COMPLETELY AUTOMATED LASER GUIDED INSPECTION ROBOT FOR THE DETECTION OF WELD DEFECTS AND CORROSION IN SHIP HULLS

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INTRODUCTION

The European ship fleet counts 23,000 vessels, accounting for the 40% of the global gross tonnage. The Marine industry is a major prosperity engine of the EU contributing a total of €147bn to the GDP and supporting more than 1.7m jobs. However, the vessels' structural integrity verification is a major issue for the shipping industry. Regulations dictate that Non Destructive Testing (NDT) inspections should be performed every 5 years for the first decade of a vessel's life and every 2.5 years thereafter. Ship hull weld inspection is a challenging process as safety-critical weld length exceeds 120km in large vessels and involves human inspectors on site using scaffolding or cherry-pickers. These procedures require long periods of drydocking incurring loss of revenue and costs amounting to more than €150k per inspection. Moreover, conventional ultrasonic techniques cannot be applied on metal plates of thickness <10mm, which are commonly used nowadays to reduce ship weight. This necessitates the use of dangerous radiographic techniques posing health and safety issues. These challenges give rise to a unique business opportunity which Spectrum Labs and Tecnitest (leading NDT equipment and service providers) along with I Know How (IKH) (dynamic high-tech company specializing in robotics) and TWI (global leader in NDT technology) aspire to seize, with the help of Lloyds' Register, the most reputable shipping service provider with 230 years of experience. We aim to redefine ship NDT inspection by commercializing ShipTest, a laser-guided robotic crawler able to automatically track the weld and inspect the hull while the ship is at sea. Through a combination of bleedingedge ultrasonic and electromagnetic techniques ShipTest can accurately inspect metal plates of <10mm thickness eliminating the need for radiography. By commercialising ShipTest we will grow our businesses by €47.7m, cumulatively over 5 years, generating €19.04m in profits and creating 398 direct jobs and 1185 indirect jobs)

HISTORY

Shiptest is an FTI project (730645-ShipTest-H2020-FTIPilot-2016/H2020-FTIPilot-2016-1) project funded by the EU under the H2020 scheme. The project is a follow up to the FP 7 project X-Scan, which was a demonstrator robot with the capability to inspect ship hulls above water. Whereas, the Shiptest robot will be able to inspect ship hulls below the water line, the aim being to have all the technologies encapsulated and tested to IP 68. This will allow inspections below the water line.

Spectre-x is the is the name and logo given to the robotic NDT inspection system developed within the framework of the Shiptest project.

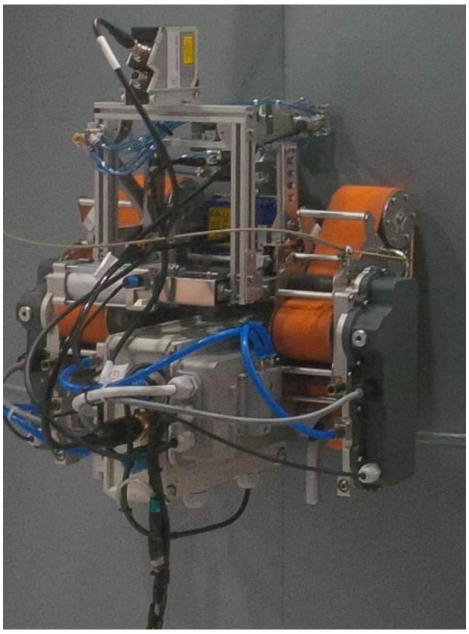

Figure 1. The Spectre X Robot

THE ROBOT

The robot was designed to move the NDT systems around the areas of inspection, specifically to follow a weld line, for weld inspection and to be able to make a scan path for plate corrosion inspection. Therefore, the robot has been designed and constructed to meet the following specifications:

- The robot can be driven by an operator through a means of a joystick.
- The operator drives the robot to access the area to be inspected, be it the start of a weld line or the start of a corrosion mapping exercise.
- The robot deploys the NDT equipment on the area of inspection upon command by the operator.
- The robot moves along the weld at a constant speed of desired value.
- For weld line inspection, the robot corrects the lateral position "error" of the NDT equipment, i.e. the offset from the centre-line of weld, based on feedback from the on-board laser profilometer.
- The robot moves vertically and horizontally on steel plates**.**
- The robot moves along the weld on significantly curved surfaces. The curvature set as target was 1m radius which is significantly more intense compared to the 2.5m that is required in most cases for hull inspection.

