Test, tuning og certificering af propel poleringsrobot

2019-136 Report, SubBlue Robotics ApS

SubBlue Robotics will help the shipping industry save fuel by performing propeller polishing operations. SubBlue Robotics develops an underwater robot that can perform the operation without the use of divers.

http://www.subbluerobotics.com/

Project goals

This project aimed to tune SubBlue Robotics propeller polishing robot product and service, so that paid propeller polishing services can be delivered to the shipping industry as soon as possible.

The product consists of an ROV (Remotely Operated Vehicle) and a robot arm. The ROV should swim the robot arm to a ship propeller and clamp itself to the propeller. The robot arm should then unfold itself and perform the polishing operation on the propeller using a spinning polishing disc. The robots control system is partially automated and partially operated by a user.

Tuning of the product includes testing of the robot arm and ROV by themselves and combined, this includes

- Testing robot arms polishing ability in harbor. Previously robot arm has been motion tested in a water tank without performing polishing
- Test the ROV’s ability to clamp itself to a propeller. Previously a smaller prototype had its ability to clamp tested.
- Combined, the components must have its physical properties (e.g. mass/buoyancy-distribution) and control software tuned. This is to ensure smooth and stable swimming
- The control of the robot arm and of the ROV must be integrated
- Furthermore, the software should be updated with more advanced control that allows the robot arm to polish a curved surface
- Combined, the robot must be capable of performing a full propeller polish

Tuning of the product also includes

- Robustness issues related to vibrations and electromagnetic radiation must be improved, preferably with official certifications

Additionally, a goal of the project was to

- tune the service provision that comes along with the product, so that the product was ready for commercial use.

Achieved goals

The product has certainly been tuned and is much closer to commercial use than in the beginning, but it not quite ready.

The robot arms polishing ability has been tested by itself and software to control polishing has been implemented. This was a success.

The ROV has had its swimming, stability and clamping abilities tuned. Successful clamping on a propeller has been accomplished.

The software of the ROV and robot arm has been integrated and improved, with a much-improved user interface. The user interface, however requires additional work for commercial use.

The project was delayed by robustness to vibrations issues several times, and the product has been made much more robust, since this issue was so pressing. However, while the product has been so robust as to not have any failure in almost a year, no official certification has been achieved as of yet.

A part of the process of tuning the products robustness was additionally to replace some components. Some components have been replaced, but not all that are necessary. For example, there has been done a lot of work on making the robot arms joints stronger for the use case, for failure modes, and be more suitable for mounting and calibration – these issues are serious barriers to commercialization. The design of the updated joints were completed, but the construction was not within the project period.

Even though the ROV and robot arm where each successfully tested by themselves, and their electronic hardware and software have been improved to be suitable for operation, the product did not perform a propeller polishing operation within the project period. It is the next step. This also means that the goal of tuning the service provision was not achieved either within the project period.

Activities

Status at project start

At the start of the project, the company had developed a robotic arm and owned a Remotely Operated Vehicle (ROV) for carrying the arm. The robot arm has the polishing disc with which propeller polishing will be done. The two components combined result in a product that can swim to a propeller, attach itself and polish the propeller. This had not been done at the start of the project.

Both components needed more testing, the arm had only been used in a water tank and needed special polishing control algorithms tested and tuned. This required testing with more space and more surface to polish.

The ROV needed to be calibrated for swimming, stability control, buoyancy and weight distribution with and without the robot arm attached. Its control electronics was not done yet at the start of the project either. The clamping mechanism of the ROV had to also be tested, as it had only been verified with a smaller ROV.

There was missing submersible electronics at the project start, so this will have to be produced. Furthermore, the robot arm and ROV are controlled by different software, and these software should be integrated and be controlled by a common user interface.

Figure 1 3D computer model of ROV, with robot arm attached

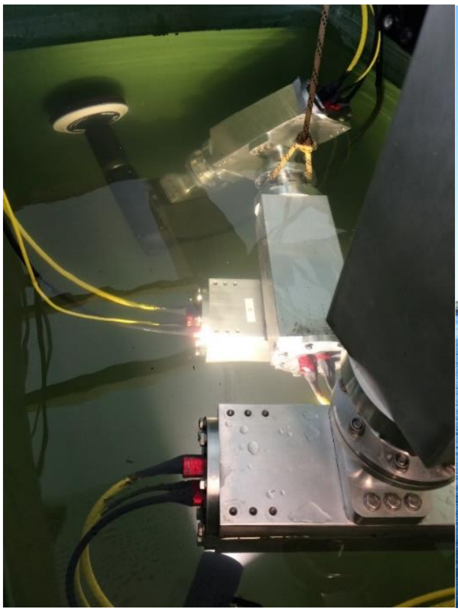

Figure 2 Robot arm in water tank

Figure 3 Remotely Operated Vehicle (ROV) at harbour

Figure 4 Robot arm and ROV combined

Robot arm

The robot arm needed testing at harbour or in a larger water tank. The old water tank didn't have enough space for proper polishing testing. We therefore designed a test-rig that can be submersed in harbor, with a large test-surface (a car hood). This allowed for testing the robot arm by itself and tuning its polishing control algorithms. The test surface could be resprayed to polish again.

