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PRIDE 3D Simulator for Virtual Verification of Remote Handling Procedures in Processing Cell

PRIDE 3D 시뮬레이터를 통한 공정셀 내부의 원격작업 가상검증

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The Korea Atomic Energy Research Institute (KAERI) constructed the PyRoprocessing Integrated inactive Demonstration facility (PRIDE) to carry out experiments on engineering scale pyroprocessing. PRIDE has a large processing cell that human workers are not allowed to access, and thus the equipment inside is operated from outside using remote handling systems. It is therefore essential to examine the operability and maintainability of the equipment in view of remote handling systems, and the equipment is thoroughly examined in a mockup cell before it is installed in the processing cell. If the equipment is tested in a virtual mockup rather than in a mockup cell, the development cost can be significantly reduced. The PRIDE 3D simulator was integrated for virtual verification of equipment that will be installed in the processing cell. All remote handling devices in the actual PRIDE were also virtually installed in the PRIDE 3D simulator. The 3D model of the equipment was loaded and located in the exact position in the virtual processing cell. A scenario to replace an actual electrode was implemented in the PRIDE 3D simulator. The design of the equipment and the working procedures in the scenario were successfully evaluated. The results demonstrated that the PRIDE 3D simulator can be used successfully as an alternative to actual mockup testing.

Keywords: Remote handling, 3D simulator, Virtual Reality, PRIDE, Pyroprocessing

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원자력 발전 이후에 누적되는 사용후핵연료를 해소하기 위한 다양한 연구가 시도되고 있으며, 특히 건식으로 사용후핵연료를 재활용하는 파이로 공정이 주목되고 있다. 파이로 공정의 공학규모 실증을 위하여 대형 공정셀을 구비한 PRIDE 시설이 구축되었다. 파이로 공정에 사용되는 용융염의 화학반응성을 고려하여, 공정셀 내부는 아르곤 분위기를 유지한다. 결과적으로, 작업자가 공정셀 내부에 진입할 수 없으며, 공정셀 내부에 설치된 모든 공정장치는 원격수단에 의해 공정셀 밖에서 원격조작을 통해 수행한다. 따라서, 공정셀에 설치되는 공정장치는, 설계단계에서 부터 원격작업을 고려하여 설계되어야 하며, 공정셀에 반입하기 전에 원격으로 작동이 가능한지 철저히 검증하여야 한다. 만약, 공정셀에 반입되어 작동하는 단계에서 문제가 발생하는 경우, 장치를 반출하여 수정한 후 재반입하기까지 많은 비용과 시간을 허비하게 된다. 공정장치의 원격성 검증을 위하여, 물리적인 목업을 사용할 뿐 아니라, 설계단계에서 3D 모델을 활용한 가상 검증이 가능하다.
본 연구는, 가상공간에 PRIDE 공정셀을 구성하고, 설계된 공정장치 3D 모델을 입력하여, 원격조작성을 검증하기 위한 PRIDE 3D 시뮬레이터 개발에 관한 것이다. 실제 PRIDE 공정셀의 형상과 공정셀에 설치되는 원격운전 및 유지보수 장치의 움직임을 가상공간에 구현하고, 공정장치의 3D 모델을 실제 설치할 장소에 위치할 수 있도록 하였다. PRIDE 공정셀에 설치될 전해공정장치의 전극교체 작업을 시뮬레이션 시나리오로 설정하여, 개발된 PRIDE 3D 시뮬레이터의 사용성을 검증하고자 하였다. 8단계로 이루어진 원격작업 시나리오를 구성하여, 각 단계의 원격작업을 성공적으로 모사함으로써, PRIDE 공정셀의 원격성 평가를 성공적으로 수행하였다.

