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Underwater Robotics Complex for Inspection and Laser Cleaning of Ships from Biofouling

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Abstract. The survey of an underwater part of ships is the mandatory procedure by rules of the Russian Maritime Register of Shipping. Periodic cleaning of the ship's hull from biofouling increases efficiency of its motion. Inspection of the underwater part of the ship during afloat is currently carried out by divers with the underwater video system, devices for non-destructive testing of hull structures, and tools for cleaning surfaces from products of biological fouling and corrosion. The purpose of this study was to develop a new technical tool for remote surveying and cleaning of ship's hull using a remotely operated vehicle (ROV) equipped with underwater laser cleaning equipment. The design of the vehicle for inspection and laser cleaning of ships has been developed during the research. The algorithms for trajectory controlling of the vehicle over the hull surface based on wheel and propulsion system has been proposed. The navigation data for the trajectory planning was received from combination of wheel and visual odometry. The proposed technical solutions allow the hull of the ship to be inspected and cleaned effectively and safely without being placed in the dry dock as well as to quickly assess the condition of the surface with the binding of the results to the ship's drawing.

1. Introduction

The survey of an underwater part of ships is the obligatory procedure by rules of the Russian Maritime Register of Shipping (RMRS) [1]. Typically, the inspection and cleaning of ship hulls and outer underwater devices are performed while the ship located in dry dock. However, in some cases, the RMRS rules permit performance of these works without placing the ship in dock. The survey of an underwater part of the ship afloat is usually carried out by divers using an underwater video system, devices for non-destructive testing of hull structures, as well as tools for cleaning surfaces from products of biological fouling and corrosion. In this case, it is mandatory to remotely monitor the quality of the inspected objects by the RMRS inspector [2].

So, the using of underwater robotic systems for inspection and cleaning of the underwater part of the ship's hull is obvious. The analysis of existing solutions of this problem revealed several inspection and cleaning systems for underwater hull structures based on remote-controlled unmanned underwater vehicles (ROV), shown in Figures 1, 2 [3, 4, 5, 6, 7, 8, 9, 10].

2. Requirements for the survey of the underwater part of ships

Existing documents regulate following evaluations of technical condition for the hull, ship devices and mechanisms [1-3]:



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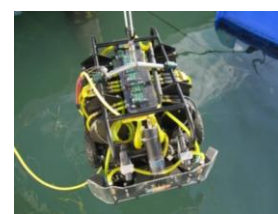
- evaluation of hull structures wearout (measuring thickness of the hull at three points on each sheet of hull or one measurement for every 5 m² are necessary. Measuring accuracy is at least 0.1 mm);
- evaluation the changes of initial shape of the hull (detection of residual deformations of the hull through the measurement of the deflection needle and the dimensions of the deformation zone in the plan; the accuracy of measuring the deformation zone in the plan is not less than 100 mm; the accuracy of measuring the deflection at the base of 300 mm is not less than 0.1 mm);
- determination of loss of integrity of the hull components (cracks and ruptures in the hull are revealed during visual inspection or using flaw detection methods, the accuracy of measuring the defect parameters is at least 5 mm are necessary, the crack parameters, coordinates and orientation relative to the building coordinates of the hull are recorded);
- evaluation of the technical condition of the ship's devices (visual inspection of the propeller, thrusters, hydroacoustic lag antennas and echo sounder, measurement of the steering wheel bearings clearance and stern bearings, defectoscopy of the propeller blades).



RovinBAT
"ECA Hytec", France



GAC ("GAC EnvironHull Limited",
UAE)



Hull BUG
("SeaRobotics", USA)

Figure 1. ROV for hull cleaning with partial inspection function.



V8 Sii "Ocean Moduls", Sweden



HAUV "Bluefin Robotics", USA



Iznos MGTU, Russia



vLBC "SeaBotix", USA



AIV "SubSea7", USA



Galtel-T IMTP, Russia

Figure 2. ROV for hull inspection without cleaning function.

