Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 10-11, 2007

A Mobile Robot for Emergency Operation of Fuel Exchange Machine

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1. Introduction

A Pressurized Heavy Water Reactor (PHWR) uses a heavy water as the coolant and moderator because it does not attenuate the neutron inside the reactor, which makes it possible to use natural uranium for nuclear fuels. However, since the uranium ratio is too low within the natural uranium, the reactor should be refueled everyday while the reactor is working.

For that purpose, there is a fuel exchange machine as shown in Fig. 1 in a PHWR which is a radiation tolerant and reliable complex hydraulic mechanical system. However as the time passes by, the durability and reliability become a problem. While the fuel handling machine exchanges the reactor fuel, it can be stuck to the pressure tube attached in the Calandra. Although this kind of situation is rarely happen, it can make the reactor be shutdown for normalizing the operation. Since the refueling is performed while the reactor is working, the radiation level is extremely high and the machine can be located at a high position up to nine meters from the floor, that is, the human worker can not approach the machine, so the fuel handling machine should be released remotely.

To cope with this situation, the fuel handling machine has a manual drive mechanism at the rear side of it as shown in the circled images in Fig. 1. If the worker can handle these manual drive mechanisms, the fuel handling machine can be released form the pressure tube. The KAERI had developed a long-reach manipulator system with a telescophic mast mechanism which can be deployed in the basement of the reactor room and manipulate the manual lever of the fuel exchange machine [1]. Since the manipulator is located in the basement, there are several problems for its application such that the plug hole should be removed before the operation and the vibration of the mast mechanism make it difficult to locate the end effecter of the manipulator.

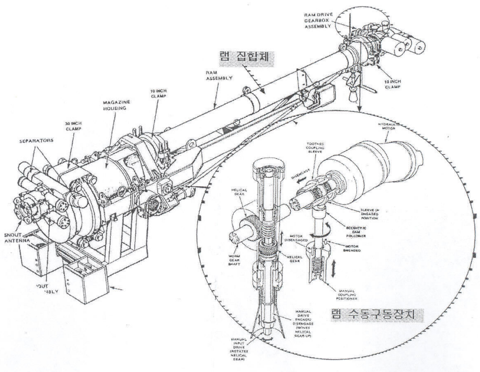

Fig. 1. The fuel exchange machine of a PHWR.

This paper describes a remotely controlled mobile robotic system to circumvent these drawbacks. The robotic system composed of a mobile robot, a telescopic mast mechanism, a 2 dof installer mechanism, a 5 dof manipulator with driving tools, control system, and video systems. The robotic system is constructed and tested in Wolseong nuclear power plant.

2. Robotic Systems

The Nuclear Robotics Lab. In KAERI has been developed a mobile robot for Calandria inspection [2]. While the purpose of the previous robotic systems are for inspection, that of the present robotic system is for maintenance. Fig. 2 shows the robotic systems.

The mobile robot is equipped with four wheels for movement and for track mechanisms in the front and rear side of the robot to cross the threshold of the shielding door, and to stabilize the robot while extending the mast mechanism. The rear wheel is made of omni-directional wheels to reduce the friction while steering which are circular wheels with two array of six small idle wheels whose axis perpendicular to the circular wheel. The weight of the robot is 150kg.

The telescopic mast mechanism is a chain driven mechanism which can reach up to 9 meters including the height of the mobile robot and is operated by using an electrical motor. While the inspection robot [2] has only cameras on top of the mast mechanism, the robotic system in this paper has a manipulator of weight by 55kg. The weight of the mast mechanism is 150kg.

