Mobile Robots and Remote Characterisation Systems for Nuclear Decommissioning – 16028

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ABSTRACT

This paper provides an updated summary of the research being conducted at the University of Manchester, UK, in support of the decommissioning plan for the Sellafield nuclear site in Cumbria, UK. The research is being conducted in collaboration with a number of companies including Sellafield Ltd, the National Nuclear Laboratory and Forth Engineering Ltd. The primary focus of the research is in support of the decommissioning of the legacy facilities on the Sellafield site, however the technology can be applied to other nuclear sites, both modern and legacy, as well as in other industries such as oil & gas, petro-chemical and the marine industry. The progress on the development of novel characterisation platforms (mobile robots) and sensing systems is presented including the AVEXIS underwater inspection system, a robot spider for remote operations and algorithms for efficient compression of Lidar point cloud data.

INTRODUCTION

The University of Manchester is one of the UK's leading institutes for the development of robotic systems for nuclear decommissioning. The majority of the work conducted is in support of the decommissioning of the Sellafield site in Cumbria, UK. The Sellafield site is very challenging due to its compact size (6 km2) and large number of active facilities (290). The plan for decommissioning is over 100 years and the work at the University of Manchester is focused on trying to reduce the time, cost and safety risks associated with it. This paper provides an update on the robotic system development which was reported in previous work [1].

ROBOTIC PLATFORMS FOR CHARACTERISATION

The research at The University of Manchester is split into two streams; novel platform development and control, and characterisation technologies. This section will provide an update on the platform development.

Aqua Vehicle Explorer for In Situ Sensing (AVEXIS)

The AVEXIS vehicles, have been in development since 2008 for the remote characterisation of the legacy ponds on the Sellafield site. There are three versions of the AVEXIS currently under development; AVEXIS MiniROV, AVEXIS Prime and the AVEXIS Micro. Fig. 1 shows the AVEXIS Prime and AVEXIS MiniROV.

The AVEXIS MiniROV is a tethered vehicle which has been designed to be deployed through a 140 mm access port. The target application is the inspection of facilities which have not been accessed for a significant period of time and which have limited access points. The vehicle has HD and IR cameras and will shortly have a radiological sensor installed as well. Fig. 2 shows the vehicle undergoing initial deployment tests. The plan is to deploy the prototype into an active facility on the Sellafield site by March 2016.

Fig. 1. The AVEXIS Prime (left) and MiniROV (right)

Fig. 2. The AVEXIS MiniROV Prototype

The AVEXIS Prime is being developed for the long-term characterisation of wet storage facilities, especially modern ones. One of the primary challenges in the nuclear sector is to learn the lessons from legacy facilities to ensure that new ones don't degrade in the same way. The AVEXIS Prime is designed to be tetherless and operate as part of a swarm. With an integrated acoustic communications and positioning system (ACPS), it will be able to localize itself and send back real-time data. Collaborative exploration algorithms will allow it to explore areas where line-of-sight communications aren't possible such as the inside of containers [2].

The AVEXIS Micro is in the early stages of development and is being designed to be deployed through a 100 mm access port. The target application for this vehicle is the inspection of facilities on the Fukushima Diachii plant in Japan and is a collaboration with the University of Lancaster.

All of the AVEXIS vehicles make use of state-of-the-art rapid prototyping techniques for the construction of their hulls. By using a combination of 3D printed materials and resins, flexible and watertight hulls can be made quickly and at a low-cost. Modifications to the hull design can be manufactured in-house within days. Issues with water absorption by the 3D materials (potentially making the vehicle a radioactive source) have been overcome by spraying them with a waterproof polyurethane coating [3].

Robot Spider for Remote Characterisation and Retrievals

An ongoing challenge across any decommissioning site is access to unstructured areas. This is particularly acute on the Sellafield and Fukushima sites where there are a number of facilities with debris on the ground which restricts the use of either traditional wheeled vehicles or people in air-fed suits.

