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Tele-operating System of Field Robot for Cultivation Management - Vision based Tele-operating System of Robotic Smart Farming for Fruit Harvesting and Cultivation Management

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Abstract

Purposes: This study was to validate the Robotic Smart Work System that can provides better working conditions and high productivity in unstructured environments like bio-industry, based on a tele-operation system for fruit harvesting with low cost 3-D positioning system on the laboratory level. **Methods:** For the Robotic Smart Work System for fruit harvesting and cultivation management in agriculture, a vision based tele-operating system and 3-D position information are key elements. This study proposed Robotic Smart Farming, an agricultural version of Robotic Smart Work System, and validated a 3-D position information system with a low cost omni camera and a laser marker system in the lab environment in order to get a vision based tele-operating system and 3-D position information. **Results:** The tasks like harvesting of the fixed target and cultivation management were accomplished even if there was a short time delay (30 ms ~ 100 ms). Although automatic conveyor works requiring accurate timing and positioning yield high productivity, the tele-operation with user's intuition will be more efficient in unstructured environments which require target selection and judgment. **Conclusions:** This system increased work efficiency and stability by considering ancillary intelligence as well as user's experience and knowhow. In addition, senior and female workers will operate the system easily because it can reduce labor and minimized user fatigue.

Keywords: Bio-production, Laser Marker System, Remote Control, Robotic Smart Farming, Smart Work, Tele-operation

Introduction

The Smart Work Center, which government has recently supported, enables flexible work environments by providing physical extension and mobility to office setting. However, this Smart Work is applied only into the office setting, not into the field work such as casting and welding or agricultural production which requires heavy physical labor. Recent Robotic Smart Work (Ryuh, 2011; Dragan and Srinivasa, 2012) allows the field worker to control a robot installed at the field with poor working condition from the office; however, little research has been conducted in the area of agricultural industry which has similar working condition.

The Robotic Smart Work System provides better working environments and high productivity to the farmers. Farmers accomplish the task with hands and foot depending on input information through the five senses. For this reason, the work productivity decreases with mental and physical limits and fatigue. Technology for tele-operation, which extends working setting and enhances the working energy, allows farmers to control the robot installed at the field and to accomplish agricultural works from cultivation to harvesting watching a screen in pleasant indoor. Thus, this technology is expected to solve the problems in agriculture and to present new paradigm in the area of agricultural industry.

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The Robotic Smart Farming System, a type of the Robotic Smart Work system applied into bio-industry, consists of a tele-operating system including a master controller and a slave robot installed at the farm. Therefore, time delay caused by the distance between the robot at the farm and the master at the office and signal delay within the system occurs; these delays should be improved to secure the work stability. Surgical robot, the DaVinci, uses this vision based tele-operating system. The master control unit of the DaVinci uses a force re-active haptic device or controls the device depending on 3-D Real Display like doctor's field of view. Practical use of the tele-operating system based on decision making and five-sense of human was proved by demonstrating a autonomous robots surgical robot which recognize the working environment and make decisions for the task in unstructured environments, but it still needs time for practical use.

Therefore, this study intended to implement a vision based tele-operating system for the Robotic Smart Farming to apply into the farm work which requires advanced recognition function for environment such as fruit harvesting and cultivation management. This study was reflected technical characteristics of the surgical robot which improved the time delay with short-range tele-operation in indoor environments. In addition, this study used a universal display, an omni-camera, and a 3-D distance information system using a laser marker system to ensure affordability instead of using an expensive Stereo camera and a real color screen which the DaVinci system employed. This study also validated the availability of the vision based tele-operating system and 3-D distance information system.

Materials and Methods

Tele-operating system

Retargeting is a key element in the tele-operating system due to the differences in structure and motion between master and slave units in the system. When the mapping function between input device of the master and output of the slave is $f: X \rightarrow P$, retargeting can be done in the ways based on joint space and Cartesian coordinates (Sousa et al., 2011; Gioioso et al., 2011). Also, the retargeting can be done by customized function and real-time tele-operation which covers the whole space instead of predefined motion (Dragan and Srinivasa, 2012; Dariush et al., 2008).

