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Development of a Debris Clearance Vehicle for Limited Access Environments*

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***Abstract* — The need for nuclear decommissioning is increasing globally, as power stations and other nuclear facilities reach the end of their operational life. Currently a lot of decommissioning tasks are carried out by workers in protective air fed suits, this is slow, expensive and dangerous. The work that is described here aims to develop a flexible mobile manipulator platform, combining a Clearpath Husky and a Universal UR5, that can be used for exploration of contaminated environments, building maps to aid in task planning, but also be used for manipulation and to sort waste. The aim is to develop a system that can be used in real world tasks but also function as a research platform to allow continued research and development. As well as developing a hardware platform, a detailed simulation model is also being developed to allow testing of algorithms in simulation before being deployed on hardware. This article focuses on the planned work for developing the system, as well as discussing the progress so far on the simulation model.**

I. Introduction

Nuclear decommissioning often involves working in areas contaminated with high levels of radiation, where human entry is only possible with the use of protective air fed suits. The use of air fed suits require a team of people to put on and take off, and following the use of the suit it becomes contaminated waste which needs to be disposed of accordingly. Besides being costly and time consuming, the working time for the operators wearing these protective suits are limited due to the radiation risk [1]. These are contributing factors to why nuclear decommissioning is expensive, slow and dangerous. Nonetheless, nuclear decommissioning remains a critical task that needs to be undertaken.

The need for decommissioning is in fact increasing as more facilities are approaching the end of their operational life. One such example is the Sellafield site in the UK, where the Thermal Oxide Reprocessing Plan (THORP) has been recently shut down, and the Magnox reprocessing plant is due for closure before 2020 [2]. These facilities are highly radioactive and contain many rooms and work areas that will require radiation cleanup and materials to be removed, processed and sorted. For these reasons the industry wants to improve safety, reduce costs and improve productivity. This is where robotic systems can come in, there are many tasks within the nuclear industry and decommissioning in particular that can benefit from robots and automation [3].

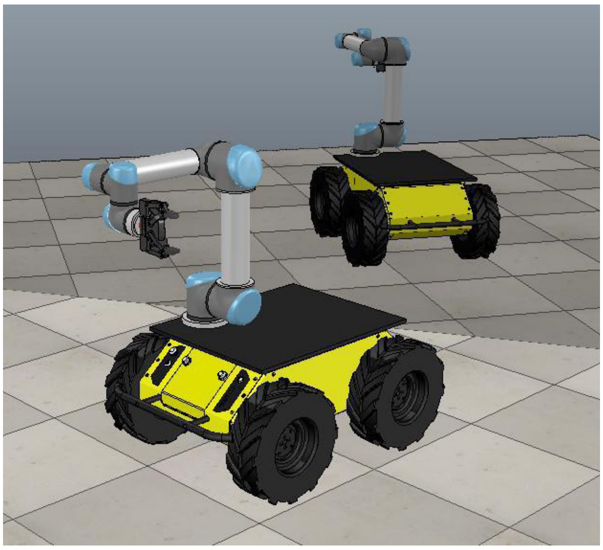

Fig. 1. V-REP simulation of a Clearpath Husky robot with a UR5 robot arm mounted to it.

With this in mind, this work aims to develop a mobile manipulator platform for remote operation in these hazardous areas. By combining a mobile base with a manipulator, namely a Clearpath Husky robot [4] with a Universal Robots UR5 robot arm [5], a platform that can operate remotely, indoors, and perform a variety of useful tasks will be created.

The Husky was chosen for being a good compromise between its small size and maneuverability for operating in confined or cluttered spaces, whilst still large enough to mount a manipulator and other sensors. For example, its small size allows it to traverse through doorways, under tables, and also over small obstacles or uneven terrain that may be encountered in a nuclear facility. The Universal UR5 arm is a widely supported manipulator, compact enough to be mounted on the Husky (see fig. 1) with a payload of 5 kg, making it useful for real-world manipulation tasks.

