UNDERWATER HULL OBSERVATION SYSTEM ARMUS

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Abstract: *The ARMUS system presents a new approach for observation of the hull of large marine vessels providing fast, but at the same time very accurate and reliable method for underwater inspection, detection and identification of various threats. ARMUS is magnetic tracks based mobile robot capable to stick-on and move along iron surfaces and operate in extreme environmental conditions, including under the water surface. Among the main advantages of the ARMUS system is its ability to reduce significantly the time for hull inspection by providing in process estimation and assessment of the hull while the ship is in motion. This advantage reduces significantly the standby time of the ships when inspection of the hull is required before entering a port. On other hand the in process inspection allows the vessels to be observed continuously during the voyage. Another important advantage of ARMUS is its capability to stay underwater as long as it is necessary. The system is powered and controlled directly by the vessel it inspects and may operate in long cycles without maintenance and recharge.*

Keywords: AUTONOMOUS VEHICLE, UNDERWATER ROBOT, OBSERVATION AND INSPECTION, SECURITY OPERATIONS

1. Introduction

The ARMUS robotic system is remotely controlled ship hull observation and inspection system based on magnetic tracks chasee that guarantee the motion of the robot on the submersed and internal (cargo) part of the vesicle. This advantage makes ARMUS the desired observation system for large marine vessels like oil tankers, cruisers and military vessels. Also ARMUS can be used in inspection of see based oil drills and water channel gates. The system is designed for search and identification of limpet objects like naval mines, improvised explosives or contraband traffic attached to the underwater hull of the ship, but it also can be used in situations related to inspection of the hull condition not only externally, but also internally as it covers the ATEX requirements and can work in hazardous environment. ARMUS system consists of three main units: mobile observation robot, combined multipurpose cable and remote control unit. The robot control is intuitive and does not require specific skills from the operator. As feedback the robot provides live visual and specific sensorial information from the observed area directly to the remote control unit and to the onboard computer network, if necessary.

2. State of the art in marine vehicle inspection robots

The hull management has always been among the most important marine issues that if organized in a proper way can even decrease the fuel consumption of the vehicle. The hull roughness plays an important role in the ship's speed and that directly affects the fuel consumption making the ship less environmental friendly. The build-up of marine organisms on ship's hull, also called bio-fouling, reduces the ship's speed by up to 10%. To compensate the drag, it is said that, a ship may have to use about 40% more fuel [1]. Many research organizations and marine companies work on the development of different remotely operated and autonomous systems for hull observation and management, but only a few of them had reached a market accepted result. Among them is "HullBUG" (Fig. 1) developed by SeaRobotics and funded by U.S. Navy Office of Naval Research (ONR) to tackle this issue.

