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A Novel Design for a Robot Grappling Hook for use in a Nuclear Cave Environment

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Abstract: Within the field of robotics there exist few designs for detachable grappling hooks. This paper focusses on the novel design of a detachable grappling hook for use within a nuclear cave environment. The design seeks to exploit the complex network of pipes that is present within a nuclear cave. It is hoped that the grapple may be used to aid with mapping and characterisation of the nuclear cave, as well as increasing the movement capabilities of robots within the cave. It is shown that our prototype grapple is able to support on average 2.4kg of mass, or thirty times its own weight. In addition when dropped from a height of 7.5cm, which removes ballistic instability, the grapple is able to engage itself 87% of the time. Finally the minimum speed that the grapple must be travelling, in order to secure itself to its target, is found to be 1.08m/s.

Keywords: Grappling hook, grapple, nuclear, decommissioning, obstacle, locomotion

1. INTRODUCTION

The requirement for nuclear decommissioning is becoming increasingly prevalent as more nuclear facilities are coming to the end of their operational lifetime. A particular problem during the decommissioning process is the nuclear cave. This is an area of a nuclear facility which much of the key pipework is routed through, and typically contains multiple pressure vessels. The desire of the nuclear industry is to use an autonomous robotic system to characterise the nuclear cave environment in order to make safe disposal of its contents possible.

As can be seen in figure 1, the nuclear cave environment presents a challenging environment for mobile robotic systems to move around in. Aside from the obvious difficulty in moving through the complex network of pipes and pressure vessels, the floor of the nuclear cave presents its own obstacles. Robots seeking to traverse the floor of a nuclear cave will encounter: slumps and channels on the floor of the cave; debris from previous excursions into the cave; unknown floor geometry; leakages caused by damaged pipe work, and inclined floors. Finally any robot seeking entrance to the nuclear cave must normally be capable of fitting through a hole 15cm (6 inches) in diameter, as this is the standard entry hole size.

Small wheeled ground robots make for a useful tool for characterisation within the nuclear cave. This is because they provide a stable platform on which an array of sensors may be placed; they have good energy efficiency, mission duration and payload capacity when compared to flying robots; and they can be miniaturised to fit through the 15cm entry hole. However when reducing the size of a robot the size grain hypothesis states: "as a body gets smaller it becomes more difficult for it to overcome obstacles due to their increase in relative size" (Noh et al. (2012), Zhou et al. (2005)). Thus a small robot moving around the cluttered nuclear cave environment is likely to encounter unsurmountable obstacles.

As a robot in a nuclear cave environment is likely to meet multiple obstacles during its mission, a supplementary locomotive modality becomes useful. This would enable the robot to access areas of the cave which would be inaccessible to a typical ground robot. There have been various studies into possible supplementary methods. One such modality is the use of small robotic hopping robots (Noh et al. (2012), Zhou et al. (2005), Sugiyama et al. (2005), Armour et al. (2007), Lambrecht et al. (2005), Stoeter et al. (2005)). A further interesting method is the use of wings to increase the speed and efficiency of ground robots (Peterson et al. (2011)). However, this paper focusses on the design and use of a grappling system to provide additional movement capabilities within the nuclear cave, and to assist with characterisation.

The grappling hook provides several useful features for the characterisation of a nuclear cave environment. The first of these is that it may be used to surmount obstacles present within a nuclear cave. A grappling hook would allow for the robot to make use of the intricate network of pipes to pull itself over channels, sumps, leakages and debris in order to continue mapping otherwise inaccessible areas. In

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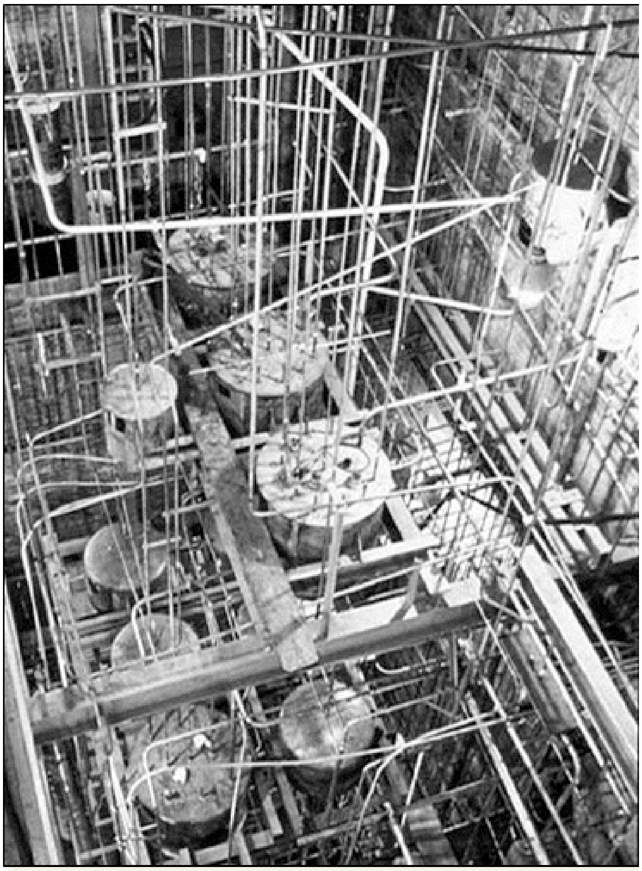

