Nuclear Engineering and Technology xxx (2018) 1–6

Contents lists available at ScienceDirect

Nuclear Engineering and Technology

journal homepage: www.elsevier.com/locate/net

Original Article

Development of a shared remote control robot for aerial work in Nuclear power plants

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ARTICLE INFO

Article history:
Received 31 January 2018
Received in revised form
10 March 2018
Accepted 11 March 2018
Available online xxx

Keywords:
Aerial Work
Nuclear Power Plant
Shared Remote Control Robot

ABSTRACT

We are developing a shared remote control mobile robot for aerial work in nuclear power plants (NPPs); a robot consists of a mobile platform, a telescopic mast, and a dual-arm slave with a working tool. It is used at a high location operating the manual operation mechanism of a fuel changer of a heavy water NPP. The robot system can cut/weld a pipe remotely in the case of an emergency or during the dismantling of the NPP. Owing to the challenging control mission considering limited human operator cognitive capability, some remote tasks require a shared control scheme, which demands systematic software design and integration. Therefore, we designed the architecture of the software systematically.

1. Introduction

The environment for maintaining tasks in nuclear facilities can be hazardous. Therefore, many automation devices are being used to inspect and repair such facilities. However, it is difficult to use fixed automation devices for nonperiodic and infrequent maintenance tasks. Therefore, remotely controlled robot systems have been proposed.

If a fuel-handling machine, one of the major components of a PHWR nuclear power plant (NPP), ages, the machine may be stuck on the pressure tube in front of the PHWR calandria. Although the machine has a troubleshooting measure of a manual drive mechanism, it is still a difficult problem to access the manual drive mechanism. When the machine is stuck, the NPP is operated such that the radiation level is extremely high and the machine can be located at a high position of up to 9 m. Therefore, a human worker cannot approach the mechanism, and the mechanism must be handled remotely. Shin et al. developed an aerial working mobile robot for monitoring a high radiation area and operating a manual drive mechanism of a fuel exchange machine (MADMOFEM) [1].

Mitigation robots used during the Fukushima NPP accident and dismantling robots for NPPs should find the exact status of the area while moving around [2–4].

Because the area of a severe accident of an NPP may be complex with various obstacles, the dismantling robot should deal with dismantled parts and may carry out cutting work. Therefore, an articulated multi-arm robot system is desirable to use rather than a robot with one task-specific device.

Using an aerial working mobile robot, we therefore designed a remote control system for maintaining and repairing tasks in an NPP. A dual-arm manipulator is going to be installed instead of a single task–specific device. We named the remote control system to be developed MARTiN (remote control system for Maintaining And Repairing Tasks in NPP). MARTiN can operate the manual drive mechanism of a fuel exchange machine and cut/weld a pipe during an emergency situation.

We developed tools for MARTiN to operate the MADMOFEM and cut a pipe. We tested the feasibility of the prototypes.

The dual-arm manipulator as a slave robot is controlled by a master device. It is important to reduce the working time and operator fatigue and to increase the stability and accuracy in the remote work by using a haptic device. In the case of complex tasks, visual and haptic virtual guide technology is useful for reducing the work time and operator fatigue. We tested the efficiency of constraining some degree of freedom (DoF) as a haptic virtual guide [5].

The target tasks and working environment vary from case to case. Therefore, it is difficult to make the virtual guide in advance. We used human intuition to generate the virtual guidance. The operator sketches the path on the visual feedback image of the remote environment. Then, the virtual guide is generated based on the sketches [6].

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https://doi.org/10.1016/j.net.2018.03.006

Please cite this article in press as: H. Shin, et al., Development of a shared remote control robot for aerial work in Nuclear power plants, Nuclear Engineering and Technology (2018), https://doi.org/10.1016/j.net.2018.03.006

Because the user operates the master device with a limited view of the cameras, he may not understand the situation of the slave robot. Therefore, he may proceed with the work even though the slave robot is approaching a poor kinematic condition such as a singularity position. We designed a master control program to provide helpful information to the operator to intuit the singularity information of the slave robot [7].

The aerial working mobile robot, with a telescopic mast, can raise its dual-arm manipulator to a height of 9 m. If the dual-arm manipulator is operated at that height, vibration at the manipulator base can be caused by the flexibility of the telescopic mast. It is very difficult for a human operator to control the slave robot while suppressing the vibration at the same time. Therefore, we propose a shared control scheme that allows the human operator to control the slave robot only and assign the vibration-suppressing task to the robot system. In addition, we tested the controller using a mockup test bed [8].

