가상 조작기를 이용한 3D 모델링 및 시뮬레이션

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3D Modeling and Simulation using Virtual Manipulator

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Abstract

The purpose of this paper is to verify and validate the maintenance tasks of the construction of a nuclear facility using a digital mock-up and simulation technology instead of a physical mock-up. Prior to the construction of a nuclear facility, a remote simulator that provides the opportunity to produce a complete digital mock-up of the PRIDE (Pyroprocess Integrated Inactive DEmonstration Facility) region and its remote handling equipment, including operations and maintenance procedures has been developed. In this paper, the system architecture and graphic user interface of a remote simulator that coincides with the extraordinary nature of a nuclear fuel cycle facility is introduced. In order to analyze the remote accessibility of a remote manipulator, virtual prototyping that was performed it by using haptic device of external input devices under a 3D full-scale digital mock-up is explained.

1. Introduction

The Pyroprocess is technology which separates and refines various nuclear materials contained in spent fuels with an electrochemical method at a high temperature. Utilization of this technology can substantially reduce the volume and temperature of spent fuel discharged from nuclear power plants. To obtain this technology, KAERI has conducted the Pyroprocessing technology linked to the electrolytic reduction since 1997. It has developed the construction design technology of the Pyroprocess mock-up facility and various hot cell equipment with fully remote operation capabilities for its safe operation and maintenance. The Pyroprocess requires that an operator must manage a process with a remote manipulator because every process has to treat high-radiation nuclear materials inside the hotcell in a nuclear fuel cycle facility. The skillful operation of the remote manipulator is one of the important factors that affect the safety of the Pyroprocess and uranium recovery rate. Especially, the operation and maintenance task of the devices by using a remote manipulator is an essential item that has been verified through simulation prior to the construction of the Pyroprocess facility. The best way to solve these tasks is by experiments in the physical mock-up facility. However, this method has a disadvantage in that it is both costly and time-consuming to produce and design the mock-up.

The DMU that depends upon only computer graphics has been used mainly by PLM (Product Lifecycle Management) and the manufacturing product development area. Previous work has stated that combining 3D graphics and haptic rendering can get a series of increasingly sophisticated simulation results [1, 2, and 3]. The remote simulator that will be introduced in this paper is a system which will fuse the DMU based on CAD (Computer-Aided Design) into CAE (Computer-Aided Engineering) technology based on a simulation that uses a kinematics algorithm of remote manipulation.

2. Remote Simulator: Functional Architecture

The simulator consists of an input module, a simulation module, and an external input module. Figure 1 shows a schematic diagram for the remote simulator. The input module imports a 3D CAD data to the simulator. To simulate the related remote manipulator by using an OpenInventor, the 3D CAD data has to be converted to a VRML format. The first thing to do in order to make a VRML (Virtual Reality Makeup Language) is to convert the 3D CAD data which was produced by a SOLIDWORKS package, into VRML file after reproducing it in an ENVISION package. The role of a XLM (Extensible Markup Language) parser creates a mechanism file (*.mec) and a factory file (*.fac) that need to make a digital mock-up.

All information of the pyroprocess facility digital mock-up that consists of devices and equipment is maintained the scene graph database. To simulate the accessibility and maintainability of the remote manipulator in virtual space, the human-machine interface is always an area of concern because input devices must be similar to devices which are used in the hotcell. External input devices selected to be simulated are Haptic device for discipline of the remote manipulator, 3D mouse for remote transmission for the BDSM and crane, Joystick for manipulating the BDSM, Shutter glasses for immersive display, and Motion tracker to view the inner side through lead glasses. To visualize the grip/release conditions of the haptic device, the blue button is used to close the gripper of the MSM and to grip the bolts.

