

# A WIRE HANDLING EXPERIMENT USING A TELEOPERATED ADVANCED ROBOTIC HAND ON ETS-VII

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## ABSTRACT

*This paper describes the result of the wire handling experiment by the advanced robotic hand (ARH) on ETS-VII. The ARH, a small robot system with multi-sensory hand, has been developed by MITI-ETL to execute precise tasks under extravehicular conditions in space in an ETS-VII robot experiment. The wire handling task has been proposed for the ARH experiment as one of such delicate tasks. It requires teleoperation because wire deformation is difficult to estimate and needs operator's judgement. A new control system has been developed to cope with the teleoperation under time delay and limited information for wire handling task using the ARH. On July 23, 1998, the experiment was carried out by the teleoperation from Tsukuba Space Center to the ETS-VII through the data relay satellite TDRS of NASA. In the experiment, the contact force was controlled within 5 N and the wire handling was done successfully using the ARH under 6 seconds round-trip delay. The validity of our proposed control method was verified.*

**Key words:** Space robot, Advanced robotic hand, Teleoperation, Time delay, Force control, ETS-VII

## 1. INTRODUCTION

Robotics is expected to play an increasingly

important role in space development. In the engineering Test Satellite VII (ETS-VII) launched in November 1997, many robot experiments have been executed with the aim of realizing the future automation and robotics of the extravehicular activities (EVA) [1]. Besides robot experiments of NASDA, other institutes participated in the experiments such as CRL, NAL, and MITI-ETL of Japan. The ARH experiment has been proposed by ETL [2]. The system has the ability to execute precise manipulation using a three-finger hand and autonomous control using multiple sensors. The robot system is different from the NASDA robot arm system. The wire handling manipulation (HWM) has been proposed one of the experiments of the ARH system [3]. Electric wire handling is considered to be an EVA task. The HWM experiment, involving a precise task for which the judgement of an operator is required for handling the flexible wire, is performed by means of teleoperation from the ground station. Features of the space experiment are time delay, the limitation of control information, and the visual range dependent on the camera location. To cope with these features, a novel control system has been proposed, consisting of a computer graphics (CG) simulator, a hand controller with 5 degrees of freedom (DOF), and a control algorithm for teleoperation using the concept of a virtual operator. This paper describes the results of the space experiment performed in July 1998.

## 2. HWM EXPERIMENT

The wire handling experiment (HWM) is illustrated in Fig.1. The purpose of the HWM experiment is to show the feasibility of executing precise tasks by teleoperation. The experimental setup consists of a wire, a peg and hole, two pins, and a fixed pin on the task panel. The end of the wire is fixed on the task panel, and the other end of the wire is connected to the peg and wound around the peg. The peg is inserted into the hole and locked by the latch lever using spring force. In the initial condition, the wire is looped around one pin. The HWM experiment is as follows: the ARH grasps the peg, the lock mechanism is released and the peg is extracted from the hole, the wire is moved to loop around another pin, and finally the peg is inserted into the hole again. The wire handling procedure is shown in Fig.2.

The diameter and the length of the peg are 14 mm and 40 mm, respectively. The clearance to the hole is about 0.05 mm. The wire consists of two twisted copper conductors with ETFE coating. The diameter of each conductor is 1.3 mm. The thickness and color are important with respect to recognition through cameras and the flexibility is considered for the manipulation. These conditions

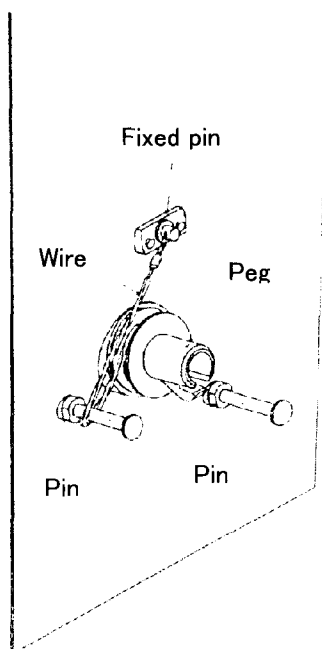


Fig.1 Experimental Setup

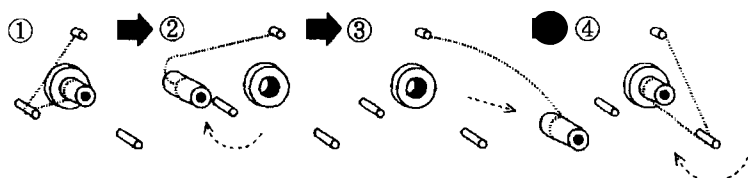


Fig.2 HWM procedure

were determined by using the test-bed at TSC.

