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Deployment analysis and remote accessibility verification for a maintenance task in a PRIDE digital mock-up

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ABSTRACT

This study introduces an advanced modeling and simulation system that can verify and optimize a maintenance procedure at the early design stage of a virtual engineering system. System architecture, which is composed of modules used to analyze deployment of devices that deal with radioactive materials in a digital mock-up, and modules used to simulate accessibility of a remote manipulator for maintenance tasks, are discussed. Based on this architecture, new technology that enables a maintenance analyst to analyze pyroprocessing is proposed. Workspace analysis for remote manipulators, which can optimize a maintenance task at the radiation control area, is introduced. The mathematical background, with respect to the forward and inverse kinematics for a virtual manipulator accessing devices in a virtual environment, is described to establish a remote accessibility. Virtual prototyping is illustrated to carry out an experiment on the deployment analysis of devices and remote accessibility by a haptic device.

1. Introduction

In order to address the challenge of spent fuel management, the Korea Atomic Energy Research Institute (KAERI) has been developing pyroprocessing technology, combined with an electrolytic oxide reduction process, since 1997. KAERI has developed a digital mock-up of an advanced spent fuel conditioning process facility (ACPF) to demonstrate pyroprocessing, which can achieve more efficient and effective spent fuel management. An ACPF is a facility with similar modeling and simulation concepts as that of the advanced fuel cycle initiative (AFCI), which is a US technology development component of the global nuclear energy partnership (GNEP). Several laboratories under the DOE in the US have developed a simulation system, such as a simulation enabled safeguards assessment methodology (SESAME) (Hebditch et al., 2007), simulation institute for nuclear energy modeling and analysis (SINEMA) (Juchau et al., 2006), and verifiable fuel cycle simulation (VISION) (Jacobson et al., 2006). The PyRoprocess Integrated Inactive DEmonstration (PRIDE) is under development at KAERI to demonstrate and correct information related to a demonstration facility.

Pyroprocessing, which can be applied to spent fuel, requires manipulation by a highly skilled human operator. A remote manipulation environment, which a human operator has to oversee, is located on the inner side of a hotcell through a lead glass window. The remote environment has many 'blind-spots' as a result of camera placement; and the lack of visual information, when operating in a cluttered environment, makes maneuvering a manipulator very difficult. When this is exacerbated by strict time limits for a task completion, then collisions between the manipulator and environment can occur, thus resulting in damage. Fig. 1 represents the telescopic servo manipulator and location of the cameras in the ACPF.

To improve the efficiency of remote operation in the ACPF digital mock-up, the remote technology lab at KAERI has researched several methods, such as a real-time graphic simulator to monitor the spent fuel dismantling devices and development of an interface module for effective application of a digital mock-up. However, simulations that depend on 3D graphics are limited to the analysis of accessibility and operability of a manipulator. Specifically, to simulate devices describing how to remove, inspect, repair, and install parts quickly, safely, and accurately, 3D graphics should be used along with information about mechanical properties. Many design and analysis tools have been developed to evaluate numerous maintenance problems; however, current tools, which are used to analyze the behavior of manipulators and deployment of devices, have too high a cost and are too difficult to develop for this system.

This article introduces a system that can model nuclear facilities and devices at low cost, and simulate deployment analysis, remote accessibility, and remote interchangeability, effectively. We also

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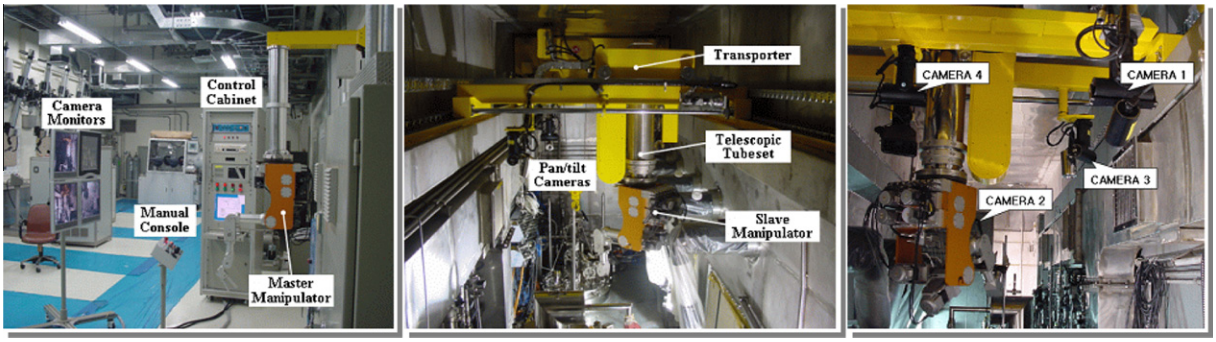

Fig. 1. Master manipulator (left), slave manipulator (center), and cameras (right) in the ACPF.

propose a scheme to enable an operator to improve remote manipulation by using a haptic device. The main function of the system that will be introduced is to build a digital mock-up of a nuclear fuel cycle facility, and to analyze the remote operability between a human operator and the virtual environment. To implement a system that is composed of various modules, we have to fabricate a graphical user interface (GUI), which enables a user to access the system easily and obtain precise results. The research results will provide basic data, from which we will extract the design criteria of the demonstration facility.