Fig. 1. Shows the nuclear cave environment, which poses a difficult characterisation task for decommissioning.

addition, the use of a grappling hook allows for a bird's eye view of the environment, which could be useful for mapping. Finally the slow ascension that can be offered by a grapple could be utilised for mapping. This could be used to perform a scan of the environment as the robot pulls itself up, allowing for three dimensional mapping of the upper areas of the cave.

The downside of traditional grappling hooks is that they are not easily detached once engaged with their target. This would not suit a mobile robot as it means that only one obstacle may be overcome. One possible solution is to carry multiple hooks, though this has the downside of additional weight, and a larger size. A more elegant solution is a detachable grappling hook.

There exist few designs for robotic grappling hooks, and for detachable grappling hooks, even fewer. One example is the Scout mobile robot platform (Drenner et al. (2002b,a)), this utilises an external spring launching mechanism with a large spiked grapple. Such a design is not detachable and currently is not able to be loaded automatically. An easily implemented method for detachable grappling hooks is exemplified by the 'HandBot' from the Swarmanoid project (Dorigo et al. (2013)). This utilises an electromagnetic grapple which may be easily switched on and off. However, within the nuclear cave environment there are few ferromagnetic surfaces so this method for grappling becomes less useful. Several interesting designs for detachable grappling hooks are explored in (Asano et al. (2010)). The first of these designs features a gripper at the end of the line, however if the gripper does not collide with the target in a specific orientation, it cannot grip it. The second design features a clamp. This is able to latch to cyclindrical pipework and is the design most akin to that presented in this paper, however it was found that the design was too heavy to be launched reliably. The final design presented in (Asano et al. (2010)) features an extendible hook. This features a bend that can be fully extended by a wire in order to detach from its target, though this is too large for use in a nuclear cave. A final method for grappling that has been explored it to use pre-installed tether points to hook onto (Stepan et al. (2009), Fearing (2013)). However, as the nuclear cave is inaccessible to humans the installation of such points becomes difficult.

Though this paper focusses on the use of the grapple for the mapping of a nuclear cave environment, there exist multiple other uses for such a design. One potential use is in the efficient erection of scaffolding. If the hook were attached to a piece of already secured scaffold, it could be used to move items from the ground to the top of the construction quickly. In addition the grapple could be easily adapted for use on tree branches. This could permit uses such as robotic traversal of forest area, or aid in forest construction tasks. As the design of the grapple allows detachable attachment to most cyclindrical surfaces, it is likely there are many more potential uses.

Overall, within robotics, it appears there is a paucity of detachable grappling hooks that could be used within a nuclear cave environment. This paper focusses on a design that is specific to such an environment, but that could be used in other areas where there is a large quantity of pipework, or cylindrical infrastructure.

The structure of the paper is as follows. First the design of the grappling hook will be outlined. This will be followed by an explanation of the experimental methodology used to examine the quality of the design. The results of these experiments will then be presented, with a discussion of the results in the subsequent section. Finally conclusions will be drawn.

2. DESIGN AND METHODOLOGY

2.1 Design

As can be seen in figure 1, the nuclear cave contains a complex network of pipes. These pipes make an excellent target for a grappling device. Previous work exploiting the nature of pipe and scaffold networks has focussed on either gripping the pipe work with an end effector (Zhou et al. (2005)) or surrounding the pipe with a platform able to travel along it (Aracil et al. (2003)). To the knowledge of the authors, there has been little or no work investigating the design of a grappling device that could be used in such an environment.

When designing the grapple the following requirements were considered:

(1) **Grip size** - The grapple should be capable of clasping pipework of diameter 40mm and below.
(2) **Grapple mass** - The grapple should be lightweight (100g or less) so that it may be easily launched.