The important small tasks in this experiment are to loop around the pin and to lock the peg to the hole certainly. Because if the peg is floating and the wire is not looped around the pin, such situation may disturb the other ARH experiments.

## 3. ETS-VII AND ARH TOTAL SYSTEM

The total system containing the ETS-VII and ARH is shown in Fig.3. The control station at Tsukuba Space Center (TSC) consists of a graphical display, a hand controller, and monitors. The control commands are transmitted to the ARH system on the ETS-VII through the NASA data transmission satellite TDRS. The ARH is a small robot system with a three-finger multi-sensory hand. The dimension of the ARH system is 500-480-480 mm. The mini-arm has 5 DOF and the hand has 3 DOF with three fingers. For this experiment, a compact hand controller has been developed to control 5 DOF of the ARH, and the software of the simulator which supports the operator and the control algorithm have been specially developed for the HWM experiment.

### 3.1 Monitors of hand-eye cameras

Two monitors for hand-eye cameras are available for the HWM experiment: hand-eye cameras on the NASDA robot arm and the ARH.

The hand-eye camera mounted on the NASDA robot arm shows the general view of the experimental setup. Since the motion angles of the NASDA robot arm are limited and the pass to the monitoring position may interfere with other experimental setups on the ETS-VII, a suitable position had been checked in advance using the test-bed at TSC and CG simulator. The operator does not watch the monitors during the operation because the time delay would be a source of confusion regarding the operation.

On the other hand, the hand-eye camera of the ARH can show the close-up view on the task panel. But the camera cannot show the gripping position because it is offset from the center of the ARH fingers. This camera is also used to confirm the situation precisely after the completion of each small task and execution of the task.

### 3.2 Simulator display

The simulator display shows the computer graphics of the experimental setup and three fingers of the ARH. The two types of the finger CG models, virtual finger and actual finger, are both

shown at commanded position from the ground and the actual position. When the operator moves the hand controller, the virtual finger moves to the commanded position first, and after that the actual finger follows the position with time delay. Thus, the operator can estimate the ARH position. Furthermore, the translational force acting on the ARH arm and the gripping force on the fingers are also shown graphically so that the situation is known well. Owing to this information, the operator can easily operate the ARH using the virtual view from the suitable angle without the influence of time delay and poor monitoring.

### 3.3 Control method for teleoperation

The proposed control system is shown in Fig.4. These software are implemented in the on-board computer of the ARH. Here, the virtual operator, consisting of low proportional control gain and limiter, is the algorithm to generate the desired force value from the ground commands respecting the ARH position. The force control is realized by the model-following control method, i.e., the position trajectory is modified by the desired force and the contact force. The dynamic model of the arm is composed of mass and damper. The ARH moves to the position where the desired force and external force are balanced, and the generated force is limited within 5 N in the HWM experiment.

Owing to this control method, the ARH cannot generate the abrupt motion in the case of a big position error between the commanded position and the actual position, and the ARH cannot generate a large force even in the contact condition. It realizes a safe operation and is suitable for the control of the space robot. Compared with the conventional method, a move-and-wait strategy, our proposed method can be called an extended move-and-wait strategy, because the operator naturally changes the operation modes such as fast operation for rough motion and precise operation for precise tasks. The load of the operator is reduced. The concept of a virtual operator raises the possibility of artificial intelligence development. In this experiment, the software of the virtual operator had to be simple for the limited capacity of the on-board computer. In Fig.4, these double line blocks were newly developed for the HWM and they have to be added to the ARH system.

## 4. RESULT OF HWM EXPERIMENT

### 4.1 Experimental pass for HWM

The ETS-VII was launched in November 1997, and the HWM experiment was carried out on 23 July, 1998. The experimental pass is shown in Table 1. Initially, five passes are allocated for the HWM: the camera setup of the NASDA robot arm, HWM program upload, operations, and the storage of the ARH. HWM operations use three passes: the confirmation of the ARH basic function including the pin-lock mechanism and calibration between the CG simulator and the actual environment, wire handling, and the recovery task, if needed. One pass is about 40 minutes containing the line connection procedure of NASA-NASDA, and about 20 minutes can be used for the HWM experiment. In the experiment, since data transmission line was not connected to NASA in the first three passes for preparation, an additional line and additional passes were used and first two passes were executed in parallel in the same pass. As the experiment proceeded successfully, the recovery of the HWM task was not needed.

