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ABSTRACT

The National Space Development Agency of Japan will launch ETS-VII in 1997, as a test bed for next generation space technology of RV&D and space robot. MITI has been developing a three-finger multisensory hand for complex space robotic tasks. The hand can be operated under remote control or autonomously. This paper describes the design and development of the hand and the performance of a breadboard model.

INTRODUCTION

As an activity in space increases, robot will play a bigger role in building space stations and performing experiments. In particular, robot will have to perform delicate and complex tasks, such as arranging and servicing equipment in unmanned space facilities. A key component is a hand with dexterous and adaptable capabilities. We are developing a hand, which we call the Advanced Robotic Hand (ARH), for Engineering Test Satellite VII (ETS-VII), which is a test bed for next generation space technology. ETS-VII will be launched by NASDA (National Space Development Agency of Japan) in 1997 [1], [2]. Our hand has a multiple degree-of-freedom (DOF) mechanism, multiple sensors and onboard control. Robots have already had some success working in space. Recently, a ROTEX robot with a multisensory hand completed a space experiment in Spacelab D-2. The ROTEX works inside a space vehicle for a week. Its hand is a 1-DOF grip-

per [3]. The ARH is an extravehicular robot with a multi-DOF hand that works in the exposed environment of space for 1.5 years. The ARH will increase the applications of robots in space. This paper presents the design of the ARH and the performance of a breadboard model of the hand design.

ADVANCED ROBOTIC HAND SYSTEM

Figure 1 illustrates the ARH system. The hand is attached to a 5-DOF mini-arm. Parts for demonstration tasks in space were placed on a task board. This task board will be installed on the outer wall of the satellite. The hand is controlled by remote control or by autonomous control.

DESIGN OF THE HAND

If a remote robot in space is controlled from the ground, signal transmission delay lowers safety and efficiency. The ARH has multiple sensors that en-

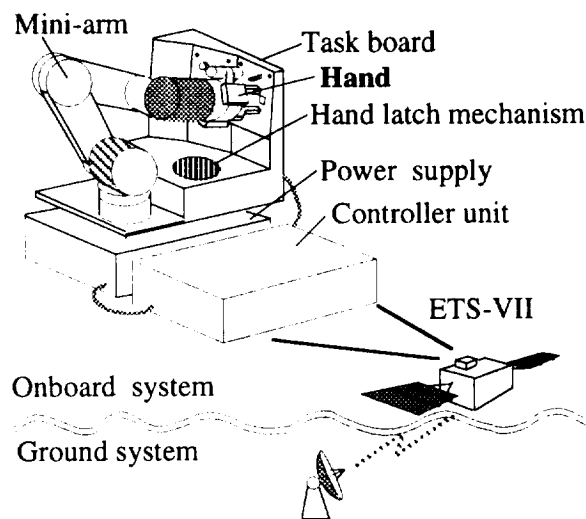


Fig. 1 Advanced robotic hand system

able it to adapt to various tasks and works autonomously. **Figure 2** shows the configuration of the hand. The finger module holds the part being manipulated and the wrist compliance device compensates for hand position errors. The signal processing module drives motors with 5-ms cycle serial control signals. It also processes sensor signals. The hand is linked electrically and mechanically to external equipment via the tool fixture. The hand is equipped with a hand-eye camera, three proximity range finders, 3-DOF wrist displacement sensor, and two grip force sensors. The mini-arm is equipped with a 6-DOF force/torque sensor at the wrist.