중심단어: 파이로, PRIDE, 공정셀, 원격작업, 시뮬레이터, 가상검증

1. Introduction

In the nuclear industry, commercially operated facilities such as a nuclear power plants, fuel manufacturing facilities, radioactive material repositories, and waste disposal sites handle various forms of radioactive material. When handling radioactive material, the facilities are required to meet all legal regulations and administrative restrictions. Safety is a top priority, and specialized handling methods and procedures are required to safely handle radioactive materials.

Glove boxes are used to contain and handle small quantities of low-level radioactive materials. The confinement that the glove box provides, and the gloves mounted in the glove box are used to protect the workers from low levels of radioactive contamination [2], as shown Fig. 1 (a).

When highly radioactive materials are present, they need to be shielded from the human workers in shielded hot cells that require remote handling systems to handle the radioactive materials and processing equipment. Many nuclear facilities have hot cells to isolate the radioactive material from the human workers. A hot cell is usually constructed of thick concrete walls and have several windows made of thick radiation resistant glass [3], as shown in Fig. 1 (b). Various remote handling systems, such as a mechanical master-slave manipulators (MSM), electrical-servo manipulators and cranes, are installed in the hot cell so that the human workers are able to handle the radioactive material from outside of the cell [4-6].

The remote handling systems are used to operate the equipment, handle the radioactive material, operate tools, and perform the functions that would otherwise be performed by hand. The equipment inside the hot cell and the remote handling systems should be designed to be remotely maintained. All tools, baskets, and remote equipment are designed to be handled by the remote handling systems in the hot cell. In particular, the equipment should be modularized for convenient maintenance, allowing for repair or replacement of the failed parts with new hardware.

Once the hardware has been installed in the hot cell, it

(a) Glove box [2]

(b) Hot cell [3]

Fig. 1. Facilities for isolating radiation materials and remote systems.

is assumed to be radioactively contaminated, and repair or replacement can become difficult and costly. Prior to being used in a hot cell, all transport baskets, handling tools, operating equipment, replacement modules, and remote handling processes should be evaluated for remote handling and operation. Prior to constructing a hot cell, adequate remote handling systems should be selected with respect to the target operation. In addition, the physical capabilities (i.e., precision, accuracy, backlash, etc.) of the selected remote handling systems must be considered and understood and factored into the design of the equipment [7-9].

An evaluation of the remote operability and maintainability is usually carried out in a physical mockup, as shown in Fig. 2. A mockup facility typically has the same remote handling systems as the actual hot cell, minus the radioactive contamination or radiation levels. Repairs to equipment performed in mockup can be costly and time consuming. If the equipment can be examined in the design stage before fabrication, the developing cost can be significantly reduced by decreasing the trial and error in the physical mockup test. Fig. 3 shows the PRIDE 3D simulator for virtual verification [10].

This paper shows a virtual verification of the PRIDE facility using a 3D simulator in advance of fabricating the equipment. Chapter 2 introduces the PRIDE facility. Chapter 3 describes the details of the PRIDE 3D simulator, and one working scenario in PRIDE that was virtually verified as an application of the developed 3D simulator.

Fig. 2. Physical mock up for actual testing of remote procedures.

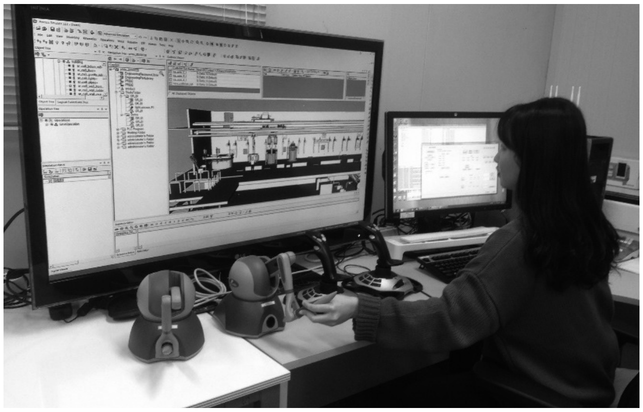


Fig. 3. PRIDE 3D simulator for virtual verification of remote procedures.

