Visualization and Analysis of Remote Operation involved in Advanced Conditioning Process

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ABSTRACT

The remote operation of the Advanced Spent Fuel Conditioning Process (ACP) is analyzed by using the 3D graphic simulation tools. The ACP equipment operates in intense radiation fields as well as in a high temperature. Thus, the equipment should be designed in consideration of the remote handling and maintenance. As well as suitable remote handling and maintenance technology needs to be developed along with the design of the process concepts. To develop such remote operation technology, we developed the graphic simulator which provides the capability of verifying the remote operability of the ACP without fabrication of the process equipment. In other words, by applying virtual reality to the remote maintenance operation, a remote operation task can be simulated in the graphic simulator, not in the real environment. The graphic simulator will substantially reduce the cost of the development of the remote handling and maintenance procedure as well as the process equipment, while at the same time developing a remote maintenance concept that is more reliable, easier to implement, and easier to understand.

Keywords : ACP, Remote maintenance, Virtual Mockup, Graphic Simulation, Tele-operation

INTRODUCTION

As the cumulative amount of spent fuel increases, the reliable and effective management of spent fuel becomes a wide mission for the world. At KAERI considerable R&D effort is being made to develop management technology that will enhance environmental friendliness and proliferation resistance as well as maximize the use of available energy resources.

One of these efforts is to develop the Advanced Spent Fuel Conditioning Process (ACP) which is a pre-disposal treatment process for spent fuel. This technology involves the process of reducing uranium oxide by lithium in a high temperature molten salt bath. Currently, lab-scale tests for the ACP are being performed. Equipment used for such a spent fuel recycling and management process must operate in intense radiation fields as well as in a high temperature. Therefore, without any remote maintenance provision, the process concepts verified by a lab-scale test cannot be implemented. Hence suitable maintenance technology needs to be developed along with the design of the process concepts.

Conventional approach to develop the process and remote maintenance technology is achieved by the physical mockup test. The mockup is identical to the actual process with a same scale excepts the fact that the demonstration of the remote handling operation is made using a simulated fuel, not an irradiated fuel. The mockup test is expensive and time consuming, since the design may need to be modified to fix the problems found during the test and the equipment needs to be fabricated again according to the design modification[1-3].

To deal with this problem, we developed the graphic simulator for the ACP. And the virtual mockup of the hot cell is implemented using a graphic simulator. Using the virtual mockup, visualization of the process are made and various analyses are carried out such as workspace analysis of the manipulator, FOV(field of view) analysis, collision detection, and path planning, etc.

GRAPHIC MODEL OF ACP EQUIPMENT

2.1 Overview of ACP

The objective of the ACP is to treat the spent fuel in a molten salt (LiCl) bath to remove volatile and high-heat load fission products and to convert the spent fuel into a metallic form more suitable for disposal in a repository. The process is to treat a high radioactive material including spent nuclear fuel. Therefore, this process is conducted in a sealed facility, called a hot cell. The ACP process consists of several equipment such as a slitting device, a voloxidizer, a reduction reactor, a smelting furnace, and non-destructive assay (NDA) system, etc[4].

The process flow of the ACP is shown in Fig. 1. The hot cell is divided into two areas, the process cell and the maintenance cell. The processes from slitting to smelting of U-metal are carried out in the process cell. In the maintenance cell, the crane and the parts whic h are failed are repaired and/or replaced.

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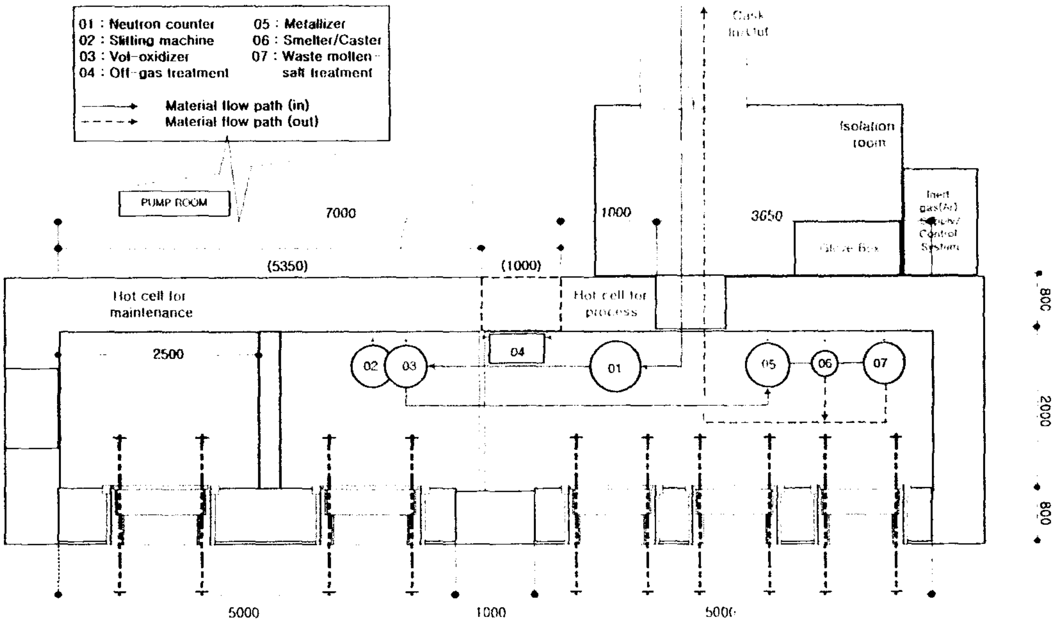


