Robotic Servicing System for Space Material Experiment

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INTRODUCTION

A containerless image furnace with a electro-static positioning device has been developed as one of material experiment facilities on the Japanese experimental module (JEM). It is characterized by heating / melting / cooling the sample whose position is kept without any contacts by actively controlled electro-static force exerted between the sample and a set of electrodes.

The experiment using the image furnace requires various servicing operations. We have been developing a robotic servicing system with an internal robot accommodated in the rack as an alternative to the crew. It aims to reduce the load of the crew by automating regular tasks and to increase the flexibility applicable to simple irregular tasks by introducing a remote teleoperation scheme.

The present robot has poor capability to replace the crew. In order to compensate it, introducing of the concept of the robot friendliness and improving the controllability of the teleoperation by the ground operator aids are essential.

In this paper, we identify the tasks to be performed by the robotic servicing system and discuss the way to compensate the capability of the robot. In addition we describe the evaluation tests using an experimental model.

SYSTEM CONFIGURATION

The total system packed into a rack as shown in Fig.1 is loaded on the pressurized module of JEM. The total system consists of an image furnace, a robotic servicing system, and a container.

The image furnace is composed of a spheroid mirror with a heating lamp inside and a vacuum equipment to process samples in a high vacuum.

The robotic servicing system is composed of a robot, CCD cameras, and a robot controller. The robot has six joints and its length is about 0.8 [m]. A force sensor and a hand camera are mounted on the wrist and a touch sensor at the hand. The robot, which is furnished in a limited volume, about 0.6x0.4x0.8[m], must have large reaching envelope in order to handle as many ampule as possible.

The container, which is a sample storage, stores about 50 ampules with a sample. Each sample is in a transparent ampule respectively so that the sample and the environment may not be

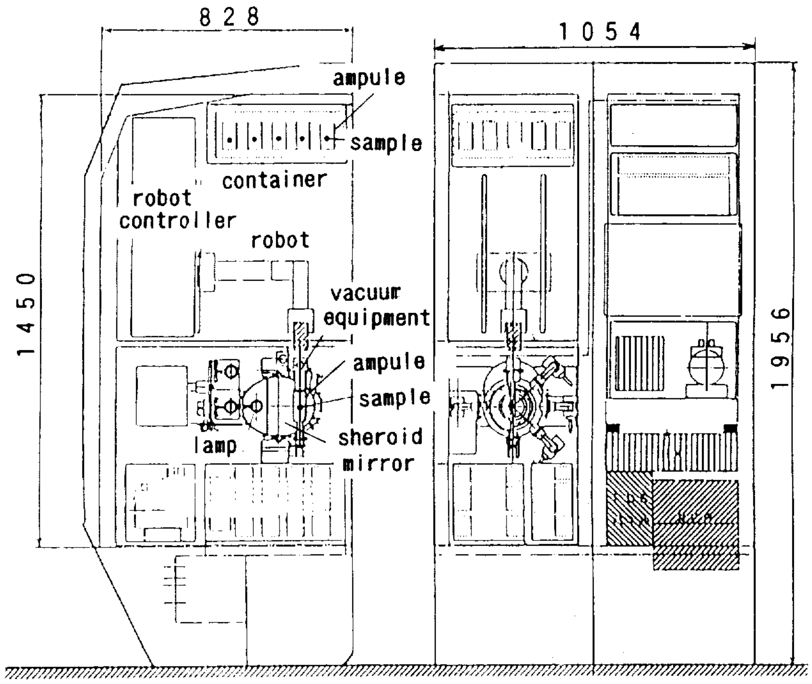

Fig.1 Total System Configuration

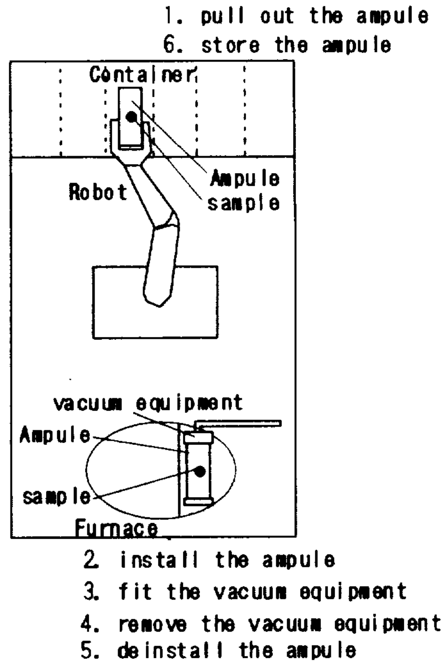

Fig.2 Regular tasks of exchanging ampule

contaminated.