Finger Module

The fingers form a gripper which is simple, reliable, and finds the gripping position easily. The finger module has one linear-movement finger, A, and two rotary fingers, B and C, arranged as shown in **Fig. 3**. As the figure shows, the finger module has three degrees of freedom: α , β , and γ . The shape profiler on the linear-movement finger ensures that the surface of the finger fits various profiles, and makes grasping more stable. The finger has multiple pins arranged in a grid that move linearly on the surface of the finger, as shown in **Fig. 4**. Each pin is pressed down a maximum of 3 mm by the gripped object. Prestressing springs equalize the grasping force and press the object and grip it firmly. The grip force sensor attached to the rotary finger is designed with isotropic output characteristics. This enables proper gripping force sensing, irrespective of force direction changes of finger B and C. Strain gauges detect bending moments in two directions of the L-shaped link, as shown in **Fig. 5**. Let V_1 and V_2 be the detection voltages from the strain gauges, F be the object grasping force, and K_1 , K_2 , and K_3 be the output characteristic coefficients. The detection voltages are then as follows :

$$V_1 = K_1 F \sin \beta$$

$$V_2 = K_2 F \cos \beta + K_3 F \sin \beta$$

The grasping force F is given by the following equation :

$$F = \frac{\sqrt{(K_2 V_1)^2 + (K_1 V_2 - K_3 V_1)^2}}{K_1 K_2}$$

Table 1 lists the grip capability.

Compliance Device

Figure 6 shows the extremely thin compliance device. It contains flat springs which deform to compensate for positional deviations in the four degrees of freedom X, Y, Z, and θz . Displacements in X, Y, and θz are monitored using the signals from strain sensors attached to the surfaces of flat

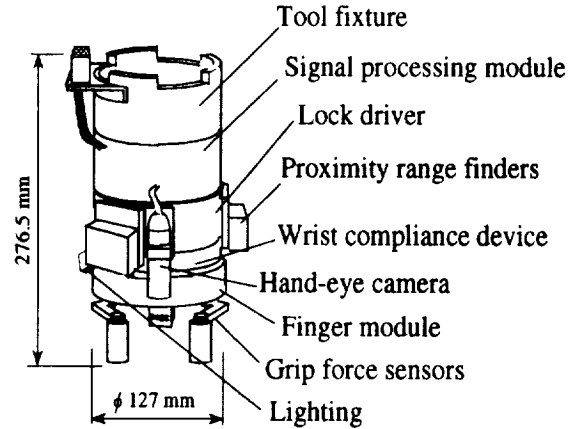


Fig. 2 Configuration of the hand

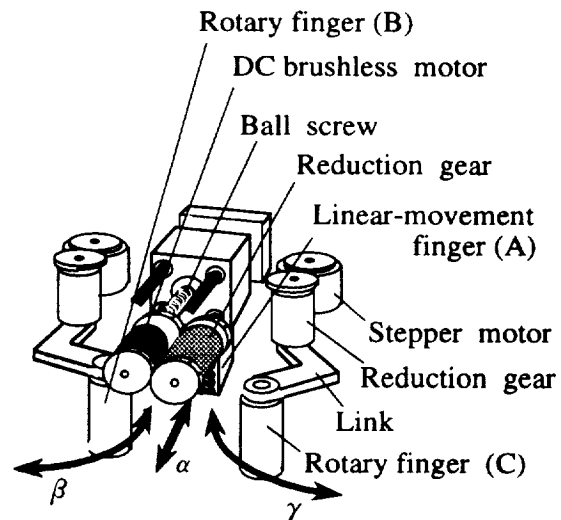


Fig. 3 Finger module mechanism

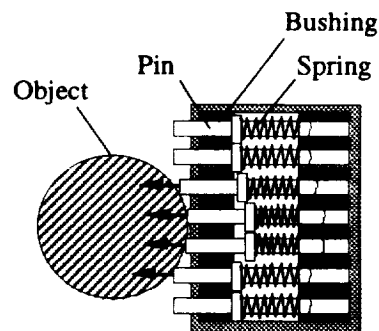


Fig. 4 Shape profiler

PERFORMANCE OF A BREADBOARD MODEL

Figure 8 is a photograph of the breadboard model. The grip force sensor gave a uniform output for all directions of a 19.3 N load (see Fig. 9). Variation of $\pm 5\%$ in range of 0 to 260 degrees is acceptable. Fig. 10 (a) and (b) show finger position and grip force data for fingers in the two-finger coordination mode respectively. Finger A and a pair B/C move the object right and left while grasping it. Fingers B and C position the object in position control mode, and finger A grasps the object in force control mode.

