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Development of Telexistence Cockpit for Humanoid Robot Control

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Abstract

METI of Japan has launched a national 5-year-project called Humanoid Robotics Project (HRP) since 1998FY. In this project, we are now developing a novel humanoid robotic telexistence (tel-existence) system, which can assist and cooperate with people. This paper describes a newly developed telexistence cockpit for humanoid robot control, and shows some technical demonstration to evaluate the developed cockpit and the robot. A human operator in the cockpit controls the robot in a remote site as if he were just inside the robot. The telexistence cockpit consists of three subsystems: 3D audio/visual display subsystem, telexistence master subsystem, and communication subsystem between the cockpit and the robot. The human operator in the cockpit observes a series of real images presented on the visual display with a real time sensation of presence, while cameras mounted on the robot capture the images. He or she can easily control the arms and hands of the slave robot through the telexistence master subsystem with force feedback.

1. Introduction

A novel robot system that is capable of assisting and cooperating with people is needed in any human-centered system in order to be used for such activities as the maintenance of plants or power stations, the operation of construction work, the supply of aid in case of emergency or disaster, and the care for the elderly people. If we consider the realization of such systems from both technical and safety points of view, however, it is clear that it is hard to develop a totally autonomous robot system for the above objectives. Robot system should therefore be realized with the combination of autonomous control and teleoperated control.

By introducing telexistence (tele-existence, tel-existence) techniques, as an advanced type of teleoperated robot system, a human operator can be provided with the information about the robot's site in the form of natural audio, visual and force feedback, thus making him or her feel that he or she exists just inside the robot at the remote site [1], [2].

In the METI national 5-year-project of **HRP (Humanoid Robotics Project)** as shown in **Fig.1**, we have applied the telexistence technology to a new type of cockpit system for controlling a humanoid biped robot. In this paper, we describe a newly developed **telexistence super cockpit** for humanoid robot control, and show some technical demonstration to evaluate the efficacy of the developed cockpit and the robot.

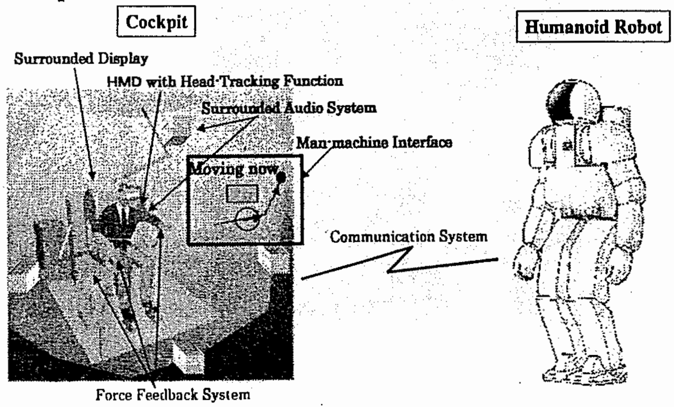

Fig. 1 Concept of Telexistence Super Cockpit System

2. Telexistence Super Cockpit

2.1 Total System Architecture

The telexistence super cockpit that has been developed in this project (**Fig.2**) consists of three main subsystems: **audio/visual display subsystem**, **teleoperation master subsystem** and **communication subsystem** between the cockpit and the humanoid robot. **Fig.3** shows the total system architecture of the cockpit and the robot.

2.2 Audio/Visual Display Subsystem [3], [4]

In order to solve the problem of a narrow visual field of view associated with HMD (Head Mounted Display), a

surrounded visual display, using an immersive projection technology (as the one adopted in CAVE [5]), has recently been developed. The surrounded visual display widely presents the real image that is captured by a **stereo multi-camera system for a wide field of view** mounted on the robot, which allows the operator to have the feeling of moving around on board the robot when he or she uses the robot to walk around.[1] On the other hand, when the human operator controls the robot to manipulate an object at a robot site, he or she needs an image precisely coordinated with his/her head motion rather than an image of wide view without coordination. Thus a **HMD system with a head-tracking function** has been developed to meet these needs. Since a binocular camera platform is originally installed,[2] the real right and left images captured by the binocular camera are presented on the HMD, while the camera precisely follows the movement of the operator's head motion in real time. Also, the augmented reality technique [6] is utilized to support the manipulation of the operator and a **virtual environment** is supplemented to the real environment images captured by the robot camera. A **surrounded audio display system** consists of 8 speakers mounted on the robot and a headphone worn by the human operator. A 3-dimensional microphone system mounted on the robot detects sound signals around the robot. The sound signals are displayed on the 8 speakers and the headphone.