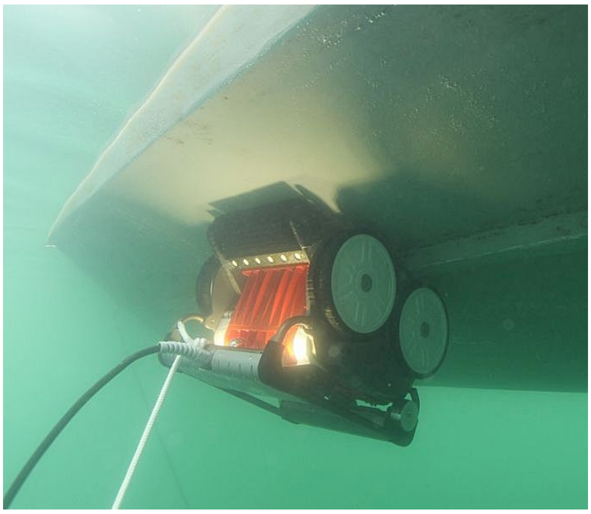

Fig. 1 *HullBUG hull cleaning robot [1]*

The Robotic Hull Bio-inspired Underwater Grooming tool (Hull BUG), is a small autonomous vehicle weighing 30 to 40 kg. It uses four wheels and attaches itself to the underside of ships, using a negative pressure device that creates a vortex between the BUG and the hull. It crawls on the hull surface and performs frequent grooming (light cleaning of fouling films). Sensors provide obstacle avoidance, path cleaning, and navigational capabilities. A fluorometer lets the robot detect biofilm and then it uses rotary brushes or water-jets to scrub the fouling film off [1]. The developer of the robot estimates that, if these robots are put into practice, there can be 5% improvement in fuel efficiency through proactive grooming, translating into a savings of $15 billion annually for the shipping industry worldwide and reduction in 1 billion tons of greenhouse gases emitted by the fleet.

Similar efforts to develop hull cleaning robots is being done by Keelcrab (Fig. 2). The product I-keelcrab is semi automatic robot fitted with ip68 high-resolution camera and can be guided by smartphone or tablet. Keelcrab-one is an underwater robot, which can be controlled by a wired remote control with live video feed [1].

Fig. 2 *Keelcrab hull cleaning robot [1]*

The inspection of the hull roughness is not the only aspect of the hull management. Marine vessels are subject to numerous and regular inspections and maintenance measures. In general, inspection of huge cargo ships for cracks, corrosion or any wear to ensure that they comply with rising safety standards is a time-consuming task for surveyors. Moreover, a big part of the inspection cannot be performed by the surveyors from inside the ship and they have to dive in order to inspect the ship's hull under the water level. In most of cases, the surveyor performs only a visual inspection. In order to reach each spot on the ship, scaffolding has to be erected in the cargo holds. Typical heights of cargo holds are 15-20 m. The installation of the scaffolding usually takes several days, before the surveyor can start the inspection process. Every day the ship stays in the dock and out of service results in a significant loss of money for the ship owner, making this (currently necessary) preparation time is very expensive [2].

The EU-funded R&D project MINOAS [3] (Marine INspection rObotic Assistant System) addresses this challenge in an attempt to develop concepts for the automation of the ship inspection process. The key idea of the project is to develop and test a fleet of semi-autonomous robots which can provide visual data as well as thickness measurement data to the surveyor without the need for setting up scaffolding prior to the inspection process.

The result of the project is a lightweight and low-cost Ship Inspecting Robot (SIR). Its prototype is capable of conducting a visual inspection of ballast tanks and hard to reach parts in huge cargo vessels. Its four magnetic wheels and overlapping wheelbase enable SIR to navigate the I-beams and other awkward obstacles found inside ship ballast. These robots can be controlled via a wireless transmitter with live video feed and its four infrared distance sensors help in detecting edges and obstacles. Figure 3 shows the prototyped robot in action.

Fig. 3 *Ship Inspecting Robot [3]*

The biggest advantage of SIR is the reduction of time and cost for inspection of the cargo holders. But the SIR system unfortunately has some disadvantages. The most critical problem of SIR is the small contact surface that its wheels have with the walls cargo holder. Even small obstacles or rust on the surface can cause the fall down of the robot. Those series of fall downs of the robot limited its commercialization. The wheels based design (Fig. 4) does not allow a larger contact surface between the inspection robot and the inspected area. Another disadvantage of SIR is the limited by the battery pack operation time and its ability to inspect only the "dry" surface of the ship.

Fig. 4 *Structure of the SIR wheel and the contact surface [3]*

The problem of SIR's small contact surface is partially solved in MARC: Magnetic Autonomous Robotic Crawler (Fig. 5) [2].

