Manipulating Flexible Parts Using a Teleoperated System with Time Delay: An Experiment

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T.Kotoku, K.Takamune, K.Komoriya and K.Tanie
Mechanical Engineering Laboratory, AIST-MITI.
1-2 Namiki, Tsukuba, Ibaraki 305 Japan
Tel: +81-298-58-7284, Fax: +81-298-58-7201
E-mail: toku@mel.go.jp

N.Matsuhira, M.Asakura and H.Bamba
R & D Center, Toshiba Corporation
4-1 Ukishima, Kawasaki, Kanagawa 210 Japan
Tel: +81-44-288-8026, Fax: +81-44-288-8210
E-mail: 000091050512@tg-mail.toshiba.co.jp

KEY WORDS AND PHRASES

Engineering test satellite VII (ETS-VII), Flexible parts handling, Predictive display, Teleoperation, Time delay problem.

ABSTRACT

This paper reports experiments involving the handling of flexible parts (e.g. wires) when using a teleoperated system with time delay. The task is principally a peg-in-hole task involving the wrapping of a wire around two posts on the task-board. It is difficult to estimate the effects of the flexible parts, therefore, on-line teleoperation is indispensable for this class of unpredictable task.

We first propose a teleoperation system based on the predictive image display, then describe an experimental teleoperation testbed with a four-second transmission time delay. Finally, we report on wire handling operations that were performed to evaluate the performance of this system. Those experiments will contribute to future advanced experiments for the MITI ETS-VII mission.

INTRODUCTION

Remote manipulation in outer space from the ground is one of the most important technologies for assisting outer space activities such as the construction and maintenance of space stations, and the operation of space laboratories. The long distances between the ground command station and outer space robots incur an inevitable time delay of communications between these two systems; there are many research activities being conducted on this time delay problem.

Several ideas have been proposed: local intelligence with sensory feedback [1], a predictive image display system which superimposes a phantom robot with no delay on the remote camera image [2], a teleoperation system using force-reflecting simulator [3,4] and a teleprogramming system which issues program segments to the remote site [5]. Space robot experiments have also been carried out on a spacelab mission [6].

In this paper we consider the tasks involved in handling flexible parts by a teleoperated system with communication delays, and focus on a wire handling task as an example of a general unpredictable task for teleoperation.

This task is complicated for two reasons: 1) the dependence of the generated path on the changes of the shape of the flexible component, and 2) the difficulty of estimating the forces generated by the deformation of the flexible part. It is difficult to estimate the effects of the wire, and pre-programmed methods are not suitable for this class of task; an on-line teleoperation system is indispensable.

We first propose a teleoperation system based on a predictive computer graphics display, then describe an experimental teleoperation testbed with a four-second communication time delay. Finally, we report on wire handling operations that were performed to evaluate the effectiveness of the system.

TELE-OPERATION SYSTEM BASED ON PREDICTIVE CG DISPLAY

In this section, we propose a remote manipulation system based on the predictive image display technique. Figure 1 shows the block structure of this system. The system consists of the master operating station subsystem and the

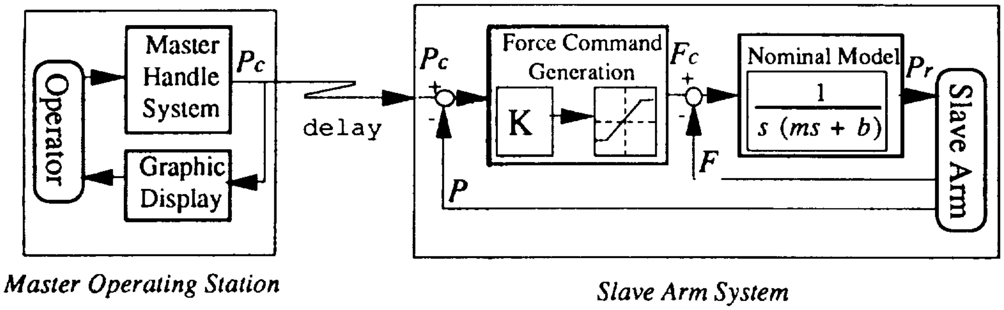

Figure 1. The proposed master-slave tele-operation system

slave arm subsystem, and these two are connected by a low-bandwidth communication line with a large time delay.

If we assume a several-second-delay, we are not able to use the conventional master-slave system which consists of a large control loop, so we adopt the predictive graphic image display technique.

The master subsystem is composed of a master handle, its controller, and a graphic simulator. This master subsystem simulates a virtual arm and displays it as a three-dimensional image. In this simulator, we ignore interactions with the environment and the hardware limitation of the slave system, hence the operator can control the virtual arm on the graphic display freely through the master handle. The series of configurations (position / orientation) of the virtual arm during operation are transmitted to the slave arm controller as a command configuration P_C.

The slave arm subsystem is composed of a slave arm and its double-loop controller which prevents the slave arm from excess loads. In the outer position loop, the operational force command F_C for the inner loop is given by

$$F_c = \begin{cases} -F_{\text{limit}} & (\text{in case } K(P_c - P) < -F_{\text{limit}}) \\ F_{\text{limit}} & (\text{in case } K(P_c - P) > F_{\text{limit}}) \\ K(P_c - P) & (\text{others}) \end{cases} \quad (1)$$

where F_{limit} is the limit force/torque to prevent the slave arm from applying excess loads, K is the gain parameter of the outer position loop, and P_C and P are the commanded and the sensed configurations of the slave arm, respectively.

