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An Optimized Design Scheme for Underwater Cleaning Robot

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Abstract

The adhesion of marine fouling organisms has been a long-term issue for all underwater equipment, especially the ship. The marine fouling organisms coating will greatly influence the procession efficiency and service life of the ship. To solve this problem, an optimized design scheme of underwater cleaning robot will be discussed in this paper. The main adhesion method and cleaning method of traditional underwater cleaning robot will be introduced and compared. In the proposed optimized design scheme, the hybrid adhesion methodology is developed which combining the electromagnetic adhesion and the thrust force adhesion technologies, makes the robot can adapt to wide range of working environments. The layout of the whole mechanical design and electronic design will be shown and explained in detail. And self-resonating cavitating (SRC) water jet technology is used to minimize the damage during cleaning process and maximize the cleaning efficiency. To demonstrate the efficiency of SRC nozzle various simulations with ANSYS Fluent will be given.

Keywords

Underwater Cleaning Robot; Robot Design; Self-resonating Cavitating.

1. Introduction

1.1 Introduction to marine biofouling

Marine biofouling refers to the unexpected accumulation of micro and macro underwater organisms on the submerged surfaces. The typical biofouling process can be classified into two categories, one is microfouling another is macrofouling (Yee, 2018). The microfouling process refers to the formation of biofilms result from the accumulation and reproduction of bacteria and diatoms. Moreover, the macrofouling means the steady attachment of both soft and hard fouling organism. Marine fouling coating is an age-old problem for underwater devices which result in enormous bad effect on efficiency, service life and safety of the underwater devices. For ships, the powering penalties results from Heavy calcareous fouling is exceeding 85%, and even slime films will result in 20% increasement of resistance and power consumption (Bressy & Lejars, 2014). Furthermore, marine biofouling will also lead to corrosion of the surface, which will lead to severe safety consequence and greatly reduced the service lifetime of the underwater devices.

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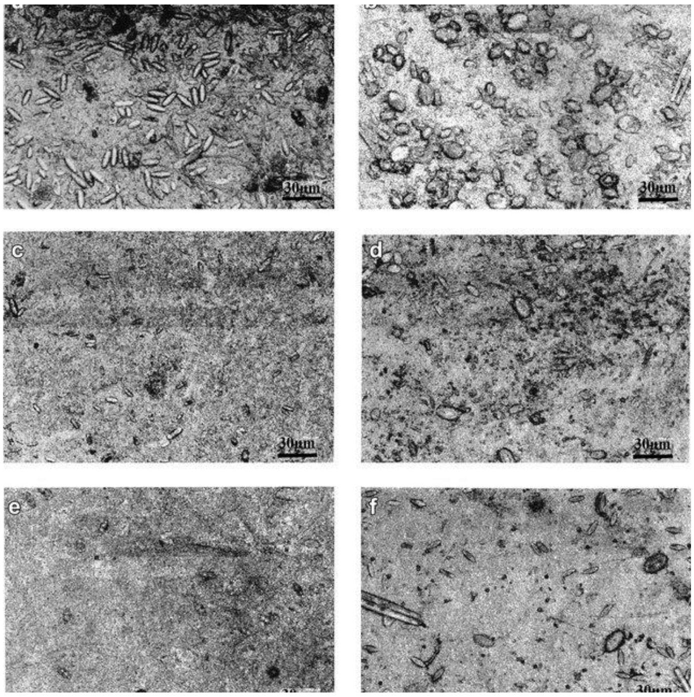

Figure 1. Microfouling type of marine biofouling. Kharchenko, Ulyana & Beleneva, Irina & Dmitrieva, Elena. 2012. Antifouling potential of a marine strain, Pseudomonas aeruginosa 1242, isolated from brass microfouling in Vietnam. International Biodeterioration & Biodegradation. 75. 68–74. 10.1016/j.ibiod.2012.05.029.

Figure 2. Macrofouling type of marine biofouling. Cheng Chin, 2019. Marine Fouling Images. Available at: https://dx.doi.org/10.21227/k07g-3t57.

