The Development of Robot Control System for Nuclear Facilities

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Abstract: Nuclear robots should be developed for the reduction of radiation exposure, lower man hours, shorter power outage, and also improved worker safety concerns in performing hazardous and dangerous tasks. Among the components of a nuclear robot system, a robot control system equivalent to a human brain is a crucial point because a nuclear robot does not work without a control system. Therefore, in this paper, we will explain the requirements for a robot control system for a nuclear robot from a general point of view and also review the robot control systems of nuclear robots that were developed domestically, to assist a researcher beginning with the design for the control system of nuclear robots. The explained robot control system will be useful to develop the control system for industrial robots, home robots and other robots which are needed for tele-operation and are controlled through the internet.

Keywords: Nuclear facilities, Nuclear robot, Robot control system, Mobile Robot, Manipulator

1. INTRODUCTION

The demands of nuclear robots have been growing in the nuclear industry to ensure the safety of nuclear facilities, detect early unusual condition of it through an inspection and to maintain its efficiently. Nuclear power now accounts for over a half of the domestic electric supply with a sizable scale of nuclear power plant operation. And also improving the safety and rate of operation of a nuclear power plant is looming large. Hence nuclear robots should be developed for the reduction of radiation exposure, lower man hours, shorter power outage, and improved worker safety concerns in performing hazardous and dangerous tasks.

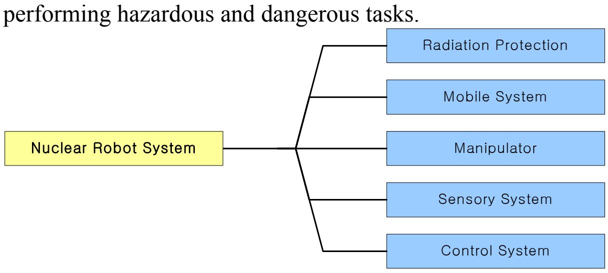

Fig. 1 The elements of nuclear robot system.

To carry out several tasks instead of a human, a nuclear robot system generally requires the following. Firstly, a nuclear robot system should be protected against radiation for operating in a nuclear power plant. Secondly a mobile system is required for a nuclear robot system to access several places in nuclear facilities autonomously. Thirdly, manipulators should be mounted onto the nuclear robot system to complete the given tasks successfully such as handling radioactive wastes and objects, etc. Fourthly, a sensory system, such as CCD cameras, ultrasonic sensors, temperature sensors, dosimetry equipments etc, is required for operators to observe the surroundings of the nuclear robot and the status of the nuclear facilities. Finally, nuclear robots necessitate a control system for the operators to control the nuclear robots. The control system generally consists of a supervisory control part for operators, remote control part for a mobile system and a manipulator, and a control architecture for coordination. The supervisory control system, which consists of a man-machine interface and joystick, is required for operators to be able to efficiently and safely manage the nuclear robots. The remote control part is required to make the mobile system and manipulator follow accurately the operator's command. To make a robot control system from a mobile system, manipulators, a sensory system, control architecture is required. The control architecture determines the interrelationships among the abovementioned systems.

The robot control system equivalent to a human brain is a crucial point for a nuclear robot, because a nuclear robot does not work without the robot control system. It is not easy for a beginner to develop the efficient control system of a nuclear robot.

Therefore, to assist any researcher beginning to design the control system of a nuclear robot, in this paper, we will explain the requirements of a robot control system for nuclear robots from a general point of view, and also review the robot control systems of nuclear robots that were developed domestically.

This paper is structured as follows. Section 2 will briefly explain the necessary requirements for a robot control system of the nuclear robots. In section 3, three robot control systems that have been developed in KAERI will be explained.