Figure 5 Bigger robot arm with polishing disc on test-rig

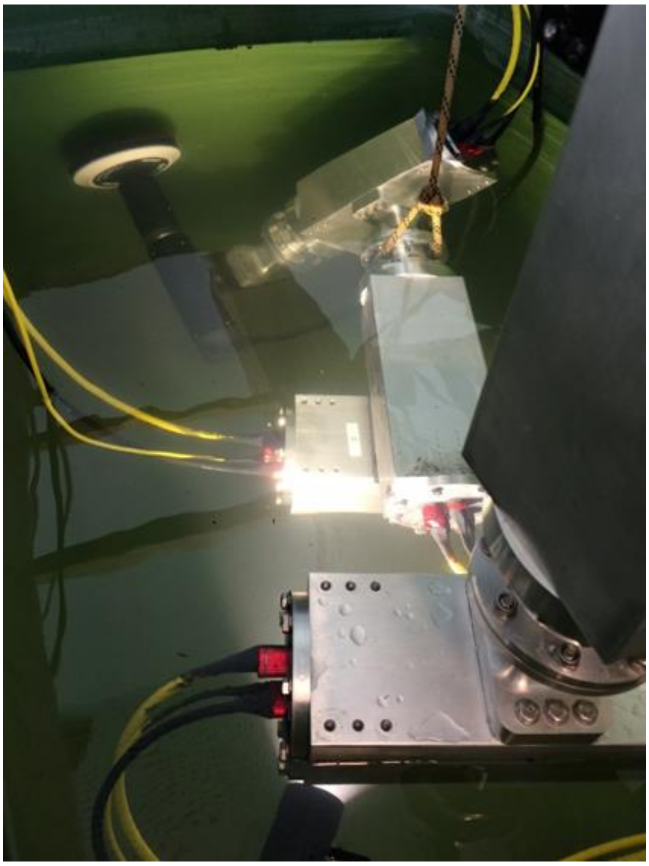

Figure 6 Test af robot arm In water tank

Figure 7 Robot arm on test-rig in harbor, while maneuvering to polish a test-surface

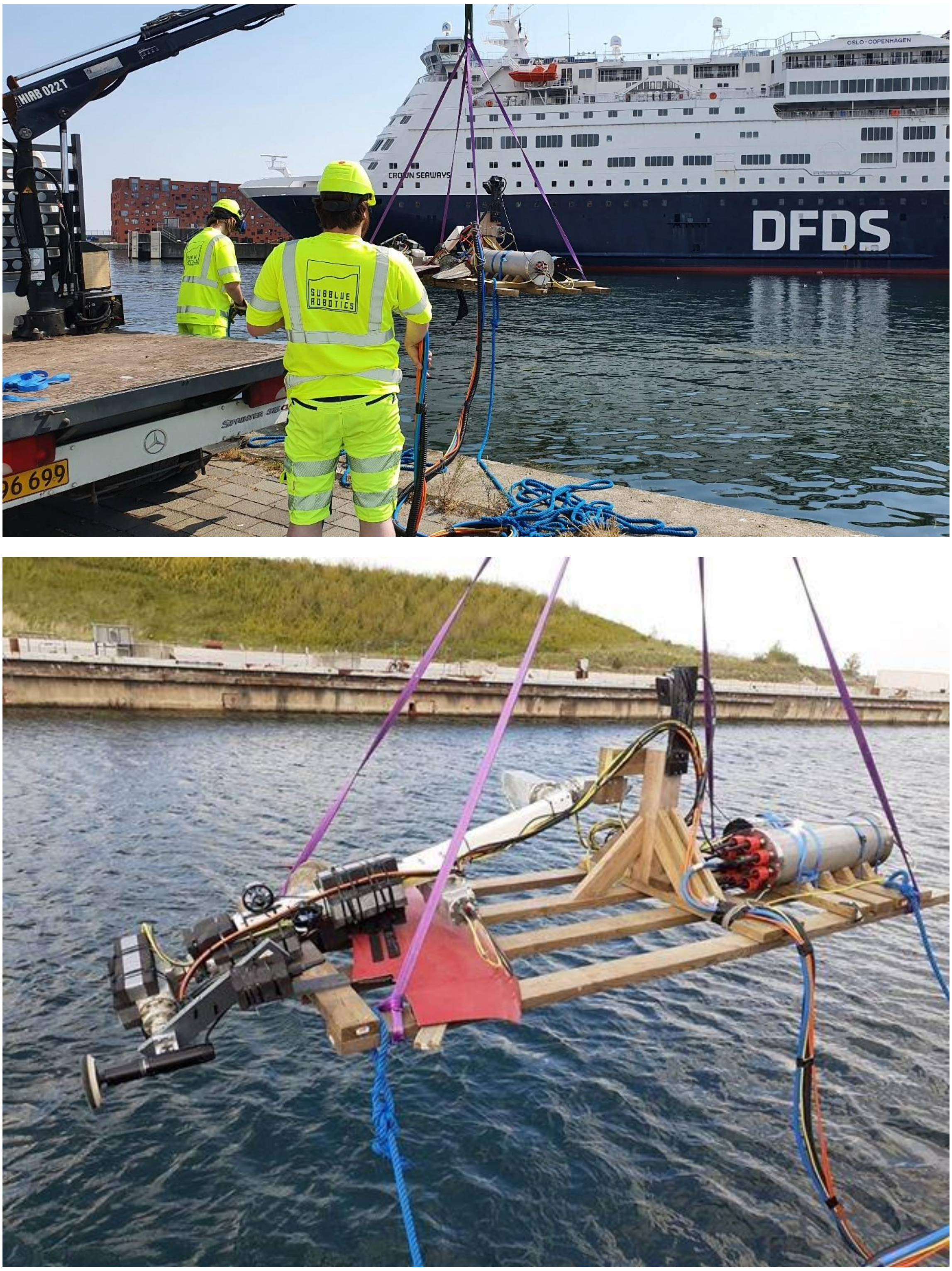

Figure 8 Robot arm on submersible test-rig with test-surface for polishing

Figure 9 Section from successful polishing test.