ROBOTIC SERVICING SYSTEM

Tasks Performed by Robotic Servicing System

It is not necessary to automate all tasks. The tasks which are rarely required and includes complicated operations are performed by the crew.

The tasks of supporting the experiment are roughly divided into regular tasks and irregular tasks. The former is standard and pre-defined tasks and the latter is not.

The former consists of two kinds of tasks. One is the ampule exchanging task performed along the following process as shown in Fig.2. The robot pulls out an ampule from the container, installs it in the furnace, and fits it with the vacuum equipment. After the experiment, the robot removes the vacuum equipment, deinstalls the ampule from the furnace, and stores it to the container. These tasks involve various subtasks such as opening/closing the lid and handling the lever to fix/release. The other is the container exchanging task required after all samples are processed. It is intended that the former is performed by the robotic servicing system and the latter is done by the crew.

The irregular tasks are needed in the cases when the operation error occurs and when ground scientific investigators request undefined operations. In the former, such as improper gripping and the collision during transportation, the ground operator who has enough information on the facility inspects and recovers the situation by operating the robot if possible. If not, the crew do it. In the latter case, the operator controls the robot according to the investigator's request. For example, when the investigator requests to observe the processed sample, the operator controls the robot to set the ampule in various orientation in front of the camera.

Trade-off in Constructing Servicing System

In constructing the servicing system there are two items to be traded off. One is the trade-off between a servicing system with a robot and with a dedicated mechanism. We selected the former as it is superior to the latter in the following aspects; complexity of the mechanism, applicability to the

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irregular tasks, and the accessibility of the crew in case of accident.

The other is the trade-off between a robot mounted inside the rack and outside. As the experiments need the dexterous operations around the furnace, we selected the former to relax the mechanical interface requirements. In addition the latter requires severer safety level since the robot and the crew are accommodated together in the aisle.

Key Technologies of Robotic Servicing System

Obviously the capability of a present robot is much inferior to that of crew. In an aspect to execute commanded tasks, the dexterity and the tip force are insufficient. In order to compensate it the mechanical design with a concept of the robot friendliness is important.

In another aspect, that is autonomy, the robot does not have sufficient ability to cope with the irregular occasion by itself. The ground operator controls the robot with the remote teleoperation scheme to cope with it. But the remote teleoperation has limited controllability because of the communication time delay. The way to improve it with the ground operator aids using computer is important.

In the following section, these two items are discussed.

Automatic Operation

Exchanging the ampule as the regular tasks are executed automatically. The reliable execution is achieved by the following robot friendly design.

- the unification in size and shape of grasped surface
- the mechanism to fix/release the object only by pushing/pulling it, followed by the firm fixation with other methods after releasing it
- the mechanism to adjust the object position only by moving it along the guide
- the mechanism to handle the object with small force

We also designed the controller with following functions.

- to adjust the hand position by force control
- to verify the fixation of the ampule before releasing it
- to monitor the operation in real time using sensor information
- to decide whether to try again or not when the error is detected

As an example, the tasks of the ampule installation in the furnace is done as following. First, with the force control scheme, the robot pushes the ampule on the positioning guide. The ampule position is automatically adjusted. Next the latch attached on the ampule automatically hooks to the furnace. The robot can fix the ampule without additional motion while grasping it. Moreover, the robot releases it only after confirming the correct fixation by trying to pull it out, in order to prevent the ampule from freely-floating.

If the error is detected by the sensors, the robot performs the task again or requires the remote teleoperation according to the situation.

Remote Teleoperation

The rather simple irregular tasks are performed with remote teleoperation. But it has the poor controllability because of the communication time delay estimated at about 10 seconds.

In order to increase the controllability, a software simulator with following functions as the operator aids is introduced to the ground system.