2. REQUIREMENTS ON NUCLEAR ROBOT CONTROL SYSTEM

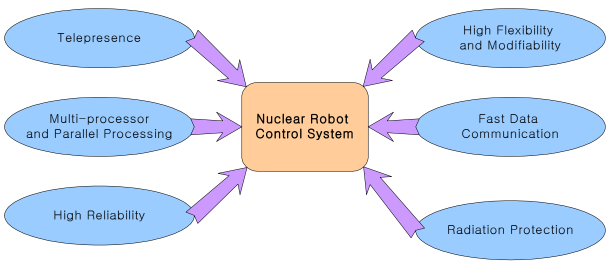

Fig. 2 The requirements of nuclear robot control system.

To be useful in designing the control system of a nuclear robot developed for nuclear facilities, it is necessary to investigate the requirements for the control system of a nuclear robot. Hence the requirements for the control system can be described from a general point of view as follows:

- Telepresence: The man-machine interface in the supervisory control part should provide operators with sufficient information of the place a nuclear robot is working in at nuclear facilities.
- Multi-processor and parallel processing: To cover a sufficient computing capacity for an advanced nuclear robot, multi-processor and parallel processing is needed.
- High reliability: The hardware of the control system should be reliable under radiation and high temperature.
- High flexibility and modifiability: The hardware and software of the control system should be changed and modified easily and quickly.
- Fast data communication: Exchanging of data between the operators and nuclear robot and among the multi-processors should be completed quickly.
- Radiation protection: The control system should be protected against radiation.

3. NUCLEAR ROBOT SYSTEM

Several nuclear robots have been developed during last decade at a nuclear robotics laboratory in KAERI (Korea Atomic Energy Research Institute). The control system of the developed robotic systems has been developed in consideration of the abovementioned requirements. Now the developed robotic system and robot control system will be explained in brief as follows;

3.1 KAEROT[2][3][4]

KAEROT was developed for operating in a hostile or unpredicted environment at a nuclear power plant. KAEROT consists of a mobile system, a 5 DOF manipulator and a sensory system, as shown in Fig. 3.

The mobile system is a special wheel type being able to climb up and down stairs with four three wheel assemblies each of which consist of three small wheels in star-like arms. On the top of the mobile system, a 5 dof manipulator is mounted.

The sensory system that is used for autonomous operation includes an inclination sensor, touch sensor and proximity sensors, as well as CCD cameras.

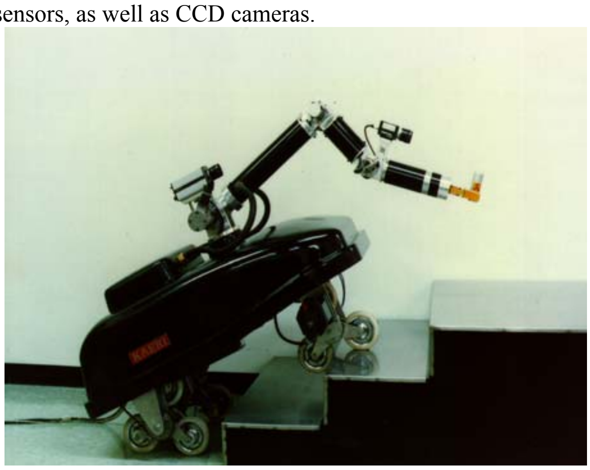

Fig. 3 The appearance of KAEROT.

Table 1 The specification of KAEROT

Item		Specification
Function		Inspection and Maintenance
Mobile System	Body Width	73 cm
	Body Length	106 cm
	Body Height	70 cm
	Front Planetary Wheel Weight	12.5 kg
	Front Planetary Wheel Weight	14.5 kg
	Min. width of Obstacle	5 cm
	Max. height of Obstacle	8 cm
	Max. Speed	1.26 km/h
Manipulator	DOF	5
	Total Length	106 cm

As shown in Fig. 4, the control architecture of the KAEROT is the distributed system architecture which consists of a supervisory control part which consists of a IBM PC 386 and a remote control part which is composed of a 8044 single board computer. At the supervisory control part which is shown in Fig. 5, operators observe the status and surroundings of the robot through the sensory system of KAEROT and control the robot by touch screen, a master manipulator, or joystick. The supervisory control part is interconnected with the remote control part by the protocol of a synchronous Data Link Communication (SDLC) and also gives a message with the speed of 2.4Mbps by adopting a communication protocol.