2. Target tasks

There can be many tasks in a high radiation area such as the operation of valves and switches. First, we are going to have MARTiN remotely operate the MADMOFEM when the machine is stuck. In addition, we are going to develop remote control technology with which MARTiN can cut/weld a pipe under an emergency situation or in the dismantling process. Fig. 1 shows an example of the target tasks.

Fig. 2 shows the concept of an aerial task in a PHWR NPP. A dual-arm manipulator on a telescopic mast on a mobile platform manipulates the MADMOFEM. A human worker in a safe area remotely operates the dual-arm manipulator as a slave robot through the master device.

3. Hardware

The mobile platform has four wheels and four flippers. Each flipper has an active small wheel at the end. The platform is able to pass through a gate of 0.9 m in width, to move with loads of 250 kg, and to cross a ditch with a width of 0.75 m and a depth of 0.25 m by using the flippers. The mobile platform changes direction using a skid-steering method, which is easy for the platform with two omni wheels at the rear side.

The initial height of the robot should be less than 2 m such that the robot can pass through the gate of the shielding aisle. Therefore, the telescopic mast is composed of identical-shaped frames sliding

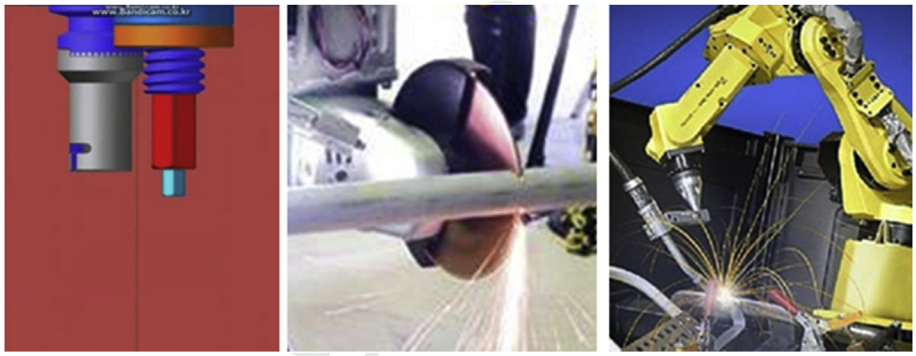

Fig. 1. Target tasks.

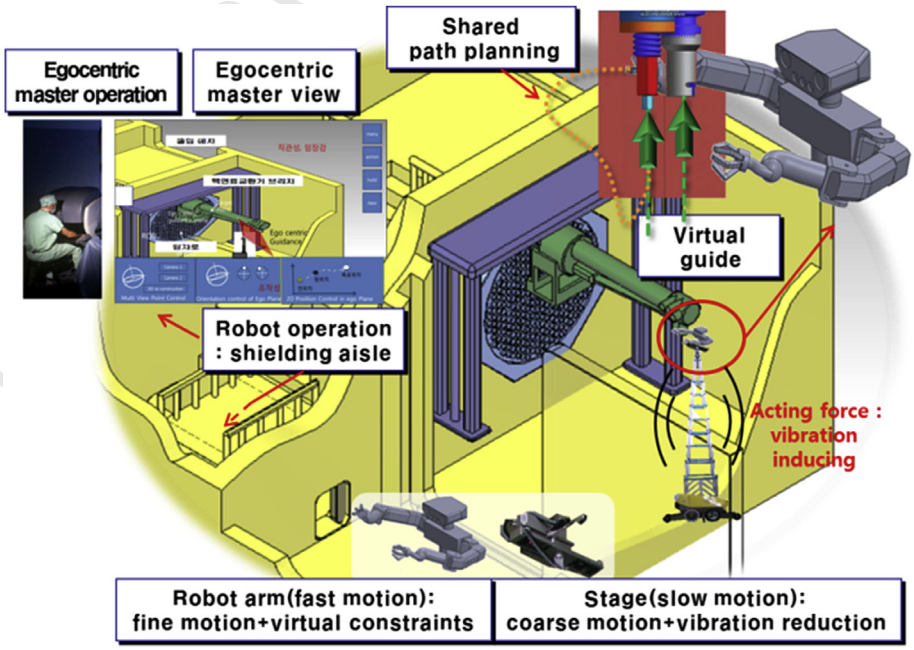

Fig. 2. Concept of maintenance tasks in nuclear facilities.

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