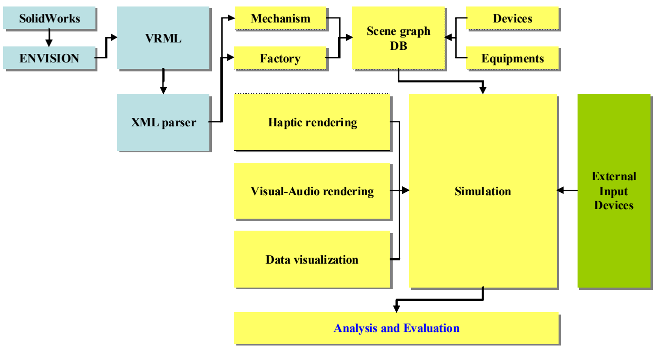

Fig. 1. Schematic diagram of the remote simulator: an input module, a simulation module, an external input module

The green button opens the gripper and can also be used for collision detection checking and feeling the collision. Figure 2 describes a procedure of grip/ungrip by using a haptic device.

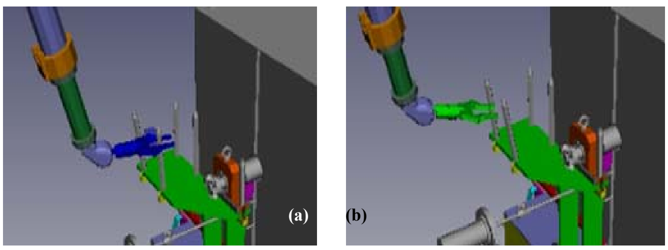

Fig. 2. Properties of haptic device buttons: (a) gripping with gray button turns blue (b) un-gripping or opening the grip turns to green color

3. Workspace Programming and 3D Visualization

A haptic device, which is one of the force response devices, was selected for a virtual manipulator to grip and to release objects on the virtual space. The haptic device plays the role of master of the remote manipulator. An analysis of inverse and forward kinematics needs to be simulated for the "slave" of the remote manipulator, which is the virtual manipulator that replaces the deteriorated part of the Pyroprocess. Kinematics data that has been used in the workspace analysis of the remote manipulator excerpted the CRL-RE model data which will be used the PRIDE. The D-H parameter of the CRL-RE model is shown in Table 1.

Table 1. D-H parameter of CRL-RE manipulator

	θ	d	a	α	range
1	$\theta_1+\pi/2$	700.0	0	$\pi/2$	$[-\pi/4 \sim \pi/4]$
2	$\theta_2+\pi/2$	19.000	0	$-\pi/2$	$[-\pi/4 \sim \pi/4]$
3	0	$1469.1+d_3$	-69.0563	π	$[-\pi/4 \sim \pi/4]$
4	θ_4	0.000	36.5125	$\pi/2$	$[\pi \sim -\pi]$
5	θ_5	0.000	0	$-\pi/2$	$[\pi/3.6 \sim -\pi/1.2]$
6	θ_6	190.00	0	0	$[\pi \sim -\pi]$

To simulate the accessibility and operability of the remote manipulator, inverse and forward kinematics are calculated from MAPPLE and PYTHON software. The result is used to input data in order to analyze the workspace of the remote manipulator at MATLAB. A calculated workspace value is used to make a 3D visualization of the workspace by using MESHLAB software. Figure 3 represents the software that is needed to make a workspace analysis and a procedure of the workspace analysis.