### 4.2 Experimental result

Fig.5 shows the overview of the experiment as four segmentations. The whole view from the hand-eye camera of NASDA robot arm is shown at upper right in Fig.5. It is important to confirm the wire position and condition. In the close-up view of the experimental setup from the ARH hand-eye camera at upper left, the view clearly shows the wire and lock condition. In the view of the simulator display at lower left, the setup and two types of fingers are shown. At the control station at TSC at lower right, the operator works the hand controller while watching the CG display. After the execution of each small task, the operator has to confirm the condition by camera views, because it is not possible for the wire to be shown in the CG simulator.

Fig.6 shows the wire conditions before and after the operation given by the ARH hand-eye camera. After the operation, the wire is looped around the other pin and the peg is inserted and locked fast judging by the location of the latch lever.

### 4.3 Position trajectory during operation

Fig.7 shows trajectories of both commanded position and actual position of the gripping center of the ARH during operation. The trajectory shown in dark is the actual position of the ARH, and the trajectory shown in light is the commanded position from the ground. This shows the features of our proposed control method clearly. In the conventional method, the robot correctly follows the commanded trajectory that the operator made in the graphics display. However, in our method,

the ARH cannot follow accurately the commanded trajectory, because the virtual operator accommodates the trajectory depending on the on-board situation such as commanded force or position. It is quite different from the conventional method that simply plays back the taught trajectory.

Fig.7 also shows the force vector on the trajectory of the ARH position. The maximum length of the vector is 5 N. It shows that the contact force is controlled under 5 N correctly by the proposed control method, and the wire is found to be looped around the pin from the force vector forward to the center of the pin. In the region where the position error is bigger, the operator gives sufficient tension to the wire to reach the hole position. It is a kind of operation skill. Before the insertion of the peg, the direction of the force vector is downward. It means that the peg is pushed to the task panel.

The transmission time delay is assumed to be about 6 seconds, and the experiment time for the confirmation of ARH basic function and the wire handling are 16 min. 46 sec. and 22 min. 27 sec., respectively. The experiment was done within the allowable time for a pass.

## 5. CONCLUSIONS

We proposed the wire handling experiment as a

precise task using the ARH by teleoperation from the ground. A teleoperated control method has been newly developed which is effective despite time delay and limited information for the space robot. In the ARH experiments, the wire handling experiment was carried out successfully under the condition of round-trip delay time of about 6 seconds, controlling the contact force within 5 N. From the results, the validity of the proposed control method was demonstrated. This is a step toward performing precise tasks by teleoperation of robots.

The authors wish to thank the technical staff of the NASDA robot system for their cooperation.

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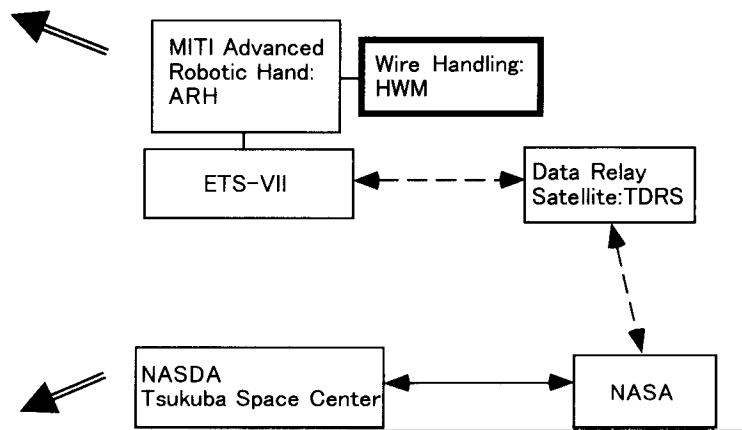
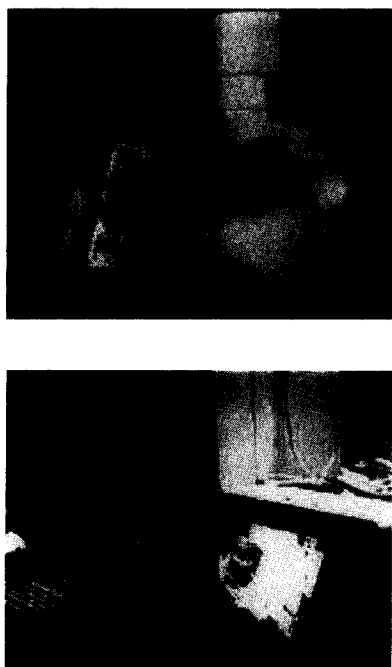