The robot arm was tested extensively for its ability to polish a surface underwater. The results were

- Basic systems function: lights/leak detector/polishing motor/joint motion control. Safety protocols were made to filter out corrupt measurements from e.g. joint position sensors. Grounding issues gave rise to signal integrity issues that have now been solved.
- The robot arm can be motion controlled with cameras – the user can move the polishing disc to the right of left relative to its own coordinate system. The computer software automatically translate between user inputs and rotary joint motion controls
- The robot arm can polish with a user-controlled force (the software automatically regulates force), even while being moved by the user. The robot arm can polish continuous lanes on test-surfaces.

- The polishing motor broke down and was later repaired with a safer mechanical construction. Several safety protocols were made in the software as to protect the polishing motor from destroying itself
- The software has functions as to help the robot arm automatically regulate its polishing discs orientation relative to the polished surface. This is done with measurements of the forces acting on the polishing disc – the robot arm can regulate its orientation to be normal to the test-surface within a narrow range. Further testing is required.

Remotely Operated Vehicle (ROV)

The company has a Remotely Operated Vehicle (ROV), which can swim in any direction and rotate around any axis. It is supposed to carry the robot arm, swimming it to the ships propeller, where the ROV must attach itself

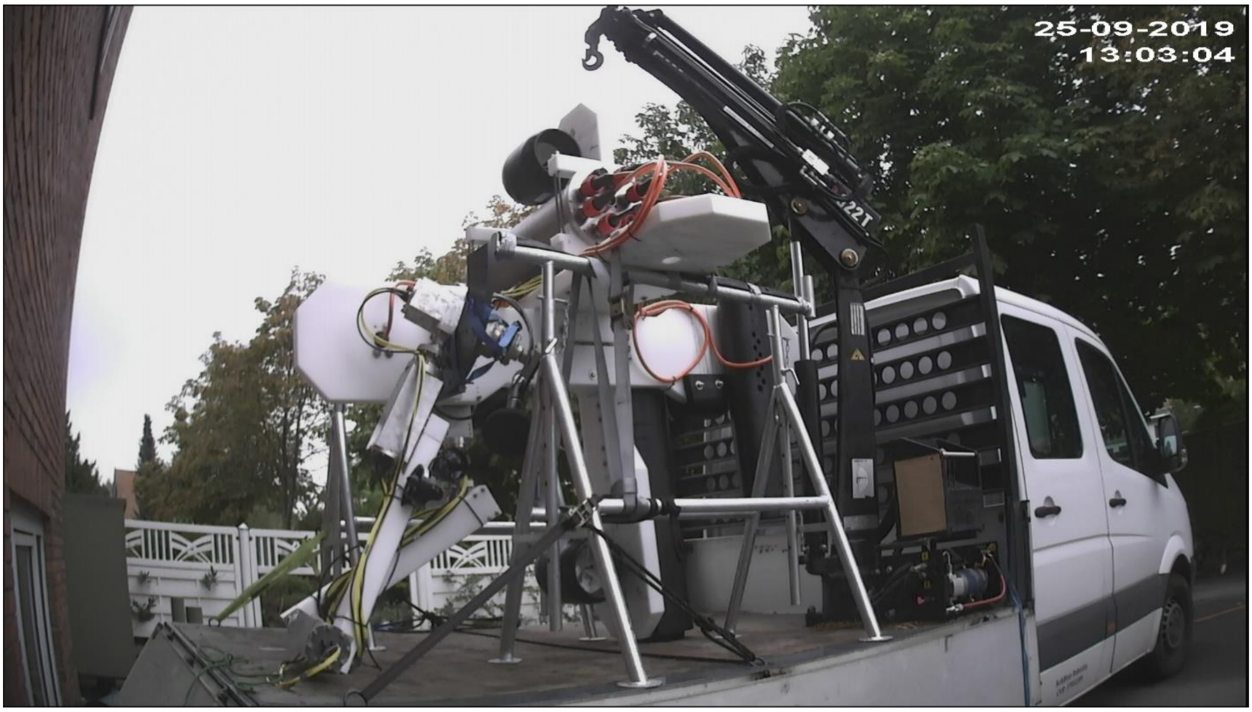

Figure 10 ROV with robot on truck with crane

The ROV was tested extensively and many challenges occurred. Issues with thruster control, corrupt buoyancy elements absorbing water, interference on its gyrocompass from outside magnetic fields leading to instability, and at one time a broken depth (barometric) sensor.

The tests were carried out using a truck with crane. The ROV is driven to a ship in harbor and lifted into the water by the crane. The ROV is powered and controlled through an umbilical with a powerline, a signal line, and independent camera lines..

