Remote Robotic Cleaning System for Contaminated Hot-Cell Floor

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1. Introduction

The M6 hot-cell of the Irradiated Material Examination Facility at the Korea Atomic Energy Research Institute (KAERI) has been contaminated with spent fuel debris and other radioactive waste due to the DUPIC nuclear fuel development processes. As the hot-cell is active, direct human workers' access, even with protection, to the in-cell is not possible because of the nature of the high radiation level of the spent PWR fuel. A remote robotic cleaning system has been developed for use in a highly radioactive environment of the M6 hot-cell. The remote robotic cleaning system was designed to completely eliminate human interaction with hazardous radioactive contaminants. This robotic cleaning system was also designed to remove contaminants or contaminated smears placed or fixed on the floor of the M6 hot-cell by mopping it in a remote manner. The environmental, functional and mechanical design considerations, control system and capabilities of the developed remote robotic cleaning system are presented.

2. Design Considerations

The successful development, in-cell installation and operation of the remote robotic cleaning system involve mutually dependant design elements - the M6 hot-cell facility, the arrangement of the fuel fabrication equipment installed inside of the hot-cell, and the operation and maintenance of the robotic cleaning system. The spatial and environmental limitations of the M6 in-cell facility, availability and location of utilities, geometrical constraints of the in-cell fabrication equipment are important factors in determining the size, mobile means, and cleaning tools of the robotic cleaning system. Remote manipulation strategies, remote repair procedures, and the capabilities and constrains of the remote handling devices that are available at the M6 hot-cell should be taken into account in the design development of the robotic cleaning system.

A compromise, therefore, should be made between these deign elements in the design process of the robotic cleaning system. In addition, the design concept must include all the environmental, mechanical, electrical, and system integration elements to produce fully functional cleaning system for the hot-cell application.

3. Remote Robotic Cleaning System

3.1 System Overview

Based on the design considerations described in the previous section, the remote robotic cleaning system was developed to decontaminate the contaminated floor surface of the M6 hot-cell by mopping it. As shown in Fig.1, the developed robotic cleaning system mainly comprises three subsystems – a mopping slave located inside the hot-cell, a mopping master and a control console located outside the hot-cell. The mopping slave that mops the contaminated floor surface consists of a tracked mobile platform, a mopping tool, and a wet mopping cloth, which were constructed in modules to facilitate a remote maintenance. The mopping slave has a configuration of 280x180x170 (LxHxW) mm when the mopping cloth is in contact with the floor to be mopped, and an ability to mop an area of 24 m^2 with a single roll of the mopping cloth. The mopping master that is installed on the control console is a man-machine interface device that allows interaction between the operator and the mopping slave. The mopping master has a three degree of freedom (dof) for controlling the mopping slave – one dof for the mopping and two dof for the navigation. The control consol provides a control location for the remote robotic cleaning system. The control console includes controller, circuitry, power supplies, and software necessary for the operation of the robotic cleaning system.

The robotic cleaning system is operated by a teleoperated control employing a bilateral force reflecting control scheme. A human operator located outside the hot-cell can perform a series of floor mopping tasks by controlling the mopping slave via the mopping master. A mopping force occurring when, in operation, the mopping tool of the mopping slave contacts with the floor surface can be reflected to the operator through the mopping master, thus allowing the operator to have a sense of a real mopping. The maximum mopping force that the mopping slave can exert to the floor to be mopped is about 27 N. The maximum reflected mopping force that the operator can sense via the gripper of the mopping master is about 8 N. The operator feels a reduced mopping force as a force scaling factor of 3.3.

3.2 Cleaning Experiment

The cleaning experiment of the robotic cleaning system was conducted on an intentionally contaminated floor surface, which was simulated by a black colored water dyeware to a stainless steel plate surface similar to the real floor surface of the M6 hot-cell and by letting it dry one day. The simulated floor surface became very stiff such that it could not be removed by scrubbing it with dry finger or a dry cloth.