The software of the supervisory control part and the remote control part was developed on MS-DOS and iDCX 51 respectively and written in C language.

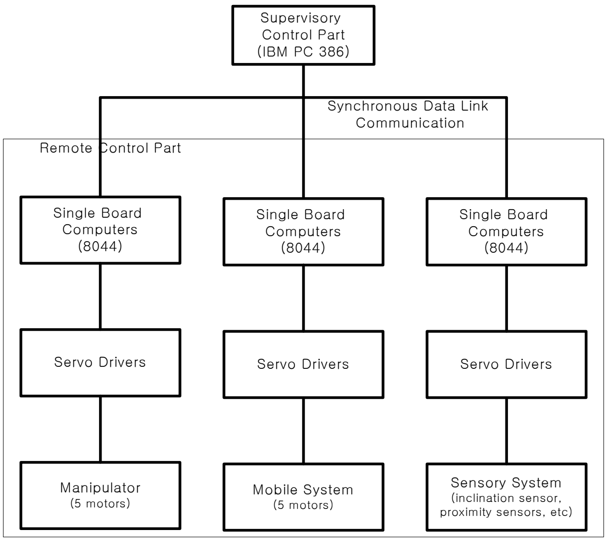

Fig. 4 The layout of control system of KAEROT

Fig. 5 The supervisory control console of KAEROT.

Table 2 The specification of KAEROT control system

Function		KAEROT
H/W	Supervisory Controller	IBM PC 386
	Remote Controller	8044 based SBC
	Communication	RS-485(wire) – 1.2Mbps
S/W	Real-Time OS	Nothing
	Supervisory Controller	MS-DOS
	Remote Controller	iDCX 51
	Communication	BITBUS

3.2 Nozzle Dam Installation/Removal Robotic System[1][4][5][6]

The nozzle dam installation/removal robotic system was developed to perform nozzle dam installation and removal tasks inside a steam generator water chamber from a remote site.

Fig. 7 The appearance of nozzle dam installation/removal robotic system.

This system consists mainly of two master/slave 6 DOF manipulators, a supporting device and a monitoring system. The slave manipulator is driven by a hydraulic manipulator and is designed to have a capacity of a 60kg load to carry the nozzle dam at the end-effector. The master manipulator is designed to have a good back-drivability, a light weight and a force reflection using a wire mechanism, as shown in Fig. 7. The supporting device has a 1 DOF rotary mechanism acting as the main lifting device and a 1 DOF linear mechanism mounted on the top of the rotary mechanism. The monitoring system was composed of camera and a light to view all the interior of the water chamber.

The main frame of this system is based on a hierarchical distributed configuration and consists of a supervisory control part and a remote control part. Fig. 8 shows the general layout and functional connections of the robot control system of this system. As shown in Fig. 9, the supervisory control part consists of the master manipulator, IRIS workstation, monitors,

