An Intuitive Robot Teleoperation System for Nuclear Power Plant Decommissioning

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1. Introduction

Over the past several decades, nuclear power plants have been established around the world. Their operating life is about 30 to 60 years, and the decommissioning of aging nuclear power plants is becoming a major issue [1]. However, the radioactive environment inside the nuclear power plant is harmful to humans so the decommissioning of the plant has to be done remotely. Thus, many studies have reported on a robot teleoperation system for nuclear power plant decommissioning and maintenance [2, 3].

Generally, a robot teleoperation system consists of a master device and a slave robot. The master device senses human intention and delivers it to the salve robot. A haptic device and an exoskeletal robot are widely used as the master device [4, 5]. The slave robot carries out operations delivered by the master device. It should guarantee enough degree of freedom (DOF) to perform the instructed operation and mobility in the environment inside the nuclear plant, such as flat surfaces and stairs. A 7-DOF robotic arm is commonly used as the slave device.

2. System Configuration

2.1 Master device

Fig. 1 shows the developed compact exoskeletal master device [6]. The master device with an exoskeletal structure has advantages over other kinds of master devices; the operator can intuitively and easily control the human-arm-like slave robot and reach a large working space.

Fig. 1. The proposed system's exoskeletal master device and stair-climbing slave robot.

However, the complexity of the human shoulder joint makes it challenging to develop an exoskeletal master device that effectively replicates human motion and provides comfortable shoulder movement and sufficient range of motion. Therefore, we developed an exoskeletal device that has two 9-DOF arms. Each arm is composed of a 6-DOF shoulder-elbow mechanism including a long stroke prismatic joint and a 3-DOF wrist mechanism to ensure comfortable and unconstrained human motion.

2.2 Slave robot

The developed slave robot consists of a stair-climbing mobile platform, a dual arm slave robot, and a 3D camera (Fig. 1). The slave robot should be able to move around inside a nuclear power plant. Thus, we used a 6-DOF wheel-linkage mechanism to construct a mobile platform for the slave robot that not only moves on flat surfaces, but also climbs stairs [7].

The developed mobile platform has several advantages. It uses two omni wheels (passive) and two in-wheel driving wheels (active) for high driving efficiency on flat surfaces; it can climb stairs with arbitrary height and depth, automatically; it uses laser displacement sensors to estimate the stair's height and depth; and it ensures that the slave robot is very stable as it climbs stairs.

The dual 7-DOF arm robot is located at the top of the mobile platform. The redundancy of the DOF in each arm enables the robot to perform various tasks, such as inspection, sorting, packaging, and moving waste materials. The 3D camera is mounted on the dual arm robot through a 2-DOF neck. This provides visual information about the working place to the operator controlling the master device from a remote site.

2.3. Sensing and control system

Fig. 2 shows the schematic diagram of the sensing and control system. The master device measures human motion using 20 absolute encoders that are installed on each joint (two encoders are used for each forearm supination joint [6, 8]), and it senses the input signal for the mobile platform. The measured human motion and input signals are converted into a work instruction packet and then transferred to the salve robot through wireless communication. The work instruction packet consists of two end-effector homogeneous transformation matrices (HTMs) and commands for the stair-climbing mobile robot.

The controller in the slave robot receives the instruction packet and controls the actuators in the dual arm robot, mobile platform, and neck. The dual arm robot and the mobile platform have separate control modules, which makes it possible to modularize each component of the device. The controller in the dual arm robot controls the position of 18 actuators in the dual arm and the neck based on the closed-loop inverse kinematics (CLIK) scheme with the proportional-derivative (PD) feedback and the HTMs.

The controller in the mobile platform generates the joint trajectories of the stair-climbing mobile robot based on the command and displacement sensor data from the sensor receiver. The motor drivers receive the commands from the mobile platform controller, and they control the four linear actuators and two driving wheels that enable the device to move on flat surfaces and climb/descend stairs.

The 3D visual information is acquired from the 3D camera on the slave robot, and it is independently transmitted to the 3D monitor at the master site through the high definition multimedia interface (HDMI) wireless communication module.

3. Results of the Experiment

To verify the performance of the robot teleoperation system, an experiment was conducted in an environment that is similar to an actual teleoperation environment. A screen wall was placed between the master site and the remote site. Only 3D visual information of the working place was transferred to the operator. Wearing the master device and 3D glasses, the operator controlled the slave robot remotely. Using the slave robot, the operator perform four tasks: a) moving on a flat surface, b) climbing stairs, c) moving obstacles (waste materials), and d) descending stairs. The slave robot received the stair-climbing/descending commands from the master device and automatically climbed/descended the stairs.

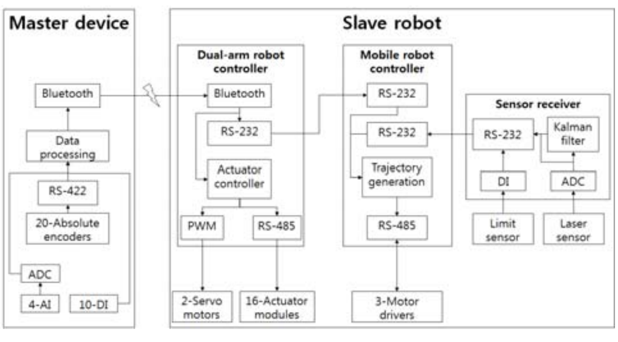

Fig. 2. Control flow chart of the proposed robot teleoperation system.

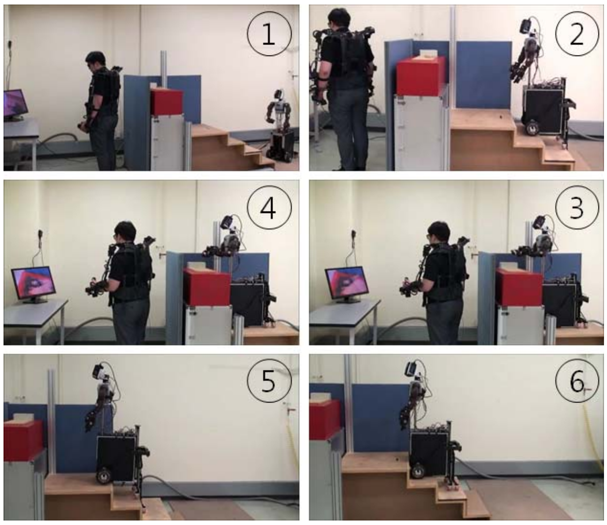

Fig. 3. Simulated robot teleoperation experiment.

For the moving obstacles task, the operator could intuitively control the dual manipulator using the proposed exoskeletal master device and 3D visual information.

4. Conclusion

This paper proposed a robot teleoperation system for nuclear power plant decommissioning. It discussed an experiment that was performed to validate the system's usability. The operator wearing the exoskeletal master device at the master site controlled the slave robot enabling it to move on a flat surface, climb/descend stairs, and move obstacles. The proposed robot teleoperation system can also be used in hazardous working environments where the use of such robots would be beneficial to human health and safety. In the future, research studies on the protection against radiation that damages the slave robot should be conducted.

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