The installer mechanism is located on top of the mast mechanism to set up the manipulator. Since the robot should be able to pass the transfer door, that is an entrance to the reactor room, the height of the robot is limited by the door. Therefore, the installer mechanism

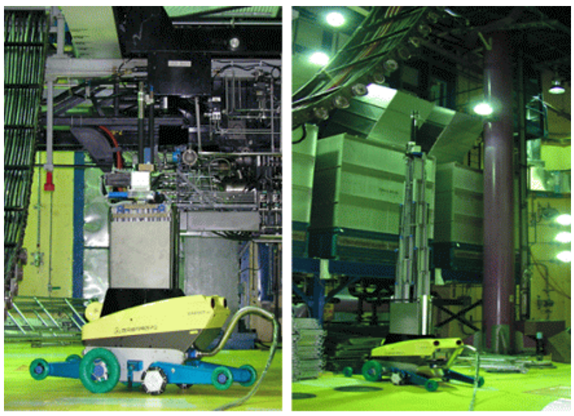

Fig. 2. Tele-operation experiment in Wolseong nuclear power Plant

is designed to reduce the initial height of the robot. Than means, initially the manipulator is folded at the side of the mast mechanism, and then after going into the reactor room, the installer is rotated in up standing position.

The manipulator has 5 dof including the tools. There are three tools for driving the auto/manual exchange lever, connecting the helical gear, and driving the RAM mechanism. These tools are constructed to meet the operating requirement as follows: the auto/manual exchange lever needs two dof. One is for pushing and pulling the lever and the other is for rotating the lever. The helical gear connecting lever needs rotation in coupled with the RAM driving lever which needs torque up to 80 lb ft. Four cameras are attached on the manipulator for controlling the manipulator, and a laser pointer is attached inside of the RAM driving tool for ease positioning of the manipulator to the lever

3. Control Systems

3.1 Radiation Hardened Robot Controller

The robots working in a nuclear power plant experiences severe radiation dose. This high radiation level damages and changes the characteristics of the material that composed of the robot. The damage on the semiconductor material is critical because the controllers of the robot are mostly composed of them. Many researches have been performed to construct a reliable controller targeted for high radiation region using commercial off-the-shelf (COTS) semiconductor devices. A radiation hardened controller is used for the robot using COTS technology [3]. The controller has two DSP controllers and one emergency controller. One of the DSP controllers is the main controller that is working in normal operation. The other DSP controller is a redundant cold standby system. This cold standby system is enabled if the main DSP controller is not working. The emergency controller is purely composed of mechanical relays which are not affected by the irradiation.

3.2 Host Controller

Figure 3 shows the host control systems. The controller is composed of a remote controller with Pentinum PC, which transfers the controller commends to the robot controller through RS485 line. The control program displayed various status of the robot which includes the slope of the mobile robot, limit sensor information, communication status, and so on. Joystick interface and button interface is provided to the operator.

The video system displays the video is transferred from the robot controller through twist pair. Five video images can be displayed simultaneously.

4. Experiments

Experiments are performed at the Wolseong nuclear power plant as shown in Fig. 1 in overhaul period. The operation is as follows: The robot is deployed inside of the transfer door, and passes the door with the installer

Fig. 3. The host controller and video system

in down position. After passing the door, set up the installer, and the robot lowers the track to pass the threshold of the shielding door. As close to the fuel exchange machine, the manual driving lever can be found in the camera image and roughly locate the mobile robot at the center of the lever. Adjust the slope of the mobile robot by using the sensor information and the track mechanism. Fine adjusting of the location of the mobile robot should be followed utilizing the laser pointer. Extend the mast mechanism and adjust the installer mechanism to locate the tools in the exact position. Insert the helical gear driving tool to the lever, and insert the auto/manual exchange lever.

Two of the location of the fuel exchange machine are tested. One is the third row of the Calandria and the other is the highest position of the machine. At a lower position, the tool is easily inserted. At a higher position, the operation is a little difficult because the location of the end of the manipulator is changed caused by the deformation of the mast mechanism. If the deviation is outside of the working range of the installer, the position of the mobile robot should be adjusted. Neverthless, it is easier than the operation by human workers.

This robotic system can be applied to a tele-operation in a high place not only in nuclear industry but also in other industry.

Acknowledgment

This work was performed under the long-term nuclear R&D program sponsored by the Ministry of Commerce, Industry, and Energy.

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