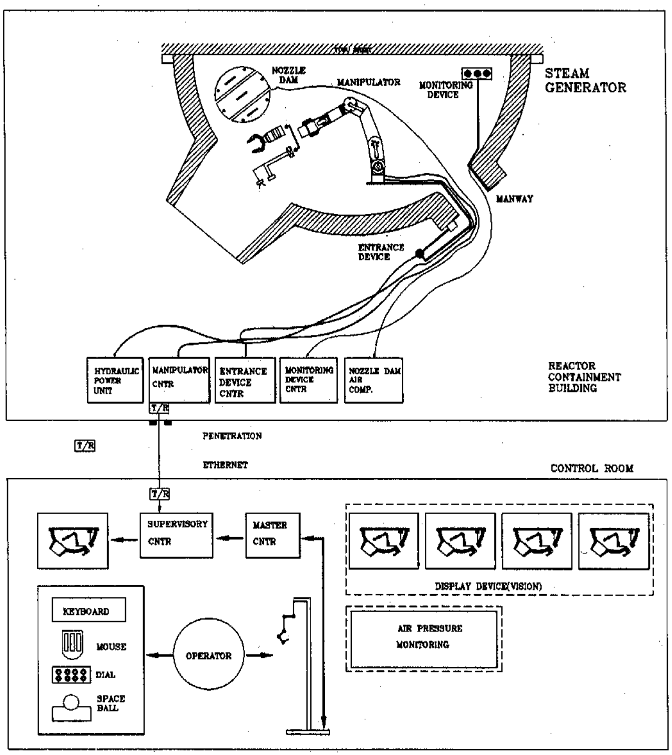

Fig. 6 The layout of nozzle dam installation/removal robotic system

space ball and dial box. Using the supervisory control part, operators operate the slave manipulator either in tele-operated or supervisory control modes. In the tele-operated mode, operators use the master manipulator to operate the slave manipulator. In the supervisory mode, this system can be operated from different levels such as a task, process, and servo levels. The remote control part consists of one master CPU board (VME-based 68040 Motorola CPU board) and three control boards. These exchange data by VME bus. The supervisory control part is interconnected with the remote control part by Ethernet which has the speed of 10Mbps.

The software of the supervisory control part and the remote control part was developed on an UNIX and VRTXsa real-time operation system respectively and written in C language.

Fig. 8 The appearance of master manipulator.

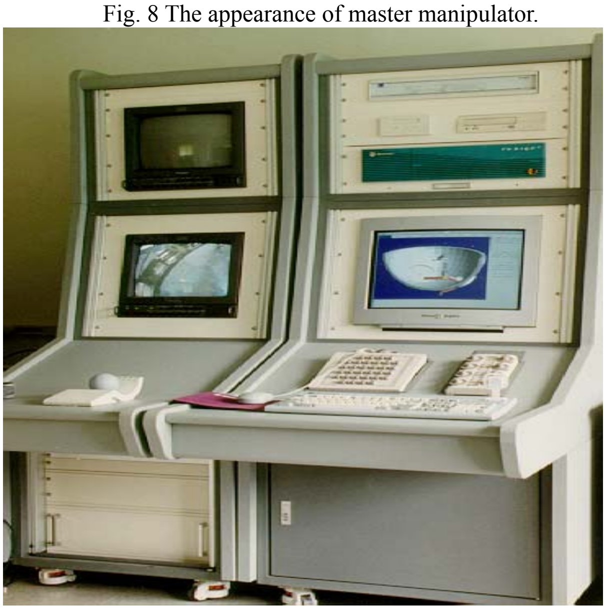

Fig. 9 The supervisory control console of nozzle dam installation/removal robotic system.

3.3 KAEROT/m1[1][5]

Safety related equipment of the Reactor Coolant System(RCS) has to be monitored and maintained to ensure the nuclear plant efficiency, availability and integrity from thermal loading, vibrations, and various types of corrosion. The RCS maintenance work conducted during a plant refueling outage involves complex tasks and the environment is inherently hazardous because of a high radiation level and contamination. Therefore, KAEROT/m1 was developed to maintain the RCS.

As shown in Fig. 10, KAEROT/m1 is a multi-functional mobile system for the inspection and maintenance of a primary system in a nuclear power plant. It consists of a mobile system, a manipulator and a sensory system.

The mobile system is designed to have the features of modularity and reliability as well as stability. It is a four planetary-wheeled mobile capable of ascending and descending stairs and navigating a flat surface with a zero turning radius. Each planetary wheel is equipped with three small omni directional wheels at an angle of 120 degrees. The omni-directional wheel is enclosed with six rollers in the shape of an ellipsoid and able to move in the desired locations.