The analysis of the problem outlined above allows the requirements for the ROV to be formulated. To perform a general inspection of the ship's hull for detection visible and hidden defects, it is sufficient to equip the ROV of the survey class with non-destructive testing equipment, deformation meters and local stripping devices for defectoscopy. The ROV should provide a highly accurate navigation reference of the survey results to the ship's drawing. At the same time during the survey it's reasonable to provide permanent contact to surveyed surface for the ROV. It's clear that the capability of continuous inspection in the automatic mode with correction by the operator and/or the RMRS inspector must be provided. The evaluation of the technical condition of the ship's equipment

is carried out in the known local areas of the hull. Herewith inspection of the equipment from different angles of view relates to the need for maneuvering ROV across all six degrees of freedom. Specialized manipulators and grippers may provide the necessary capabilities for accurate measurements in hard-to-reach places of the ship's hull. The operations of technical state evaluation of local equipment may be performed only with teleoperated mode by the commands of an experienced operator.

3. Methods for cleaning the underwater part of the ship's hull from biofouling

The importance of control biofouling is followed from the economic effectiveness of ship operation. It directly relates with the cost of delivery of goods, as well as the duration of marine hydraulic structures and structures operation. The biofouling adversely affects the hydrodynamic characteristics of the ship during the marine operation, which leads to the deterioration of its running properties, to decrease of speed and to increase in its operating costs. So, fuel costs are about 80% of the operating costs of any ship. Reducing cruise speed requires additional engine power and increased fuel consumption. The weight of small shells on the ship's hull is 50 kg/m². So, due to the layer of fouling about 2-3 cm and 3 thousand square meters of the ship, more than 150 tons of excess biomass weight are transported by the ship. Thus, the "smooth" body is one of the main factors of economical operation of the ship.

Cleaning of ship's hull can be carried out by following methods [11, 12, 13, 14, 15, 16, 17]:

- mechanic cleaning assumes the use of brushes, cutters, vibrating knives;
- hydrodynamic cleaning assumes the use of water jets under pressure with cavitation effects;
- laser cleaning assumes the use of scanning systems of laser radiation.

Mechanic cleaning (Figure 3) allows huge outgrowths on a large area to be removed. The main equipment for mechanical cleaning is special brushes with hydraulic drive. Disadvantages of mechanical cleaning are follows:

- high probability of the existing coating damage during the cleaning process, that is inadmissible for a floating ship;
- the fragility of the cleaning tool, the durability of ones often is not enough even for cleaning one ship;
- high energy cost of the cleaning process;
- the complexity of cleaning ship with a large curvature of the hulls.



Figure 3. Different types of mechanical cleaning implementation.

Hydrodynamic cleaning (Figure 4) is the best method for mild outgrowths and it's prevents coating from damaging. This method is based on using water jets under pressure with cavitation effects. The different kinds of outgrowths and rusts are removed by this method. The vehicle can use both seawater or fresh water during cleaning. Cavitation effects forms smooth ship's hull that ensures slowed growth of biological outgrowths and reduces the frequency of cleaning.



Figure 4. Different types of hydrodynamics cleaning implementation.

Laser cleaning (Figure 5) is based on impact of scanning laser radiation on the treated surface. Compared with mechanic and hydrodynamic surface cleaning, the laser cleaning method has following advantages [18, 19, 20]:

- the possibility of selective treatment of the treated surface;
- non-contact and local of laser influence;
- ability of process control by software adjustment of radiation parameters;
- possibility of obtaining a high rate of cleaning the treated surface.
-

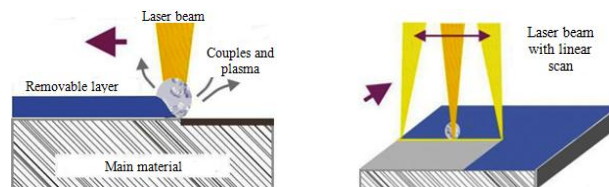


Figure 5. Technical implementation of laser cleaning.

During the research the sufficient continuous laser radiation of 800 ± 200 W power was determined at a linear scanning of 40 mm/s velocity. Effective drainage of the chamber volume is ensured by a compressed air pressure of 0.4 ± 0.2 MPa. The result of underwater laser cleaning of the test plate from the biofouling are shown at Figure 6.



Figure 6. The result of underwater laser cleaning of the test plate from the biofouling (continuous mode, 100 W, velocity scanning 40 mm/s).