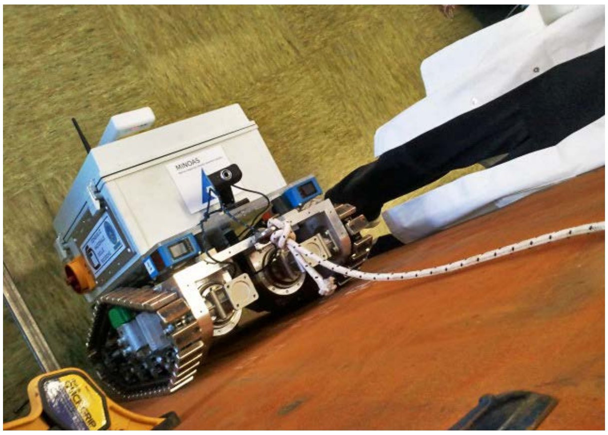

Fig. 5 *MARC final release, during vertical climbing test [2]*

As published by the authors [2] the MARC actuation system is basically constituted by a couple of magnetic tracks, actuated by an electrical motor coupled to a gear-head through a suitable mechanical interface. The magnets are lodged in dedicated housing connected to a chain to constitute a track. The weight of the robot is approximately 50 kg. and it is powered by batteries. The system is not capable to work underwater and to inspect the external part of the hull. It can operate only in the cargo holders. Magnetic tracks are selected as passive adherence system maximizing the contact area with the metal surface. In particular, in virtue of the exerted force, neodymium magnets are used. These magnets, also known as NdFeB, NIB, or Neo magnets, the most widely-used type of rare-earth magnets, are permanent magnets made from an alloy of neodymium, iron, and boron to form the Nd2Fe14B tetragonal crystalline structure. In the particular case, the employed magnets are characterized by a dimension of 40x22x9 mm and a 20 Kg attraction force. The driving element is composed by an aluminum frame where magnetic tracks, motors and traction gears are fitted. Magnetic elements are covered with anti-skid tape (Fig. 6) in order to increase the friction factor between the surface and the magnet itself, increasing the traction factor. A couple of small rear wheels are mounted in order to increase stability and adherence on vertical surfaces, avoiding possible rollovers.

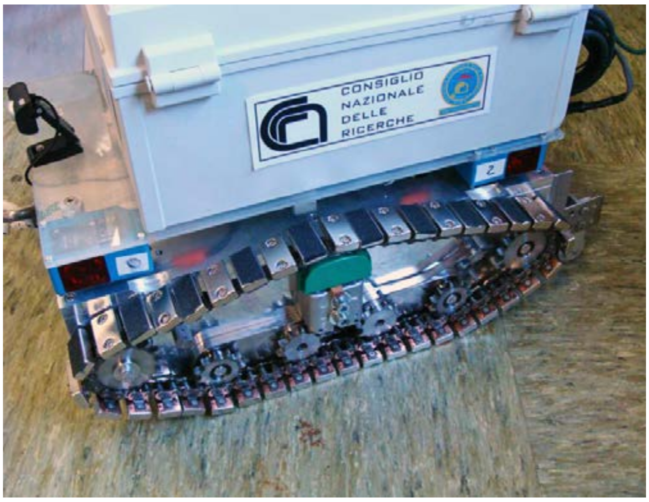

Fig. 6 *Rectangular magnets and anti-skid tape [2]*

What is easily noticeable from the tracks' configuration shown on Fig. 6 is that the suspension system of the robot is very much like the suspension of the systems that are forced to the surface by the gravity. Most of the track support wheels are placed on the lower part of the track that will be in contact with the inspected surface. But during the contact with the surface the force of the gravity and the weight of the robot will try to flip it over and the track will try to escape from the support wheels. Another disadvantage of the robot is that it does not use effectively all of its magnets. It is noticeable from the figures that the robot contact with only a quarter of its magnets to the surface. This approach require use of stronger magnets that on other hand increase the overall weight of the systems and reduce its efficiency.

3. ARMUS underwater hull observation system

The ARMUS robotic system takes into consideration all current and past developments in the field of hull observation and inspection systems. The first generation of ARMUS robot (Fig. 7) is designed in a way that the robot reverently works under water. It is a three axes tracked system that attract to the hull with the help of neodymium magnets. The total weight of the robot is 20 kg. and it is remotely controlled by cable that can be as long as 100 meters. The connection cable is used only for the control of the robot and transfer of video signal from the robot to the control unit.