Fig. 1 Hot cell layout and process flow of ACP.

2.2 Process Equipment

The process equipment consists of a slitting device, a voloxidizer and a reduction reactor. etc. The slitting device extracts the spent pellet from the rod cut. The voloxidizer transforms the UO_2 pellet into the U_3O_8 powder, by heating and supplying air into reactor. This equipment consists of a furnace, vibrator and air cylinder for moving up and down the powder collection vessel.

The reduction reactor converts U_3O_8 powder into the U metal. The reactor consists of a furnace for heating the U_3O_8 powder and the lithium, an air agitator for mixing the lithium and U_3O_8 powder, and a valve for exhausting the uranium and lithium solution. All the parts are graphically modeled and assembled for the simulation of the maintenance operation as shown in Fig. 2.

(a) Slitting device (b) Vol-oxidizer (c) Reduction reactor

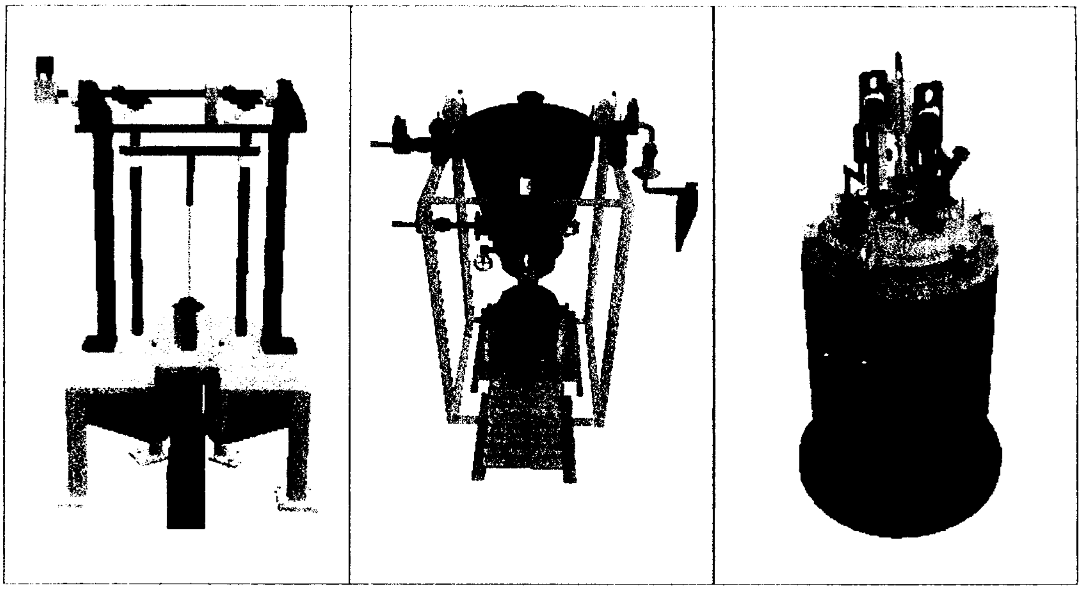
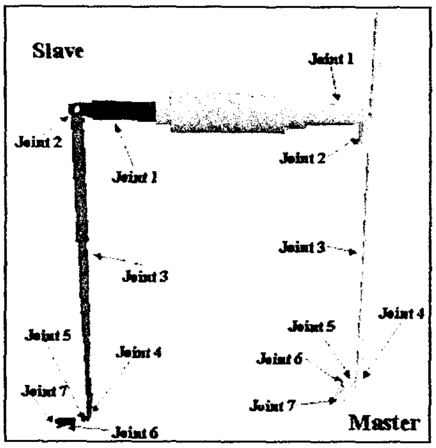
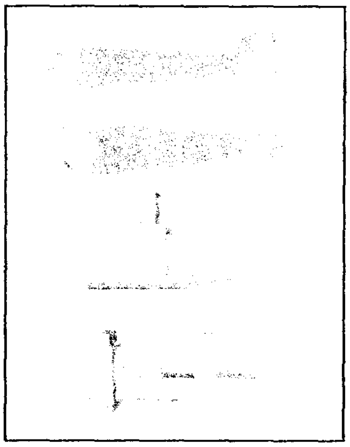


Fig. 2 3D model of process device for ACP.