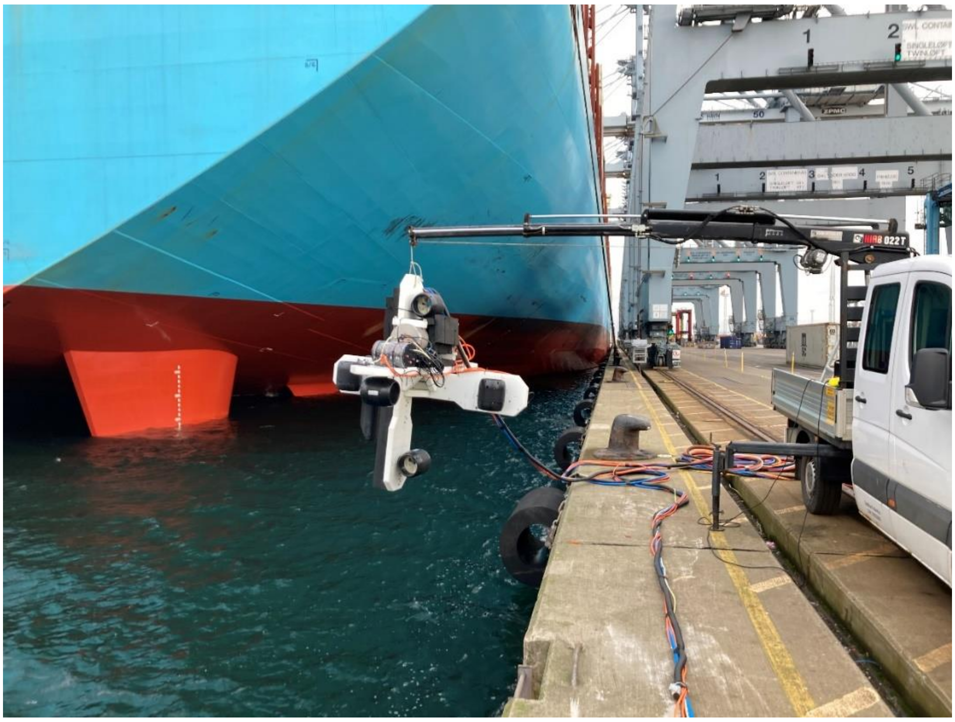

Figure 11 ROV about to be lifted into water in harbor.

Figure 12 ROV swims by rudder. Temporary buoyancy elements are added during this buoyancy tuning session.

Several tests have been successfully concluded upon

- The ROV's buoyancy has been tuned
- The ROV's stability properties have been tuned to ensure stable swimming
- The ROV's thruster control has been calibrated so that operator commands (forward/left/down ect.) lead to desired motion
- The ROV's depth hold and orientation control feedback parameters have been tuned to ensure stable swimming and stable depth control
- The ROV's ability to clamp to a propeller

The ROV's ability to swim to and clamp to a propeller is the most important quality, as it will allow for the attached robot arm to unfold and polish afterwards. The ROV has two rubber pieces that it will position the propeller blade between. After positioning the propeller, the ROV uses its thrusters to twist it around, clamping it to the propeller.

