Paper: Development of CLAWAR Systems that combine the functions of Monitoring, Mobility, Manipulation and Measurement for Industrial Inspection Tasks.

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KEYWORDS:
Climbing Robots, Mobile Robots, Non-Destructive Testing, Aircraft Inspection, Ship Hull Inspection, Steel Plate Inspection, Storage Tank Inspection, Pipe Inspection, Nuclear Plant Inspection.

Most industrial and civil infrastructure, whose safety is critical to prevent loss of life and environmental damage, tends to be of large size and be located in exposed weather conditions and contain hazardous materials e.g. offshore oil platforms, nuclear power plant, shipyards, petrochemical and other storage tanks, aircraft, buildings, bridges and railways etc.

Its Non-Destructive Testing and Evaluation (NDT and NDE) therefore poses the problem of first gaining access to areas to be tested e.g. for testing weld integrity, finding corrosion, cracks, and other internal defects. Erecting scaffolding to gain access is hugely expensive whilst abseiling to test sites is both dangerous and not conducive to good large area inspection in exposed environments. The second problem therefore is to replace the Human NDT operator with a machine so that the operator is not exposed to dangerous tasks and the quality of data on which the plant assessment is based can be significantly improved by removing fatigue induced errors, imprecise manipulation and deployment of NDT sensors.

The solution to these problems is to use mobile wall climbing robots to reduce the cost of performing the inspection by providing access to test sites that are remotely located on large structures and/or in hazardous environments and hence not easily accessible to humans. Further cost reduction is obtained by developing multi-function inspection robots that are readily transportable between different sites, and are able to move over floors, change surfaces or climb over walls, ceilings and other structures of variable curvature whilst carrying NDE tools such as multi-axis scanning arms and a payload of NDT sensors.

Defect detection can be significantly improved by using the ability of robotics to improve sensor probe repeatability/positioning accuracy and its programmable

flexibility to optimally deploy a wide variety of sensor probes and inspection techniques.

Systems to perform NDT remotely in non accessible areas are required to perform four main functions known as the four M's. These are Monitoring of the test site, Mobility of the inspection instrument, Manipulation of the NDT sensors, and Measurement of defect depths and sizes.

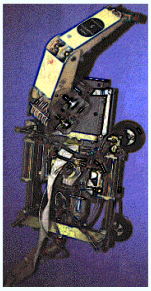
The paper describes the requirements and solutions for implementing the four functions of monitoring a test site to plan, schedule and navigate climbing and walking robots to a test area; enabling mobility of the robots on vertical walls, ceilings and curved surfaces; manipulating a payload of ultrasonic, eddy current, and visual sensors with scanning arms; and measuring and displaying defects with different non-destructive testing techniques.

These requirements and solutions are identified with reference to the development of a number of inspection robot prototypes by the authors for real industrial tasks.

These include the development of

- Three inspection robots of different payload capability for climbing flat walls and ceilings e.g. the external walls of large crude oil storage tanks, buildings and civil structures. The robots carry 6 DOF scanning arms to deploy ultrasonic sensors NDT with.
- An inspection robot that inspects the internal floors and walls of oil and chemical storage tanks when full of liquid.
- A robot that climbs on 3D curved surfaces e.g. Spherical Storage Tanks.
- A lightweight climbing robot that is able to climb on varying surface curvatures presented by aircraft fuselage and wings while carrying a 4 DOF Cartesian scanning arm that inspects long rows of rivets on aircraft wings and fuselage with ultrasonic zero degree compression probes, dry-contact wheel probes, phased arrays, acoustic cameras and eddy current techniques.
- A steel plate inspection robot that autonomously maps the internal defects in a plate and classifies the plate into levels of acceptance defined by a British standard. The robot deploys an array of 16 ultrasonic probes.
- A climbing robot that inspects nozzle welds on 860 mm diameter primary circuit coolant pipe in a nuclear power plant and welds on a stainless steel pressure vessel. The robot carries a 7 DOF scanning arm and ultrasonic sensors to inspect the full length of weld around the nozzle joint.
- A climbing robot that uses permanent magnets for adhesion to the hull of large cargo container ships while carrying a 7 DOF scanning arm purpose-built for the scanning of unknown surfaces. The arm deploys ultrasonic sensors to inspect cross welds on the hull.

The following slides illustrate the robotic systems that have been developed and some NDT results that have been obtained on test pieces.