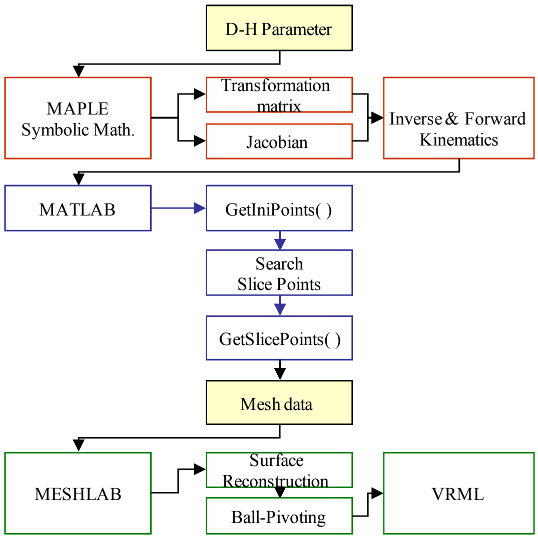

Fig. 3. Flow diagram of procedure of the workspace analysis

To find out if the workspace analysis could be calculated precisely, the workspace was calculated by using the same data in ENVISION made by Dassault, Ltd. ENVISION embodies a cohesive product/process development and prototyping environment. ENVISION focuses on the integration of the product, process, and system information with a powerful three-dimensional CAD physics-based graphical simulation environment. Figure 4 shows the result of the workspace analysis between the remote simulator and ENVISION.

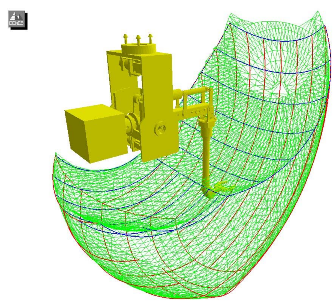

Fig. 4. 3D visualization of the result of the workspace analysis between the remote simulator and ENVISION

On the picture, the dot line is the result of the workspace created by ENVISION. The mesh shape with a green color is calculated by the remote simulator. The picture represents that both of them agreed exactly.

4. Validation of Verification of Workspace Analysis

In order to verify the result of the workspace analysis, a simulation of a deployment analysis was carried out based on construction drawings that were produced at the early design stage. The experiment conditions of the verification of the workspace analysis and the procedure of the simulation are as follows:

① Initial design value of powder mixing equipment was located at X=4.1m, Y=0.0m, Z=-2.55m with a rotation value of X=180°, Y=0°, Z=180°.

② The range of HMSM transport device which is installed at the wall of the PRIDE is 1.250m ~ 8.050m with X axes.

③ The user finds out if powder mixing equipment could be located within the workspace during scanning by using 3D mouse with left/right movements after attaching a virtual HMSM to the 3D visualization of the workspace result.

The result of the workspace analysis was that powder mixing equipment was out of the workspace range, as shown in Figure 5(a). In order for the powder mixing equipment to get into a workspace area, the simulation carried out several times. The result obtained was that the optimum deployment value is X=4.1m, Y=0.0m, Z=-1.8m (Figure 5(b)).

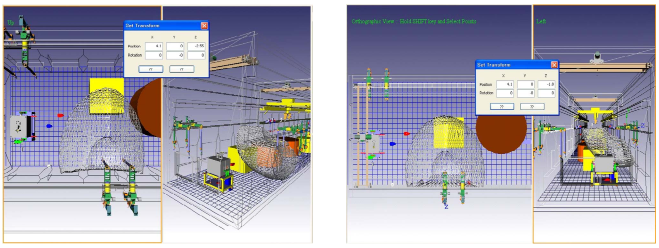

Fig. 5. Simulation of the deployment evaluation of devices using workspace analysis; (a) scene that a device is out of range from workspace at a initial design value(x=4.1, y=0.0, z=-2.55) (b) Scene that a device is within a remote manipulator's workspace after reassigning value(x=4.1, y=0.0, z=-1.8)

5. Virtual Prototyping

A remote technology laboratory carried out a maintenance and performance evaluation of process devices at ACPF. The result of maintenance tasks of about 12 selected modules showed that a maintenance rate of 11 modules succeeded over 91.7%. Table 2 shows the maintenance results of 4 major devices and items should be improved. In virtual prototyping, mesh rotate motor (12kg), which is in the middle of the performance test in order to simulate the accessibility of the remote manipulator, was selected. Figure 6(a) describes a real Vol-Oxidizer, and the red box is mesh rotate motor. Figure 6(b) represents a maintenance procedure by using a remote manipulator at the ACPF. The experiment assumes that the Vol-Oxidizer mesh rotate motor has to be replaced due to its breaking down.