Figure 1 shows the process of retargeting to convey the control command based on intuitive observation to the slave robot (manipulator). This figure represents the cardinal concept of tele-operation interfaces and the Robotic Smart Farming System for bio-production (e.g. fruit harvesting and cultivation management). The system was implemented in an intranet to improve the speed,

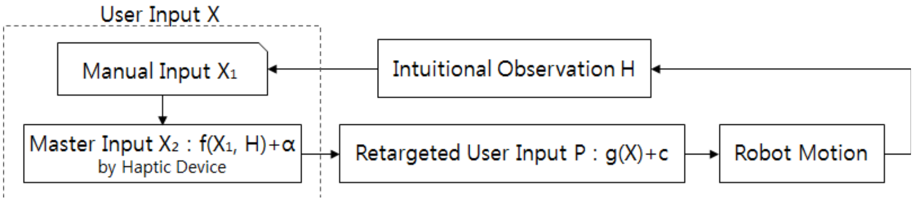

Figure 1. Tele-operation interfaces that retarget the user's input onto the robot.

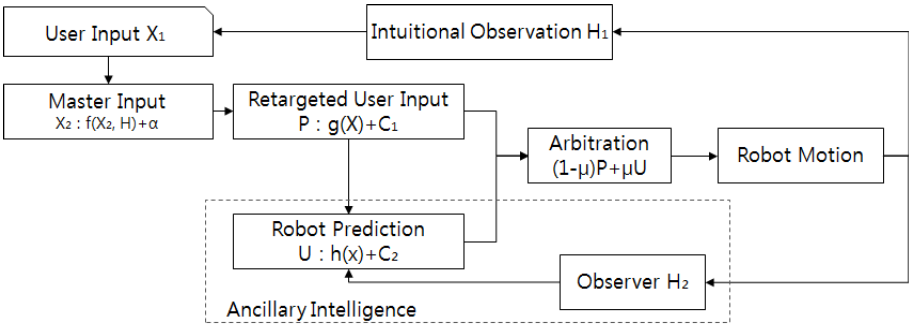

Figure 2. Tele-operation interfaces that retarget the user's input onto the robot with ancillary intelligence.

and the master controller was composed of a camera and a haptic device for easy operation with manipulability and convenience.

It is ideal to have a real-time 1:1 match between input of the master and output of the slave; however, it is efficient to operate the robot with an ancillary intelligence such as user's intention and task type because of the time delays and control errors which exist inevitably in the system. For example, in the harvesting work in to overcome the time delay and to increase productivity, ancillary intelligence assists the pre-identifying objects for the task, working order and user's intention.

System architecture

Figure 3 shows a block diagram of the tele-operating system which enables intuitive control based on the visual information from worker's field of view. The upper diagram shows the basic structure of the tele-operating system with 1:1 matching (master:slave). This structure operates the robot with only force and velocity delivered to the master without any feedback of working site information. The lower diagram shows the tele-operating system based on the field of view.

Figure 4 shows the configuration of the tele-operating system with a haptic device. An industrial robot (HA006) from Hyundai Heavy Industries was used for harvesting robot. The HA006 robot is the smallest robot in the Hyundai Robot range. It is a 6 axis robotic arm with a 6kg payload and 1394 mm reach. Detailed specifications refer to the Appendix I. And Phantom Omni was used for input device of the master. The Phantom Omni had 6-axis input and 3-axis force feedback; two buttons attached on the effector enabled the robot to grip(Refer to the Appendix II for detail information). This vision based tele-operating system enabled the robot to access to the target and to manage the cultivation intuitively. In addition, when the