4. Preliminary design of the cleaning robotic complex

Analysis of models of using and of the requirements for goal achieving made it possible to determine the functional composition of the robotic complex and the constructive appearance of ROV. The main attention during the designing was paid to the integration of laser cleaning equipment into the robotic complex. The propulsion system of the vehicle consists six identical thrusters (four vertical and two horizontal thrusters) and two caterpillar drives for moving on the treated surface. Linear moving of the vehicle on treated surface is determined by odometry data from of caterpillar drives. Figure 8 shows the functional scheme of the proposed complex.

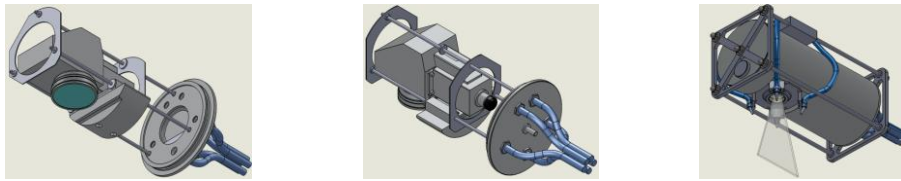


Figure 7. Technical solution for waterproofing the optical scanning head MiD-Power Scanner (IPG Photonics).

Navigation accuracy of the vehicle and accuracy of binding of clearing results are reached by follows equipment:

- standard set of navigation equipment (vehicle depth, pitch, roll, yaw and angular velocities);
- long-base line hydroacoustic navigation system with one/two beacon-repeater dropped from the ship;
- wheel-based odometry system;
- visual odometry system based on photo data from on-board camera.

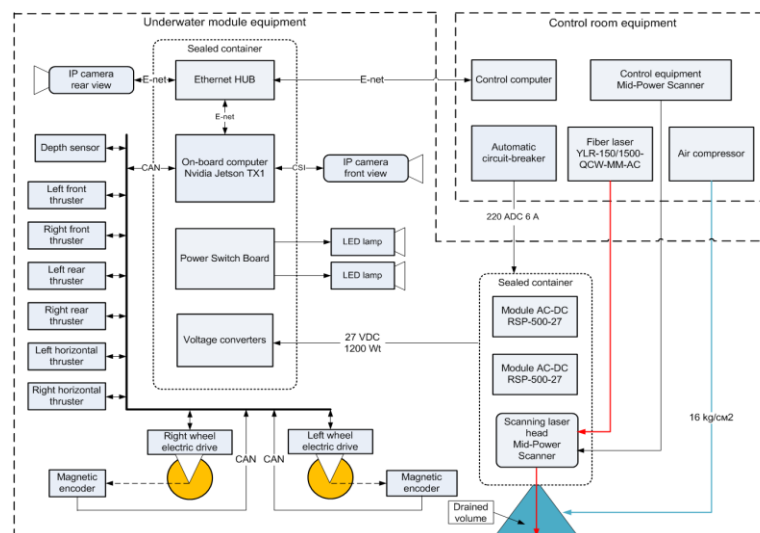


Figure 8. Functional scheme of the robotic complex for underwater inspection and laser cleaning.

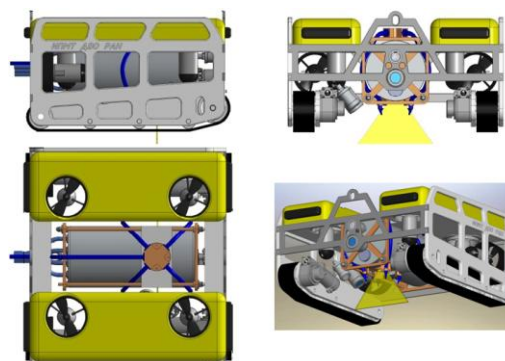


Figure 9. The general overview of ROV with built-in laser cleaning module.

5. Conclusion

During the research following results were obtained:

- the laser ablation features of metal and composite surfaces at the nano and micro level influenced by fouling due to the vital activity of marine biofouling are studied;
- possibility of integration the module for laser cleaning is proved;
- the equipment set for ROV and control unite providing the complex using is defined;
- proposed video system allows the inspection of the hulls with hull cleaning to be combined;
- the manipulator system on the robotic complex is required for evaluation technical condition of the ship's equipment with sufficient accuracy within requirement of the Russian Maritime Register of Shipping.

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