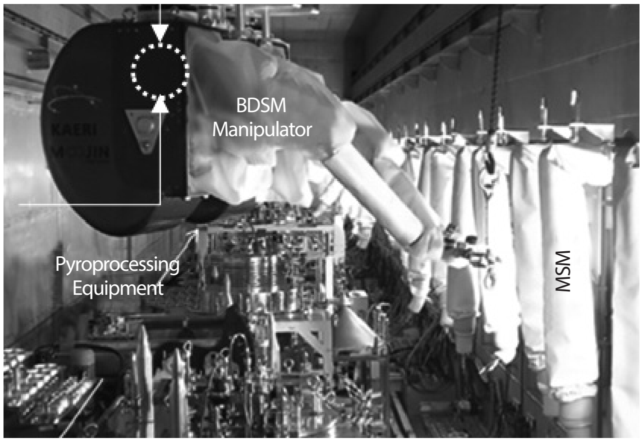


Fig. 4. Inside of the processing cell on the second floor in PRIDE .

2. PRIDE facility

PRIDE was built at KAERI for the purpose of demonstrating engineering-scale pyroprocessing experiments. A large Argon processing cell (40.3 m × 4.8 m × 6.4 m) was constructed on the second floor in PRIDE. Fig. 4 shows the inside of the processing cell. The cell was enclosed by stainless steel plates and polycarbonate windows were sealed by rubber O-rings to guarantee gas tightness. One 3-ton crane, 17 pairs of master-slave manipulators (MSM), and a bridge transported dual arm servo manipulator (BDSM) were installed for remote operation in the processing cell. One large transfer lock (LTL), one small transfer lock (STL), and two gravity tubes were included for material and equipment transfers into and out of the cell. Argon gas conditioning utilities were located on the first floor for regulating the amount of oxygen and humidity levels inside the hot cell [4, 11].

3. PRIDE 3D simulator

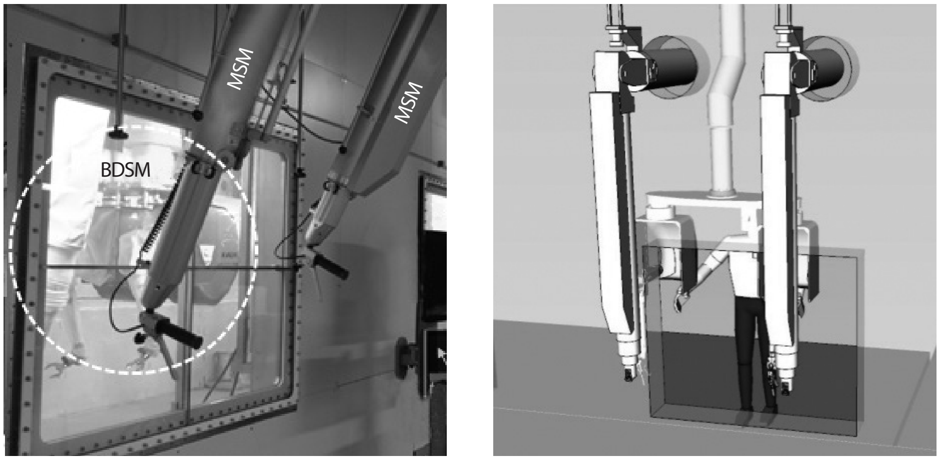
The PRIDE 3D simulator was developed using an industrial solution for enhancing the performance and reliability of the actual PRIDE equipment. Siemens and Dassault are leaders in 3D simulation technology, and they provided the simulation solutions of a factory design for an automotive vehicle to a production time analysis in manufacturing an automation system, or to the evaluation of new production lines with the branded solution names, Technomatix and Delmia. Both have proven their reliability and accuracy for long time periods in the industrial market. The PRIDE 3D simulator was integrated using Siemens Technomatix for a faster handling of 3D models and an easier integration of the user functions.