To overcome this problem, the University of Manchester, in collaboration with Forth Engineering Ltd., is developing a 1.5 m wide hydraulically actuated robot spider which will be able to walk over obstacles and conduct both characterisation and retrieval operations. Fig. 3 shows the prototype design.

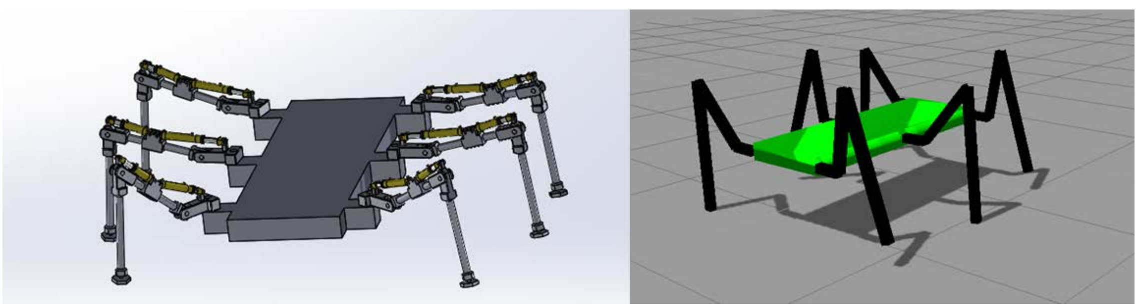

Fig. 3. The Prototype Robot Spider

The vehicle will have a payload of over 50 Kg and will have two actuators on the front (hydraulic cutters and grippers) which will be used to conduct in-situ retrievals. A characterisation suite will include Lidars, stereoscopic cameras and radiological sensors. The motion planning of the spider is being done using the Gazebo simulation environment in combination with the ROS framework.

Aligned with mechatronic development of the robot is a project concerned with the human control of it. Augmented Reality (AR) control using an Oculus Rift is being investigated. As well as the technical challenges of augmenting the live 3D video, there is the more psychological question of how a human with two hands can control a vehicle with up to eight limbs.

Mobile Platforms for Restricted Access Characterisation

There are a number of ongoing projects related to remote inspection of dry storage facilities where there is restricted access. The MIRRAX project (Mini Robots for Restricted Access Exploration) is investigating the development of small-scale wheeled robots for the characterisation of enclosed dry storage ponds. The vehicles will be able to be operated remotely or autonomously and will have charging stations so that no human contact is required after deployment. They will also be able to work as part of a swarm to both speed up the characterisation process and ensure robust communications and localisation.

A number of sensor balls are being developed which can be deployed through 50 mm access ports. One ball will be able to move around a floor taking characterisation readings [4], shown in Fig. 4, whilst the other is being designed to inspect the inside of pipes.

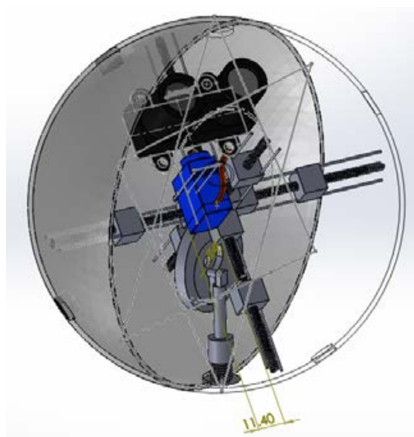

Fig. 4. Visualization of Proposed Final Design and Internal Mechanics for the Sensor Ball [4]

Radiation Tolerance of Electronic Components

Work is ongoing at the University, through the Dalton Cumbrian Facility [1], to identify the failure modes of common electronic components used in robotic systems. Fig. 5 shows the results from testing a discrete voltage regulator [5]. The aim is to identify the causes of failure and how to identify if there are any novel mitigation schemes that don't rely on specialist components or large amounts of shielding (such as real-time thermal annealing).