Figure 13 Computer model of ROV with rubber pieces in front for clamping

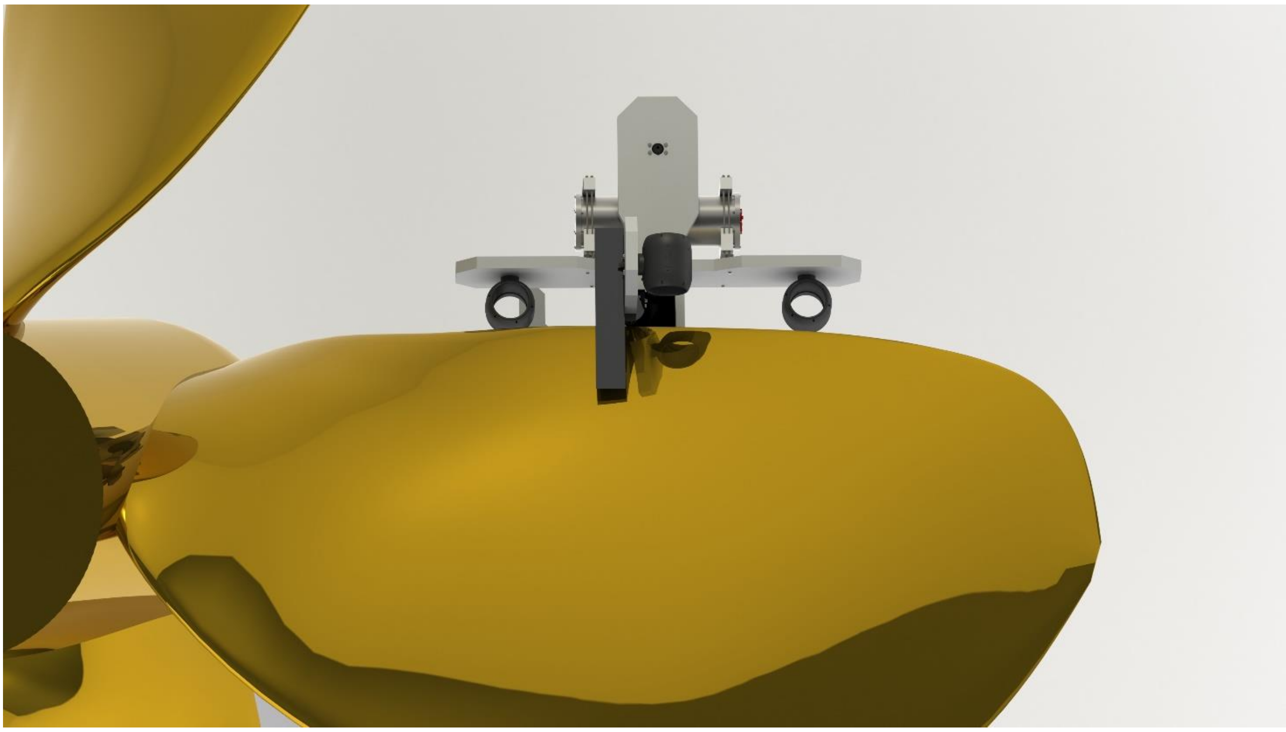

Figure 14 Computer model of ROV, clamped to a propeller

The clamping of the ROV to a propeller had many challenges and was reached only towards the end of the project. It was a success though, the ROV is now capable of swimming and attaching itself to a propeller. All the remains is to attach the arm capable of polishing a surface to this ROV and then the product can polish a propeller. We will here show some pictures from a successful ROV clamping test.