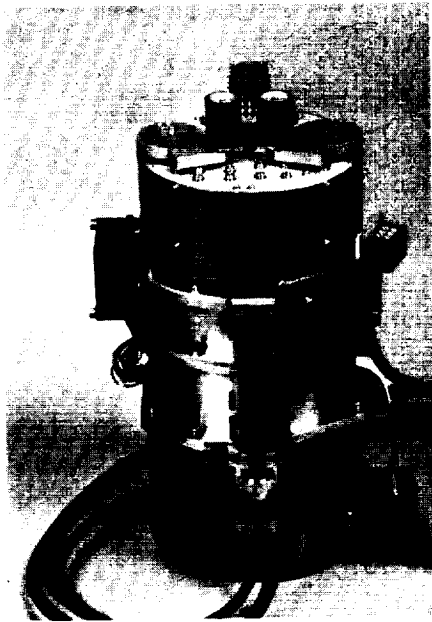


Fig. 8 Breadboard model

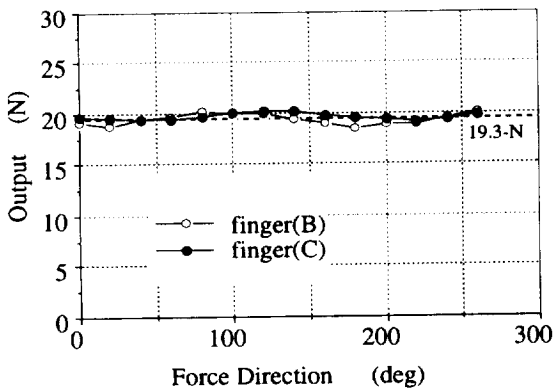


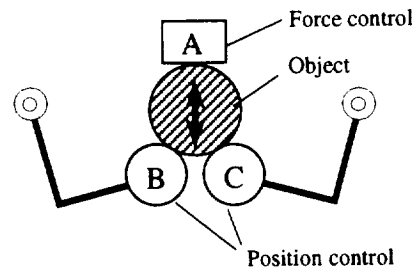
Fig. 9 Directional characteristics of
grip force sensors

SUMMARY

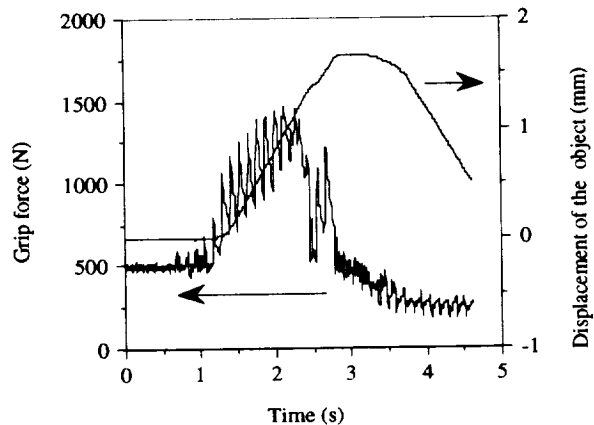
We developed an experimental gripper-type 3-finger 3-DOF hand with multiple sensors for space applications. The hand features a hand-eye camera, three proximity range finders, two grip force sensors, and a wrist displacement sensor. The multiple sensors make autonomous operation possible.

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(a) Control of the fingers



(b) Results of tests

Fig. 10 Two-finger coordination motion

springs. The compliance device has a locking mechanism operated by torque from the lock driver. The locking mechanism prevents the finger module vibrating when it moves. Table 2 lists the specifications of the wrist compliance device.

