Viewpoint Presentation for Teleoperation of Robot Manipulation in Fuel Debris Removal Task with 3-Dimensional Obstacles

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***Abstract*—In this study, we extracted the techniques for viewpoint presentation in teleoperation under a complex environment. Teleoperation is often used for construction sites, and the main focus of related works is on optimal viewpoints in flat ground without taking into account changes in the terrain. However, in some special situations, such as inside the pedestal of a nuclear plant crushed in a disaster, the working environment could be complicated, including mountain-like fuel debris and broken structure materials. In this study, we investigated the problems of teleoperation under the environment with 3-dimensional obstacles, and summarised the techniques for viewpoint presentation.**

***Index Terms*—teleoperation, viewpoint selection, robot manipulation, obstacle-ridden environment.**

I. INTRODUCTION

After the Fukushima Daiichi Nuclear Power Plant accident of the Tokyo Electric Power Company, Incorporated (TEPCO), which occurred in March 2011, fuel debris was left inside the pedestal of the plants. Presently, efforts are in progress to decommission the plants. The removal of radioactive fuel debris inside the reactor containment vessel is one of the challenges [1]. According to the report [1], grasping and suctioning are considered methods for removing debris. Teleoperation, in which the human operator manipulates the construction equipment from a safe remote location, was used to protect operators from radioactive contamination. However, the efficiency of teleoperation is approximately half of the efficiency of onsite work during excavations [2].

To improve efficiency, several studies have focused on visualizing the surrounding environment for operators in remote sites [3] [4]. Gualtieri et al. [5] showed that a significant improvement in the average accuracy of the grasp can be done by selecting the correct viewpoint. In teleoperation, viewpoints are often fixed. Kamezaki et al. [6] proposed an autonomous camera control system using six displays to reduce the blind spots caused by fixed viewpoints. However, multi-display systems increase the cognitive load on the operator and require skill and experience for the operator to determine the optimal viewpoint [7]. Therefore, it is crucial to select a single optimal viewpoint.

Different from the flat terrain, the environment inside the pedestal of the nuclear power plant is complicated due to the accumulated fuel debris and structural component broken down during the earthquake and the following explosions. According to the report, mountain-like fuel debris and broken structure materials are formed inside the pedestal [8]. Techniques for viewpoint presentation are expected to improve the work efficiency in this unprecedented working environment.

In this study, we extracted the techniques for viewpoint presentation in teleoperation under a complex environment through trial and error inside the laboratory.

II. PROPOSED METHOD

In this study, five members of our research group who had no teleoperation experience before manipulated the robot arm to grasp specific targets. Through trial and error, the techniques for viewpoint presentation in teleoperation under a complicated environment are extracted.

Figure 1 shows the top view of the experiment environment. Using cardboard, a contour model was made assuming the shape of the fuel debris to be a normal distribution. The contour model was made of about one-tenth of the real size. In addition, as shown in Fig. 2, sticks and obstacles were made to have a shape similar to the fallen structural components of the plant. The sticks and obstacles are placed on top of the fuel debris to reproduce the scene.

After the experiment begins, the camera operator sends the camera video to the monitor in real-time, and the robot operator is asked to sit in front of the monitor and operate the robot arm with a joystick while grasping the target. Under

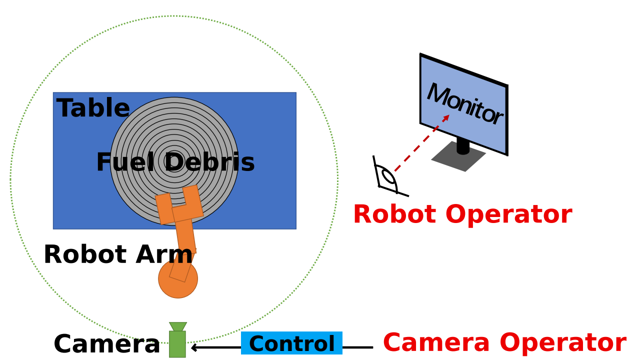

Fig. 1: Top view of the experiment environment

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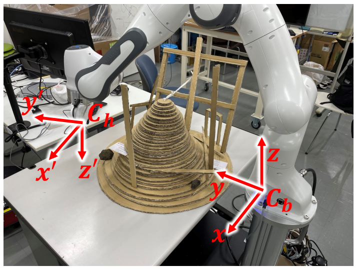

Fig. 2: Contour model and robot arm

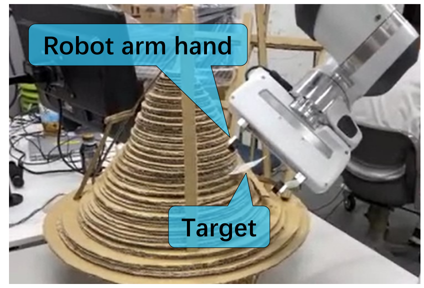

Fig. 3: Difficulty in the depth detection. The depth relationship between the target and the robot arm hand cannot be easily recognized by the robot operator in the 2-dimensional image.

any circumstances, the robot operator can only receive visual information by looking at the monitor instead of looking at the fuel debris directly. The position and altitude of the camera can be changed according to the request of the robot operator. A robot arm, whose name is Panda Arm, manufactured by Franka Emika was used.