2.3 Remote Maintenance and Handling Device

The crane and the master-slave manipulators (MSM) along with the remote tools shown in Fig.3 are widely used as remote handling devices in the hot cell. Besides these to cover the area out of working range of the MSM, the servo manipulator(SM) has been developed. The SM is sustained by a telescoping tube set which moves the SM in the vertical direction. The tube set is attached to the trolley-girder system which provides the travel and traverse motion of the SM. In this way the SM can be located anywhere inside the hot cell. Also, three viewing cameras are installed at the girder as shown in Fig. 4 for monitoring the remote operation of the SM.





(a) Master-slave manipulator (b) Handling tools

Fig. 3 Graphic Model of Master-Slave Manipulator and tools.

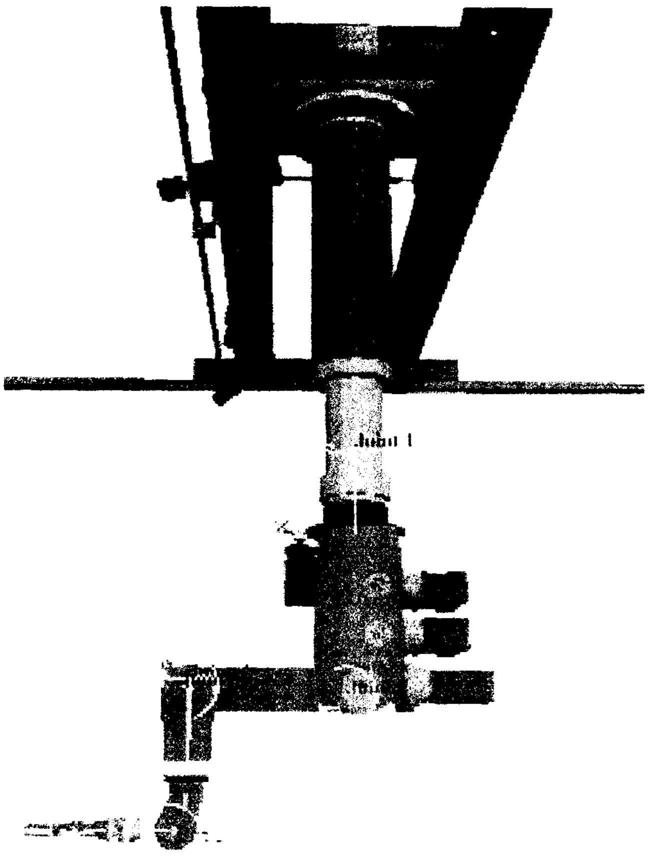


Fig. 4. Graphic model and kinematics of servo manipulator

3. VIRTUAL MOCKUP OF THE ACP

The virtual mockup of the ACP is implemented using IGRIP[5], the graphic engineering simulation tool, to analyze and define the maintenance processes of the process equipment instead of using a real mockup which is very expensive and time consuming. For the implementation of the virtual mockup, the process equipment and maintenance devices are modeled in 3-D graphics, and the appropriate kinematics are assigned as described earlier. Also, the virtual workcell of the ACP is implemented in the graphical environment, which is almost identical with that of real environment. Fig. 5 shows the virtual mockup of the ACP. Using this mockup visualization of the process and various analysis can be made typical examples are workspace analysis of the manipulator, FOV(field of view) analysis, collision detection, path planning, and graphic simulation of the processes, etc.