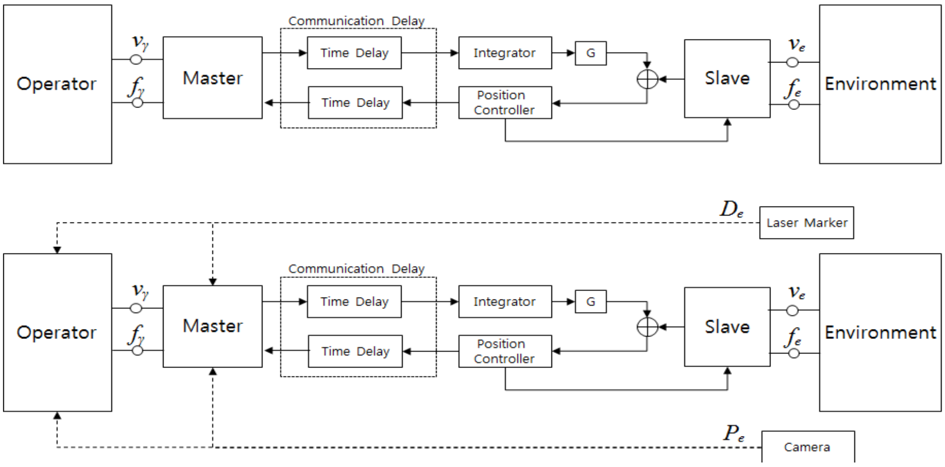

Figure 3. Tele-operation system (upper) based on field of view (lower).

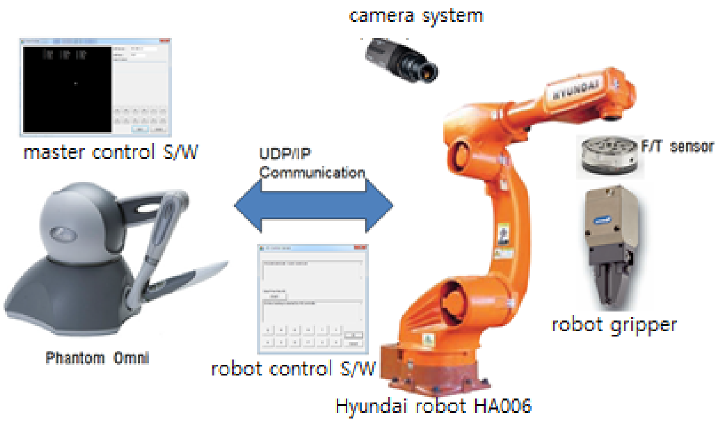

Figure 4. System Construction.

user button was pushed, the robot was ready to receive the command from the user.

If broken data or wrong command was delivered, the robot stopped the motion and switched into the safe stop mode.

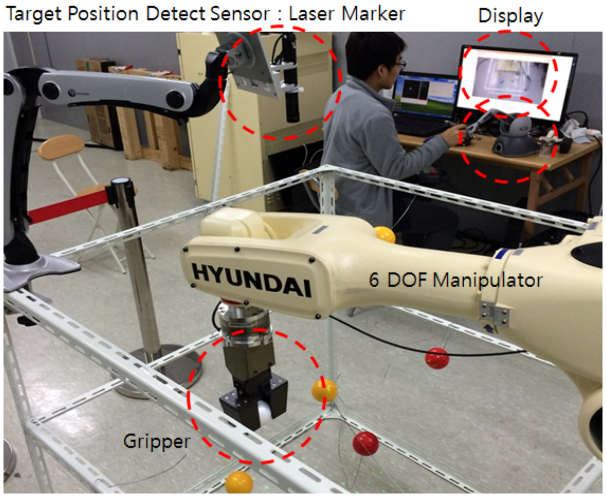

Figure 5. Tele-operation system using HA006(6 DOF, 6 Kgf payload HHI) based on field of view(Vision).

The user could carry out the task safely and intuitively, based on the field of view away from the slave robot as in Figure 5.

In Figure 6, TCP and UDP communication were used for this study. TCP channel sent the data produced by operating the haptic device and received information of the robot. UDP channel for the slave robot and the slave PC sent the control command and received 3-dimensional coordinates and rotation angle of the slave robot. Control cycle was set to 5 ms for accurate control of the robot.

