Control System Design of Reactor Robot for Object Salvaging Underwater

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Abstract. A reactor robot for object salvaging underwater was designed to reduce the labor intensity of operators under the nuclear radiation environment. The control system of the robot, composed of control system hardware and control system software, was designed to be compact and radiation resistant. The control algorithm of the robot based on current, velocity, and position feedback of each motor makes the robot achieve the goal of salvaging exactly and rapidly. In order to verify the stability of the control system, the salvaging foreign matter experiment was tested in nuclear base. The result shows that the control system of the robot is stable enough.

Keywords: Reactor robot · Object salvaging underwater · Control system · Control algorithm

1 Introduction

As the development of nuclear power plant automation, the robot technology is widely used in this field. The robot can replace the operators to accomplish some tasks, avoid the hazards caused by long-term exposure of operators to the nuclear environment. Therefore, using robot to replace the operator has become the consensus [1–7].

In recent years, especially after the accident of Fukushima Nuclear Power Station, many robots have been applied in the nuclear plant. "Packbot 510" is a robot developed by American iRobot company. Fin-shaped support wheel is mounted on both sides of this robot's underpan which uses caterpillar structure. The size of the support wheel is 889 mm in length, 521 mm in width, and 178 mm in height. There are two models of 4-DOF manipulator matching for the robot, and their maximum grasp ability is 13.6 kg and 6.8 kg, respectively. Different kinds of sensors can be mounted on the robot. This robot was the first batch of the rescue robot which entered in the accident scene of Fukushima Nuclear Power Station. It moved in the wreckage and returned the data of the nuclear accident site [8–10]. "Rosemary" is a robot which is developed based on the robot named "Quince" by Chiba Institute of Technology in Japan. It consists of a crawler mobile platform and a manipulator fixed on the mobile platform. All the key

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components are replaced by the radiation-resistant ones on the basis of “Quince”. After 11 main components have been tested, the result of the irradiation experiment proved that the robot could work for at least 400 h in the radiation environment [11–16]. In addition, for different demands, the researchers in China, Germany, France, England, Canada, South Korea, and other countries have done majority researches and developed a series of specialized purposed robots for nuclear power stations [17–20].

During the normal operation of the nuclear power plant, underwater inspection is a routine task. Once foreign matter is found underwater, operators need to use salvage equipment for underwater salvaging operations. To solve this problem, a reactor robot for object salvaging underwater was designed to reduce the labor intensity of operators under the nuclear radiation environment.

2 The System Composition

According to the functional requirements, the robot is divided into robot mechanical body and robot control console. Figure 1 shows the system composition of the robot. The robot mechanical body, including wheeled mobile platform, 4-DOFs manipulator, and camera system, is used as an executive mechanical structure for underwater foreign matter salvage. The robot control console, including control instruction interactive system, data acquisition system, video capture system, and other hardware, “Robot real-time control system” software, is used as control core unit to remote control the robot. The control instructions are issued through the man–machine interaction interface, while the sensor information installed in the robot mechanical body is received and displayed in the robot control console.

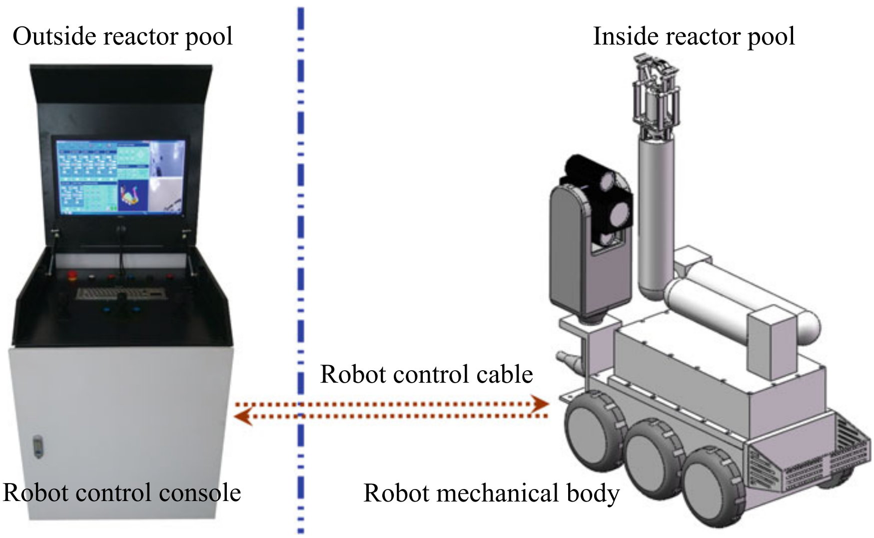

Fig. 1. The system composition of the robot

3 The Robot Control Console

Considering the robot running in the RX plant where the nuclear power plant reactor pressure vessel is placed, the robot control system is integrated into a control console as much as possible due to the high safety requirements of the system. Through the study of the working area, robot uses the mechanical body to realize the design target. And the control system ensures the safety of the operation, the accuracy of the location, and the speed of the grabbing. According to the requirements of the function, the robot chooses the reasonable hardware equipment and the reasonable control strategy to optimize the foreign matter salvaging operation.