A general procedure to integrate a 3D simulator is composed of 4 steps, as listed below:

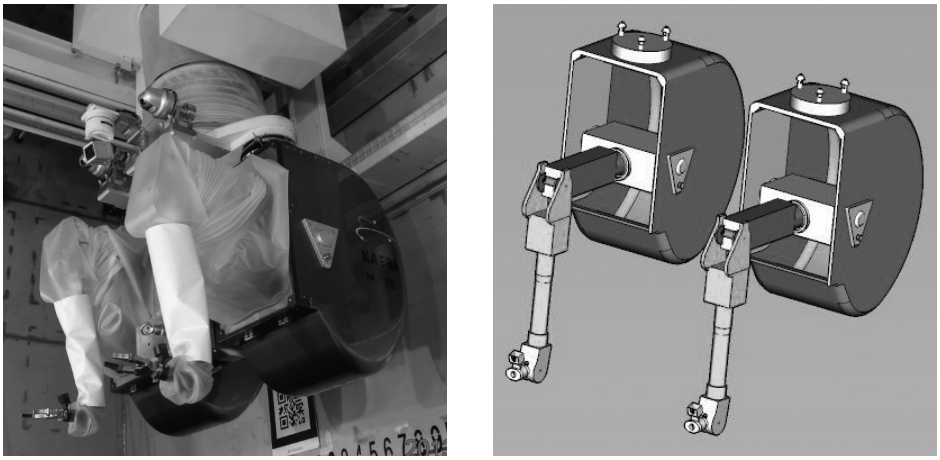
Step 1 : preprocessing and importing a 3D model
Step 2 : relocating the 3D model
Step 3 : assigning the kinematics
Step 4 : building the logics of each device, and generating the motion

Preprocessing is the first step to prepare and simplify the 3D model and convert it into JT format. Fortunately, 3D modeling of the PRIDE facility and equipment was carried out in the design stage, and the as-built drawings were also updated after PRIDE construction. Most of the 3D CAD data were acquired, and the rest were easily modeled from the as-built 2D drawings. The acquired 3D model was simplified to reduce the complex features for faster handling during the simulation. For example, bolts, bearings, and fasteners were removed. Curvatures and surfaces were adjusted as linear and flat. Finally, the simplified 3D model was converted into JT format, the only accepted format in Technomatix, which reduces the data size of the 3D CAD model by extracting its essential parameters.

The second step of integrating a 3D simulator was to locate the 3D model in a virtual space. Technomatix can load a JT formatted 3D model and relocate the loaded virtual equipment to the exact location for simulation. Fig. 5 shows the virtual remote system in the PRIDE 3D simulator, as compared with the actual system in PRIDE.



(a) Actual and virtual MSM



(b) Actual and virtual BDSM

(c) Actual and virtual LTL

Fig. 5. Actual and virtual remote systems in PRIDE and simulator.

(a) Actual view from camera (b) virtual view emulated by simulator

Fig. 6. Actual pictures from camera and the emulated viewing volume in the PRIDE 3D simulator.