Fig.3 ARH experiment system

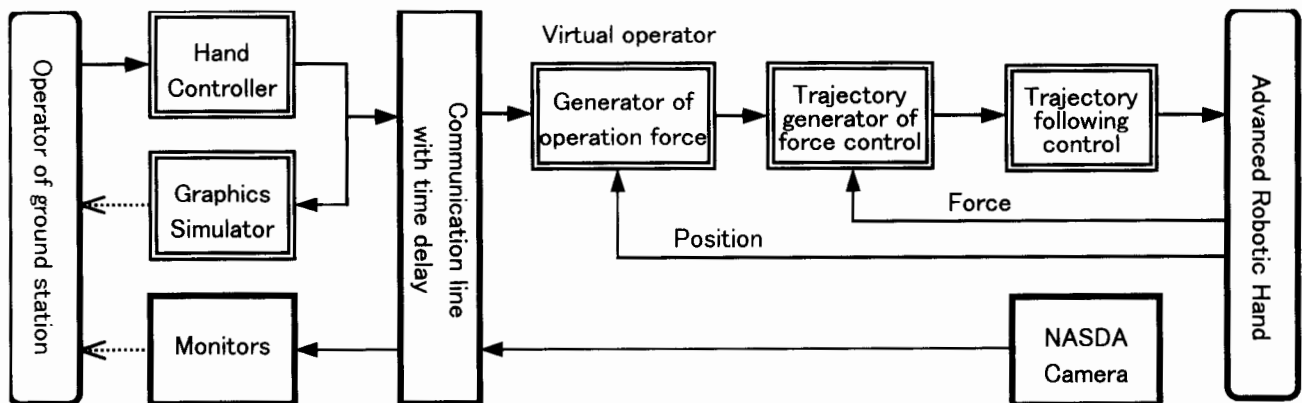


Fig.4 Proposed control system

Table 1 HWM experimental pass

| Pass | Time        | Plan                              | Result                                   |
|------|-------------|-----------------------------------|--|
| 1    | 3:03~3:45   | NASDA Camera Setup                | Not connected to NASA                    |
| 2    | 4:45~5:27   | HWM Program Upload                | Not connected to NASA                    |
| 3    | 6:28~7:10   | HWM,<br>ARH Basic Function        | Not connected to NASA                    |
| 4    | 8:11~8:53   | HWM,<br>Wire Handling             | NASDA Camera Setup<br>HWM Program Upload |
| 5    | 9:55~10:37  | HWM, Recovery Task<br>ARH Storage | HWM,<br>ARH Basic Function               |
| 6    | 11:37~12:19 |                                   | HWM, Wire Handling                       |
| 7    | 13:30~13:59 |                                   | ARH Storage                              |