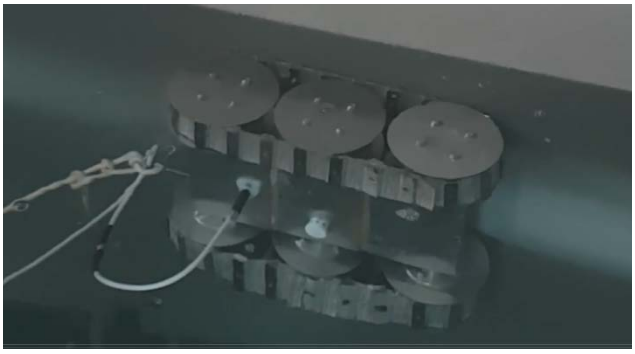

Fig. 7 *First generation ARMUS robot inspecting ship's hull under the water line*

The first generation of the ARMUS robot offers only visual inspection of the hull. The robot is powered by two DC motors coupled with gearboxes. The power is provided by batteries that are mounted inside the robot. The video signal is broadcasted as a radio signal through the connection cable. The same is with the control commands of the robot for speed and direction. Each track is controlled independently. The attraction force that the robot tracks provide to the surface is 336 kg.. This attraction force is enough to keep the robot limped to the hull surface even when the robot is operation while the ship is in motion. This is one of the major benefits of the robot as it reduces significantly the time for inspection as it can start and continue during the approach of the ship to the port and does not require the ship to be in standby mode. The biggest disadvantage of the first generation ARMUS robot is the limited by the batteries operation time that is up to two hours, depending on the hull's condition. A second disadvantage is the limited maneuverability on a dry iron surface. Those disadvantages are overcome with the second generation of the ARMUS robot shown on Fig. 8.

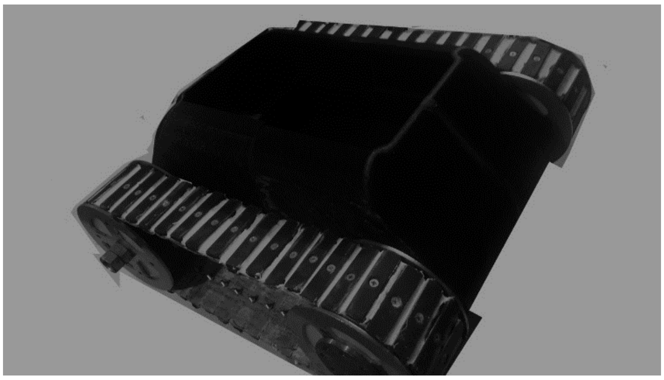

Fig. 8 *Second generation ARMUS robot designed to work both underwater and on "dry" iron surface*

The second generation of the ARMUS robot is a designed in a way to be able to stay unlimited time underwater and to work on both sides (external and internal like cargo holders) of the ship's hull. The robot overall weight is 35 kg. and the attraction force of the tracks is 672 kg., doubled from the first generation. The robot uses a different approach from the first version. It is connected to the ship by a cable that supplies the robot with current between 110 V and 220 V. The same cable is used for the communication and control of the robot. The length of the cable can be up to 200 meters. The track system of the robot uses a two wheels type suspension without the use of extra support wheels. This type of suspension guarantee the successful maneuverability of the robot on a dry and wet surface and at the same time does not allow the robot to lose its attraction force and to fall down from the inspected surface. The good attraction between the tracks and the iron surface gives the robot the ability to overcome different obstacles even when it is climbing the walls of the cargo holder or the underwater part of the hull. The schematics of the robot submerse system is given on Fig. 9.

