Miniature Inspection Robot for Restricted Access eXploration (MIRRAX) - 18324

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ABSTRACT

The MIRRAX remote inspection vehicle has been developed to explore and characterize enclosed legacy facilities on the Sellafield site which have limited access ports. Its reconfigurable design means that it can be deployed through a 150 mm port before changing its footprint shape to provide a stable platform for mobile characterization. It can support both geometric and radiometric scanning.

INTRODUCTION

The inspection and characterization of a facility which may contain irradiated material is an important step in the decommissioning process. The Sellafield nuclear site in the UK has a number of facilities which are classified as 'active', meaning that they may contain radioactive material inside them.

Many of the facilities at Sellafield have been sealed for an extended period of time and initial access is often restricted to 150 mm diameter entry ports. Once the contents of the facilities have been identified, these entry ports may be increased in size to allow retrieval operations (remote or human).

The distribution and make-up of potential radioactive material is sometimes unknown and whilst the characterization process could be conducted by humans, the safety risks associated with the inspections are often deemed too high.

To overcome this problem, robotic solutions are being investigated. The use of robots for the inspection of nuclear facilities was relatively limited prior to the Fukushima incident in 2011 [1, 2]. Even after the incident, the majority of the robots which were developed were either specialist (pipe inspection, underwater, manipulation) [3] or not designed with restricted access as a constraint [4].

Taking inspiration from the Hitachi snake robot which was deployed into one of the Fukushima reactor pressure vessels in 2015, the University of Manchester and Sellafield Ltd have developed the MIRRAX robot for restricted access exploration and characterization of dry nuclear facilities.

This paper outlines the problem overview, mechatronic design of the MIRRAX remote inspection vehicle, a review of existing robot nuclear inspection vehicles, progress that has been made so far, as well as the future work for this platform.

PROBLEM OVERVIEW

The aim of the MIRRAX project is to develop a robot which can be deployed through a 150 mm entry port and inspect a large area, with varying levels of autonomy.

Once deployed, the robots cannot be retrieved for recharging or maintenance. Fig. 1 shows an example area for inspection[1].

The initial deployments are likely to be tele operated using a tethered vehicle, however the long term goal is to deploy the vehicles autonomously which raises a number of challenges.

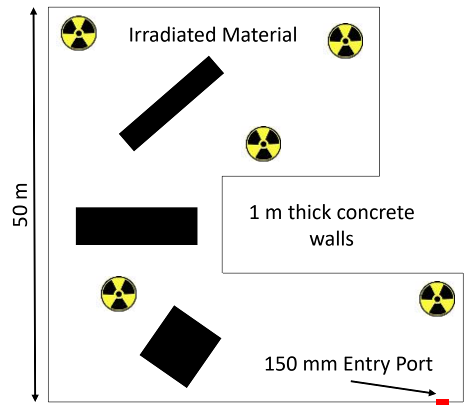

Figure 1. Example Area for Characterization

The operational area is enclosed and surrounded by concrete walls which are up to 1m thick. The design of these walls can have a significant impact on the ability to transmit wireless data to the outside [5]. Irradiated materials may be located anywhere within the facility and there may be an unknown number of obstacles throughout.

Due to the size of the area to be explored, it is unlikely that a single robot will be able to complete a detailed inspection in one mission. This means that it will either have to recharge, or a group of robots will have to be deployed. In reality, a combination of both is likely to be used.

A base station could be deployed through the access port with a wired connection to the outside for communications and power. This would allow the robots to recharge and for communications with the outside operators.

Robust communications is required for both operator control and the transmission of environmental data back from the robot. A wired link from the base station to the outside world overcomes some of the communications issues, however there is still a range and obstacle challenge for wireless transmission to the base station due to the size and shape of the facilities.

The hazardous nature of the environments and the size of the robots mean that there is a strong possibility that a robot will fail due to radiation damage to the electronics [6]. This vulnerability to radiation means that a traditional store-and-dump approach to data gathering, where information is recorded on the robot and transmitted at a later time at the base station, may not be robust.