Because the pebble-like debris and plate-like debris are reported as fuel debris inside the pedestal [9], we use two pebbles and two name cards to represent the real fuel debris as shown in Fig. 2. The original camera position is behind the robot arm as shown in Fig. 1. The angle and position change depending on the requests from the robot operator. After the experiment, an interview is conducted to collect their comments and thoughts during the experiment.

III. DISCUSSIONS AND RESULTS

Two coordinates are defined as shown in Fig. 2. The C_b coordinate system represents the body coordinates, and the C_h coordinate system represents the hand coordinates. Based on the observations, we consider that the behavioral pattern of the robot operator can be divided into two phases.

1) Phase one (Approaching phase): The phase in which the robot arm moves to the vicinity of the target. In this phase, the robot operators used the C_b coordinate system to give verbal instructions and the main focus was on the positional relationship between the robot arm and the fuel debris.

2) Phase two (Target grasping phase): The phase in which the robot arm grabs the targets. The main focus was on the positional relationship between the gripper of the robot arm and the target. A problem in phase two is depth perception. For example, as shown in Fig. 3, one of our members was trying to grab the name card but finally managed to grab it after four attempts.

A. Viewpoint presentation techniques for each phase

1) Techniques for phase one: The most commonly used viewpoints were those perpendicular to the direction of movement of the robot arm. The top view was used frequently because the movement in both the x-direction and the y-direction was clearly visible from the top view.

2) Techniques for phase two: The most commonly used viewpoints were those on the $y^{'}$-$z^{'}$ plane and the $x^{'}$-$z^{'}$ plane of the C_h coordinate system. Because the distance between the gripper of the robot arm and the targets was close, the robot operators began to fine-tune the position of the gripper carefully. As a result, the comprehension of the surrounding environment is vital. Showing the top view and the side view multiple times repeatedly could help the robot operator to improve the understanding of the surrounding environment.

IV. CONCLUSION

In this study, we extracted the techniques for viewpoint presentation in teleoperation under a complex environment. In the future, we would like to propose an active viewpoint presentation algorithm that can be adapted inside nuclear power plants.

REFERENCES

[1] Tokyo Electric Power Company Holdings, Inc.: "Mid-and-Long-Term Decommissioning Action Plan 2022" (in Japanese), March 31, 2022, https://www.tepco.co.jp/decommission/progress/plan/pdf/20220331.pdf, accessed July 13. 2022.

[2] K. Chayama, A. Fujioka, K. Kawashima, H. Yamamoto, Y. Nitta, C. Ueki, A. Yamashita, and H. Asama: "Technology of Unmanned Construction System in Japan", *J. Robot. Mechatron.*, Vol. 26, No. 4, pp. 403–417, 2014.

[3] R. Komatsu, H. Fujii, Y. Tamura, A. Yamashita, and H. Asama: "Free Viewpoint Image Generation System Using Fisheye Cameras and a Laser Rangefinder for Indoor Robot Teleoperation", *ROBOMECH Journal*, Vol. 7, No. 1, pp. 1–10, 2020.

[4] Y. Sugasawa, S. Chikushi, R. Komatsu, J. Y. Louhi Kasahara, S. Pathak, R. Yajima, S. Hamasaki, K. Nagatani, T. Chiba, K. Chayama, A. Yamashita, and H. Asama: "Visualization of Dump Truck and Excavator in Bird's-eye View by Fisheye Cameras and 3D Range Sensor", *Proceedings of the 16th International Conference on Intelligent Autonomous Systems (IAS)*, pp. 480–491, 2021.

[5] M. Gualtieri and R. Platt: "Viewpoint Selection for Grasp Detection", *Proceedings of the 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pp. 258–264, 2017.

[6] M. Kamezaki, J. Yang, H. Iwata, and S. Sugano: "An Autonomous Multi-camera Control System Using Situation-based Role Assignment for Tele-Operated Work Machines", *Proceedings of the 2014 IEEE International Conference on Robotics and Automation (ICRA)*, pp. 5971–5976, 2014.

[7] D. E. Crundall and G. Underwood: "Effects of Experience and Processing Demands on Visual Information Acquisition in Drivers", *Ergonomics*, Vol. 41, No. 4, pp. 448–458, 1998.

[8] Tokyo Electric Power Company Holdings, Inc.: "Fukusima daiichi gensiryoku hatudensyo 3 gouki gensiro kakunouyouki naibu tyousaeizou karano 3jigen fukugen kextuka" (in Japanese), April 26, 2018, https://www.tepco.co.jp/nu/fukushima-np/roadmap/2018/images1/d180426_08-j.pdf#page=35, accessed July 13. 2022.

[9] Tokyo Electric Power Company Holdings, Inc.: "Fukusima daiichi gensiryoku hatudensyo 2gouki gensiro kakunouyo uki naibu tyousa jixtushi kextuka (sokuhou)" (in Japanese), February 13, 2019, https://www.tepco.co.jp/decommission/information/newsrelease/reference/pdf/2019/1h/rf_20190213_1.pdf, accessed July 13. 2022.