- The robotic system has ingress protection IP68, with 30m depth.
- The robot is able to overcome small profile obstacles such as welds in the case of cross-section and screws.
- The robot has integrated means for lifting the sensors in case the system detects that there is a possibility to damage them due to the variation of the surface where the robot operates.
- Permanent magnets hold the robot on the surface of the area of inspection and can overcome convex and concave structures.
- The NDT equipment is deployed on the robot, along with the electronic equipment necessary for the operation of the NDT equipment sensors, the laser profiler, the encoders and the movement of the robot.
- The electronic boards are cooled by the water used for the irrigation of the Phased Array Ultrasonic transducers. This cooling system has proved to keep the electronic enclosures below 30ºC, the Graphical User Interface (GUI) continually monitors the temperature of the electronic enclosures and the operator has the ability to turn off the cooling system if necessary.
- The robot also has 2 cameras for monitoring the position of the robot during an inspection. The operator may not be able to see the robot from the operating station and these camera give an optical view of the position, displayed on the GUI.

THE NDT METHODS

The NDT methods used are mounted on the robot and the system comes in 2 different configurations:

- Weld inspection

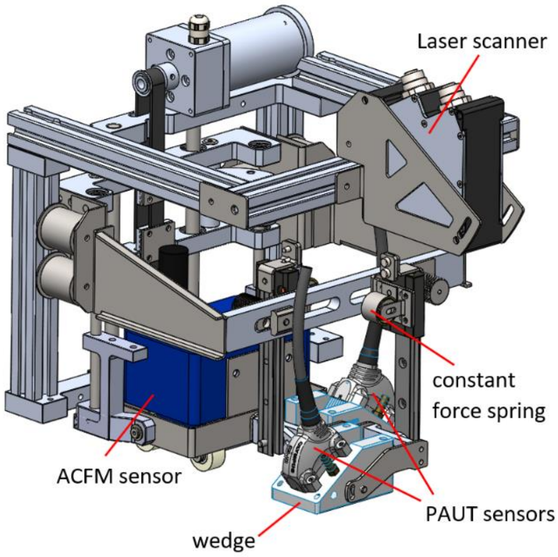

Figure 2. Weld Inspection Configuration

- Corrosion inspection

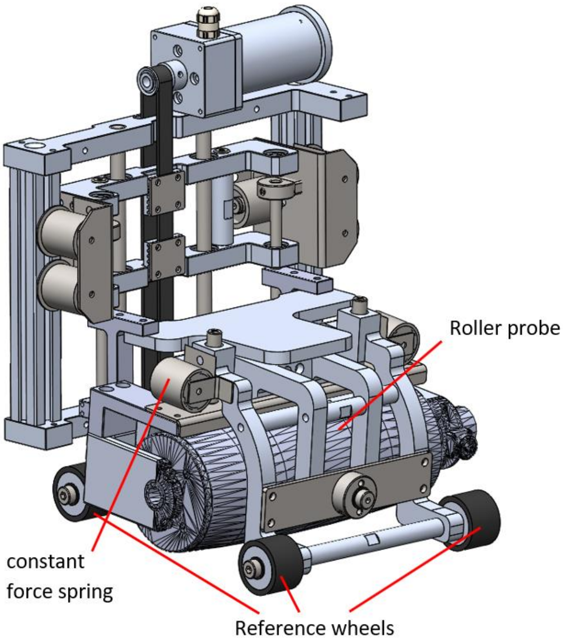

Figure 3. Corrosion Inspection Configuration

Weld Inspection Configuration

For the weld inspection configuration, the system uses 3 different methods of examination:

- Phased Array Ultrasonics (PAUT)
- Alternating Current Field Measurement (ACFM)
- Laser Profiling

Phased Array Ultrasonics (PAUT)

The PAUT system used for the Weld Configuration system comprises of an AOS 128/64 PAUT board and 2 x 32 element 5MHz phased array transducers from Olympus. This configuration is use to detect any volumetric defects in the weld. Using the PAUT transducers allows the inspection at angles varying from 35º to 65º in one pass as the robot moves over the surface of the ship. The transducers are kept within 2-3mm or their original position in relation to the weld. This is achieved by using the laser mounted on the front of the robot, which in turn monitors the position of the weld ands moves the robot to ensure that the transducers, and indeed the robot, on track. The AOS board is mounted on the robot in an IP68 sealed box with special connector to ensure water tightness.