Real-time transmission of the data is the only way to guarantee efficiency (not having to scan an area again which has been explored by a dead robot) so a wireless link is required. Communication repeater beacons could be placed around

[1] This does not represent any specific facility on the Sellafield site.

the facility, however this would have to be done by the robot and there are issues relating to power for them. The alternative solution is to use a collaborative group of robots which act as mobile repeater beacons. This would allow for optimal positioning to maximize data rates.

If the other robots are only used when communications are lost, other areas could be explored by them, decreasing the completion time. A similar approach is being considered for underwater inspections of nuclear storage facilities using the AVEXIS™ underwater vehicles [7].

NUCLEAR INSPECTION VEHICLES

Nuclear inspection vehicles have to access and operate within a varied range of environments. Ground [8], air [9] and water [10] based systems have all been developed to access areas which humans cannot go.

The majority of vehicles which have been developed and deployed for indoor use, have been based on traditional wheeled or tracked designs from other industries such as explosive ordnance disposal [12]. There are few robots able to enter restricted access facilities. OC Robotics' Snake Arm robot [13] is able to enter through small access ports, however it is a manipulator rather than a mobile robot and therefore its range is limited in large areas.

The MIRRAX design has been inspired by the shape changing robots designed by IRID member company Hitachi-GE Nuclear Energy [14, 15] (Figure 2). This robot extended into a line so that it is able to drive down a 110mm pipe and into the Primary Containment Vessel at the Fukushima Daiichi Nuclear Power Station. During a survey in April 2015 one of the robots had got stuck due to its tracks getting caught in the floor grating.

Figure 2. Hitachi-GE Nuclear Energy Robot [16]

Hitachi-GE Nuclear Energy's robot is radiation resistant and survived a six day survey. It is equipped with camera and is controlled and powered through a tether relaying back camera data to a control team. The survey was considered successful and showed useful information to aid in the planning of the 30 to 40 year decommissioning plan of Fukushima.

MECHATRONIC DESIGN

The main challenges that were considered during the development of the MIRRAX robot were locomotion and payload delivery. This section discusses the mechatronic designs for both of these subsystems.

Locomotion

MIRRAX is a mobile, omnidirectional reconfigurable robot. The robot can fully extend itself into a linear pipe shape so that it is capable of pushing itself through the access port of a cell. Rather than traditional wheels, omni-wheels are used, which have passive rollers, as shown in Figure 3. This allows the robot to move in any direction in any configuration without the need to rotate. The cross sectional diameter of the robot is 147 mm, in this mode and has a length of 1225 mm.

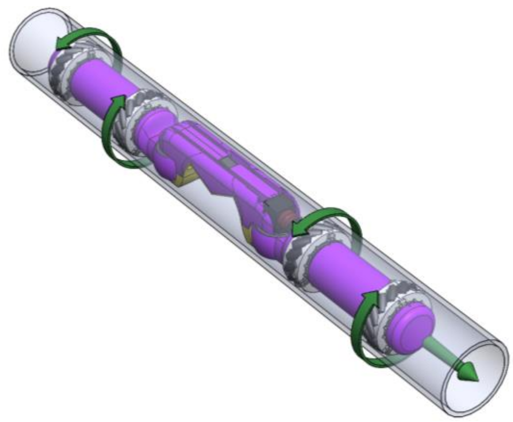

Figure 3. MIRRAX driving through an access port. The omni-wheels alternating directions moves the robot parallel to the wheel axes so it can drive through a tube.

Once the robot has been deployed into the cell, it reconfigures into a u-shape which provides a large supporting polygon footprint with dimensions of 475 mm x 497 mm. This makes the robot very stable so that it can raise an arm with the sensor package mounted on it as shown in Figure 4. The robot can also be reconfigured into any three link shapes to allow it to maneuver around obstacles while still remaining fully controllable as shown in Figure 5. There is a limitation with respect to the use of the arm as the configuration reaches the singularity of a straight line as the stability is reduced. In these configurations, the arm is retracted whilst the robot performs its maneuver.