2. Related works

This section reviews the status of remote manipulator, haptic device, and virtual reality technology to improve the quality of validation and testing, with respect to a maintenance procedure in pyroprocessing facilities. In the nuclear industry, advanced computer graphic technologies, which can simulate various phenomena by using a digital mock-up, have improved. In the manufacturing industry, there have been efforts to develop a virtual simulator to validate control programs visually (Park et al., 2006) and establish maintainability-engineering tools that automate generation assembly/disassembly procedures. These techniques use computer aided design (CAD) visualization systems with human figure models in virtual reality systems, where engineers can interact with the system by using virtual input devices (Jeffrey et al., 2003). The mechanical engineering laboratory (MEL) in Japan has developed maintenance technologies for a multi-robot collaboration in remote environments by using the internet and robotics. This system consists of web-based mobile manipulation, a local master station, a multimedia communication server, and an on-line graphic simulator to perform maintenance work, where a fixed robot grips the holdfast on a bolt-on lid while another mobile-based robot approaches it to loosen and remove the bolt, in a plant mock-up. Application research on a remote manipulation has also been undertaken in a virtual orthopedic surgery training simulator (Sourina et al., 2000). Force feed-back devices are advanced technology that redoubles the simulation effects, which approximates real-world sensations in virtual, teleoperable, and hazardous environments. CEA has been developed as a real-time simulator for maintenance tasks, with force feed-back in an immersive environment (Caroline et al., 2005). In remote operation technology for spent nuclear fuel facilities, COGEMA and CEA developed a telemanipulator that has been applied to the decommissioning area (Desbats et al., 2004). Ando et al. (2001) proposed a VR simulator and workspace display systems for micromanipulators based on workspace analysis. Cavusoglu et al. (2001) created a quantitative method to evaluate the kinematic ability of surgical manipulators to perform critical tasks, such as suturing, by using open surgical suturing motion data, collected from experiments done with an expert surgeon.

3. System architecture for modeling and simulation

To build a high-quality system that can analyze remote manipulation under a virtual environment, a system analyzer and

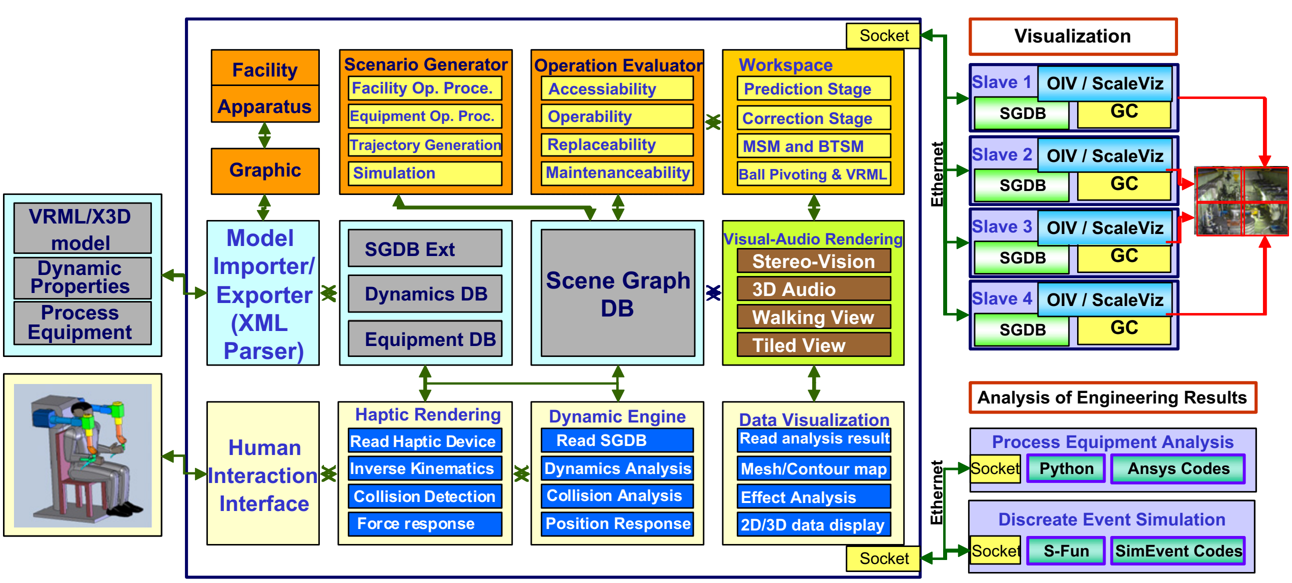

Fig. 2. Schematic diagram of the system architecture for a modeling and simulation tool.