User Interface Technology to Reduce Mental Transformations for Tangible Remote Dismantling Simulator

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1. Introduction

The dismantling activity over the major components is one of the most difficult activities in numerous activities of nuclear facility decommissioning. In the planning step, the selection of dismantling equipment and organization of dismantling processes suitable for the site have a significant effect on the cost and safety of the whole decommissioning [1]. High-level radiation of the major components restricts access by human workers, and makes an accident or outage during the dismantling process more difficult to deal with. Since unexpected situations causes waste of budget and an aggravation of safety, the preliminary verification of the dismantling processes and equipment by the tangible remote dismantling simulator is very important. The design optimization of the dismantling processes and equipment is one of the most important objectives of the tangible remote dismantling simulator, as well.

This paper proposes a user interface technology to reduce mental transformations for the tangible remote dismantling simulator. At the dismantling process simulation using the tangible remote dismantling simulator, the most difficult work is the remote operation handling the high degrees-of-freedom (DOF) manipulator due to complex mental transformations. The proposed user interface technology reduces mental transformations with constraints using the point projection and direction projection.

2. Methods and Results

In this section technical characteristics of the tangible remote dismantling simulator and technology for mental transformations reduction are described.

2.1 Tangible Remote Dismantling Simulator

The tangible remote dismantling simulator means the simulator that the operator handles the remote dismantling equipment to segment the major components of the nuclear facility in the immersive virtual environment. The tangible remote dismantling simulator consists of a high-definition display, haptic joystick, and ergonomic simulator platform. Fig. 1 shows that an operator cuts a control rod guide tube with a seamless remote dismantling system [2] using the tangible remote dismantling simulator.