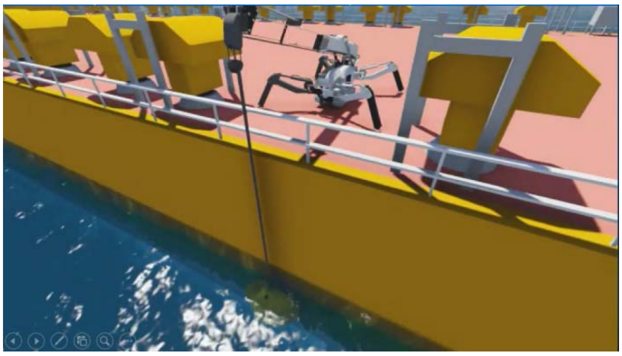

Fig. 9 *ARMUS submerse system*

The robot is controlled trough a specific graphical user interface. The control system consists of two main parts – remote control unit and onboard control unit. The onboard control unit is a computer linked to a series of controllers that are used for the control of the motors, the communication and the observation systems. The robot generally carry one pair of cameras – a high resolution observation camera and a secondary rear camera. The robot can carry also a set of scanning sensors depending on the particular needs of the customer and the type of observation that is necessary to perform. The engines are powered by AC – DC convertors. The second generation of ARMUS has a unique design of the suspension as the motors and the gearboxes of each track are mounted outside the sealed area of the robot body. Each motor is placed separately in a sealed chamber and the torque is transmitted to the track leading wheel by an open type clutch. The use of simple DC motors allows the robot motion even the motor chamber is flooded. The motor drivers are designed in a way to work even if the motor is in a short connection. This will help the operator to control the evacuation of the robot from the water in case of decompression of any robot's seal.

The remote control unit is a box that provides the power a communication supply to the robot. It also broadcast a control communication signal on a private network to a tablet from which the operator drives the robot and observes the provided data. The control box is given in Fig. 10.

Fig. 10 *ARMUS control unit*

An important issue of the control system is that the graphical user interface of the control is designed to be user friendly and does not require a specific skills of the user in order to deal with the robot control. The control system has its internal procedures that prevent the operator of giving tasks that can cause a damage or malfunction of the robot.

Another advantage of ARMUS is that it can stay in hibernation as long as necessary. The system is of the type plug and play. The moment ARMUS control unit is plugged to the power supply of the ship and the connection cable of the robot is plugged to the control unit ARMUS is ready for action. The system for observation of the hull of large vessels is designed to search and identify limpet objects like naval mines, improvised explosives or contraband traffic attached to the underwater hull of the ship. It is able to perform tasks under various weather conditions during the ship motion. It has two main operational modes:

- Semiautomatic - in this mode the system motion is manually controlled while the automation supports the search and identification.
- Automatic - in this mode the system autonomously follows the predefined root.

Technical specification of ARMUS

- Capability to stick to an iron hull and travels underwater during the ship motion;
- Power supply to observe hulls with 275 meters in length and 16 meters depth;
- Maneuverability while ship sustains 20 knot water flow;
- Cognitive abilities to identify ship system (hull features) and hull structures and to define its own relative location;
- Generate hull refer point coordinates and transmit them for hull map generation;
- System is capable to avoid or traverse over typical hull shape obstacles (steps, grates, patches, weld seams);
- Remote control based on:

  radio + umbilical cable communication.
- Up to 30 days standby mode (manual activation at any time);
- Up to 6 months hibernation mode (only programmed activation).
- Once activated - Autonomous Operation within 10 minutes;
- Complete ship survey within 72 hours;
- Extra a payload of 2 kg.;
- Operational Temperature: -5° to 25° C of water and -25° to + 50° C of the air;
- Storage temperature: -35^{o} to 55^{o} C.

4. Conclusion

The ARMUS underwater hull observation system is the only one known available at the moment robot capable to travel attracted to the ship surface both under the water and on the "dry" ship body like the cargo holders. ARMUS is the ideal tool for fast and reliable ship observation in order to perform hull management. Its ability to stay underwater as long as necessary and more important to perform its tasks during the ship motion makes ARMUS a desired tool for security measures. The use of ARMUS is organized in natural manner and does not require specific skills from the personnel. The complete system is designed in a way to be durable and easy for maintenance. All materials used are corrosion free and resistant to aggressive and hazardous environment. Moreover ARMUS is designed in accordance with the ATEX directive and can work in hazardous and explosive environment like oil tanks.

5. References

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