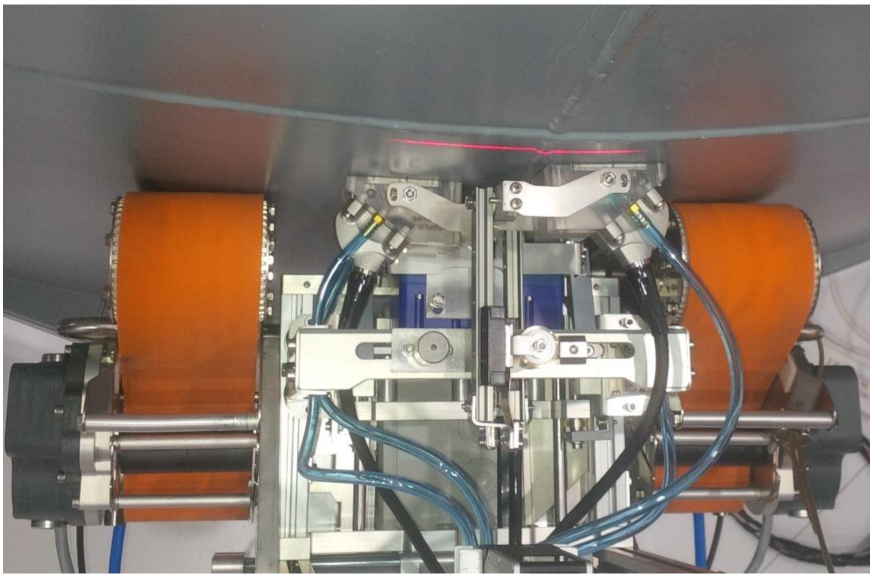

Figure 4. Position of the 2 PAUT Sensors

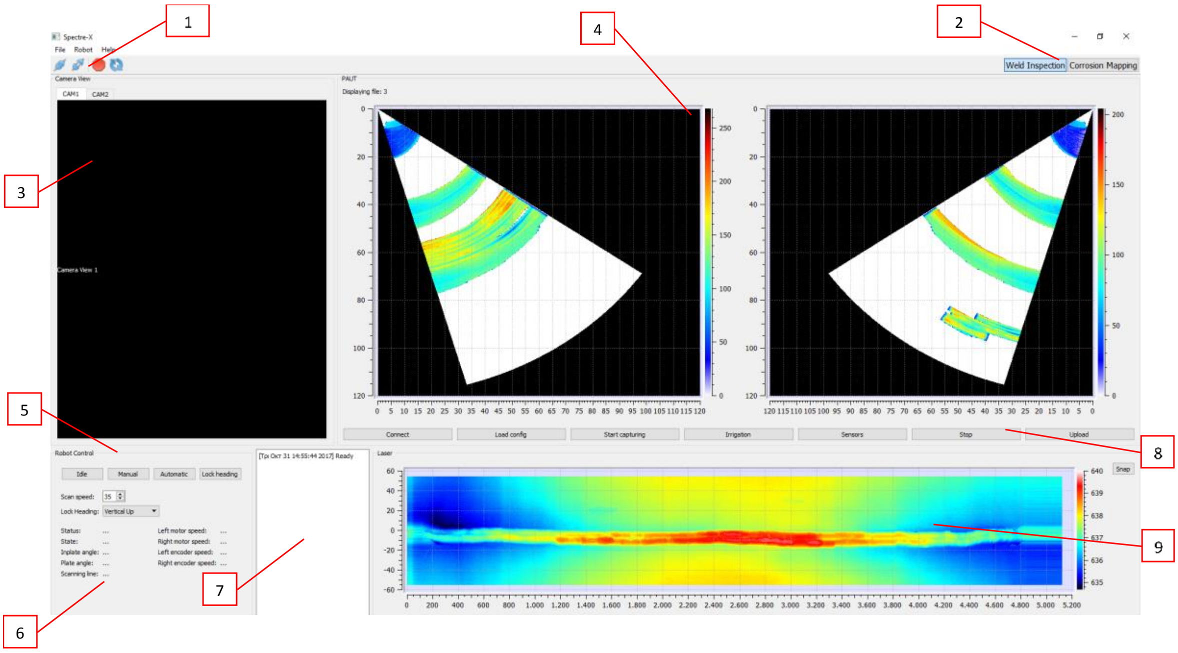

Figure 5. A typical PAUT weld inspection showing ‘A’, ‘C’ and Sector Scans

Alternating Current Field Measurement (ACFM)

The ACFM system is mounted behind the PAUT sensors (figure 7, PAUT Transducers removed for clarity), but on the same removeable structure. The ACFM system is used to detect surface and near surface defects in the weld cap and the adjacent heat affected zone (HAZ). The system along with the electronics was supplied by Technical Software Consultants (TSC) (now Eddyfi Technologies). The probe has 8 sensors that are sprung loaded so that the probe/sensors can cope with the uneven surface of a weld. A typical scan from an ACFM inspection is shown in figure 8. The X image shows the depth of the defect detected, the Z image shows the start and end of the defect and the ‘butterfly’ image on the right shows the combination of the X and Z scans. The significance here is the forming of the image, which indicates the scan direction, for example, clockwise for forward and anti-clockwise for backwards. Normally the individual sensors are marked with ‘A’ and ‘C’, moving the probe with the ‘A’ at the front is clockwise and likewise ‘C’ at the front anti-clockwise.