Applications for this system will range from visual inspection and mapping, to manipulation and waste sorting. This will give operators a view inside these hazardous facilities, some of which have not been entered for many years, allowing necessary tasks to be identified and a plan

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created. Then using the same system some of these tasks can be completed, such as moving and sorting waste material, or collecting samples. This would allow for example, an inspection to be carried out and then the clearing of a path for a larger more specialised system to enter the area exactly where it is needed, with a work plan in place.

The challenges presented by these environments extend beyond the obvious radiation risks, and include:

- Chemical hazards
- Operating in confined spaces
- Operating in potentially unknown environments as some facilities have been closed for many years
- Communication challenges presented by thick steel reinforced concrete walls
- Materials may have perished over time e.g. metal rusting which may affect the handling of objects

In a robotics context the communication challenges are one of the most important. Due to the work environment wireless communication would be unreliable, and as such a tether is proposed to allow communication between the operator and the robot. This also gives the advantage of extending operation time beyond the limited on-board battery. The downside is that using a tether presents its own challenges, especially in a cluttered environment where there are lots of obstacles for the tether to catch on. As such, part of this work is to develop a tether management system that will consider the tether during path planning and limits the cable deployed, for example back tracking to allow the cable to be wound in then travelling around obstacles.

Another challenge that has to be considered with the deployment of robots in radiation contaminated environment is what happens to the robot post operation, or if it breaks. The robot will have become radiologically contaminated and thus requires a complete radiation cleanup which is very difficult and often deemed not worth the time and cost, or more commonly disposed of creating more contaminated waste that needs dealing with. This forms part of the motivation for making a flexible system that can perform a variety of tasks rather than making a highly specialised robot for one particular task.

With this in mind, we chose to make use of proven off-the-shelf components to create the mobile manipulator platform, rather than building a bespoke solution. This approach yields a highly reliable system, extending the mean time between failure (MTBF), which is of high importance for the target application. We will also design the system to be modular, allowing parts such as sensors to be easily replaced if they get damaged. Although the replacement of parts requires human intervention, this approach extends the lifetime of the system, reducing both cost and further contaminated waste.

II. Originality

The use of mobile robots in the nuclear industry is not a new idea, [6] gives a detailed review of mobile robots deployed in the nuclear industry over the last few decades. Many robots used previously have been used in response to accidents such as at Chernobyl or Fukushima, with relatively few robots being used in decommissioning tasks. A similar platform to the one discussed here has also been developed by the nuclear and applied robotics group at the University of Texas at Austin, called Vaultbot [7]. Their system combines a Husky with dual UR5 manipulators. However their system required extensive modification of the Husky platform to allow 2 manipulators to be fitted, and is also battery powered so has a short run time. In contrast our system requires almost no modification and so is kept modular and retains the MTBF of the off the shelf hardware. It will also utilise a tether with a novel tether management system, allowing extended periods of operation and maintain communication in environments where wireless communication is unreliable.

The main contributions of this work is the combination of expertise from The University of Manchester, Bristol Robotics Lab and The University of Birmingham to create a reliable mobile platform with semi-autonomous grasping abilities, a tether management system to prevent cable tangling with obstacles and an intuitive user interface that is effective and simple to control the platform. The platform will be developed focusing on real world challenges but will also allow novel research into areas such as grasping, manipulation and human robot interfaces. The aim is to develop a system that in the short term can be deployed in the real world, and with minimal operator training be used by nuclear industry workers, whilst simultaneously in the longer term be used as a research platform to develop industry relevant functionality.

The authors are aiming to develop the platform and participate in ENRICH 2019 [8], a robotics trial scheduled in summer 2019 for testing robots in a hazardous materials response operation. This involves testing of the robot inside a real nuclear facility that was built in Austria but never went online, giving a real world test but in a safe environment.