Figure 15 ROV front camera before diving to clamp on propeller

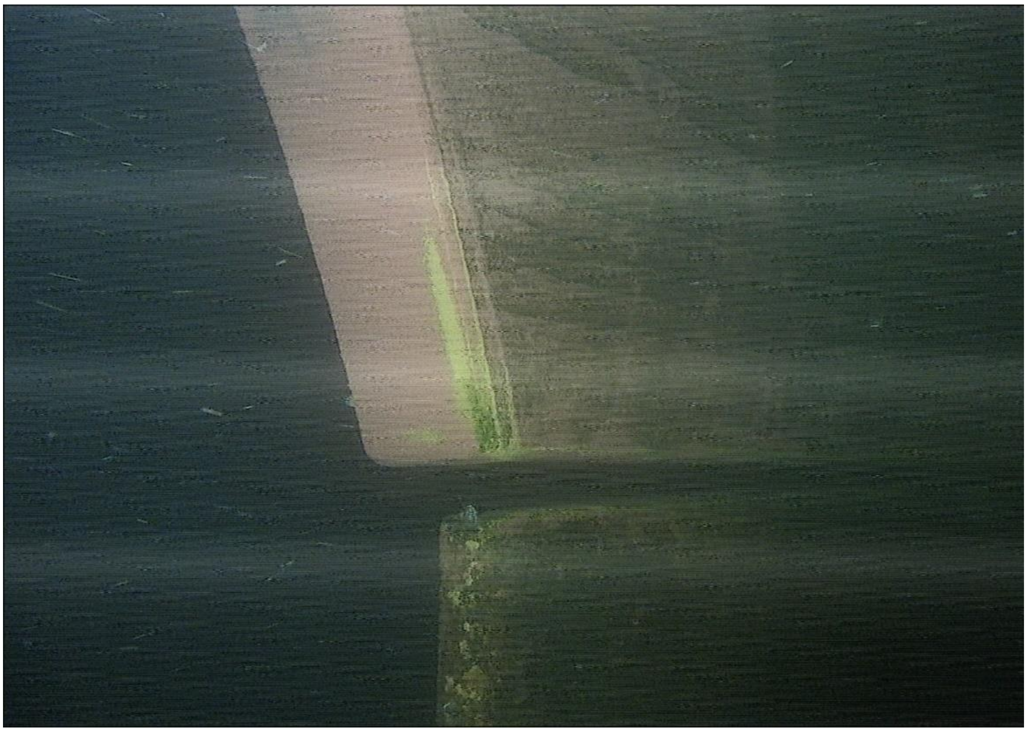

Figure 16 The ROV is navigated to the ship rudder

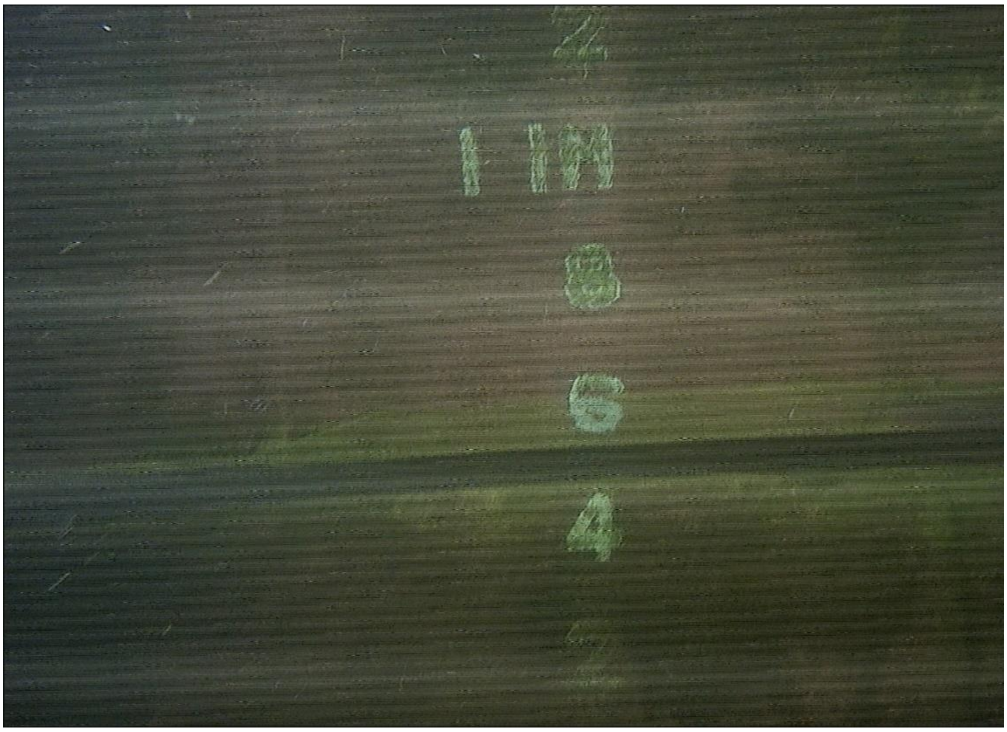

Figure 17 ROV is controlled sideways to the ships depth markers. Then it is moved downwards until it reaches the depth of the propeller

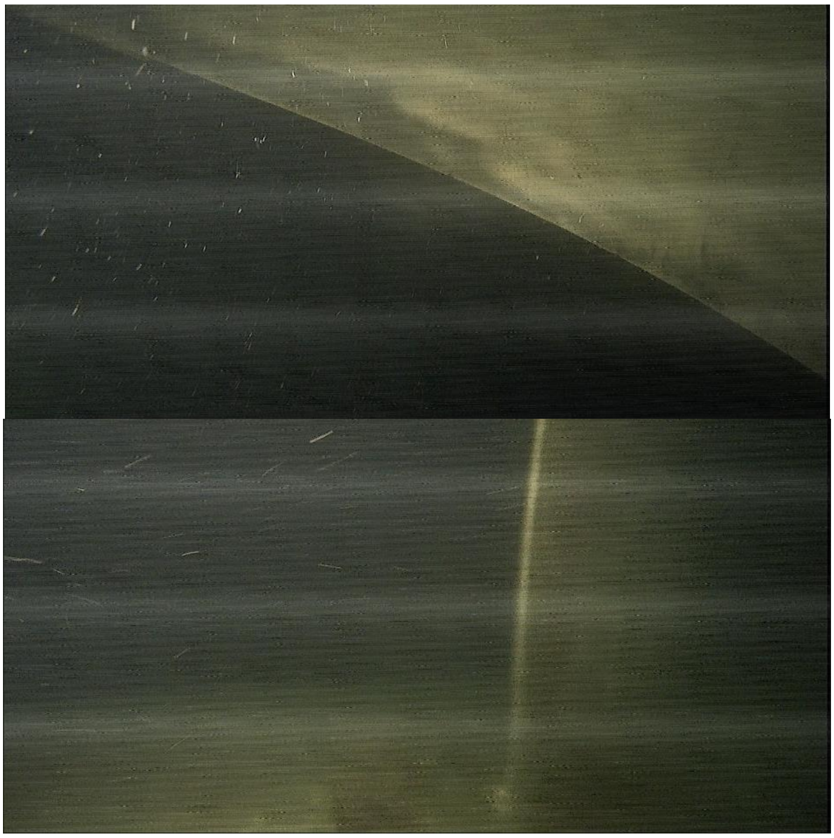

Figure 18 After diving to a proper depth, the ROV is sideways controlled until it reaches the propeller. Here is the propeller edge.

Figure 19 This is the ROV's back camera, looking forward just before and after a successful clamping. In the latter picture, the ROV is clamped to the propeller firmly, and can stay there for as long as required.

Electronics and software

One of the missions of the project was to upgrade its electronics to be more robust to the environment the robot operates in (with regards to vibrations and EMC). Steps have been made to make a more robust electronics that is encapsulated in a submersible tube. Components inside at risk of electromagnetic radiation have been dealt with, by shielding with cable shielding and metal cages.

Another mission of the project was to integrate the ROV and robot arm software control. This has been done, and a more user-friendly interface has been created.