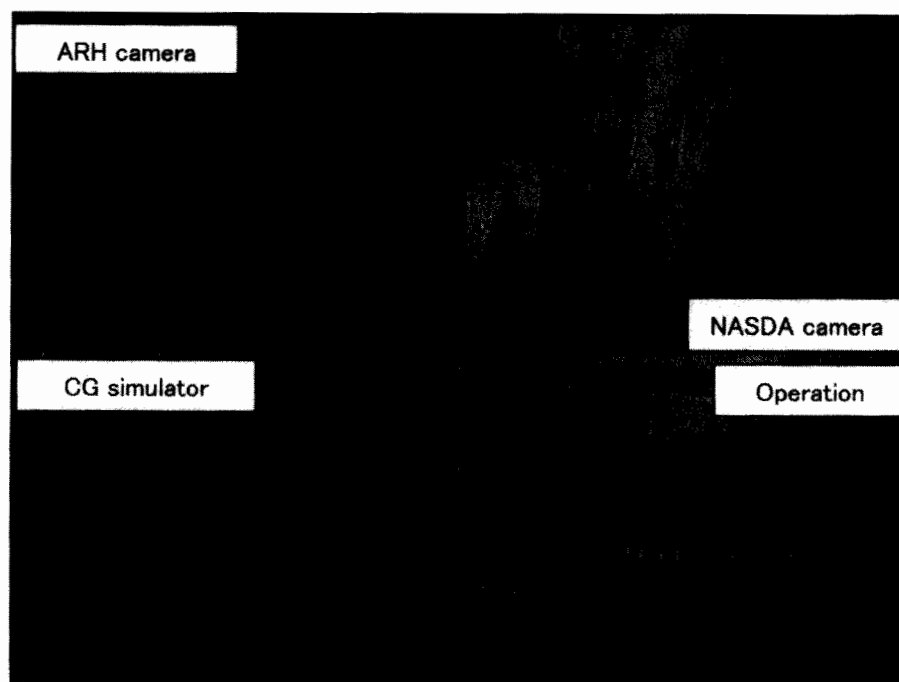
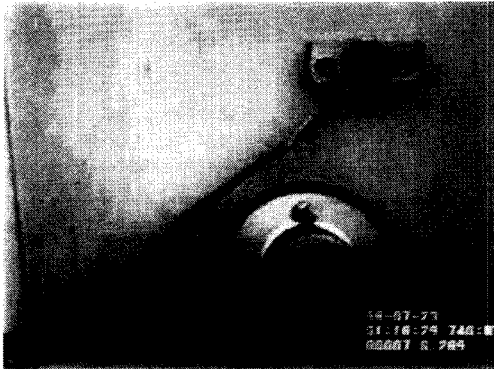
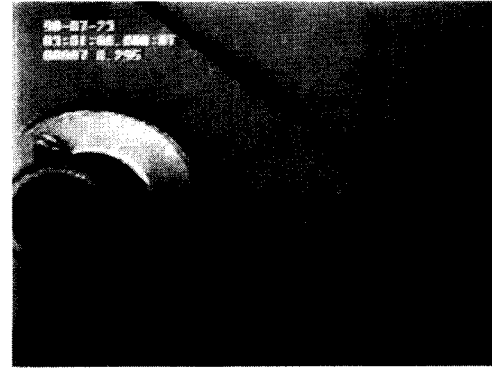


Fig. 5 Overview of HWM experiment



Before the operation



After the operation

Fig.6 Before and after the operation

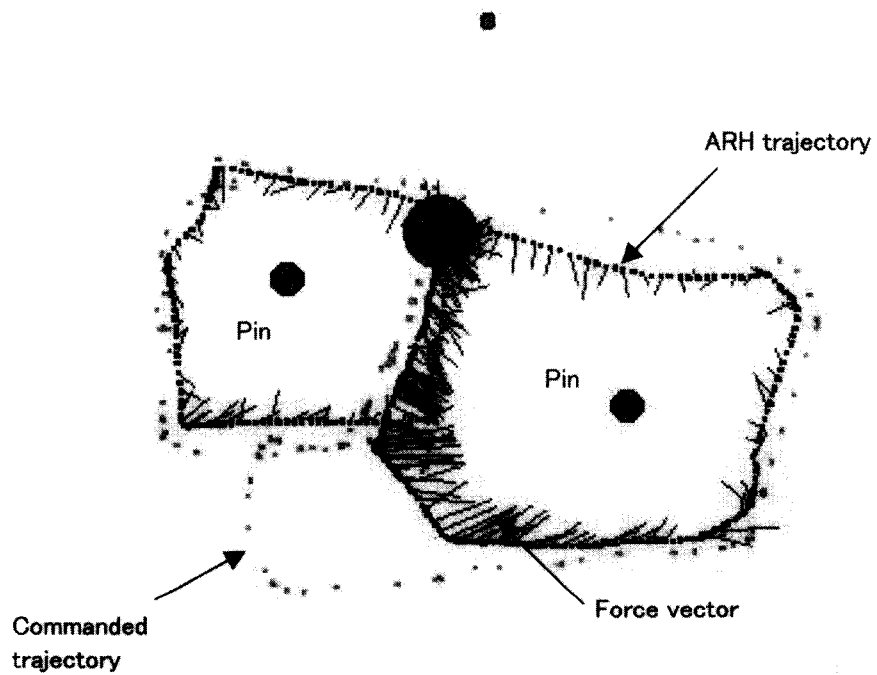


Fig.7 Trajectory of the ARH