There is also scope to use it as a platform for research, for example, into human factors experiments, studying the effects of different cameras on ease of tele-operation, or different input methods and levels of automation. This would involve carrying out a series of tests with different cameras attached, e.g. a fixed camera, fixed stereo cameras, pan-tilt camera system, fish eye or 360 camera, and also comparing between on screen images with the use of a VR headset. To investigate different input methods and levels of automation, a study comparing e.g. keyboard tele-operation, game pad control and point and click interactive target markers could also be carried out. These two areas overlap, as the control method has a direct impact on the information required by the operator.

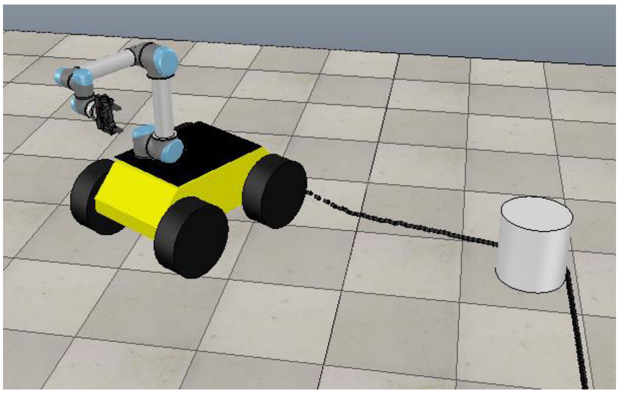

Fig. 2. Simplified model of Clearpath Husky in V-REP with UR5 mounted and power/communication tether attached.

III. SIMULATION

Whilst the hardware is purchased and assembled to create the mobile manipulator, a simulation model has been created in the V-REP simulation software [9]. The Clearpath Husky model was not included in V-REP hence the simulation model was created using the CAD file Clearpath provided as a base, and the finished model has a UR5 manipulator attached as shown in fig. 1. Due to the detail in this model, particularly the geometry of the tyres, the physics based simulation runtime was very slow, and so a simplified version was also created as shown in fig. 2. While this version has simplified geometry, properties such as mass and friction are maintained so the dynamics of the real system is still represented closely.

Both of these models can be integrated through V-REP with ROS, eliminating code porting between the real and simulated robot. This allows new algorithms to be quickly and safely developed in simulation before being deployed on the hardware. It also allows the possibility of operator training on a simulated robot, using the same control interface, before using the hardware. This is particularly useful whereby following the mapping of the environment, the environment can be simulated allowing manipulation tasks to be evaluated prior to executing the same tasks in the real world.

As part of the simulation, a tether has also been created, shown in fig. 2 (note that the tether can be added to the detailed model also). Again, V-REP does not provide available cables hence it has been developed from the ground up. The tether is fixed to the rear of the platform and has both mass and friction so acts realistically as it is dragged along the floor. Including the tether allows the effect it has on the system to be investigated, for example the effect of tether length and weight on performance, and the effect of the tether being caught on objects. Including the tether in the simulation also allows the tether management solution to be evaluated as it is developed, reducing the chances of potential damage the hardware. There has also been work done on simulating a rotating drum for winding the cable in and out, which would be needed for the tether management, however it is not shown here for brevity.

During the development of the simulation model it became apparent that the placement of the manipulator has a

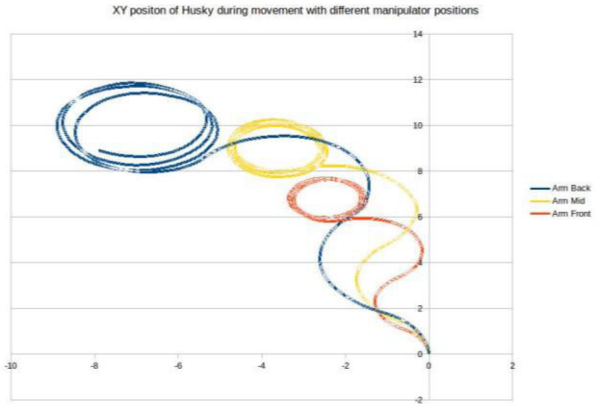

Fig. 3. Initial results showing XY position of the platform, with the same motor input, for 3 different manipulator mounting locations.

noticeable effect on the performance of the system. Results of an initial investigation placing the manipulator at the front, middle and rear of the simulated Husky and monitoring the XY position of the robot when given identical motor inputs are shown in fig. 3. This is an area that needs further investigation as the difference seems much larger than would be expected. It is assumed that the difference is caused by the change in the robot's centre of mass affecting traction. To determine whether this is exaggerated in the simulation a test using the real Husky will be carried out when the hardware is available. This may have an impact on the control of the system when objects are being carried, so understanding if this is as noticeable on the real robot is important. It will also help to improve the simulation model if the effect is not observed on the hardware.