We assume a position-controlled slave arm. In the inner force control loop, the reference position P_r for the slave arm is calculated by using a nominal model of the slave arm. Its transfer function is as follows,

$$P_r(s) = \frac{1}{s(ms+b)}(F_c(s) - F(s)) \qquad (2)$$

where F is the sensed force at the tip of the slave arm, and m and b are the inertia and the damping parameters respectively of the nominal model. These parameters are designed to keep the bandwidth of the output reference position P_r within the bandwidth of the slave arm.

The operator manipulates the virtual arm on the graphic display using the master handle, sometimes watching the monitor of the slave arm system to check the motion of the slave arm for any failure of the wire-wrapping task. In the event of any such failure, the operator returns the virtual arm to its previous state and retries the wire wrapping.

EXPERIMENTAL TELEOPERATION TESTBED

To confirm the function of the proposed system, we constructed a teleoperation testbed with a four-second time delay. Figure 2 shows an overview of this experimental setup. The sequence of the command positions from the master subsystem is stored once in a ring buffer program which simulates a four-second communication time delay. The response of the slave arm is thus delayed by four seconds.

An IRIS workstation (Crimson / Reality-Engine) is used for the three dimensional computer graphic display, and a newly designed hybrid master system (Fig. 3) is used for the master handle. This handle has three degrees of orientational freedom, and the orientation of the virtual arm follows the orientation of this master

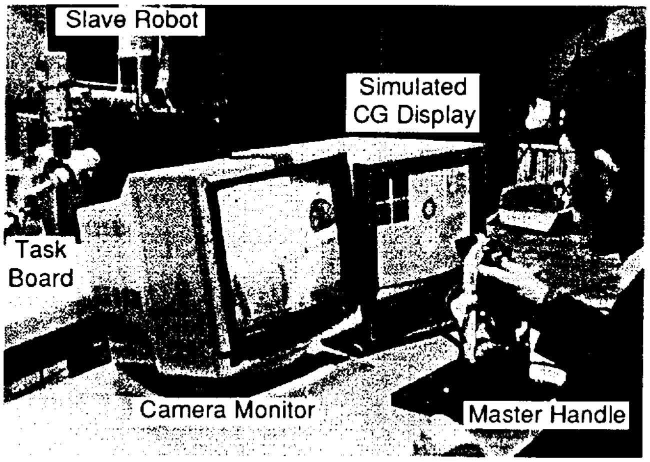

Figure 2. Overview of the experimental setup

handle. A six-axis force/torque sensor is installed at the base part of this handle, and the translational velocity of the virtual arm is proportional to the force which is applied by the operator.

Two monitor displays are used for the master operating station, one to display the computer graphics which simulate the virtual arm, and the other to display the delayed camera image of the slave arm system. On the graphic display, the front view of the task board with two holes and two poles, and the manipulated peg, are displayed as 3D solid models.

To check the real motion of the slave arm, the information of the real peg is also displayed super-imposed on this window as a 3D wire-frame model. On the top-right corner of the graphic display, a small window displays a side view of the slave arm system. On the top-left corner of the graphic display, another small window displays the force information of the slave arm.

A direct-drive arm with six degrees of freedom is used for the slave arm. At the tip of this arm, a six-axis force / torque sensor is installed to detect the forces generated by the interaction with the environment. A slave arm control algorithm described before is implemented on a parallel processing system of transputers. The force limit F_{limit} was set to 5N to protect the slave arm from excess loads during operation.

WIRE HANDLING TASK

As an example task of manipulating flexible parts, we tested a wire handling operation. We used a simple task-board with two holes, two poles and one manipulated peg with a thin copper cable. The clearance between the peg and the hole is 0.035mm.

The task is principally a peg-in-hole task involving wrapping a wire around two posts on the task-board. The task consists of three stages; first, extracting the peg from the hole, second, wrapping the wire around the two poles, and third, inserting the peg into the initial hole.

The results of the experiments are shown in Fig. 4 as a sequence of wire handling operations. Despite of the large communication time delay in this teleoperation system, we confirmed the success of the wire handling operation.

To maintain consistency between the virtual arm space and the real slave arm space, we calibrated the system prior to the experiments.

CONCLUSION

In this paper, we investigated a wire handling task as an example of an unpredictable task. We proposed a teleoperation system with the predictive image display and the double-loop slave controller, constructed a master-slave teleoperation testbed, and performed the wire handling task with a four-second communication delay.

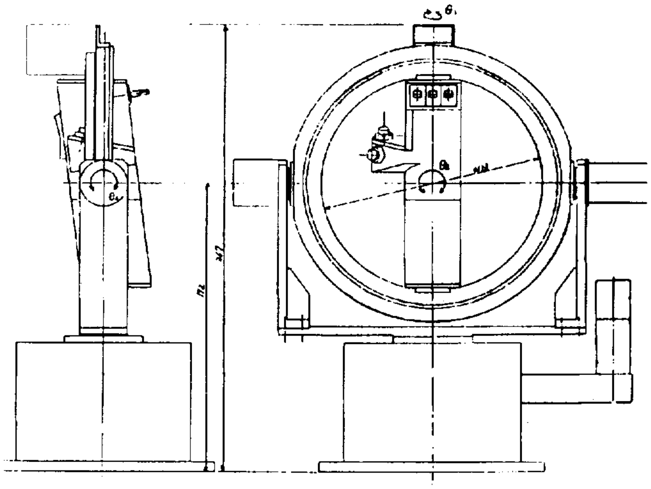

Figure 3. Structure of the hybrid master handle

MITI is planning to participate in the space robotic experiment on the ETS-VII [7], and an advanced robotic hand (ARH) with multiple degrees of freedom and sensors has been developed for this mission [8]. This experiment will contribute to future advanced experiments for the MITI ETS-VII mission.

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Figure 4. Task sequence of a wire handling