Fig.2 General View of Telexistence Cockpit Developed

The surrounded visual display is composed of 9 pieces of screens shown in Fig.2. Each screen has 60 inches for the diagonal distance. On backside of each screen, two projectors are allocated to display the stereo-images, which is to be realized by polarizing the right-eye and left-eye images. The operator wears polarizing glasses to recognize a stereo image.

The stereo multi-camera system for the wide field of view mounted on the robot is shown in **Fig.4**. There are two sets of 4 small cameras: each set corresponds to each eye, allocating the distance of 65mm from each other. Each camera corresponds to each screen. The real images captured by the multi-camera system are presented on the 4 screens of the surrounded visual display: left, right, center and bottom. Thus, the vision field is set at 150 degree in the horizontal, 19 degree in the upper vertical and 58 degree in the lower vertical directions.

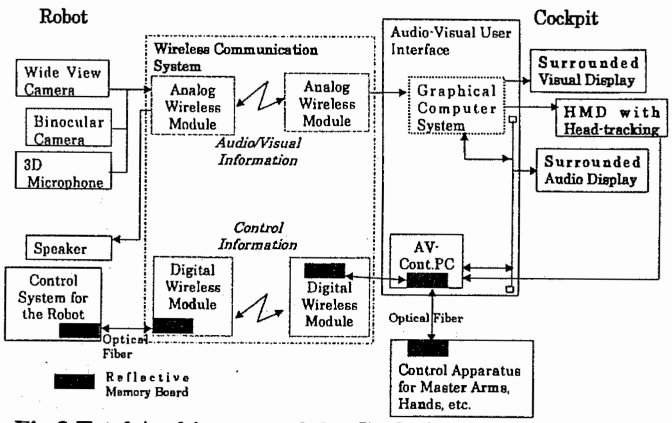

Fig.3 Total Architecture of the Cockpit and the Robot

If a visual user interface provides the operator with only camera image during teleoperation of the robot, it may happen that the operator gets lost, in which case (s)he is unable to navigate the location or orientation of the robot. This is because the operator has to perceive and assess the situation around the robot based on the local information provided from the camera image. In order to support the operator to assess the situation and to decide his control action for the robot in an appropriate way, not only local information from camera image but also global information should be provided to the operator. Thus, we have introduced the novel system of augmenting camera images with global information that supports the operator to navigate the robot. Here, we have constructed a computer graphics (CG) model of the humanoid robot operating in the virtual environment (VE) shown in **Fig.5**, using the VRML (Virtual Reality Modeling Language) and we have both the CG model in the VE and camera images presented on the surrounded visual display as shown in Fig.2.

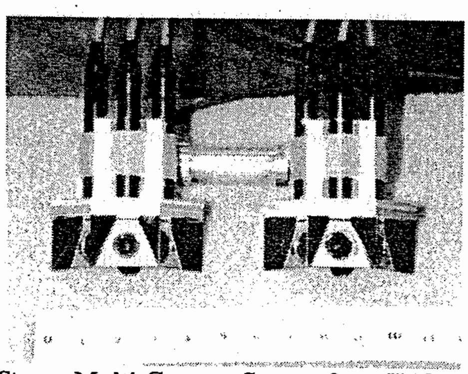

Fig.4 Stereo-Multi-Camera System for a Wide Field of View , where scale is shown in cm.

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[1] When people walk around, a wide field of view has an important effect on a sense of movement. In particular, the outward-directing vectors in a peripheral view give a high sense of movement.

[2] We utilized the binocular camera platform that was previously installed on the robot by Honda, Ltd.

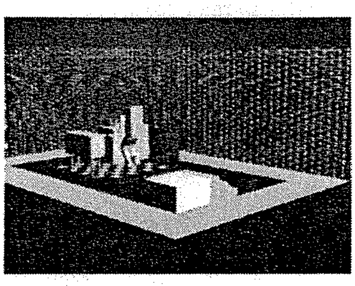

Fig.5 Graphical Model of the Humanoid Robot in a Virtual Environment

2.3 Teleoperation Master Subsystem [7],[8]

The telexistence teleoperation master system consists of right and left master arms with a gripping operation device for each arm, a motion-base, and a 3-dimensional mouse. **Fig.6** shows an outlook of the teleoperation master system.