Figure 4. MIRRAX in its driving and sensing configuration. When in a cell the wheel segments fold to make a stable platform and the sensor package is raised.

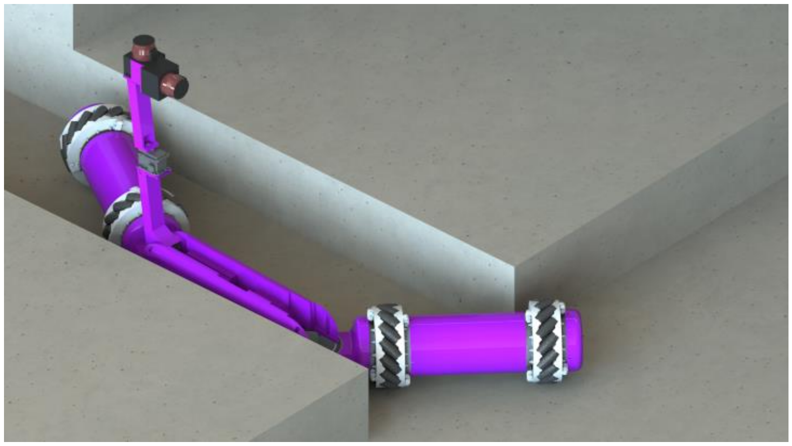

Figure 5. MIRRAX maneuvering obstacles. The wheel segments can be folded into different configurations to maneuver around obstacles while still remaining fully controllable.

The central link of the robot has an ‘M’ shape profile which has been designed to allow a ground clearance so that the robot can move up and down small steps.

The omni-wheels are driven by a pinion and internal gear, as shown in Figure 6. This allows wires to pass through the wheel. The wheels are held in position by two sealed bearings each which makes MIRRAX dust proof and splash proof so that it can be decontaminated and washed after use. The wheel motors and the LiPo batteries are positioned in the lower half of the robot so that when the robot is fully extended the center of mass is off center and the robot will naturally self-correct itself when in the straight line configuration. When the arm of the robot is fully deployed, a servo is built-in to the arm allows a full 360^0 of yaw motion. This rotates a sensor package at the end of the arm, to accurate generation point cloud of the surrounding environment.

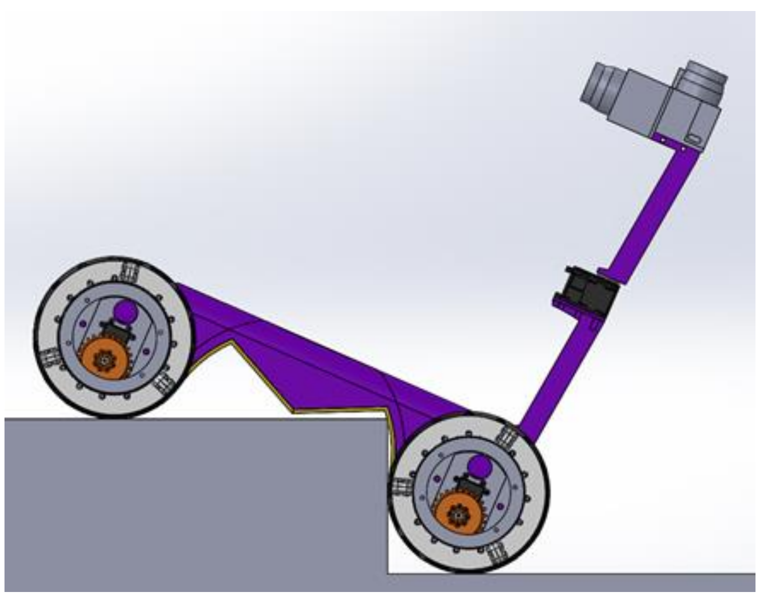

Figure 6. Ground clearance when descending steps. Also shows positions of pinion gear driving wheels (orange)

Payload

The primary sensors on the robot are two LIDARs which are used to generate 3D point clouds. They have a range of 20m and a resolution of 0.9° The LIDAR operating in the horizontal plane is used for 2D simultaneous localization and mapping (SLAM) whilst the LIDAR scanning in the vertical plane is used to create a 3D point cloud. The sensor package also includes a radiation sensor and the data from the LIDARs and radiation sensor will be combined to make a map of where in the cell are contaminated.