The manipulator mounted on the top of the mobile system is a 6 DOF joint-controlled manipulator. The electrical-driven manipulator is designed to handle a 5kg payload at the end-effector at a full length, with a resolution of 0.3mm on all the axes for fine positioning of the end-effector. It provides a dexterous motion available for tele-operations. And elbows-out configuration at a maximum extended reach of 155cm. Joint positions are provided by encoders and consists of a base link, two links and wrist, all of which are linked through rotary joints. The body of the KAEROT/m1 is made of corrosion resistant glass fiber material for easy decontamination.

The control architecture of KAEROT/m1 is based on a hierarchical distributed configuration and consists of supervisory and remote control parts, as shown Fig. 11. The supervisory control part, which is located at the control center, consists of force-reflection joysticks, the control system of the force-reflection joysticks, SUN Sparc workstation and monitors as in Fig. 12. Hence an operator controls the mobile system by force-reflection joysticks. The remote control part is composed of several 68030 based single board computers, I/O board, A/D board and LAN controller. These change information by VME bus. The motion control board is to control the mobile system and the manipulator. The sensing module measures the values of an ultrasonic sensor, incline sensor, force/torque sensor and proximity sensor. The supervisory control part is interconnected with the remote control part by wireless Ethernet which has the speed of 10Mbps.

The software of the supervisory control part and the remote control part was developed on an UNIX and VxWorks real-time operation system respectively and written in C language.

Fig. 10 The appearance of KAEROT/m1

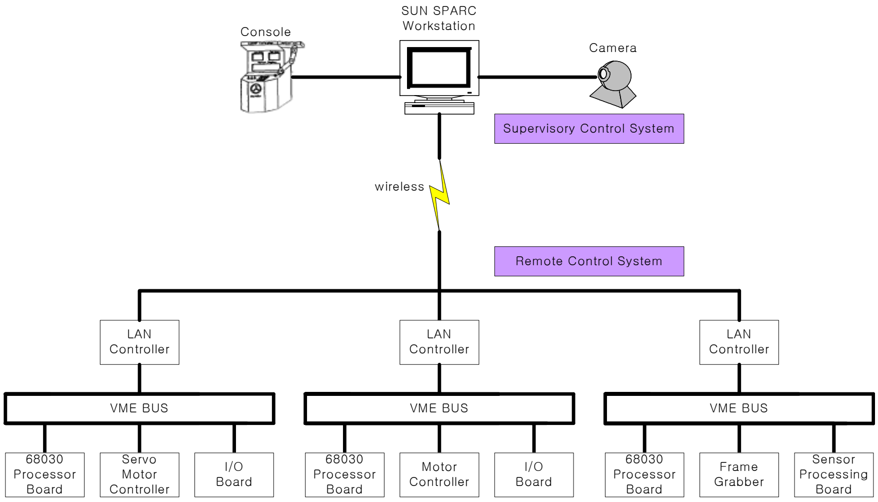

Fig. 11 The layout of control system of KAEROT

Table 3 The specification of KAEROT/m1 control system

Function		KAEROT/M1
H/W	Supervisory Controller	SUN Sparc Workstation
	Remote Controller	680x0 based SBC
	Communication	Ethernet(wireless)-10Mbps
S/W	Real-Time OS	Spectra
	Supervisory Controller	UNIX
	Remote Controller	VRTXsa
	Communication	Socket

Fig. 12 The supervisory control console of nozzle dam installation/removal robotic system

4. CONCLUSION

In conclusion, we suggested the main requirements of a robot control system for nuclear facilities and showed the three robot control systems that have been developed for nuclear robots in consideration of the requirements, to assist any researcher beginning to design the control system of a nuclear robot.

The abovementioned robot control systems will also be useful in developing the control system for industrial robots, home robots and other robots which are needed for tele-operation and are controlled through the internet or a wireless mobile phone.

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