Sensor Based Control

Multiple sensors are used in sensor based control to perform accurate and reliable work, as shown in Fig. 7. Three proximity range finders measure the distance to an object in the proximity area within 80 mm with an accuracy of 1 mm. The sensors are used for approach control and orientation control of the hand to face a task board. A CCD hand-eye camera is used for object recognition by image processing. The hand sets the local work coordinate with these functions of the proximity range finders and hand-eye camera. Noncontact sensing is effective for recognition over a wide area, and is used to navigate the hand. Grip force sensors are equipped to control the grip force. The sensors also detect the position of the object accurately with a touch-and-identify strategy. A 6-DOF force/torque sensor is equipped to measure the external force applied to the hand. An external force is always observed so that the tasks are carried out safely. Wrist displacement sensors measure small position errors of the hand with high accuracy. Another important role of the sensor is to measure the external force with the stiffness data of the wrist compliance device. This measurement is more sensitive than that of the wrist force/torque sensor. This function is especially useful for delicate tasks such as parts assembly.

Table 1 Grip capability

Finger	Grip force : Max 20 N Object size : ϕ 8-50 mm
Sensor	Range : Max 25 N Accuracy : 0.7 N

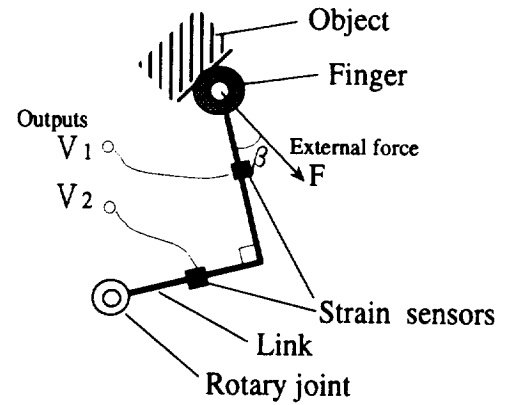


Fig.5 Grip force sensor

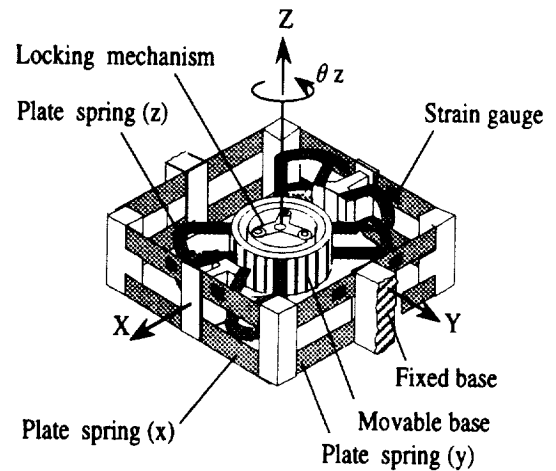


Fig.6 Wrist compliance device

Table 2 Compliance device specifications

Movement range	x, y, z : ± 1.5 mm θz : ± 2 deg
Compliance level	x, y : 0.17 mm/N z : 0.08 mm/N θz : 2.9 deg/Nm

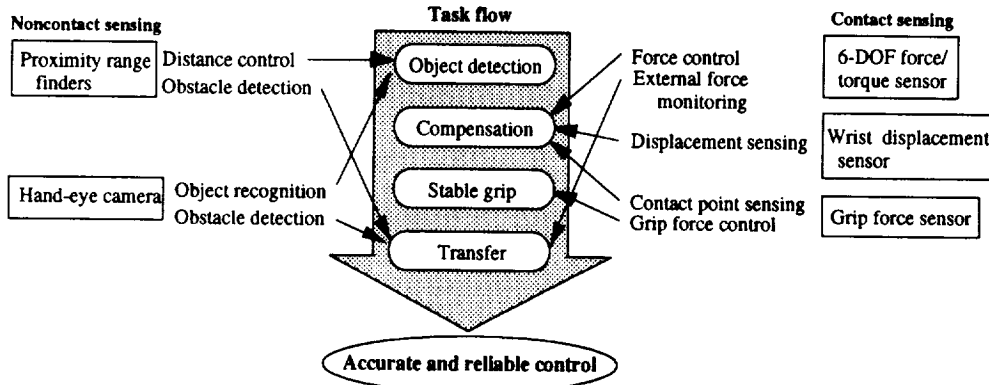


Fig. 7 Sensor based control