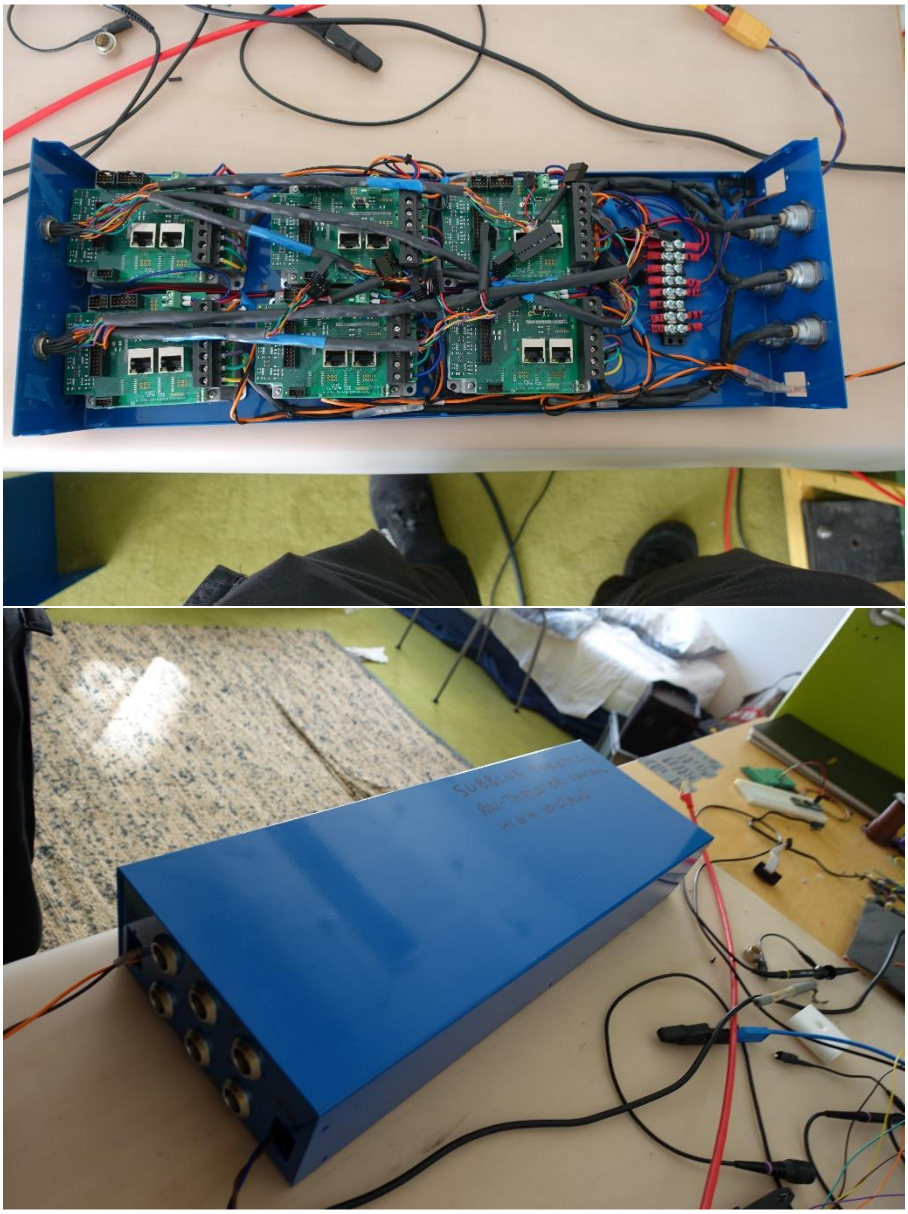

Figure 20 At risk electronics encapsulated and shielded from radiation from radiation