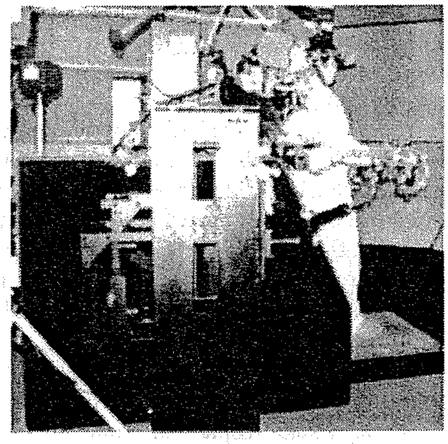

Fig.6 General View of Teleoperation Master System

When using the teleoperation master system, a human operator leans on a seat of the motion base and grips the master-arm and attaches the gripping operation device. Through the master arm and the gripping operation device, the operator can remotely manipulate the robot arms with hands. The motion base can display vibration, shock, and acceleration acting on the robot and upper body's relative displacement to a reference position set at the robot and inclination to the operator.

The master arm is designed as an exoskeleton type and has seven degrees of freedom (DOF) for each arm. Owing to this redundant DOF, the operator can instruct redundant posture of a slave arm directly using his elbow posture, the motion of which is being tracked by a joint motor of the master arm and measured by optical sensors located on the lower link of the master arm. The other joint motors generate appropriate force (up to 10 N) based on the feedback force from the slave arm so that the operator feels force and moment naturally.

Each master arm has a newly developed gripping device with which an operator can easily operate open-close motion, by feeling gripping force of the slave robot. In order to realize a small and light-weight mechanisms and wide operation space for a thumb and an index finger, we took a wire tension mechanism with a passive DOF to allow thumb's radial abduction and ulnar adduction.

The developed motion base system makes the operator experience locomotive motion of a humanoid robot. The system can present acceleration, posture, and motion with a sensation of reality by using measured acceleration and posture of the humanoid robot. The motion base provides the operator with a sensation of walking, displacement, and inclination of upper body by driving the seat position under the operator's standing posture. In order to keep the displacement of an operator's eye point small enough, the motion base system is designed to present locomotive motion only by 3 DOF translation: back and forth (surge), left and right (sway), and up and down (heave).

The teleoperation master system has a 3-dimensional mouse. Using the mouse, an operator can input commands to the main control program of the whole system such as control mode change.

We have carried out various teleoperation tests by using the developed teleoperation master system. The results show that kinesthetic presentation by using the master system with visual image greatly improves the operator's feeling of walking and dexterity of manipulating objects.

2.4 Communication Subsystem

The communication system between the cockpit and the robot consists of two main subsystems: one for communicating audio/visual information and the other for control informationl. The audio and visual information is transmitted through an analogue communication module. The control information is exchanged and shared through a shared memory module called Reflective Memory module, which are shared and accessed by the audio/visual display subsystem, the teleoperation master subsystem and the control system of the robot itself.

3 Hand Teleoperation System

3.1 System

A robot hand teleoperation system has been developed to teleoperate a slave robot hand with 4 fingers. The slave robot hand is controlled by the movement of a master hand in real time. We have used a Cybergrasp system as the master hand. The master hand system consists of a Cyber glove which senses each finger angle of the operator, and a Cybergrasp, which displays the information of the slave hand, the operator. We have utilized a Polhemus tracker which can sense position and rotation in three-dimensional space for measuring operator's wrist position in order to control the robot arm. This tracking device is attached to the Cybergrasp system. These devices are connected to the EWS shown in **Fig.7**. The software on the EWS translates the information of the master hand into the control command of slave hand and translates the information of slave hand into the control command of master hand.

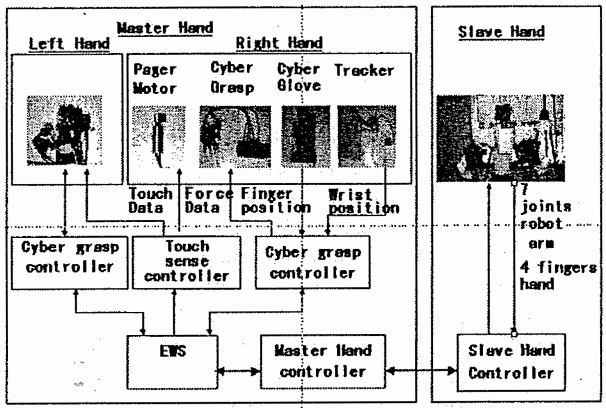

Fig.7 Hand Teleoperation System

3.2 Function

We have developed two function modules for translating interactive information of master and slave hand systems.