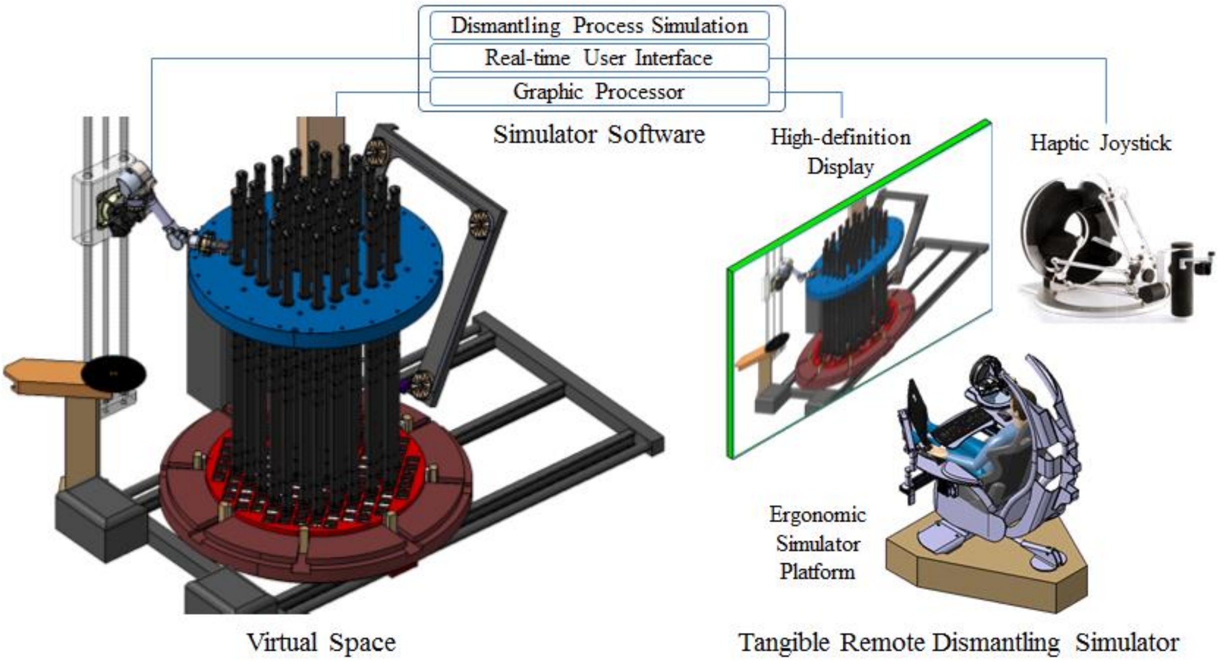

Fig. 1. Tangible Remote Dismantling Simulator

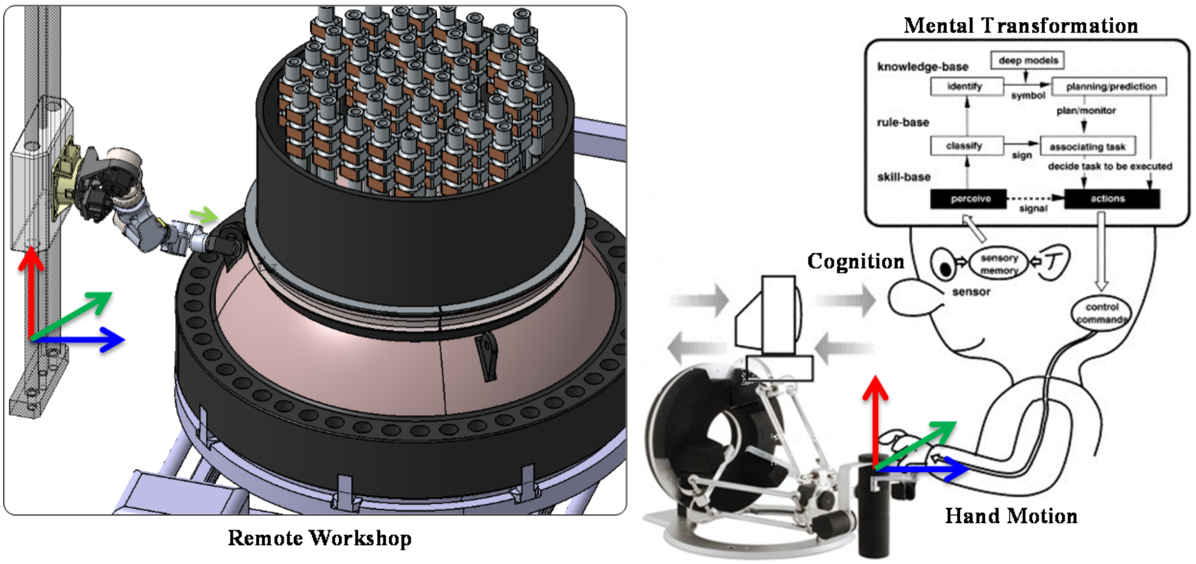

Fig. 2. Mental Transformations of Remote Operator

2.2 Technology for mental transformations reduction

The spatial operation of the high DOF manipulator loads the remote operator with considerable mental transformations which means the sequential mental work from cognition of the remote workshop to hand motions for the joystick controller of the manipulator [3] (see Fig.2).

In this paper, the technology to reduce mental transformations by creating spatial constraints with the virtual fixture and exerting the reaction force to the operator with the haptic joystick is proposed. The spatial constraints are created by the point projection and the direction projection.

1) Point Projection Technology
The point projection technology is to reduce a single DOF by constraining P_1 of the end-effector from penetrating the virtual fixture (see Fig. 3). When the P_1 is required to move on the specific surface of the cutting objective, the point projection technology lets the operator be free from the depth-directional handling by locating the appropriate virtual fixture beneath the objective surface. The haptic joystick provides the operator with the reaction forces corresponding to the stiffness of the surface and penetrating depth in the normal direction of the surface.

2) Direction Projection Technology
The direction projection technology is to reduce a couple of DOF by constraining the orientation of the end-effector within the normal direction of the virtual fixture. Fig. 4 shows that the orientation of the end-effector is forced to be identified with the normal direction of the virtual fixture. T_M, T_L, T_E, and T_V are the transformation matrices corresponding to the coordinate systems of the manipulator, link, end-effector, and virtual fixture. When the P_1 is required to move on the specific surface of the cutting objective in the direction perpendicular to the surface, the direction projection technology lets the operator be free from the orientation handling by identifying the orientation of the end-effector with the normal direction of the virtual surface.