3.1 The Hardware of the Control System

In order to provide sufficient operability, the Advantech industrial computer is used as the main control unit which provides adequate hardware interface to facilitate the integration of control instruction interactive system, data acquisition system, and video capture system. In the control instruction interactive system, each joint uses Copley driver and Maxon servomotor as the driving unit. In order to minimize the connected cable weight between robot mechanical body and control console, and provide reliable instruction interaction at the same time, each node and the main control unit uses CAN bus as the control protocol. In the data acquisition system, analog data acquisition card is chosen to collect analog information of three joysticks. Number one joystick controls the manipulator end executor of MRR along the X, Y, Z three-axis linear motion and wrist joint rotation movement in the Cartesian coordinate. Number two joystick controls the wheeled mobile platform of MRR front, rear movement, and pivot steering movement. Number three joystick controls the main camera PTZ horizontal, vertical rotation, and camera lens focal length zoom. In the video capture system, the main camera controller uses P150R camera controller of Ahlberg Electronics Corporation. The output signal port connects the MRAD-S color radiation-resistant camera through a radiation-resistant cable. The input signal port connects I150USB camera signal converter of Ahlberg Electronics Corporation via a dedicated cable. Operating personnel realized the control of the main camera through this series of hardware connections. Compared with the main camera, auxiliary camera has fewer functions. Only using a separate controller fixed to the dedicated mounting holes of control console connected N29F radiation-resistant camera via a dedicated cable, operating personnel realizes the control of the auxiliary camera. In addition, in order to realize the video display of the main camera and the auxiliary camera, the main camera controller and auxiliary camera controller are designed with a dedicated image signal output port which is connected to the video capture card. Figure 2 shows the structural composition of the control system hardware.

3.2 The Software of the Control System

To ensuring safe, controllable, and efficient control of the robot, the control system software of the robot is designed to provide reliable multimode motion control of the robot. The control command for the desired action is issued in the human–computer

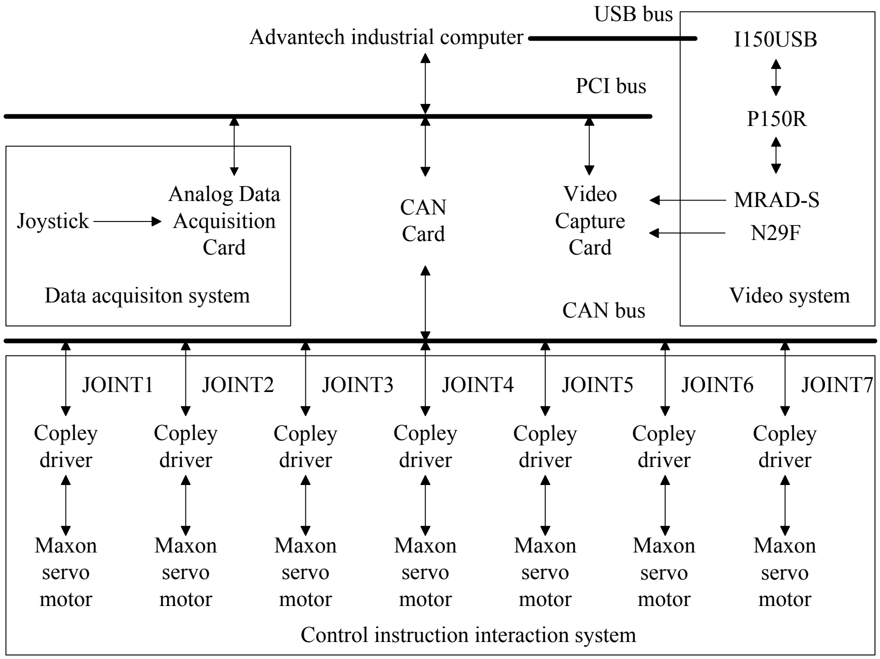

Fig. 2. The structural composition of the control system hardware

interaction interface through the mouse, keyboard, and joystick. Meanwhile, the human–computer interaction interface in real time displays the sensor information installed in the robot mechanical body. The response of the front panel of the control system software is operated through the man–machine interaction interface. According to the function, the control system software can be divided into seven modules, namely, three-dimensional model real-time simulation module, parameter configuration module, single-axis control module, multi-axis linkage module, teleoperation module, main camera display module, and auxiliary camera display module. Figure 3 shows the control interface of the software for robot's remote control system.

4 The Control Algorithm of Salvaging Foreign Matter

The control algorithm of salvaging foreign matter based on current, velocity, and position feedback of each motors uses the combination mode of semiautomatic on a massive scale and manual operation on a small scale. This method can make the robot achieve the goal of salvaging exactly and rapidly. Specifically, it designs "pre-set setting zone" in the control system software. There are five pre-set setting zones which are "calibration location", "pre-working location", "grabbing location", "place location", and "zero location" in the human–computer interaction interface. In the process of operation, the fixed algorithm is written on those five pre-set setting zones, with

Fig. 3. The control interface of the software for robot's remote control system

semiautomatic being used in the operation. Then, the operator operates relevant position via one-click way which is a button in the human–computer interaction interface.

5 Experiment

To test the comprehensive performance of robot and verify the control algorithm of salvaging foreign matter, we were being the experiment of salvaging foreign matter in a nuclear base. The way of the experiment is that operator controls robot to search and salvaging foreign matter. First, when the robot is in the initial state, the operator uses the main camera pan–tilt to search environment and check the position of foreign matter. Then, the operator controls the robot to salvaging foreign matter and puts the foreign materials into the container. Finally, the operator makes the robot get back to the zero position.

In this experiment, the operator issued the order to the human–computer interaction interface by mouse, keyboard, or analog stick, and robot completed the test of salvaging foreign matter successfully. Hence, it can verify that the control system of the robot is stable enough.

6 Conclusion

In order to reduce the labor intensity of operators under the nuclear radiation environment, a reactor robot for object salvaging underwater was designed. The robot control system is integrated into a control console as much as possible due to the high safety requirements of the system. The control system of the robot, composed of control system hardware and control system software, was designed to be compact and radiation resistant. The control algorithm of salvaging foreign matter based on current, velocity, and position feedback of each motor uses the combination mode of semi-automatic on a massive scale and manual operation on a small scale. The salvaging foreign matter experiment was tested in nuclear base and the result shows that the control system of the robot is stable.

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