This virtual prototyping carried out an experiment according to a new scenario, as follows:

① Loosen a lever surrounding the motor by using a haptic device and bring it down to 30 degrees to the side in order to lift up the motor

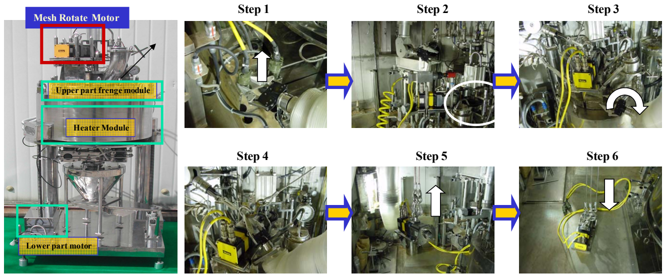

Fig. 6. Process device and maintenance task procedure drawing that was used the virtual prototyping: a) Components of Vol-Oxidizer and Mesh Rotate Motor b) Maintenance task procedure of Mesh Rotate Motor

② Lift the wireholder from the crane and hook it with a motor-ring

③ After lifting the motor with a crane, bring it down to the floor and separate the wireholder

④ Hook the new motor to the wireholder of the crane by using a haptic device(MSM)

⑤ Transfer the new motor to the initial position by using a crane

⑥ Separate the wireholder that was hooked to the new motor by using a haptic device

⑦ Lift the lever that was down 30 degrees with a haptic device(MSM)

Based on the experiment that was carried out and the information related to the maintenance task at the ACPF hotcell, a digital mock-up similar to a real hotcell was modeled, and a simulation of the replacement an old motor with a new one by using an external input device was implemented. A representative case of the simulation that was done in virtual prototyping is shown in Figure 7. Figure 7(a) describes moving a new mesh motor with the crane in order to replace a old mesh motor. Displaying a blue circle at the end-effector, it informs the user that the end-effectors have been gripped a lever successfully. At this time, the user feels a force response. Figure 7(b) shows that the crane has lifted up a new motor and is moving it.

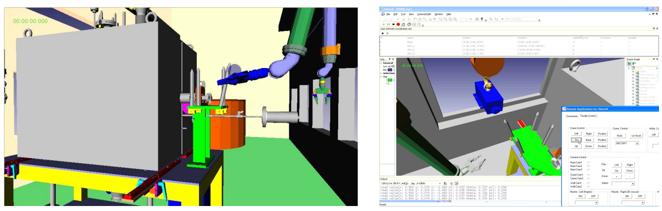

Fig. 7. Remote accessibility analysis by using haptic device and external input device: (a) Scene that haptic device grasps a lever. (b) Scene that crane is lift up new motor and moving it

The difficulty of the maintenance task in order to get a procedure of the maintenance through the simulation must be evaluated. To do this, there is a need for more research such as dynamic simulation by using a haptic device, collision detection related to equipment and utilities, and a tool center point(TCP) function to attach/detach tools.

6. Conclusions

The simulator has a variety of modules in order to solve a specific problem related to remote manipulation within a hotcell. But on the other hand, it has a disadvantage in that it is too complicated to use. To solve this problem, a GUI that enables the user to easily work the simulator and to improve its design was developed. A designed GUI proved to be able to archive successfully producing a digital mock-up of the Pyroprocess, analyzing the remote deployment of the process devices, and evaluating the accessibility analysis of the remote manipulator through virtual prototyping.

A deployment analysis of a remote manipulator and process devices in order to verify the result of the workspace analysis has found that it can realign the processes after identifying that they are out of range. A distance measurement method that was proposed in this paper has limits in order to measure a distance that a remote manipulator is capable of reaching when replacing major maintenance materials because of the distance on the 2D plane.

The mechanical and analytical cutting edge of the simulator was proven as an interface between the external input device and digital mock-up and played an important role in analyzing the accessibility of the remote manipulator and deployment analysis between process devices. This system is still going to be studied for gathering technical specifications, managing of requirements, and assisting with the design and procurement of new equipment and tools.

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