Software architecture

Operating the master in the tele-operating system depended on experiences and judgments of the user. Thus, user's command (i.e. operating the haptic device) and a transmitting system for the generated information were needed to accomplish the task with the slave robot. The system consisted of a program for transmitting control command from the master and a control program for the slave, which did not use the visual information and depth information because they were considered as reference data. The control program followed the flow

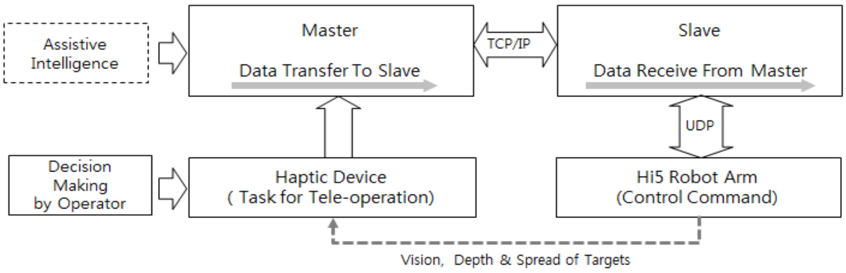

Figure 6. Architecture of communication system.

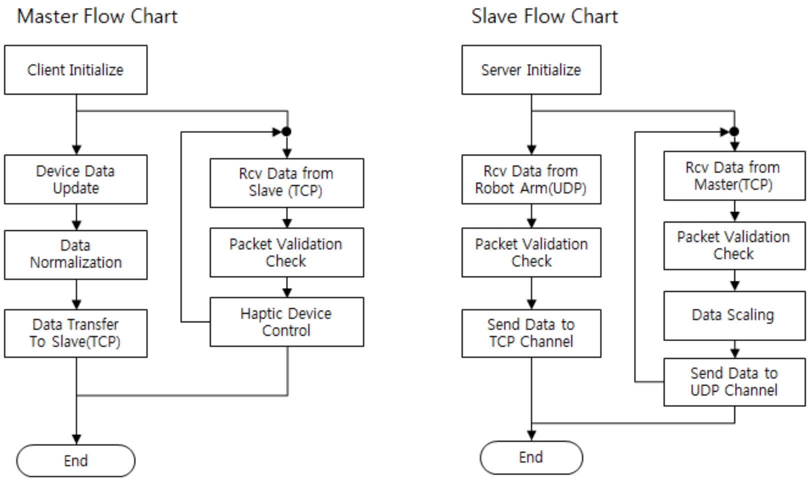

Figure 7. Flow chart of control system.

chart shown in Figure 7 to control the input from the master for the slave's motion.

Laser marker system

Additional location and distance information were needed because identifying locations of the target through the vision of 2-D space was not easy. This study measured the distribution of fruits and the distance between fruits on the screen with laser marker. As shown in Figures 8 and 9 and 10, the distance between two dots in the laser marker changed proportionally to the distance. Since the laser marker had various grid patterns with different grid widths, the grid patterns was changed based on size and distribution of the target fruits. Namely, a large grid width was used for close targets, and a small grid width was used for distant ones. The laser marker was good enough to be used as a sensor for ancillary intelligence to decide the task order though it had some slight distortion with the close target, but ensured linearity within the workspace of the robot.

Grid width in Figure 9, which was the distance of Laser Mark Points on the target ball, was obtained through the

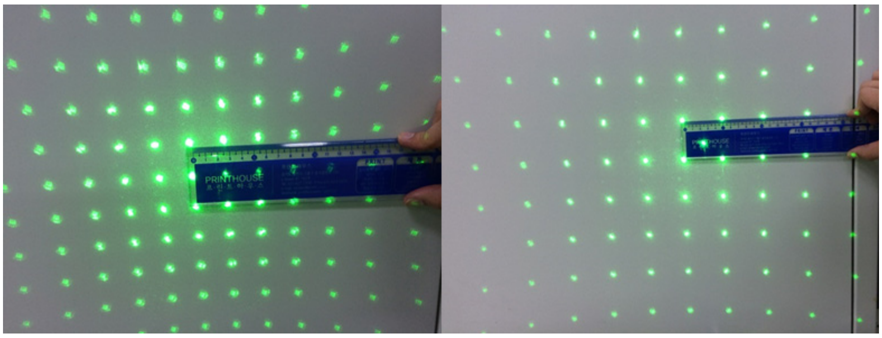

Figure 8. Medium grid pattern: distance 30 cm, grid space 2.5 cm (left) distance 60 cm, grid space 5.0 cm (right).