The robot also has a camera to allow the operator to have visual feedback in addition to the geometric mapping generated by the LIDARs. The camera is located at the end of one of the links and is actuated to allow the operator to use it in tunnel mode and any driving configuration. .

The sensor arm contains both the LIDARs and a GM tube. The GM tube provides dose rates within the area. It is not able to isolate the location of a source, however it can provide a dose rate map from which source locations can be inferred. The arm is raised so that the GM tube (or other sensor in the future) does not get overloaded with background radiation from the floor.

Nuclear Deployment Considerations

The vehicle has been developed to be both sacrificial and modular for decontamination. The cost of the robot is > £10k, so if it fails due to radiation or it cannot be retrieved, the replacement cost is not significant. The body is fabricated using 3D printing technology to reduce costs and increase design flexibility. If the robot is retrieved, the wheels have been designed to be easily removable as the passive rollers on the omni-wheels act as contamination traps. These can be disposed of separately and replaced whilst the rest of the robot is washed and decontaminated.

PROGRESS

Figure 7 shows the latest prototype of the MIRRAX robot. This has been tested in a non-active facility (the accelerator hall at the Dalton Cumbrian Facility (DCF) at the University) and the results of the 3D scans are shown in Figure 8. Active tests in at DCF are due to take place in November 2017 with a view to deployment in an active facility at Sellafield by the end of 2017.