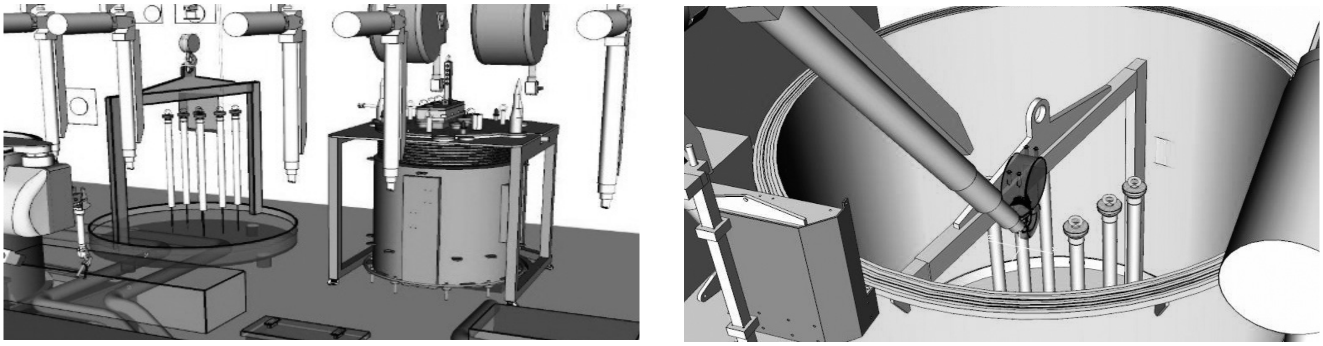


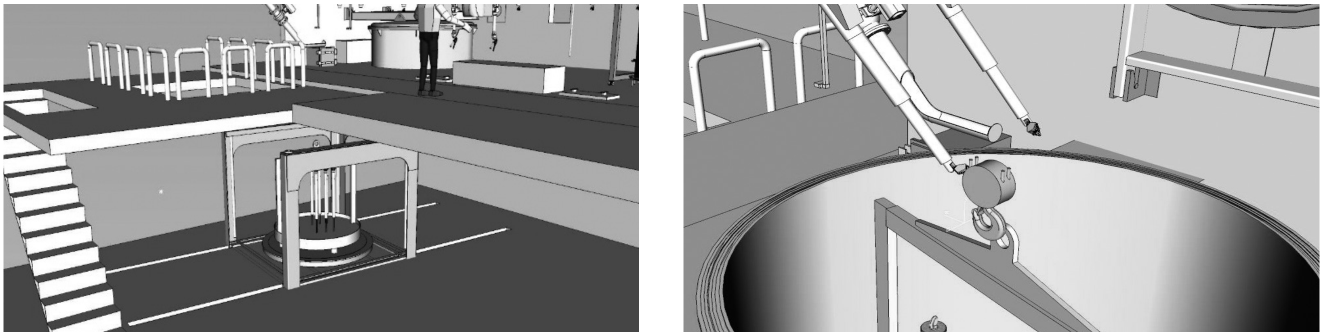
Fig. 7. Collision detection between objects in the PRIDE 3D simulator.

After finishing the virtual construction of all devices and equipment in a virtual facility, the constraints of mechanical motions of the devices and equipment are defined in step 3. Technomatix provides an intuitive method to assign the kinematics on a device, which is simply connecting each link and selecting a joint type by using drag and drop motion with a mouse so that the kinematics can be defined.

The last step is to make a logic sequence for the motions of the remote systems or equipment. This means to input the time information or condition to start or stop moving. In the PRIDE operation, human workers decide when and what to move by controlling the remote systems. Thus, the PRIDE 3D simulator provides control panels to manipulate the virtual remote systems.