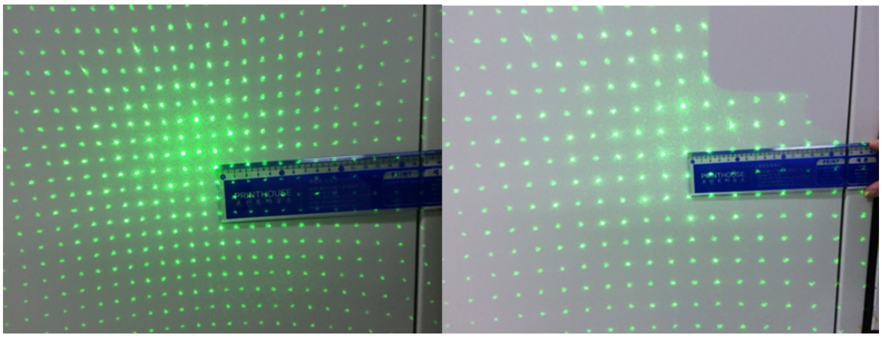

Figure 9. Small grid pattern: distance 30 cm, grid space 1.3 cm (left), distance 60 cm, grid space 2.6 cm (right).

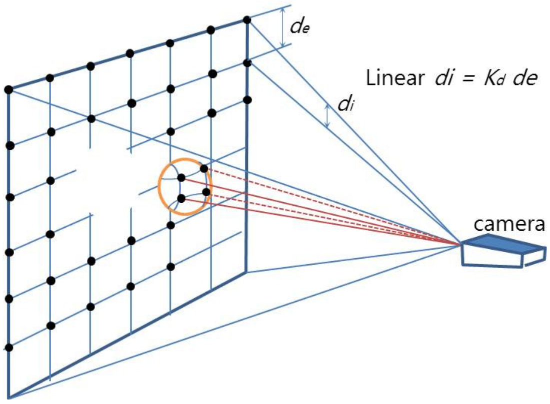

Figure 10. Linearity of grid distance and projected grid on target.

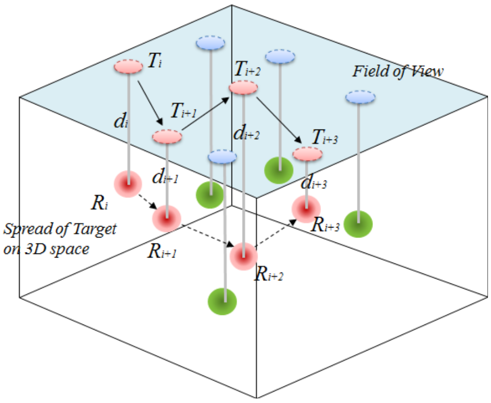

Figure 11. Work process based on scenario by user.