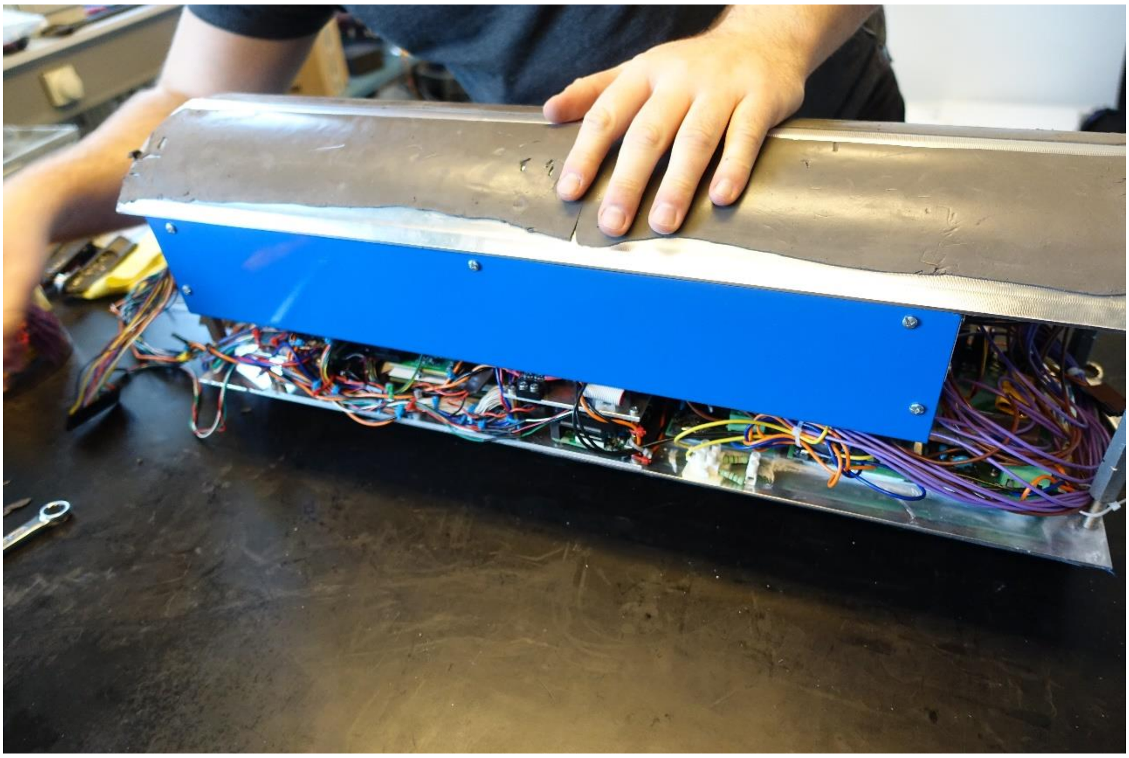

Figure 21 Construction to hold electronics

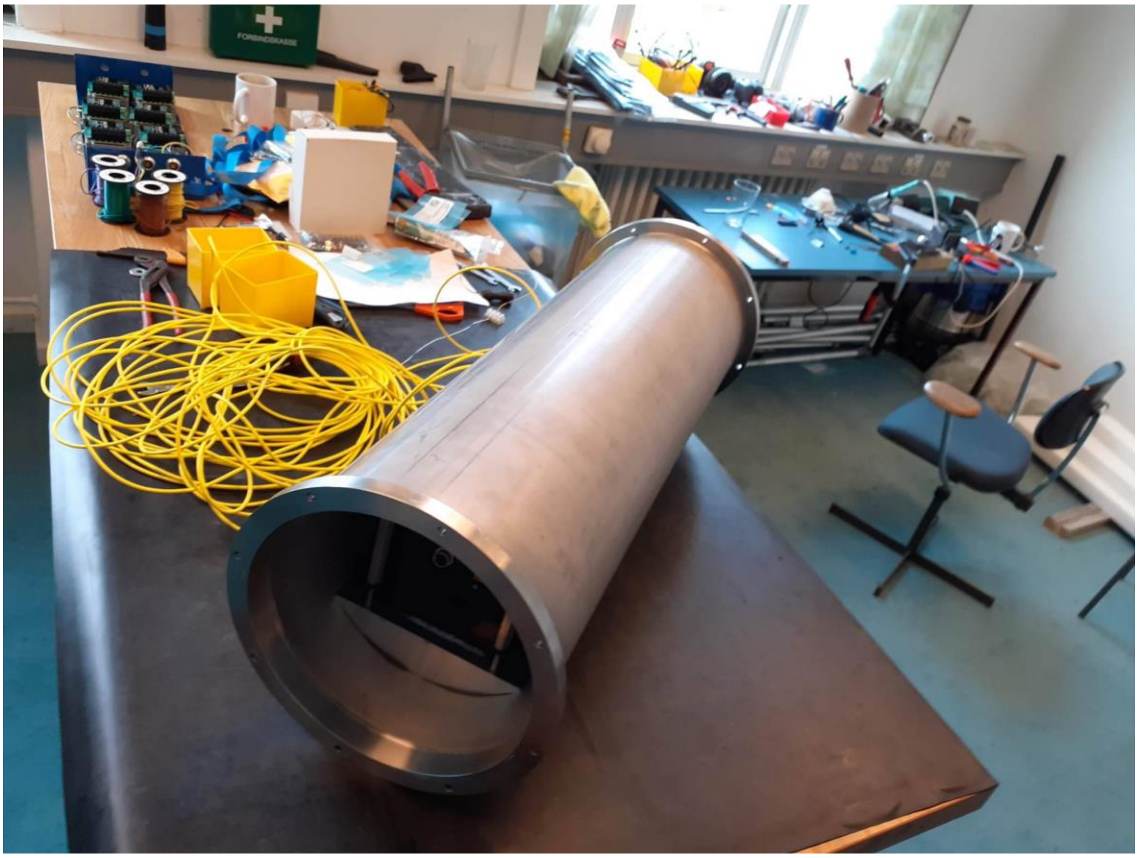

Figure 22 Submersible tube for holding electronics

Redesign of robot arm joints

The next step after the project is to combine the ROV and robot arm and perform a full propeller polishing operation. We discovered some issues with the robot arm that makes combining the components problematic

- The calibration of the robot arm must be done at every start-up manually. This is a difficult process with safety concerns
- The current robot arm joints have some fragility in its bearing design. Excessive shocks could damage them

Therefore we have designed new robot arm joints that will replace the old one to one with the same controls. The joints have been designed but have not been integrated on the robot as of yet.

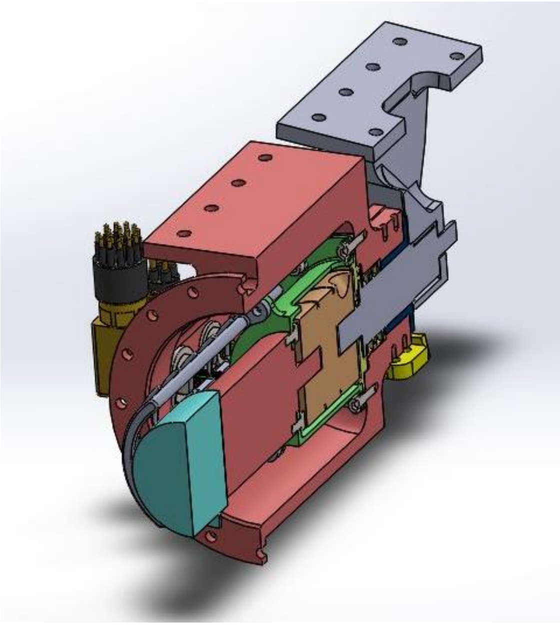

Figure 23 Section of new more robust robot arm joint

Conclusion

SubBlue Robotics have been testing their product together with several ship owners in Denmark. This is due to the interest of the shipping industry for saving fuel by improving propeller efficiency. This is interesting both to save money from reduced fuel consumption, and to reduce emissions. That the operation can be done in a safer way

The competences of the company has been expanded upon, with an addition to the ownership circles with competences within business and shipping.

No sales have been as of yet. During the project, SubBlue Robotics has searched for investors and are completing an investment round immediately following the end of this project for Den Danske Maritime Fond.

The robot is close to performing its first propeller polish, which can confirm the business case and bring in revenue. It is suitably durable for the operations it is doing now. For commercial use of the product, there will be required some additional work on receiving certification, procurement, production facilities and a more friendly user interface.