In the experiment, the mopping slave was installed on the simulated floor, and the operator, via the mopping master, performed the mopping operation by controlling the mopping slave. As shown in Fig. 2, the experiment was carried out by varying the speeds of the mopping slave and roller, while the mopping force driven by the operator is constant. The operator felt and controlled the mopping force which, during the operation, the mopping cloth of the mopping slave was pressed against the floor surface to be mopped. An image processing technique, as shown in Fig. 3, was used to quantitatively evaluate the extent of the surface decontamination – how clearly the contamination was removed. This technique utilized the source images of the simulated floor surface captured before and after the mopping. The gradiation of each source image captured was eliminated in order to minimize any effects of illumination. Then the gradiation eliminated images were binarized to acquire the clarified images for the swept and unswept areas. After the binarization, a comparison was made of the number of pixels from the acquired binarized images before and after mopping, thereby identifying the extent of the decontamination. The experimental results showed that the speeds of the mopping slave and the roller influence the extent of the decontamination. It is concluded that, for the same speed conditions, the decontamination ratio reaches 99.9% for accomplishing the perfect surface decontamination of the simulated contaminated floor.

4. Conclusions

The remote robotic cleaning system developed in this work demonstrated the robotic application for performing decontamination tasks in a high-radiation field. The significance of this development is in providing on the robotic cleaning system which can be operated from a remote location to mop and clean the contaminated floor of the M6 hot-cell of the IMEF at KAERI. The developed robotic cleaning system is under performance tests at the mock-up and will be installed in situ for service.

ACKNOWLEDGEMENTS

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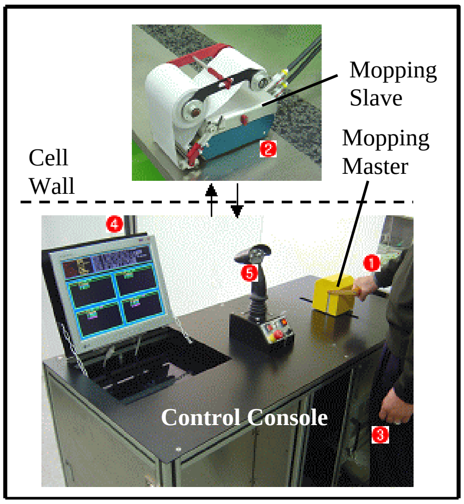
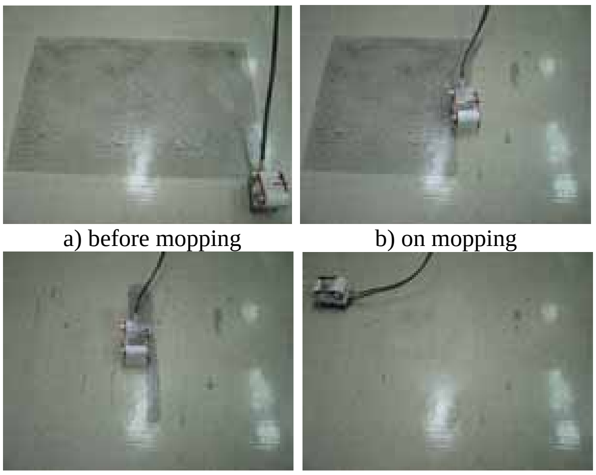


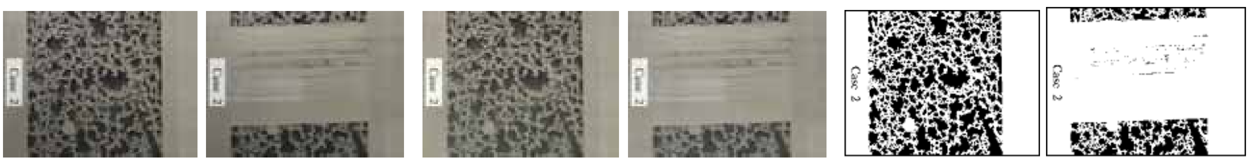
Figure 1. Functional connections of the remote robotic cleaning system.



a) before mopping b) on mopping

c) on mopping d) completion

Figure 2. Cleaning experiment of the remote robotic cleaning system.



a) source images b) gradation eliminated images c) binarized images

Figure 3. Image processing for determining the extent of the surface decontamination.