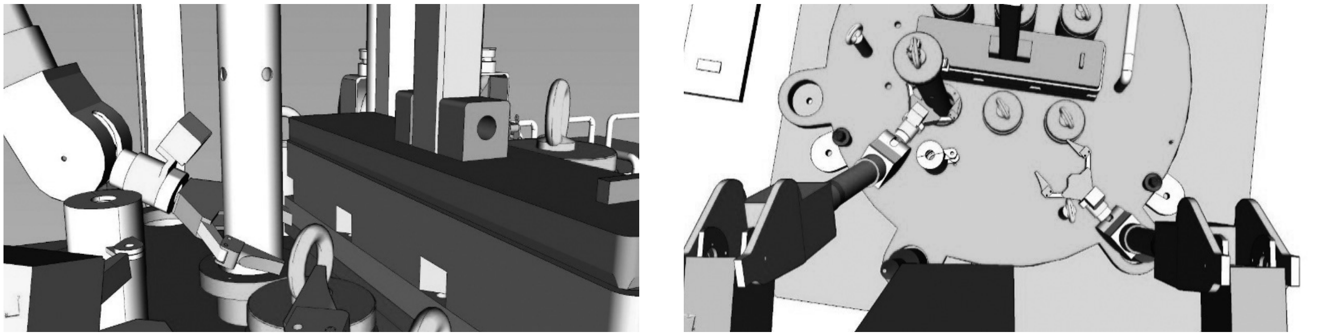
Two more functions, a viewing volume simulation and a collision detection, are implemented in the PRIDE 3D simulator. The remote handling starts from the proper observation of the target object. An out-of-sight target object results in it being out of control of the worker. Thus, one essential feature of the PRIDE 3D simulator is to provide an exact view from the camera at the installed position, or the sight of the human operator in front of a window, as shown in Fig. 6. The viewing volume from a position was calculated in the PRIDE 3D simulator. When important objects such as a valve knob or basket handle are occluded during an evaluation of the operating procedure, such information is fed back to enhance the equipment.

The collision detection is calculated in the PRIDE 3D simulator. This is useful when docking the modules, checking the work space, or finding the movement tolerance. When an object collides into other objects, it turns to red for visualizing the collision, as shown in Fig. 7. The collision detection consumes the computing time, especially when more objects or more complex features are involved. To ac-



(a) LTL operation in task 1.

(b) MSM and crane operation in task 4.



(c) BDSM operation in task 7.

(d) Hoist operation in task 8.

Fig. 8. Virtual verification of the procedure to replace an electrode.

celerate the simulation speed, the number of objects to be calculated was limited in the PRIDE 3D simulator.

4. Virtual verification of remote handling procedures

Virtual verification of the remote handling procedure in PRIDE was carried out using the 3D PRIDE simulator. The target scenario shows how to replace an electrode in equipment located in the processing cell. The scenario was composed of 8 operation tasks, as shown below:

Task 1: LTL operation to import a new module to be replaced
Task 2: Opening the LTL door in the argon cell
Task 3: Crane operation to approach the module
Task 4: MSM operation to connect the hook to the new module in the LTL
Task 5: Crane operation to move the module in the vicinity of the processing equipment
Task 6: BDSM operation to connect the hook of the axillary hoist to the module
Task 7: BDSM operation to approach the replacing spot in the processing equipment
Task 8: BDSM operation to insert the module into the installing slot

The main purpose of the simulation is to verify the feasibility of the operating procedure for each task and to give feedback for updating the existing operations manual. In each task, the related remote handling system was enabled. The operator grips the PHANToM, 6DOF input devices to manipulate the MSM and BDSM, or handles two joysticks to control the crane and hoists, as shown in Fig. 3. By using the interface window, the operator controls LTL/STL and monitors all information in the simulator. When the user successfully finishes each task, the simulation moves to the next procedure. The images in Fig. 8 were captured while the operator demonstrated each task. After completing the prepared scenario, the results were fed back to update the equipment design and the procedure manuals, and the usefulness of the PRIDE 3D simulator was sufficiently proven.

5. Conclusion

The PRIDE 3D simulator was integrated for virtual verification of the remote handling procedure in the PRIDE processing cell. All remote systems in the processing cell were virtually implemented in the PRIDE 3D simulator, and the remote systems were able to be controlled by the user interface including the input devices. The viewing volume of the camera was emulated, and the collisions between virtual objects were calculated in the simulator. The procedure used to replace an electrode was evaluated using the 3D simulator. The procedure included 8 tasks, and the related remote systems for each submission were activated. The operator controlled the appropriate remote system to transport and replace the electrode in each stage. Finally, the operator successfully completed the procedures, and the results were incorporated to update the equipment and manual, and thus the usefulness of the PRIDE 3D simulator was sufficiently proven.

Acknowledgement

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