UTILIZATION OF MOBILE ROBOTS IN MARITIME MAINTENANCE APPLICATIONS

Author Tomáš Hrubý

Faculty of Mechanical Engineering, Brno University of Technology
Institute of Automation and Computer Science
Technicka 2896/2, Brno 616 69, Czech Republic
xhruby26@vutbr.cz

Abstract: *This is a paper about usage of mobile robots in marine applications it is focused on possible robot utilization on large transport ships*

Keywords: *maintenance marine robots industry hull seafaring ship inspection*

1 Introduction

With an increasing number of usage and availability of robots in worlds industry and transportation, where mobile robots are fulfilling numerous tasks contributing to satisfying increasing efficiency and work optimization requirements, the maritime industry offers many interesting applications.

Sea trade plays significant role in global economy. There are more than 90 000 commercial ships in the world fleet from which 58 000 merchants ships are responsible for global international cargo transport of goods employing over a million seafarers. Therefore

2 Ship maintenance robots

2.1 Importance of maintenance

Keeping a large ship clean is costly and never ending process. Average lifetime of a ship is around 25 years where every 5 years an ship inspection and maintenance is carried out in a dry dock. The lifespan of a modern container ship is 10.6 years on average, which is the shortest lifespan of vessels in general use. Bulk carriers and oil tankers have around 17 years. [1]

Dry dock is therefore a necessary stop in the life cycle of a ship. Cleaning of a ship's hull is costly, it takes between 100,000 to 200,000 US Dollars on average. Whole process takes around 8 days to complete and the vessel is out of service during that time.[11] For large ship the whole process is estimated to cost 1.2 to 1.6 million dollars and the ship's stay in a dry dock is counted in matter of weeks.[7]

While at sea voyage the ship's hull is exposed to several detrimental sources of contamination. Bio-fouling consists of plants such as various forms of algae, slime, and seaweed, also animals like barnacles, mussels, and other adhesive shellfish that adhere to any underwater surface and reproduce in great numbers. Bio-fouling organisms attached to the underwater surfaces vary in size, shape, complexity, and behavior. For example, sizes can range from microns for unicellular diatoms to several centimeters for tubeworms. [9]

As the surface occupied by sea organisms grows and increases on size it is causing degradation to the paint and metal structures on the previously smooth hull, the resistance of the water will increase too. This negative effect on hull's hydrodynamics slows the ship and is counteracted by an increasing demand on fuel to power the ship forward, also together with fuel's emissions.

Estimation in numbers are that The build-up of marine organisms on ship's hull, 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.[8]

2.2 Hulls maintenance

Prevention of bio-fouling of a ship' hull is an important task for crew and ship building facilities. Hulls need a series of operations and treatments before they are ready to sail.

Methods for inhibition of organic and inorganic growth on wet surface are various but most of of the anti-fouling systems rely on application of a form of protective coating. However many previously used coating substrates were banned for environmental reasons. [3]

Coating application is mostly done in shipyards dry dock where it is done mostly by human workers. Coating application of the protective layer is an immense, time consuming process which occupies a lot of workforce.

Most of the process takes place in heights and possess a risk of injuries. Another issue which should be placed in consideration is that applied materials are mostly toxic for human especially during application.

All these reasons makes this area of marine industry well suitable for utilization of robotic systems. One part of possible using of robots are autonomous or semi-autonomous platforms which are spraying the coating substance layer by layer the same way as the human worker would do. These robots have a various shapes depending on the area they are used on and the size of hull. Ground robots are accessing a ship hull with the supports of crane systems. However, because of to the size of the ship's hull, it is challenging to work with just one crane, and multiple units must be positioned all around the ship. [10]

2.3 Robots operating on hulls surface

Robots that can climb hull of the ship are thanks to many advantages increasingly more present in the marine industry from implementations in dry docks where they are used as supportive workforce to robots that are used during sea voyage to prevent degradation of the hull.