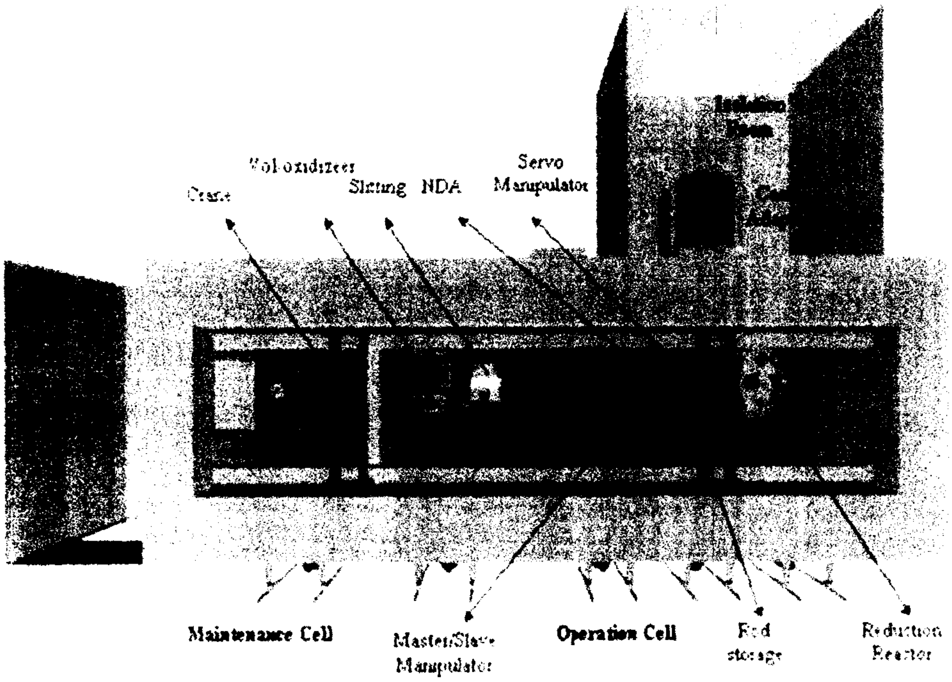


Fig. 5. The virtual mockup of the ACP.

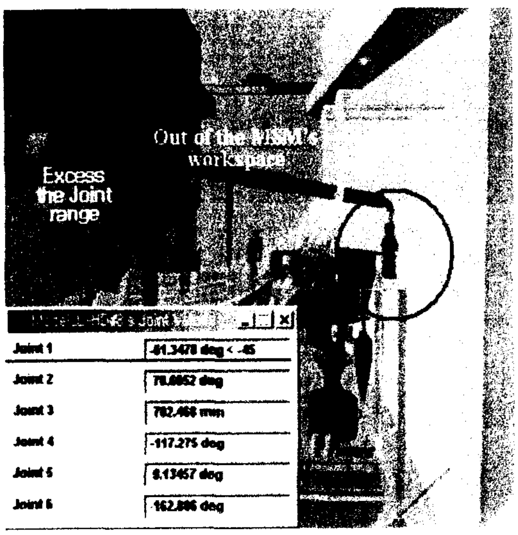
4. ANALYSIS OF REMOTE OPERATION

4.1 Analysis of MSM workspace

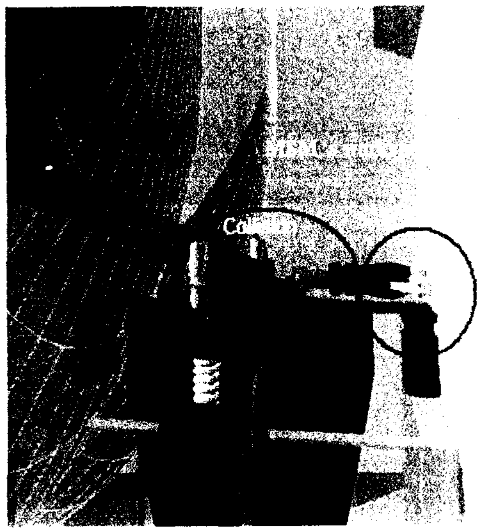
Using the virtual mockup, the workspace of the MSM in the hot cell is analyzed. Also, for the dedicated maintenance operation, the detailed work space of the MSM is analyzed in accordance with the position and orientation of the manipulator end effectors. And the parts of the equipment that are located outside of the MSM's workspace are specified.

Even though parts of the equipment are located in the workspace of the MSM, there may be the case that these parts cannot be reached by MSM because some joint limits of the MSM are exceeded, or the hot cell is too crowd as shown in Fig. 6 (a) and (b). Also, even though parts are located in the workspace of the MSM, according to the posture of the MSM and the orientation of the end effectors, some parts cannot or can be reached by the MSM as shown in Fig. 6 (c) and (d).