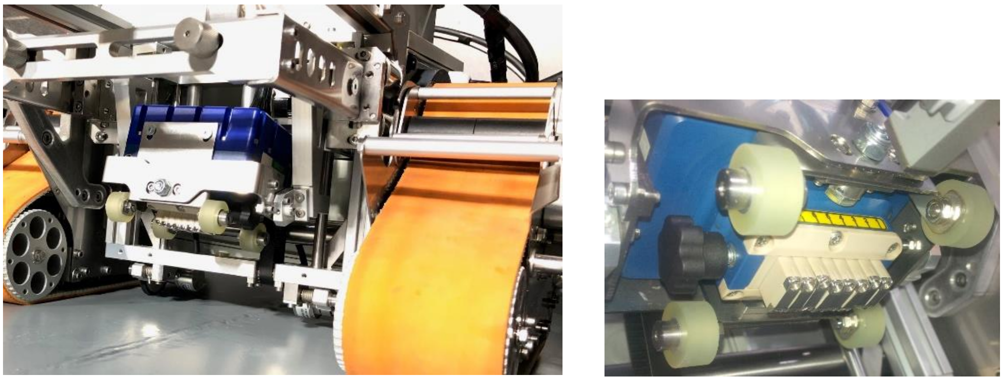

Figure 7. Position of the ACFM Sensor

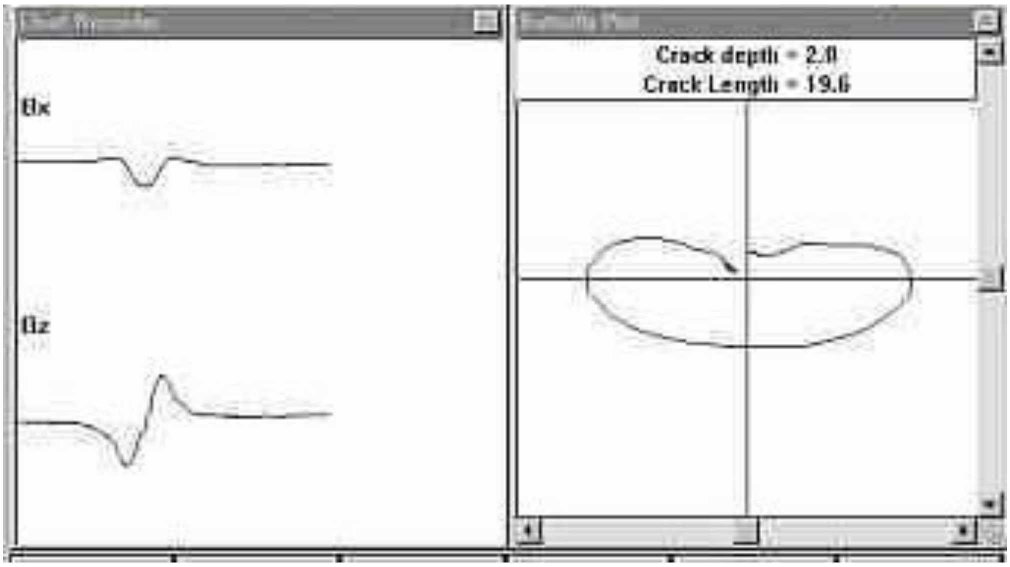

Figure 8. A typical ACFM presentation

Laser Profiler

The laser profiler, mounted on the front of the robot (Figure 9), has 2 purposes; the laser is used to keep the robot in place as the weld is being inspected (figure 10) and it can also detect surface breaking defects in the weld in the heat affected zone, such as the undercut shown in Figure 11, the undercut can clearly be identified at the start of the weld. The special software that has been designed for this purpose uses the detection of the weld cap to ensure that the robot stays on the weld for inspection, sending feedback to the motors to adjust the robots position throughout the inspect.

Figure 9. Position of the Laser Profiler

Figure 10 The Laser Profiler on a typical weld

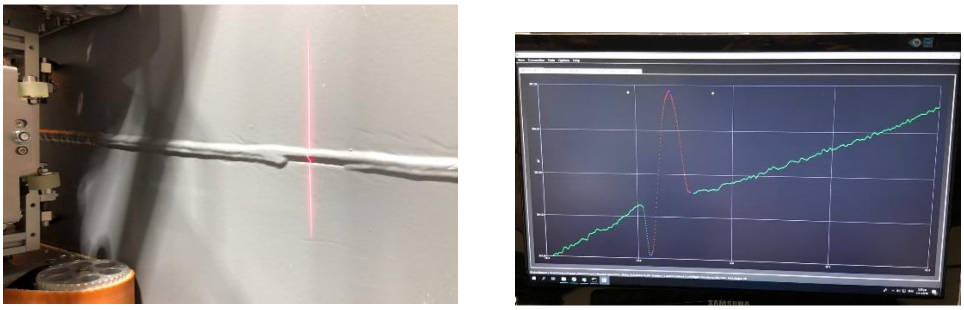

Figure 11. Actual image showing an undercut and the resultant Laser Profile image

Corrosion Inspection Configuration