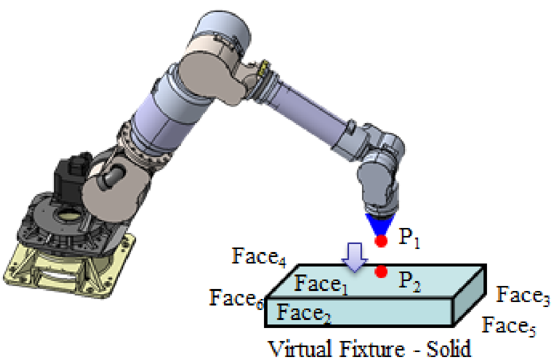

Fig. 3. Point Projection Technology

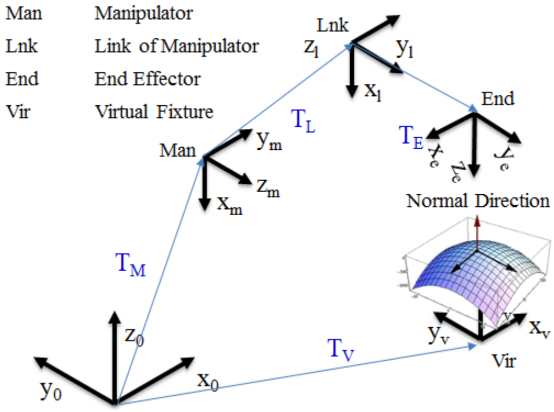

Fig. 4. Direction Projection Technology

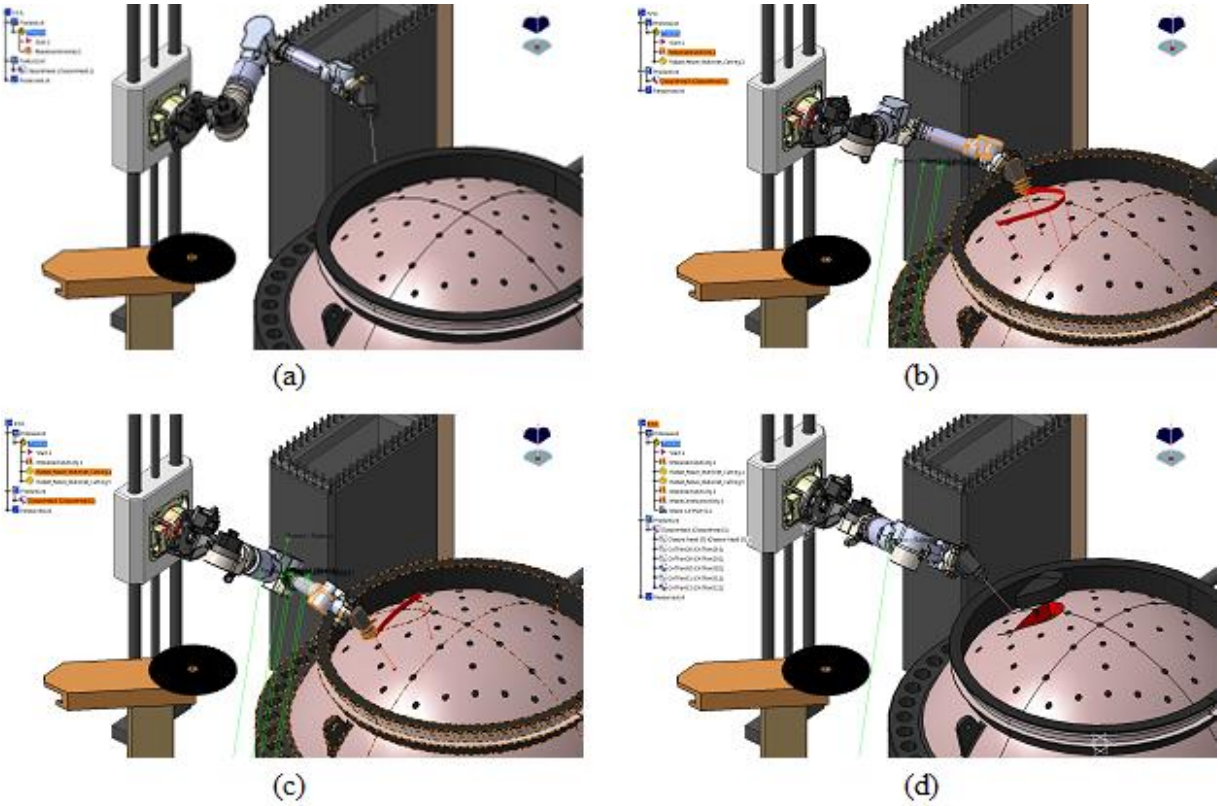

Fig. 5. Test Results (a) initial condition of segmentation process, (b) first cut along curved path on hemispherical surface, (c) second cut cross over curved path, (d) final condition of segmentation process

2.3 Test Result

The proposed mental transformation reduction technology is applied to the cutting process over the closure head of the reactor pressure vessel (RPV) for the purpose of the verification test. The cutting process over the closure head of the RPV using the high DOF manipulator and abrasive water jet cutter is one of the most difficult cutting processes for the remote operator because the remote operator has to control the position and orientation of the water jet nozzle to keep the specific distance between the water jet nozzle and the hemispheric surface of the closure head and the orientation of the water jet nozzle perpendicular to the hemispheric surface, as well. In fact, the previously described control is impossible for the remote operator.

The mental transform reduction technology is demonstrated successfully by the test result. The remote operator of the tangible remote dismantling simulator easily performs the cutting process simulation using the haptic joystick.

3. Conclusions

The test result of the cutting process over the closure head of the RPV demonstrates that the proposed mental transformation reduction technology is operated successfully in the tangible remote dismantling simulator, and lets the operator be easy to control the high DOF manipulator even in the most difficult operation by reducing DOFs to be controlled manually. The proposed technology is expected to increase the productivity of the tangible remote dismantling simulator, and to be able to contribute to the development of the advanced remote dismantling system.

Acknowledgements

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