For the coat painting applications robot climbing on surface is capable of optimization of painting and prevents significant portion of the toxic gases from pollution of air's environment. These painting robots can also contribute to effective and even painting distribution and mitigation of excessive paint consumption. [13]

Beside painting the main part of robots usefulness lies at maintenance which includes water jet blasting, powerful water stream is aimed systematically in semicircles ship's hull. Hydroblasting is the most effective way of removal of the paint, rust and bio-fouling from the surface. Blasting is high-pressure and non-abrasive and the water is can be pumped up to 2400 bar pressure according to requirements. [12]

2.3.1 Cleaning underwater

For underwater applications some cleaning systems also use brushes or other physical tools to scrub the hull, in addition to or instead of water jets. Fouling material is typically dislodged from the hull and allowed to float away. These underwater robots are mostly controlled by human operator.[13]

Brushes are mostly in a pair both rotate opposite each other and with opposite direction. Filaments have its inertia in motion and drag the bio-fouling which has a different hardness with which the brushing system must be able to cope therefore different brushes are used from nylon to steel, the selection is also based on type of material of the hull and type of a coating. [9]

Beside jet-blasting contactless cleaning can be done by cavitating jet nozzle which is more effective because the pressure is more stressed locally. Other method is based on use of ultrasonic technology, cleaning is done by generation of energy pulses which is pulsating over number of frequency ranges. The alternation of positive and negative pressure produces tiny bubbles that implodes and removes marine organisms from surface. Cavitating water jets and ultrasound shock waves are ideal to utilize in tandem for maximum efficiency.

Next technology involves utilization of laser high-energy strobe lamp. Heating method can be also effective when the bio-fouling is not much overgrown and likewise radiation of ultraviolet light used in water sterilization. [13]

2.3.2 Magnetic wheels

The motion of maintenance robots is done mostly via magnetic wheels which are thanks to nature of the ship's hull more effective as suction cups.

These robots rely on the principles of permanent magnetic adhesion during its locomotion.[15] Magnetic wheels increase the normal force to the metallic surface and allow the robot motion to be more independent from the direction of gravity. The direction and strength of the magnetic force depends on the orientation and polarity of the magnets. By controlling the orientation and polarity of the magnets, the robot can control the direction and speed of movement. As the required torque for climbing vertically is much higher than for robots which only move horizontally, the actuators need to be considerably stronger. [5]

2.3.3 Planing of robot's maintenance path

Maintenance of hull can be planned and the path can be based on previous diagnostics of state of hull. To save energy and to fully utilize robots cleaning potential several path planning algorithms are being researched, together with perceiving and decision-making algorithms as well as multiple image reconstruction methods.

Complete Coverage Path Planning algorithms or CCPP similar to those applied in floor cleaning robots are used for scheduling the pathway. Most of these use offline methods that count with static workspace and assume that information about traveled environment is well known before the robot starts the motion. Some of the offline methods used are based on for example solving a Traveling Salesman Problem by reinforcement learning, use of evolutionary algorithms such as genetic algorithm and ant colony optimization. CCPP methods are developed to cover both energy efficiency and full workspace path coverage, however mostly they are fragile to dynamic change of environment and obstacle avoidance.[10]

However, online CCPP methods which are using real time data for ship's hull maintenance are novelty in maritime industry. One of those methods which is promising is based on Glasius Bio-inspired Neural Network (GBNN). GBNN method's energy model takes into account robots energy consumption as function of changes in directions, distance and vertical placement. This model is guaranteeing complete coverage and safe obstacle avoidance. GBNN is a discrete-time Hopfield-type neural network, does not require training and is topographically ordered into the 2-dimensional Cartesian workspace. [10]

Glasius network consists of series of interconnected processing nodes that are arranged in two layers, sensory and motor layer. Sensory layer is modeled on basis of given map updated by real time map obtained from robot sensors. Motor layer is obtained from signals that control the robots movement. [14]

3 Inspection robots

Inspection of ship is crucial at surveying locations with deficiencies and knowing overall state of a vessel. Unmanned Aerial Vehicles (UAVs) became more prevalent in inspection tasks as they are can move freely and can carry multiple perception systems, however although easy to use UAVs suffer from danger of processes like blasting and other equipment engages during maintenance. [10] Fouling and rust in ship is occurring especially in contact with water and making a full inspection during normal service is impossible without use of the work of scuba divers or help of underwater robots.