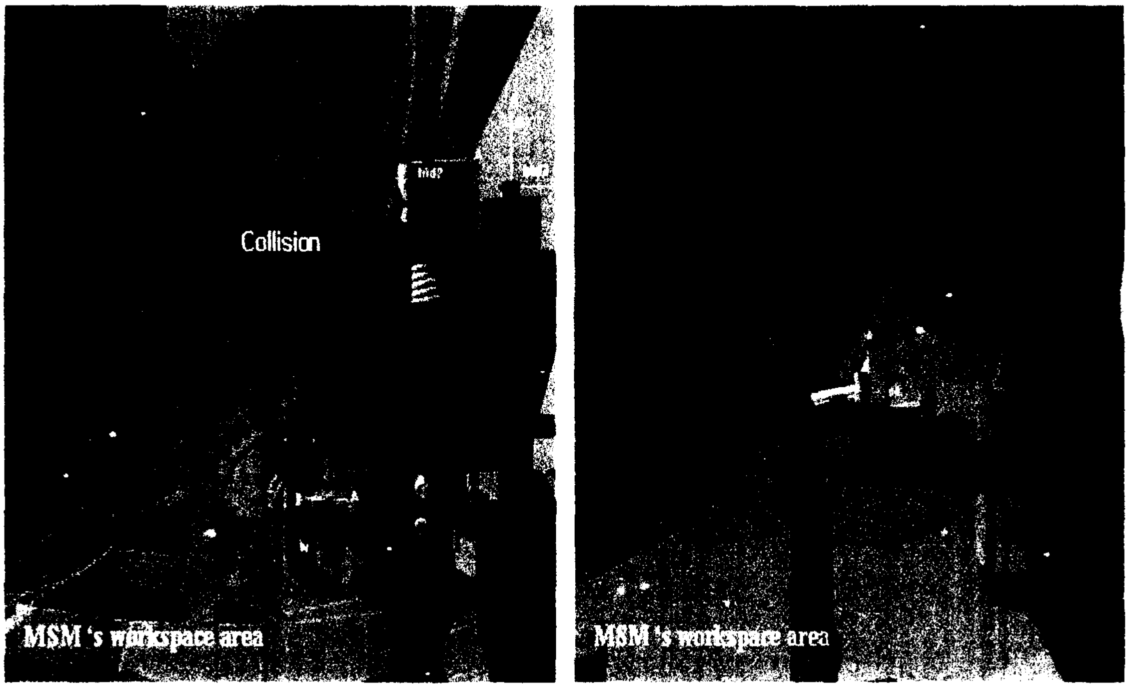
In these cases, the maintenance methods for the parts should be provided by using the other maintenance device, such as a servo manipulator.



(a) Inaccessible configuration



(b) Inaccessible configuration



(c) Inaccessible configuration **(d) Accessible configuration**

Fig. 6. The analyses of the MSM's workspace.

4.2 Analysis of Operator's view

The clear operator's view is very important for the remote operation. The operator's view through a shielding windows is analyzed. Fig. 7 shows the viewing area through the window based on the normal view of the lead glass in the virtual mockup. As shown in the figure, there are some areas out of the view range in the hot cell. So, to monitor the process in these areas, additional viewing devices, such as cameras in the hot cell, are needed

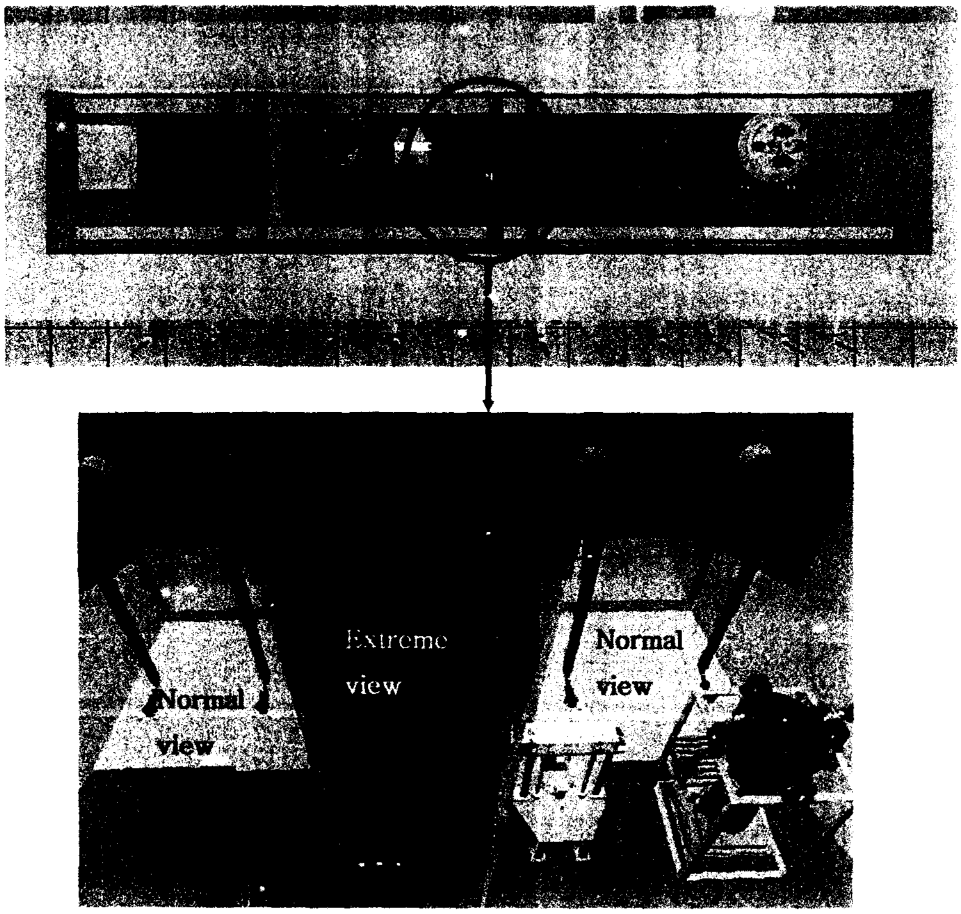


Fig. 7. The operator's view through the shielding windows.