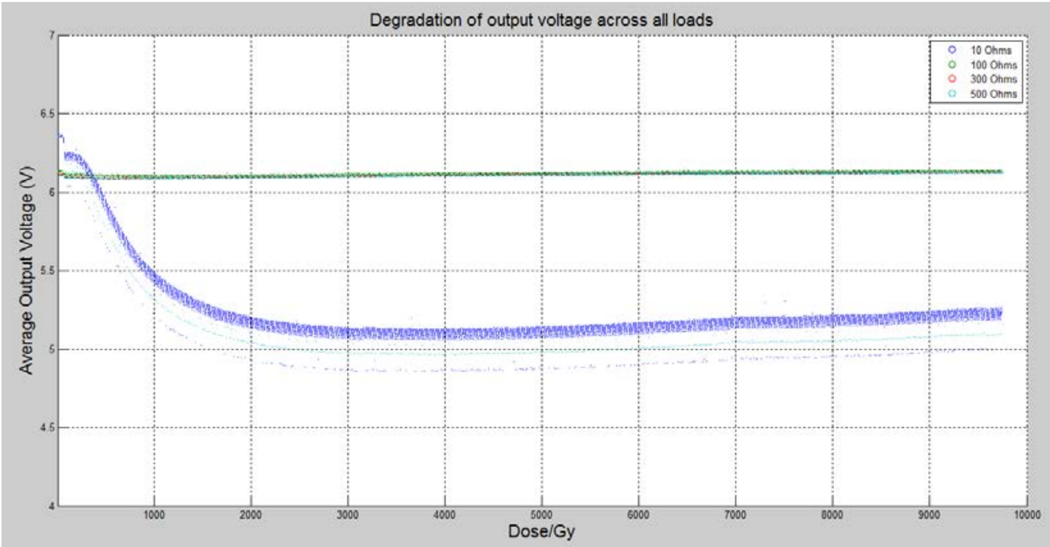

Fig. 5. The output voltage of a discrete regulator voltage board exposed to almost 10kGy with varying load currents [5]

REMOTE CHARACTERISATION SYSTEMS

This section will introduce some of the work being conducted on the characterisation technologies.

Geometric Characterization of Waste Packages

After visual inspection, geometric mapping is the most important characterisation process in nuclear decommissioning. Understanding what the size and shape of objects are is key to a robust and reliable retrievals plan. The traditional methods of geometric mapping are through the use of Lidars, stereoscopic cameras, Kinects or acoustics.

The most common output of geometric mapping sensors is a point cloud. These can be very large depending on the area surveyed, often containing several hundred thousand points. The University of Manchester is developing algorithms to compress this data and still extract the relevant information, Fig. 6 [6]. Work is also ongoing with regards void detection in point clouds when scanning objects on remote cutting platforms.