- to estimate the robot motion without the time delay
- to overlay the estimated robot motion on the actual video image
- to correct the internal model by manually moving the estimated images on the actual ones
- to display the graphical image from appropriate position
- to record, edit, and play the command

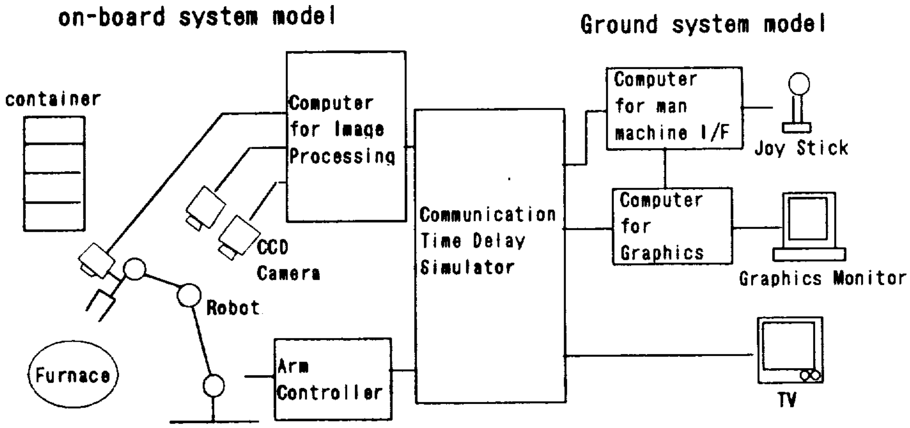

Fig.3 Block diagram of the experimental model

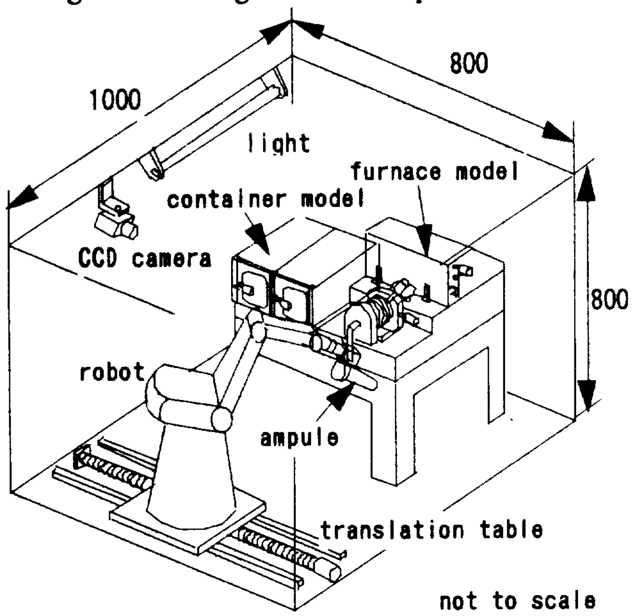

Fig.4 Outlook of the experimental onboard system

- to check and display the sensor data

Using the simulator, the operator can control the robot without feeling the time delay as he interacts with the graphically simulated environment. In addition, he can send the motion command to the onboard, only after verifying the commanded motion through the preview display. The simulator increases the reliability of the operation as well as the controllability.

EVALUATION TESTS

Evaluation tests are performed using experimental model. The objectives are to verify the feasibility of the robotic servicing system and to improve the reliability and the dexterity.

Fig.3 shows the block diagram of the experimental system. It consists of an on-board system model and a ground system model which are connected via the communication time delay simulator. Fig.4 shows the outlook of the onboard system model. It is composed of a robot, a container model, and a furnace model. The robot hand is newly designed but the robot arm is an industrial one because the robot configuration is not main issue.

Two experiments are performed. One is to perform a sequence of the ampule exchanging task automatically. The other is to install the ampule in the furnace with remote teleoperation. At the present state, the experimental results make sure that the tasks can be performed by the robotic servicing system.

CONCLUDING REMARKS

The material experiment using the image furnace needs various servicing tasks which are desired to be automatically performed without the crew. We have been developing the robotic servicing system to perform the tasks of exchanging samples and simple exceptional handling. The system can reduce much crew time. This paper identified the tasks to be performed by the system and discussed two important items to construct it; the mechanical design with the concept of robot friendliness and the way to improve the controllability by the ground operator aids. In addition we constructed the experimental model and verified the feasibility.

We are now constructing the bread-board model including a newly designed robot, and will evaluate its capability considering the effects of the limited work space and 0-g environment.