4.3 Analysis of Remote Maintenance Operation

4.3.1 Parts to be maintained

For the demonstration of remote maintenance concept using the virtual mockup, the vibrators that are parts of the Voloxidizer are considered to be replaced for instance. Fig. 8 shows the MSM's accessibility to the vibrators and the operator's view through the shielding windows. As shown in the figure, the MSM can't reach the parts and the operator's view is not clear.

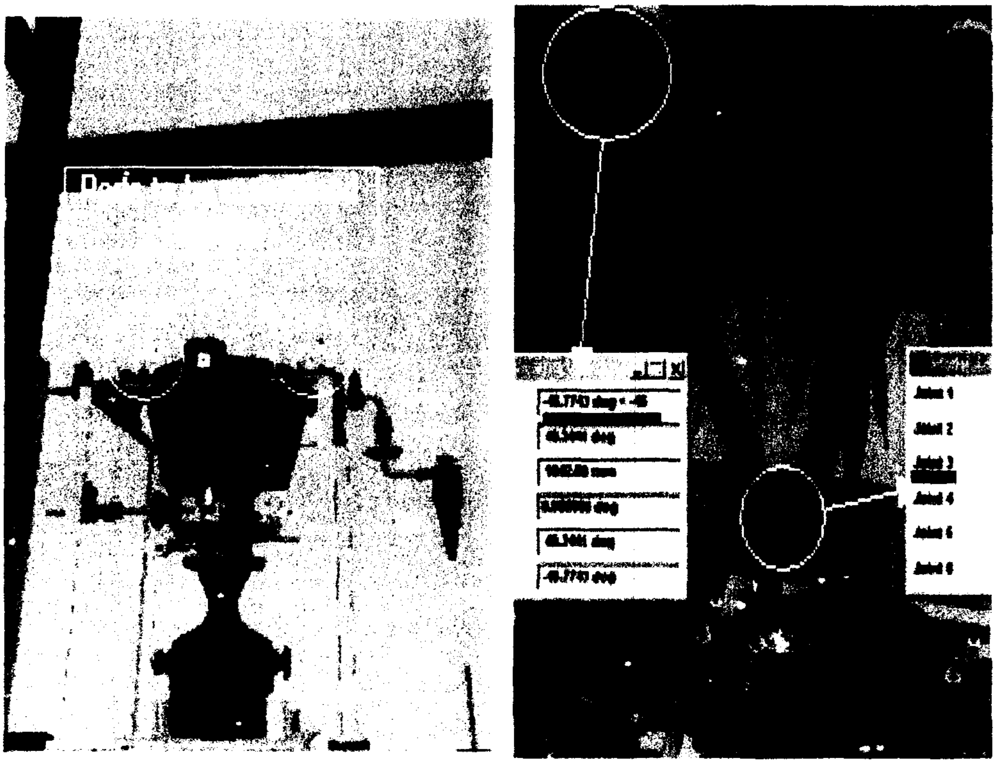


Fig. 8. Parts to be maintained and MSM's accessibilities.

4.3.2 Path planning

For safe and effective maintenance of the process equipment using a servo manipulator, a collision-free path planning method of the servo manipulator is suggested using the virtual mockup. The method is to find the optimal path for the manipulator using the function of collision detection imbedded in the virtual mockup. Fig. 9 shows the procedure of path planning to find the optimal path in the hot cell.