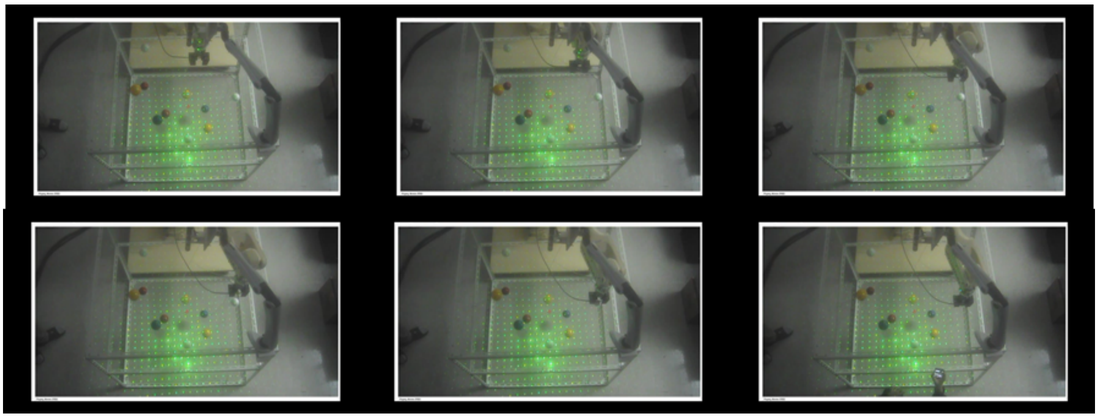

Figure 12. Targeting & gripping (Target: White ball).

camera on the ceiling. In the field, however, it was obtained from the manipulator and camera attached on the mobile robot. Actual process was defined following the target which user had set as in Figure 11, and the path was controlled with the directional tele-operation which transmits the command from input of the master to the slave or with generating new one through the assistive autonomous. This study intended to examine the performance of directional tele-operating system based on the user's decision. Field of view in Figure 10 shows distributions of the targets on 2-D plane, but depth information (d_i) was needed to accomplish the task. Since there were leaves, twigs and immature fruits on the floor in real environment, an obstacle avoidance scheme of the robot should be considered. Generating task path needed depth information, target distribution, and 3-D spatial position information; however, the user accomplished the task only with 2-D information like depth information from the laser marker based on the user's field of view.

R_i, actual 3-D position information, was represented by T_i, 2-D position information and d_i, depth. Therefore, the task was completed by choosing the path intuitively which excluded path interferences due to the obstacle.

For new equations, all assumptions and initial boundary conditions should be stated, and a sufficient derivation should be provided for the reader to understand its development. Only those mathematical steps required for comprehension should be shown. All important equations should be displayed on separate lines with consecutive numbers enclosed in parentheses (1) and positioned at the right margin to facilitate their reference within the manuscript.

$$e = me^2 \tag{1}$$

Table 1. Task scenario

Master	Slave	Remarks
1. target selection through field of view: {}		camera
2. identifying depth information - Identifying d_i by user		laser marker
3. identifying obstacle map		
4. transmitting master command		UDP
	1. receiving control data from master	TCP/IP
	2. performing task (fruit hHarvesting)	
5. reconfirming next target information from field of view		camera

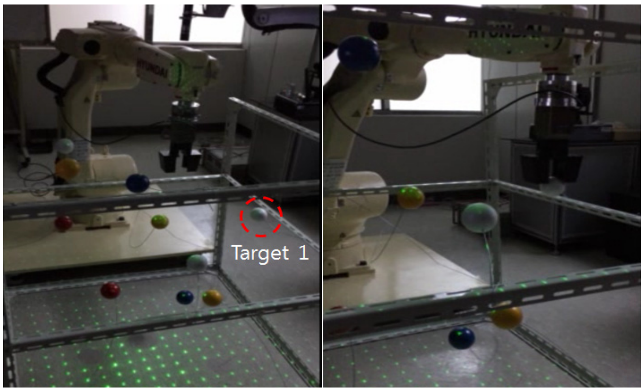

Figure 13. Target selection and slave control.

Results and Discussion

Scenario for the task

Input selection in master controller used the user's judgment to harvest crops based on visual information. Stability was assumed to be kept as the general robot.

Table 1 shows the scenario for performing the task with selected targets based on the field of view. Gripping and picking up the target 1 was accomplished by operating the master controller with only visual information as shown in Figure 13.