Another area that is currently being investigated is what sensors are needed on the robot. It is desirable to keep the system as simple as possible whilst also making it capable enough to be easily controllable and with some semi-autonomous behaviours. It is anticipated that at a minimum a 2D Lidar, a camera and a radiation sensor will be needed. The 2D Lidar will allow SLAM (Simultaneous localisation and mapping) so that the environment can be navigated. A camera on the Husky will allow the operator to see what the robot can see, this is essential for tele-operation. Additionally using stereo or depth cameras would allow a 3D point cloud of the environment to be created which would aid planning of tasks and visualizing the area. It is also likely a second camera would be needed on the manipulator, to act as an eye in hand camera to allow grasping. A radiation sensor would allow both monitoring of the environment to identify radiation level and also aid in separating items into high and low level waste. Date from the radiation sensor could potentially be combined with a 3D point cloud, to give a 3D environment map showing areas of contamination.

The simulation model being integrated with ROS allows different combinations of sensors to be tested in simulated environment and the output displayed in RVIZ, as it would be with real hardware sensors. This allows quickly testing

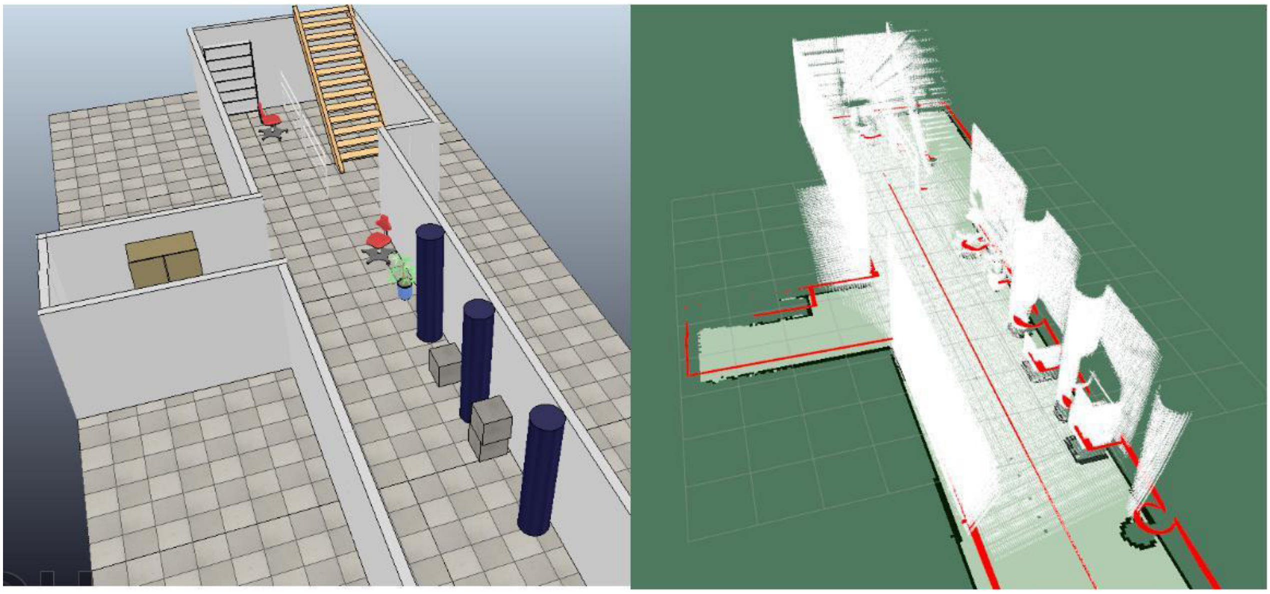

Fig. 4. (left) initial test scene created in VREP (right) Simulated 2D Lidar and depth sensor data combined in Rviz. Created by the mobile platform moving in a straight line in a single direction in simulation.