1.2 Introduction to anti-fouling method

Source prevention and cleaning treatment is two key method to solving the marine biofouling issue. To prevent the adhesion of marine biofouling, different types of anti-fouling coating is developed, such as the Biocide-Based Coatings and Fouling Release Coatings, which can effectively inhibit the settlement of the underwater organism (Bressy & Lejars, 2014). As for the cleaning treatment, manual cleaning is still common for small ship and underwater equipment, the efficiency and quality of manual cleaning is non-ideal and labor cost is high. Davison et. al (2008) had examined that there is still about 40% of the marine fouling adhesion remain after a manual cleaning operation with the

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brush. With the improvement of robotics technology, the underwater cleaning robot with high technology is replacing the human cleaning and traditional cleaning mechanism. This paper will focus on the underwater cleaning robot technology.

Table 1. The summarization of anti-fouling method

Anti-fouling method	
Prevention	**Anti-fouling coating**
Cleaning treatment	Manual cleaning
	Traditional cleaning mechanism
	Smart underwater cleaning robots

2. Challenges and requirements of modern underwater cleaning robot

2.1 Working environment restriction

For modern ships and other underwater devices, the material used for the surface is changing. Hi-tech nonferrous metal alloy and composite is becoming widely used for the advantage of high strength, low density and capable of achieving other technical requirements, such as anti-biofouling. The geometry of the submerged surface is also becoming complex to achieving better fluid performance and specific working function. This would cost much to design specific cleaning robot for every different submerged shape and different surface condition. Moreover, after the adhesion of marine biofouling coating, the geometry of the surface to be cleaning will become rougher and unable to predict. Many aspects are concerned to reach the requirement of universality, such as the material used and mobility of the robot.

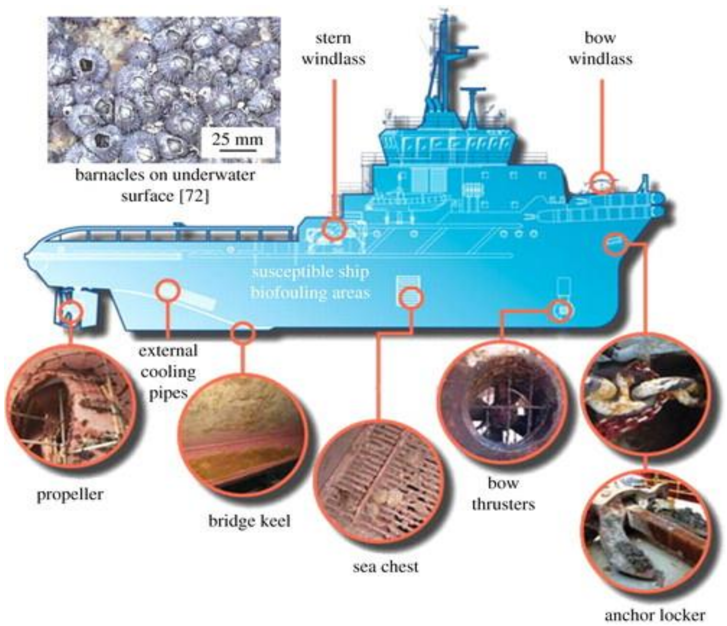

Figure 3. Marine biofouling on ships. Bixler, G.D. and Bhushan, B., 2012. Biofouling: lessons from nature. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 370 (1967), 2381–2417.

2.2 Communication, localization and navigation challenge

Because the robot's underwater working environment is more complex, the current position information of the robot is the basis for controlling the robot. Since GPS signals on land cannot be transmitted in deep water, other navigation and positioning systems are required. To meet the requirement of accuracy, a combination of multiple sensors is essential.

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2.3 Function and performance challenge

In the industry, the cleaning process should be conduct efficient, safe and no damage to the cleaning surface. And the robot should be easy-maintained and upgradeable to extend the product life cycle which means the robot should be modularity.