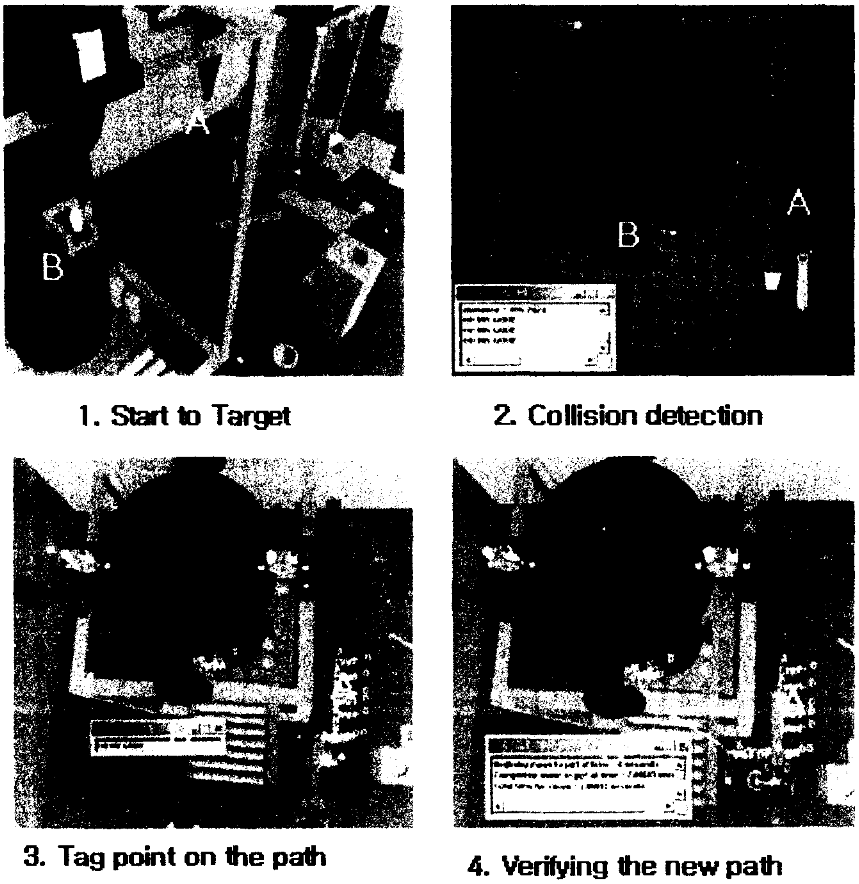


Fig. 9. Procedure of the path planning.

4.3.3 Operator's view

The operator's view in remote operation is a very important factor. In this study, to monitor the hot cell process remotely, and to obtain a clear view of the workers, the virtual display system by a virtual camera in the graphic environment is proposed.

To implement the system, Axxess in the IGRIP is used. Axxess is a flexible API (Application Programmer Interface) framework in which the user can easily integrate its own software with the IGRIP.

Fig. 10 shows the virtual display system in the virtual mockup to simulate the maintenance process. Two virtual cameras are installed near the servo manipulator and the camera view windows for these virtual cameras are implemented in the virtual mockup using Axxess. As shown in the figures, the cameras are tracing the parts and the gripper respectively. This system can monitor the hot cell operation remotely.

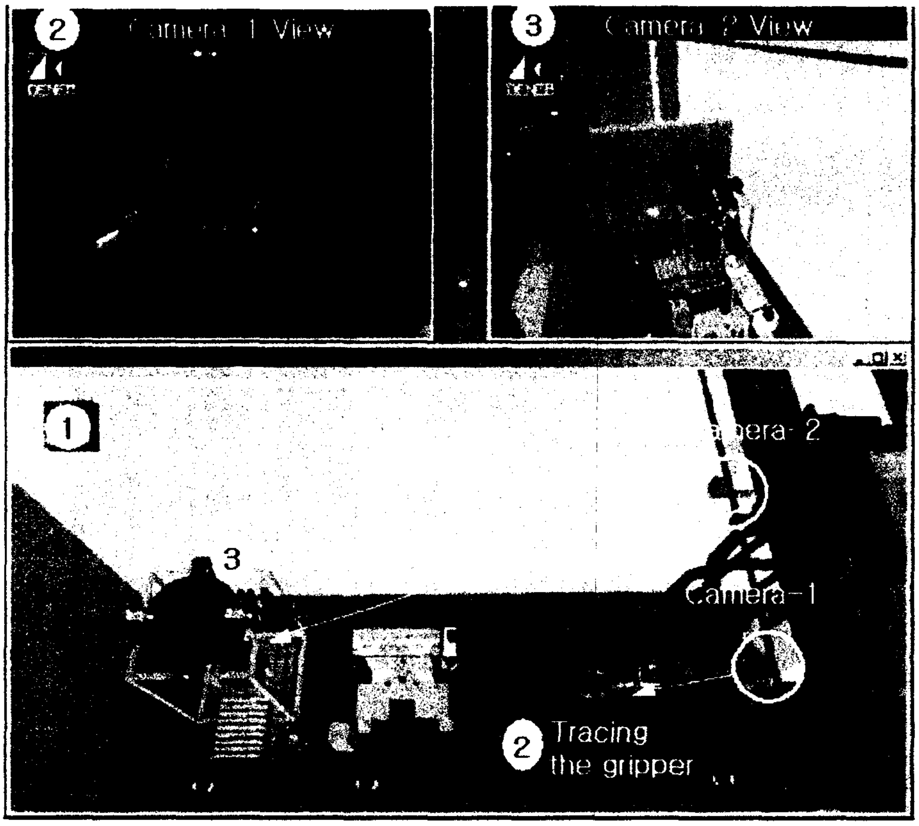


Fig. 10. The virtual display system.