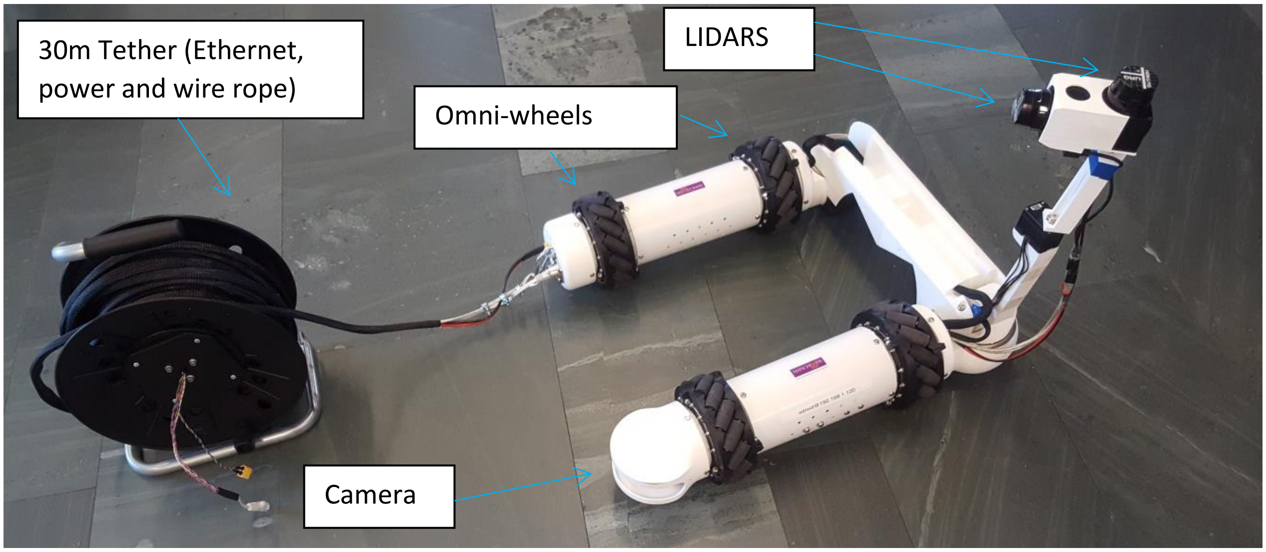

Figure 7. Current prototype of MIRRAX that will be deployed on Sellafield

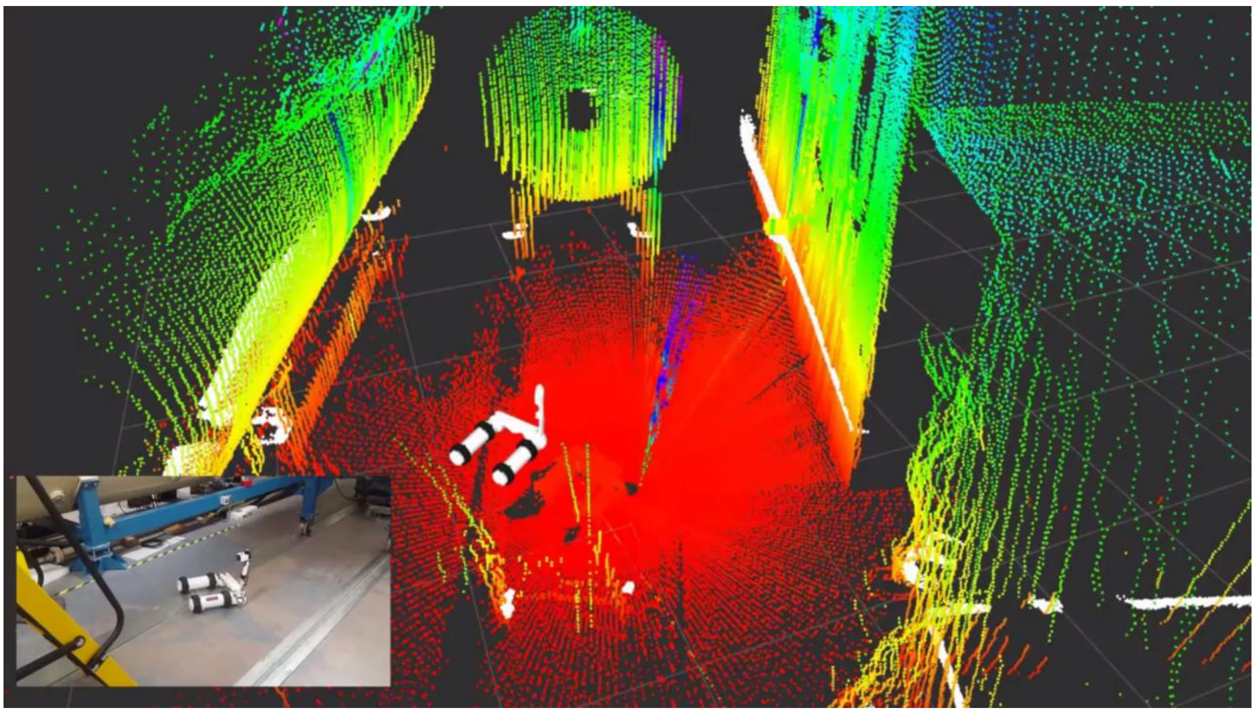

Figure 8. MIRRAX laser scans of accelerator room at Dalton Cumbrian Facility, UK

CONCLUSIONS AND FUTURE WORK

The MIRRAX robot has been developed to characterize and explore legacy storage facilities which have restricted access points. It can provide geometric and radiometric mapping. Non-active deployments have been conducted with active deployments planned for the end of 2017.

The initial deployments of MIRRAX will be remotely operated using a tethered vehicle. Autonomous navigation and exploration capabilities will be added at a later stage. These have been developed and are being tested as part of a parallel inspection robot project called CARMA (Continuous Autonomous Radiation

Monitoring Assistant). To support this capability, robust wireless communications and charging stations will need to be developed.

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