3. State of the art

3.1 Cleaning mechanism for underwater cleaning robot

Table 2. Main cleaning technology of underwater devices

Type		Theorem	Advantage	Disadvantage
Mechanical cleaning (Brushes and other cleaning mechanism)		Friction caused by relative motion between cleaning mechanism and surface to be cleaned	Simple structure, low cost of technology	Low efficiency and cleaning speed
Negative pressure suction cleaning		Suction force generated by vacuum pump.	Simple structure, low cost of technology, moderate cleaning performance	Could not effectively deal with the firm attached organism.
Water jet cleaning	High pressure water jet cleaning	Impact produced by high-speed water jet	High-level Efficiency, fast cleaning speed, environmental friendly (Yin et. al, 2019)	High energy consumption, damage to the submerge surface, safety issue

3.2 Adhesion technology of underwater robot

Table 3. Main adhesion technology of underwater devices

Type		Theorem	Advantage	Disadvantage
Vacuum suction		Negative pressure and suction force produce by the pump	moderate adhesion performance	Requires flat working surface, slow reaction speed because of time needed to generating negative pressure, seal elements need replacing frequently
Magnetic adhesion	Electronic magnetic adhesion	Electromagnetic force controlled by	Excellent adhesion ability on ferrous material, quick reaction speed	Not able to work on nonferrous material surface, weak magnetic force, bad performance when the surface is severely polluted by marine fouling
	Permanent magnetic adhesion	Magnetic force produces by permanent magnet	Simple structure, moderate adhesion performance	Complex structure, not able to work on nonferrous material surface,
Thrust force adhesion		The thrust force produced by vertical thrusters	Universality, flexibility, and quick reaction speed	High cost of energy

3.3 On-wall movement mechanism for underwater cleaning robot

Table 4. Main on-wall movement mechanism of underwater devices

Type	Theorem	Advantage	Disadvantage
Wheel	Multi-wheel mechanism driving by motor	Simple structure, easy to control, fast speed	Limit contact surface
Special designed mechanical structure	Special designed movement structure for specific working scenario	Good adhesion ability, good mobility	Limit scope of application and high design cost
Clawer	Two parallel clawer driving by motor	Big contact surface, fast moving speed,	Hard to diversion, low mobility
multi-legged	Multiple robotics leg walking mechanism	High mobility	Design, control and maintains is complex

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4. Overview of the design scheme

Figure 4. The rendering picture 1 of the cleaning robot

Figure 5. The rendering picture 2 of the cleaning robot

The underwater cleaning robot is equipped with cavitation cleaning technology for cleaning process. Multiple propeller and hybrid adhesion system is developed which enables flexible underwater movement to meet the requirements of underwater cleaning operations. According to the function and performance requirements of the underwater cleaning robot, the underwater cleaning robot is decomposed into six main part, the overall structural system, motion control system, cavitation cleaning device, high-pressure flushing device, power and information transmission system and overwater control unit. In view of these six systems, the scheme design of each sub-system is carried out, and based on each sub-system scheme, the multi-disciplinary optimization design is carried out, and the overall scheme and shape structure of the underwater cleaning robot are finally formed. The optimized underwater cleaning robot shown in figure 4 and 5 is modeled by Solidworks and rendered by Photo360.

The navigation module can provide information on the position, speed and attitude of the underwater cleaning robot, and the most used position calculation method under the water is the inertial navigation system (INS) based on the micro-electromechanical gyroscope (MEMS). Sensors in INS are called inertial measurement units (IMUs) and typically consist of three accelerometers and three gyroscopes. The IMU measures acceleration and rotation. Position, speed, and posture can be obtained indirectly by integrating IMU data. Except IMU, INS also has micro controllers and other electronic components. However, this technique can easily produce drift. Combining GPS positioning with IMU results in more accurate positioning, which improves the accuracy of ROV attitude estimation.

5. Conclusion

The main content of the design in this article is to optimize and improve the design of an ordinary underwater cleaning robot, and design the buoyancy material of the underwater cleaning robot as a structure that can adjust its height with a telescopic arm. This structure reduces the buoyancy The material rises or falls in different environments to adjust the relative positional relationship and

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separation degree of the center of gravity and the center of buoyancy, and on this basis, realize two different working modes-movement mode and observation mode. According to the investigation, the existing underwater cleaning robots cannot realize the two working modes mentioned in the article at the same time. Therefore, the design scheme in the article will make up for the gaps in the relevant aspects of underwater cleaning robots in practical applications in the future.

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