A small remotely controlled or Autonomous underwater vehicle (AUV) submarine that operate outside of ship is also a likely option. [4] Other ship's spaces such as ballast tanks are however unreachable with classical means while is the ship in the operation.

3.1 Ballast tanks

Ballast tanks make up a large portion of a ship's supporting structure. They are situated between the outer hull and the cargo holds, and they are made of beams and stiffeners that are divided by bulkheads.[6]

Tanks are used to stabilize the ship's displacement. This is especially important part of cargo ships where the amount of weight is fluctuating. While the ship is unloading the water is poured in the ballast tank and vice versa. Together with the process many marine organism can board and then travel large distances. Traveling of invasive species threatens survival of vulnerable sea ecosystems residing on the paths of sea trade routes. Therefore it is recommended to take a precautions and to periodically inspect ballast tanks.

3.2 Ballast inspection robot

Ballast inspection involves navigating hard-to-reach spots with no line of sight, often in the presence of intense heat, humidity, and hazardous gases, it is normally done by human inspectors in dry docks. Main advantage of mobile robots capable of ballast inspection is that it can be done while the ship is in operation.

Robotic inspection of ballasts is therefore an ideal assignment, however due to the interior of the ballast's T-, L-, bulb-, and I-profiles as well as its convex and concave edges, it provides a considerable navigational problem to any robotic inspection system. A few prototypes have been created so far, but the majority of these systems are large and heavy, and they require cables (for power and communication), which considerably reduces their mobility and range.[6]

Utilization of inspection robot has following scenario :

1. Robot is deployed several times to systematically inspect ballast interior, each time according to its batteries and speed potential.

2. Data from inspections are analysed suspicious areas are marked. Every time a new inspection is done map of ballast's damage is updated.

3. Once the time for dry dock maintenance occurs the map is checked and equipment with material is ordered prior the entering of the dock.

4. In dry dock ship is vented and repairs start without delay. Substantial inspection time is reduced. And inspectors focus on damaged areas or difficult locations that are not reachable for mobile inspection robot.

One of the possible solutions was done by team of students from ETH Zurich.[2] The robot consists of four overlapping magnetic wheels able to navigate in sharp angles and overhangs. Robot carries a transmitter and micro-controller for bundling sensor. Majority of processing task are carried out on board on external base station that runs the Robot Operating System, allowing the robot to be lightweight and power-efficient.

Sensory consists of four infra-red distance sensors, motion tracking system, a camera supported by lightning. Two systems perform the communication. First one is stable analog 2.4 GHz (WLAN frequency) for controlling of the robot with almost any delay. Second one is a common wireless video transmitter used for operating camera. [6]

Mobile inspection robots with magnetic wheels like the one described above and others similar to it have its use also outside of marine industry. Many of these robots were made for inspections of large tanks carrying liquids and gas as well as for survey of pipelines.

4 Conclusion

This article was focused on mapping some of the possible options of usage of mobile robots in ship maintenance, cleaning and inspection which are necessary for keeping ship in good state and to increase longevity of ship. All those methods described in article are nowadays increasingly used as intensively researched for its advantages for its efficiency, economical and ecological reasons.

Given how large the maritime industry is, the space for improvements by using modern technologies and mobile robots are vast. Together with increasing demand on ecological footprint, speed of delivery, efficiency, safety and economical factors, mobile robots operating on ships providing inspection and maintenance are changing this industry for better and with broad implementation of these technologies mobile robots will likely play a key role in future of seafaring.

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