4.3.4 Graphic simulation of the maintenance process

For the verification of the maintenance process and the virtual display system proposed in this study, graphic simulation using a virtual mockup is performed. As shown in Fig 11, the proposed maintenance process is well simulated without any collision and any other problems in the virtual workcell during the simulation. The verification of the maintenance process in the real hot cell for spent fuel management should be carried out in the future.

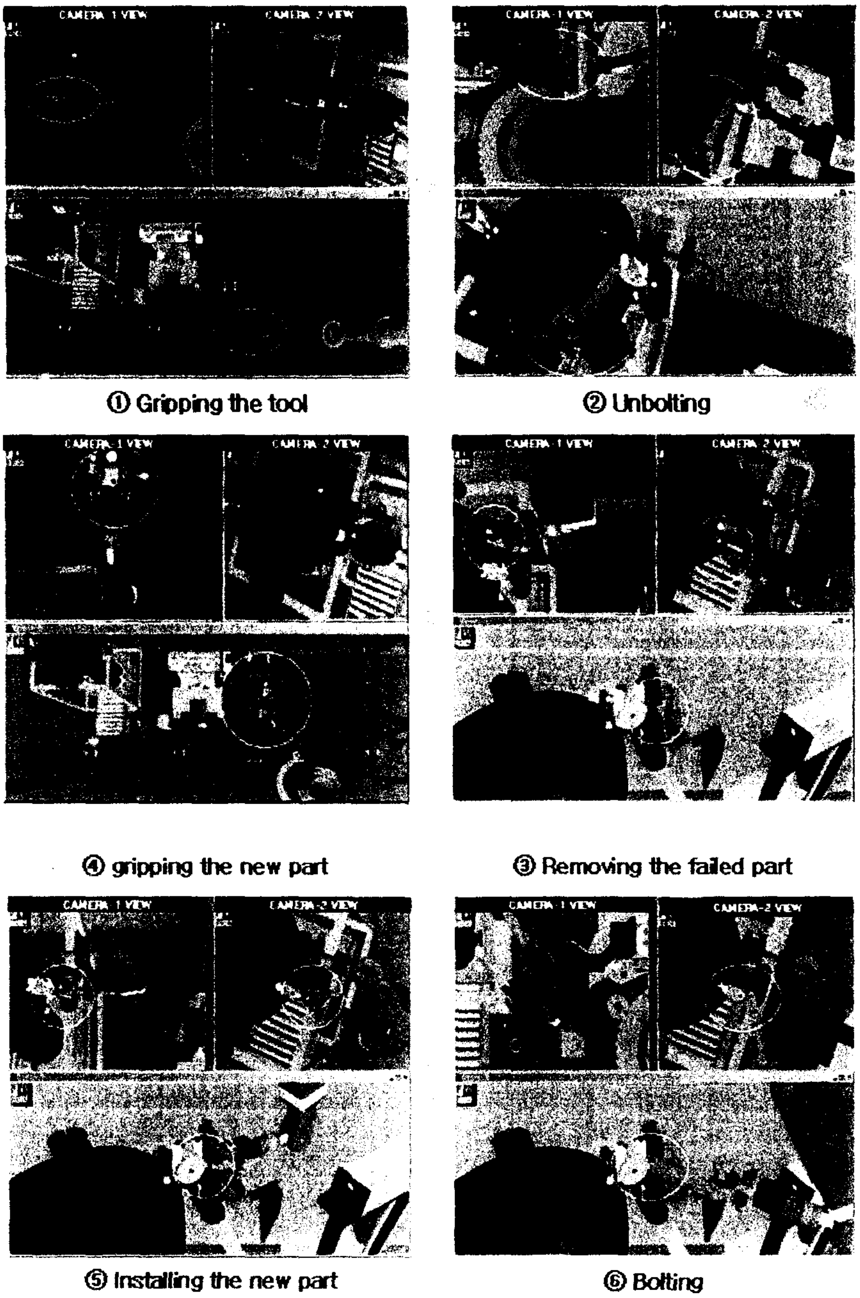


Fig. 11. The graphic simulation of the maintenance process.

CONCLUSIONS

The equipment in the hot cell should be optimally placed within the workspace of the

MSM for a remote operation. But, due to the complexity in the hot cell, there are some parts of the equipment that cannot be reached by the MSM. In this study, a maintenance process for these parts of the equipment was proposed using virtual prototyping technology.

The virtual mockup of the hot cell process was implemented and the various analyses, such as workspace of the maintenance devices and operator's view through the shielding windows, were carried out in the virtual hot cell. Based on the result of these analyses, a maintenance process using a servo manipulator was proposed. And, for the verification, the graphic simulation of the proposed maintenance process was carried out.

The proposed remote maintenance process of the equipment can be effectively used in the real hot cell operation. Also, the implemented virtual mockup of the hot cell can be effectively used for analyzing the various hot cell operations and enhancing the reliability and safety of the spent fuel management.

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