The response rate of manipulator was set low for the stability

Conclusions

This study proposed the Robotic Smart Farming, a tele-operating system using a 6-axis industrial robot arm and a master. The system perceived accurate movements of the user's arm and wrist using a low-cost haptic device and a laser marker system for positioning, and the retargeting was implemented in Cartesian coordinates. Thus, the system enabled the user to operate the gripper attached on robot arm without difficulty. In addition, the system provided more intuitive and precise movements, and low delay error environments. As a result, it was proved that suitable harvesting and cultivation management could be possible in the bio-production industry which heavily depended on worker's experience and knowhow. Generally, tele-operation of the slave robot arm using the master controller implements the H/W interfaces; however, mutual time delay in transferring information and less realistic simulation made it hard to control the system. This study showed that the tasks like harvesting of the fixed target and cultivation management were accomplished even if there was a short time delay (30 ms ~ 100 ms). Although automatic conveyor works requiring accurate timing and positioning yield high productivity, the tele-operation with user's intuition will be more efficient in unstructured environments which require target selection and judgment. Therefore, the tele-operating system is more effective for precise gripping and harvesting that the user should select the fixed target and make the robot access to the target.

Further studies are needed to use the tele-operating practically: 1) a study of configuration to generate and perform the task path based on the user's selection utilizing ancillary intelligence, 2) a study of pre-screening targets or identifying the error of the selected target, 3) a complementary study of this study (i.e. a study of compensation for the time delay and securing stability at the field work), and 4) a study of sensor development to get depth information and to secure field of view for the manipulator on the mobile base.

Conflict of Interest

No Potential conflict of interest relevant to this article was reported.

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Appendix I. Specification of HA006(Hyundai Heavy Industry)

Item				Specification
Model				HA006
Payload				6Kg
Mechanical Structure				Articulated
Max. Reach				1,394mm
Degree of freedom	Maximum accessible distance			6
Installation				Floor/Wall/Ceiling
Max. Working Envelope	Arm	S	Swivel	±180°
		H	For/Backward	+150° ~ -90°
		V	Up/Downward	+200° ~ -160°
	Wrist	R2	Rotation 2	±180°
		B	Bending	±135°
		R1	Rotation 1	±360°
Max. Speed	Arm	S	Swivel	170 °/s
		H	For/Backward	170 °/s
		V	Up/Downward	170 °/s
	Wrist	R2	Rotation 2	335 °/s
		B	Bending	335 °/s
		R1	Rotation 1	500 °/s
Wrist Torque		R2	Rotation 2	1.0Kgf·m
		B	Bending	1.0Kgf·m
		R1	Rotation 1	0.5Kgf·m
Accuracy of position repeatability				±0.05mm
Ambient Temperature				0 ~ 45°C (273~318K)
Relative Humidity				20 ~ 85%RH
Robot's Weight				155Kg
Working Envelope Section Area				2.71㎡

Appendix II. Specification of Phantom Omni

Model	The PHANTOM Omni Device
Force feedback workspace	~6.4 W x 4.8 H x 2.8 D in
Footprint	> 160 W x 120 H x 70 D mm
Physical area the base of device	6 5/8 W x 8 D in
occupies on the desk	~168 W x 203 D mm
Weight (device only)	3 lb 15 oz
Range of motion	Hand movement pivoting at wrist
Nominal position resolution	> 450 dpi ~ 0.055 mm
Backdrive friction	<1 oz (0.26 N)
Maximum exertable force at nominal (orthogonal arms) position	0.75 lbf. (3.3 N)
Continuous exertable force	(24 hrs.) > 0.2 lbf. (0.88 N)
Stiffness	X axis > 7.3 lb/in (1.26 N/mm)
	Y axis > 13.4 lb/in (2.31 N/mm)
	Z axis > 5.9 lb/in (1.02 N/mm)
Inertia (apparent mass at tip)	~0.101 lbm. (45 g)
Force feedback	x, y, z
Position sensing	[Stylus gimbal] x, y, z (digital encoders)
	[Pitch, roll, yaw (± 5% linearity potentiometers)]
Interface	IEEE-1394 FireWire® port: 6-pin to 6-pin*
Supported platforms	Intel or AMD-based PCs
OpenHaptics® SDK compatibility	Yes