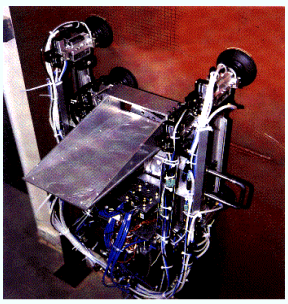


Mass 15 kg

D 490x380 mm

Arm 2 kg

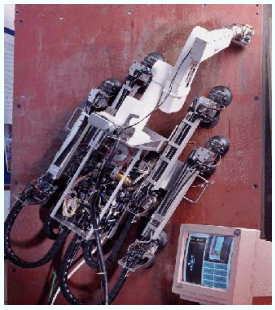
Payload= 15 kg



Mass 29 kg

D 740x540 mm

Payload = 35 kg



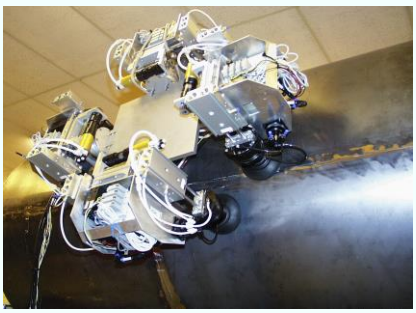
Mass 45 kg

D 750x700

Arm = 13.5 kg

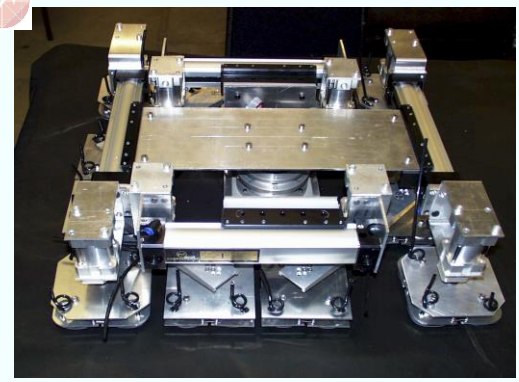
"Centres of Excellence" PCFC Funded project to develop inspection robots for climbing flat walls and ceilings e.g. Large petrochemical storage tanks and ship hulls

ROBTANK: European funded project. Inspection robot for the floor and walls of oil and chemical storage tanks when full of liquid

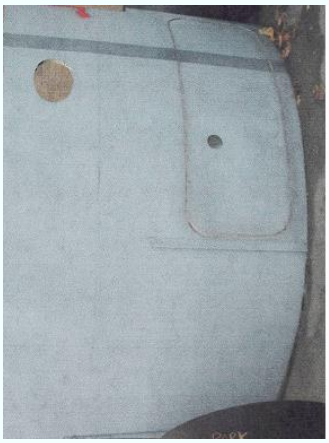


EUROPEAN PROJECT: REMOTE ROBOTIC NDT

Robot for climbing on 3D curved surfaces e.g. Spherical Storage Tanks



ROBAIR: EUROPEAN PROJECT. Lightweight climbing robot to inspect rivets on aircraft wings and fuselage



ROBAIR EUROPEAN CRAFT PROJECT: Climbing inspection robot that is able to climb on varying surface curvatures presented by aircraft fuselage and wings

REMOTE ROBOTIC NDT: EUROPEAN PROJECT CO-ORDINATED BY THE CENTRE. Climbing robot to inspect nozzle welds in a nuclear Power plant on 860 mm diameter primary circuit coolant pipe.

RRNDT: EUROPEAN PROJECT

Climbing Robot inspecting welds on a 6 ton mock-up of a stainless steel pressure vessel, Nuclear Power Plant, Torino, Italy.

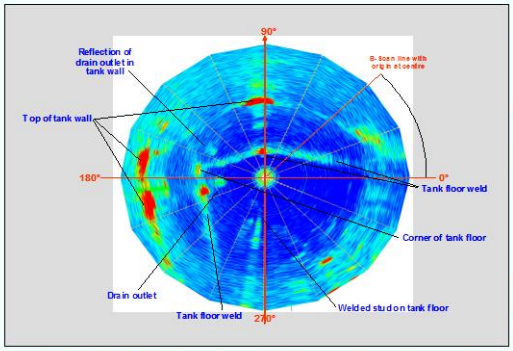
RRNDT EUROPEAN PROJECT

Climbing Robot to inspect welds on the hull of cargo container ships

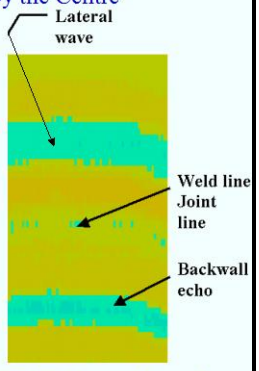
PLATE INSPECTOR: BRITISH STEEL PROJECT

Self-navigating robot for inspecting steel plates of any size in steel rolling mills. Deploys a 16 ultrasound probe array to detect defects and classify plate to a BSI Standard.

Examples of Non-Destructive imaging of defects with various techniques used by the inspection robots developed by the Centre

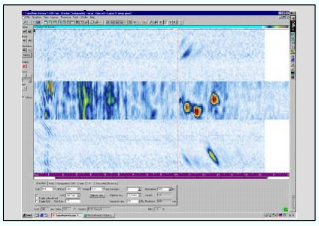


ULTRASONIC Rotating Bulk wave imaging of floor defects in oil and chemical storage tanks

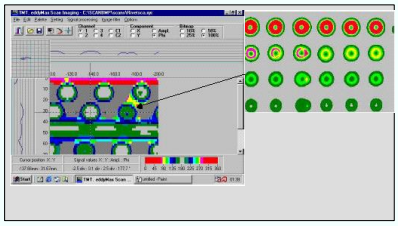


TOFD inspection of weld, RRNDT project

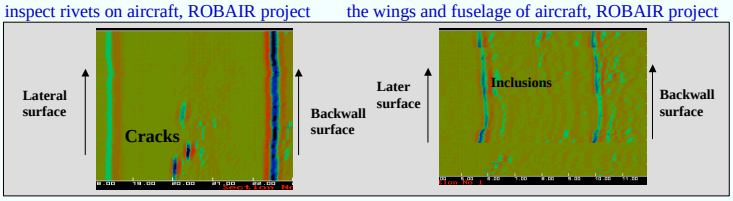
Examples of defect imaging with various NDT techniques used by the Centre's inspection robots



ULTRASONIC PHASED ARRAYS to inspect rivets on aircraft, ROBAIR project



EDDY CURRENTS inspection of rows of rivets on the wings and fuselage of aircraft, ROBAIR project



ULTRASONIC TIME-OF-FLIGHT DIFFRACTION (TOFD) inspection to detect defects in welds, near surface cracks and material inclusions, RRNDT project