For the corrosion inspection configuration, the system uses a 128 element PAUT 5 MHz transducer, in an Olympus roller probe (figure 12) and utilizes the same AOS board used in the weld inspection. Can be moved to the inspection site using a remote-control joystick. The current method of carrying out a corrosion survey on ship is to use single or twin crystal thickness gauging of specific areas where the surveyor see that there is a possible problem. The size of the probe is generally 10mm diameter and the operator may need scaffolding, a cherry picker or a lift system to get to the area of inspection. The robot can be moved to the inspection site using a remote-control joystick, the system is then deployed to carry out a preprogrammed scan area, covering at least 100mm with the roller probe.

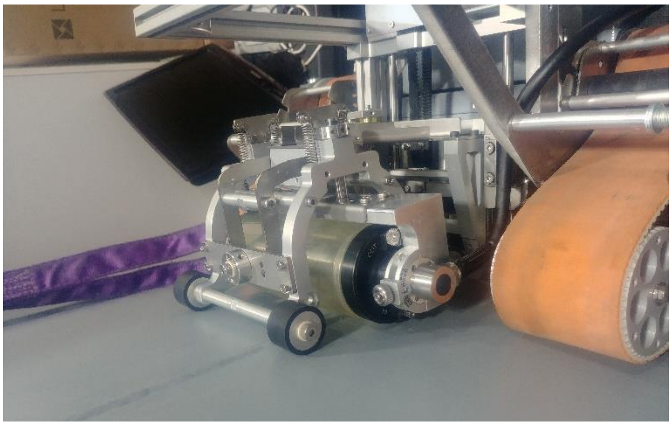

Figure 12. Corrosion Inspection Roller probe

Utilising the software, the GUI and the ships drawings, a scan path can be easily defined, giving the start point, the length of each pass, individual turn points, up or down, left or right, and the end point.

