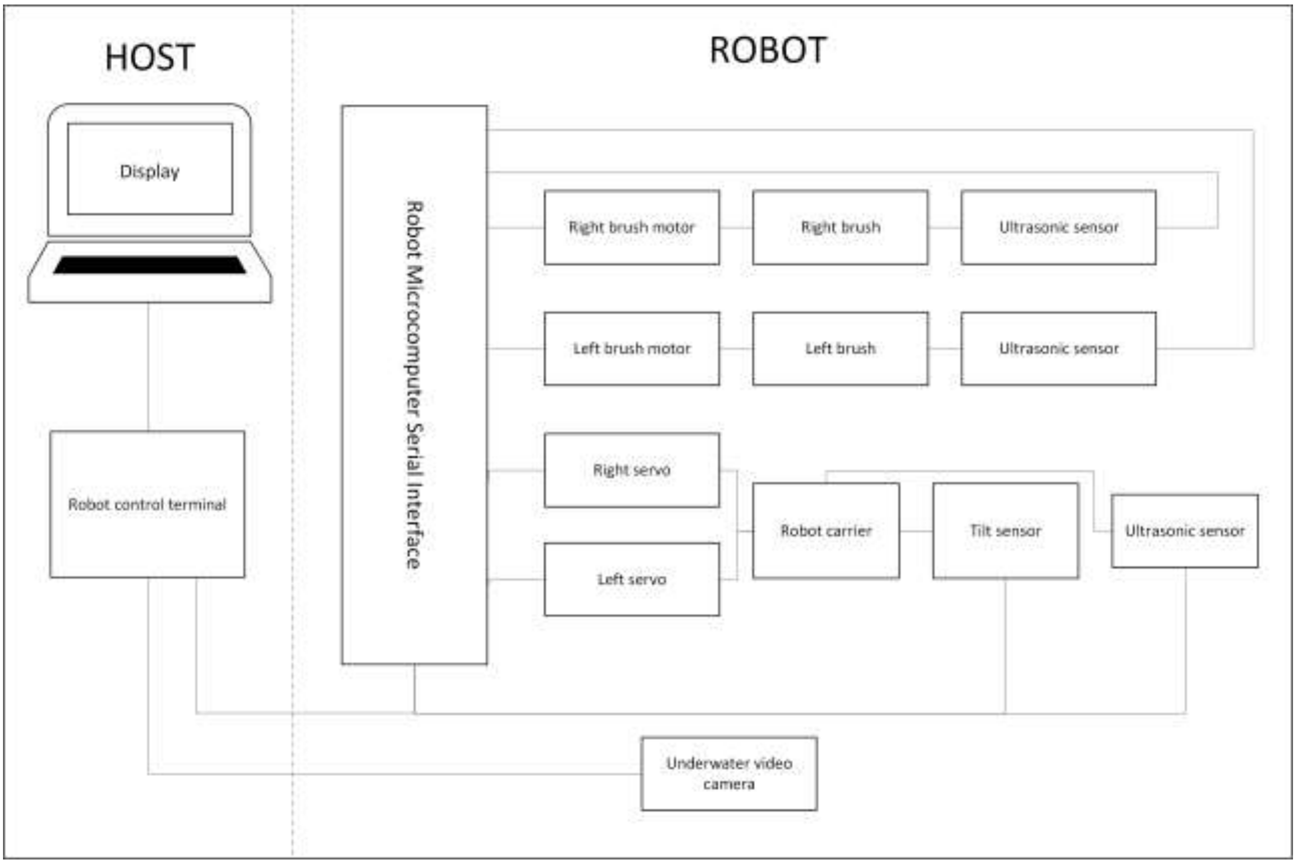

Fig. 3. Robot diagram

The underwater drone's workflow for inspecting and cleaning ship hulls from biofouling begins with its descent underwater, where it inspects the ship's hull or specific parts of it, such as the bottom and side. To obtain high-quality images of the propeller group (propulsor), it is necessary to stop the vessel, which avoids vibrations and allows the drone to record high-quality, high-resolution images. Once the full hull inspection is complete, the convolutional neural network analyzes the images obtained, finds and classifies biofouling based on pre-trained data (Morrisey, Woods, 2015). A decision is then made on the type of drone and the corresponding cleaning equipment required to effectively remove the identified type of biofouling as (Figure 4; Hua et al., 2018). In particular, it is recommended to use a drone that can attach to the ship's hull using the low-pressure method, which ensures reliable fixation and maneuverability in the underwater environment (Kostenko et al., 2019). This method is also preferable, since magnetization is prohibited on military ships, making it not a universal solution.