different sensor combinations and seeing the output on the user interface before implementing with expensive hardware. An example of this is shown in fig. 4, which shows the combined output of a simulated 2D Lidar and a low resolution depth camera (64x64 pixel) in a simulated corridor. The 2D Lidar data is used with a SLAM algorithm to produce a 2D map of the area and the depth camera creates a 3D point cloud. This example was created by driving in a straight line in one direction, as such the point cloud is lacking detail but still gives a good indication of what is in the environment, the columns and boxes on the right are all clearly identifiable as are the staircase and railing at the end of the corridor. The investigation into different sensor combinations is ongoing, and more work is required to identify suitable sensors. A user study may be carried out to identify what data the operators want which can then help identify necessary sensors.

IV. Conclusion

A need for reliable flexible robotic systems within the nuclear industry is clear, with the number of facilities requiring decommissioning continuing to rise and current methods being slow, expensive and dangerous. This paper has focused on the plans for the development of a mobile manipulator platform for use in nuclear decommissioning tasks, which is currently in the early stages of development. The platform will combine a mobile base with a manipulator and multiple sensors for visualising the environment.

Currently the work is at a simulation stage whilst the various hardware components are obtained and assembled. Details of the simulation model, which was developed by the present author, are given and some initial results of testing the simulation presented, including a simulated tether and visualisation of combined sensor data. This model will allow testing of different sensor combinations in simulation so the right choice can be made when implemented on hardware,

Next steps include investigating tele-operation interfaces such as joystick or game-pad controllers and implementing one for the simulation model, this together with the sensor output will allow work on the user interface to begin. At the same time the hardware can be assembled to make the platform and testing can begin, making use of the same algorithms as well as testing of new control algorithms and novel tether management systems. There is also potential to use the model for training of new operators as it will share a control interface with the hardware platform.

References

[1] C. Bayliss and K. Langley, Nuclear decommissioning, waste management, and environmental site remediation. Elsevier, 2003.

[2] NDA and Innovate UK, “Robots compete in nuclear decommissioning challenge.” https://www.gov.uk/government/news/robots-compete-in-nuclear-decommissioning-challenge, Jan 2018. Accessed: 2018-12-10.

[3] D. W. Seward and M. J. Bakari, “The use of robotics and automation in nuclear decommissioning,” in 22nd International Symposium on Automation and Robotics in Construction ISARC, pp. 11–14, 2005.

[4] Clearpath Robots, “Husky-unmanned ground vehicle.” https://www.clearpathrobotics.com/husky-unmanned-ground-vehicle-robot/, 2013. Accessed: 2018-12-14.

[5] Universal Robots, “Ur5 technical specifications.” https://www.universal-robots.com/media/50588/ur5en:pdf, 2014. Accessed: 2018-12-14.

[6] I. Tsitsimpelis, C. J. Taylor, B. Lennox, and M. J. Joyce, “A review of ground-based robotic systems for the characterization of nuclear environments,” Progress in Nuclear Energy, vol. 111, pp. 109–124, 2019.

[7] A. Sharp, K. Kruusamae, B. Ebersole, and M. Pryor, “Semiautonomous dual-arm mobile manipulator system with intuitive supervisory user interfaces,” in Advanced Robotics and its Social Impacts (ARSO), 2017 IEEE Workshop on, pp. 1–6, IEEE, 2017.

[8] Enrich, “Enrich 2019.” Theenrich.european-robotics.eu, Jul 2019. Accessed: 2018-12-10.

[9] M. F. E. Rohmer, S. P. N. Singh, “V-rep: a versatile and scalable robot simulation framework,” in Proc. of The International Conference on Intelligent Robots and Systems (IROS), 2013.