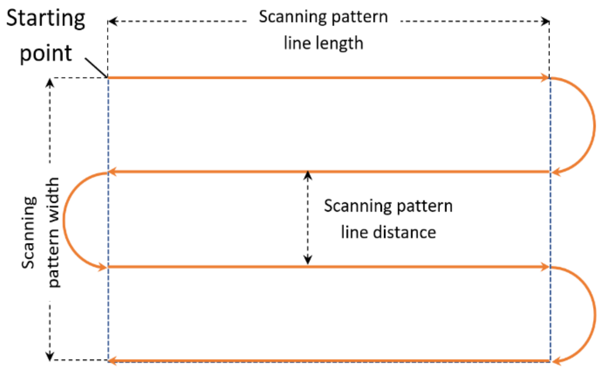

Figure 13. Easily Defined Scan Path

THE SOFTWARE AND GUI

Spectre-X has a GUI to control and operate the main functions of the platform in manual mode using a wireless handheld controller or in fully autonomous mode. The GUI allows system setup, monitoring the NDT instruments' deployment and accessing the IP68 cameras onboard the robot. It has advanced safety algorithms implemented that do not allow or restrict motion depending on the terrain using inclination and optical sensor data.

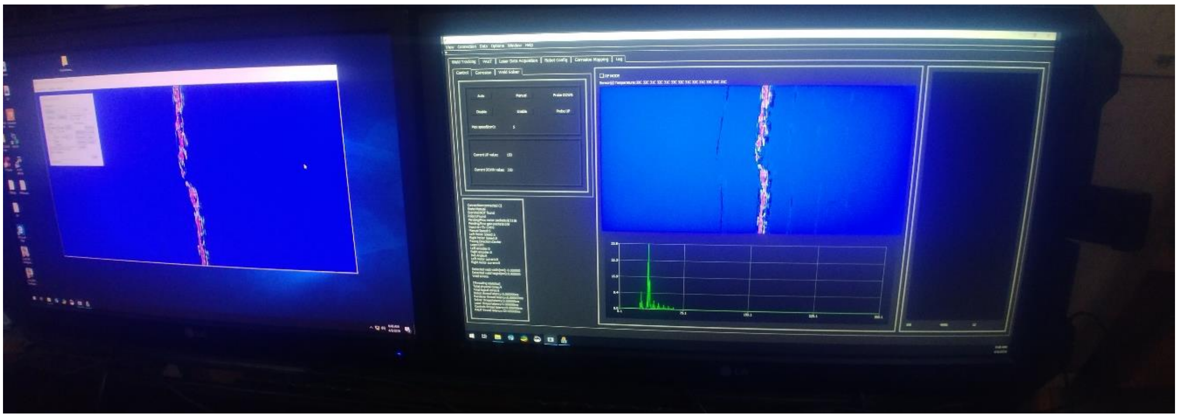

Figure 14. The Graphical User Interface, with 2 Screens

Figure 15. The Remote Control Unit

FIELD TRIALS

Field trials are due to take place on a submarine, predominantly looking for corrosion, but also to carry out trials of the laser following software on the submarine due the fact that the weld cap is ground to almost the flat surface which could prove interesting. A report on this trial will be given as part of the presentation at the conference with the permission of the submarine owner. However, as a stand by the ACFM system could also be sued for this purpose. A second trial will be carried out on a ship in Athens where the PAUT and ACFM inspection of welds will be made.

CONCLUSION

The Spectre X can carry out volumetric inspections of the weld using PAUT and can inspect the weld cap using ACFM and to some extent the Laser Profiler. Changing the configuration, the crawler can inspect the plates on the vessel for corrosion.
The Spectre X cannot inspect areas where the base material is not Ferromagnetic.
There are some crawlers that will carry out inspections above water, but they do not have the capability to cover the areas that can be covered with the Spectre X. Furthermore, the

Spectre X will be able to carry out inspections below the water line. However, one limitation would be the presence of marine fouling that would need to be removed from the below water line area. There are such cleaning robots available.
This project funded by the EU aims to provide a system that can be used by NDT service companies and ship owners around the world, although our principle aim is to intraoduce it into Europe first.