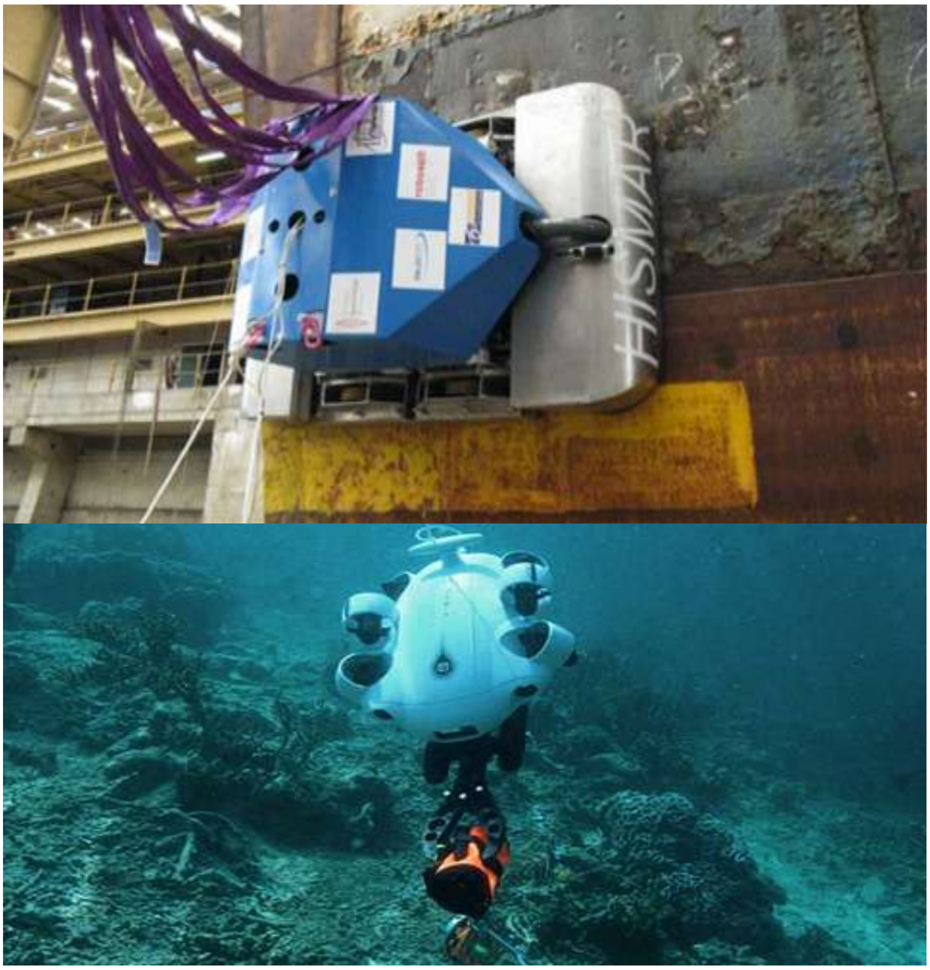

Fig. 4. An example of drones operating in dry dock and underwater mode to combat biofouling

Construction of underwater cleaning device

The underwater cleaning device is the drive of the underwater robot body cleaner. It consists of brushes, a power actuator (motor) and a support (Murphy et al., 2006). The cleaning tray, a stainless-steel half-coupling and a metal brush wire, which is also made of stainless steel, make up the brushes. To achieve high cleaning efficiency, a steel brush wire with good hardness and elasticity should be selected (Nassiraei et al., 2012). The cleaning tray is made of aluminum alloy and is fixed on its coupling, which is connected to the drive motor. The support is made of aluminum alloy, and the bearing is waterproof. Two cleaning devices are installed in the front part of the robot carrier, which rotates in the opposite direction.

Development of a management system

The control system of the underwater hull cleaning robot adopts two-level control (Oliveira, 2017). The main computer, which is placed in the container and moves on the deck, can perform human-machine interface interaction, input of the initial values of the environment, designation of the task, path planning and display of the robot information, etc. The slave computer is fixed on the carder of the robot, receives instructions from the main computer, controlling the task of moving the structure and cleaning unit. Information and power are transmitted through the umbilical cable. The position and gesture are determined by the inclinometer and the ultrasonic sensor, which controls and plans the task of the brushes. The underwater camera displays the information of the robot, and also checks the underwater hull of the vessel.

3. Conclusion

It is found that understanding the type of biofouling on the hull of a ship plays an important role in developing effective diagnostic and control methods. The application of AI to classify biofouling on ship hulls using images obtained by underwater drones is a promising area to help optimize operations in the maritime industry.

The proposed AI-powered drone scheme can be very effective, as it creates an efficient scheme of operation where underwater drones not only inspect but also help maintain the cleanliness and safe operation of vessels, providing a high degree of automation and minimizing human intervention.

This will improve the efficiency and timeliness of actions to prevent and remove biofouling, which, in turn, will help to increase the service life of the vessel and reduce its operating costs.

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