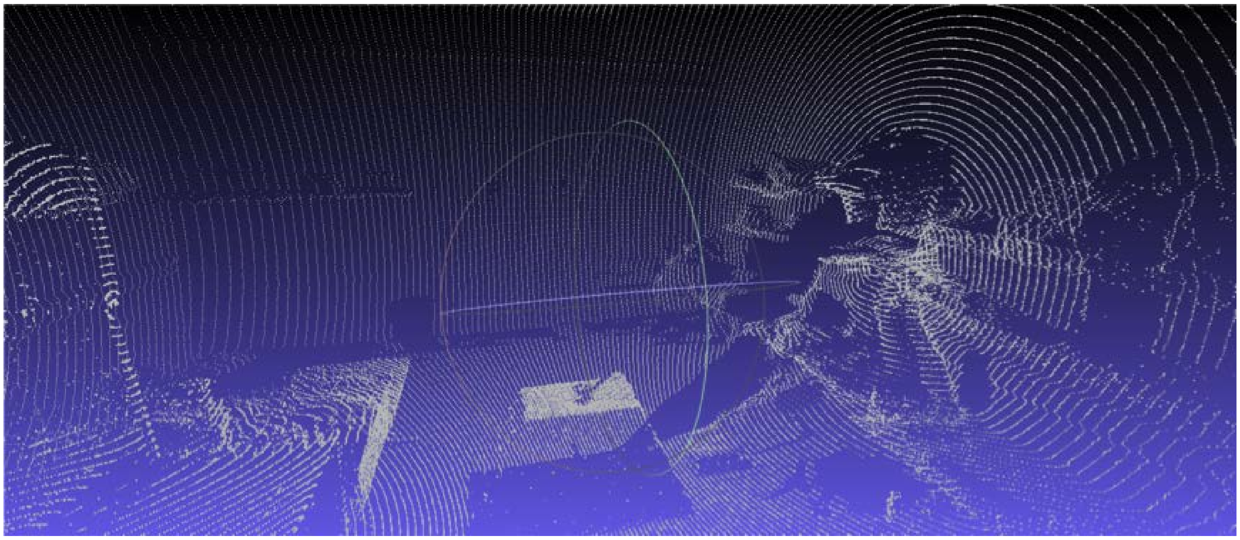

Fig. 6. Simplified point cloud volumetric clustering algorithm using geometric average excluding points that fall within a radius of 800 mm front orientation [6]

In-Situ Sludge Characterization

Sludge is a major issue in wet storage ponds across the world. The radioactive particulates at the bottom of the pond pose challenges on a daily basis as well as in the retrievals process. Sampling the sludge to identify what particulates are present so as to better understand their composition is key to the retrievals planning process.

Limited access to the ponds means that only a limited number of samples can be taken for analysis. The University of Manchester is working with Sellafield Ltd to understand the statistical analysis behind the sampling process and the uncertainties and confidence levels that are associated with them. The long term aim is to understand how many samples need to be taken to get an acceptable confidence level given the restrictions of the application. Fig. 7 shows the particle size distribution (PSD) maps for different sampling and analysis strategies compared to the original [7].

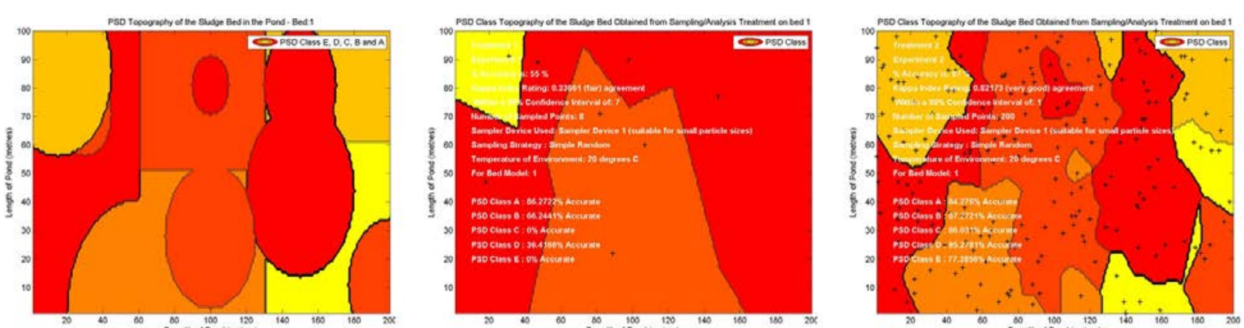

Fig. 7. PSD Classifications for different sampling strategies: Original (left), 8 Samples (middle) and 200 samples (right) [7]

DISCUSSIONS AND CONCLUSIONS

The University of Manchester leading of the development of mobile robots and remote characterisation systems for nuclear decommissioning of legacy nuclear sites. The primary challenges are related to limited access of radiologically hazardous areas and the operational lifespan of the vehicles. The systems under development could help speed up the decommissioning process as well as reducing costs and improving safety.

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