(1) Translation by using five to four correspondences: The module translates the data of five fingers of the master hand into the data of four fingers of the slave hand. This was developed for grasping an object. **(Fig.8 (a))**

(2) Translation by using four to four correspondences: The module translates the data of one finger of master hand into the data of the corresponding finger of the slave hand. This was developed for picking a small object. **(Fig.8 (b))**

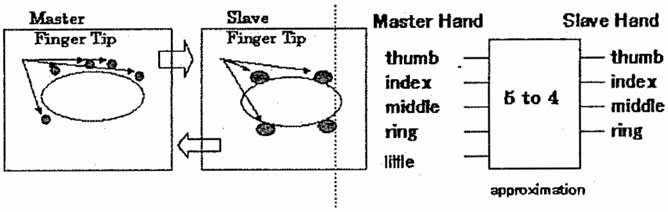

Fig.8 (a) Five to Four Translation

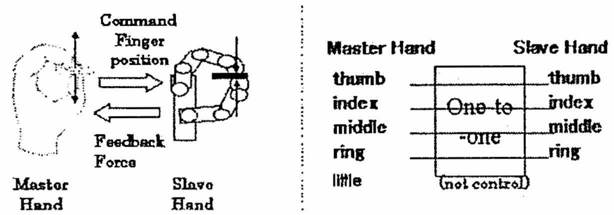

Fig.8 (b) Four to Four Translation

4 Evaluation of the Developed Cockpit

4.1 Evaluation of the Telexistence Cockpit

In order to evaluate the usability of the developed super cockpit for HRP robots, we have carried out an experiment that allow the operator to walk around and manipulate some stuff by utilizing a humanoid robot as his/her surrogate. To demonstrate the possibility of using the developed system in the field of service robots, we set up a mockup showing a shopping zone in a real environment of 3.5m (D) x 6.0m (W) in size. We set a humanoid robot inside the mockup, and human operator in the telexistence cockpit in the remote site, who controls the robot with a sensation of presence. The operator navigates the robot as if (s)he were inside the robot, and manipulates the robot arms and hands to handle a stuffed animal, to stack blocks, to open and close a glass window to pick up a can from inside, and to hold and put the can into a basket, etc.

When the operator controls the robot to walk around, (s)he wears a polarizing glass and leans on the sheet of the motion base. On the left-bottom screen of the surrounded visual display, an operational menu appears as shown in **Fig.9**. The menu includes a 2-dimensinal map of the environment and a series of operational commands to the robot. The operator uses the 3-dimensional mouse to indicate a location and orientation of a goal where the robot should reach on the map, and the menu system automatically generates a path to reach the goal. If the operator issues a command to move the robot, the robot actually walks to the goal. While the robot walks around, the real images captured by the multi-camera system for the wide field of view are displayed on four pieces of screens of the surrounded visual display shown in **Fig.10**. This makes the operator feel as if he were inside the robot walking around the robot site. On the right-bottom screen of the surrounded visual display, the CG model of the robot in the virtual environment (Fig.5) is displayed. This CG model of the robot is represented and updated according to the current location and orientation received from the real robot. The CG model of the robot in the virtual environment augments the real images captured by the camera system and supports the operator to navigate the robot.

Fig.11 shows a photo illustrating the ways in which the robot steps down the stairs. Since the series of real images presented on the visual display are integrated with the movement of the motion base, the operator feels the real time sensation of walking or of stepping up/down.

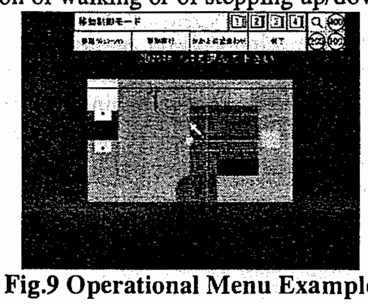

Fig.9 Operational Menu Example

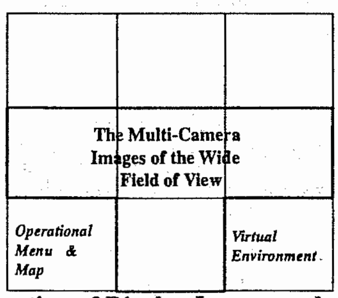

Fig.10 Allocation of Display Image on the Surrounded Visual Display

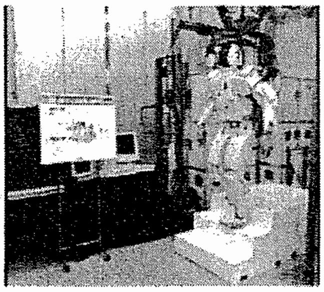

Fig.11 Robot Stepping Down the Stairs

In order to change the control mode from walking to manipulation, the operators selects the menu, wears the HMD and left and right master arms and hands to control the slave arms and hands of the robot. He can observe the real images presented on the HMD as shown in **Fig.12**.

Fig.13 shows a photograph of picking up a can as an example. The operator observes the binocular camera images presented on the HMD, and catches a can through the arms and hands of the robot by operating the master arms and hands, while (s)he feels a force feedback received from the robot hands shown in **Fig.14**. **Fig.15** illustrates that the robot hands over the can to a child.

Fig.12 Displayed Image on HMD

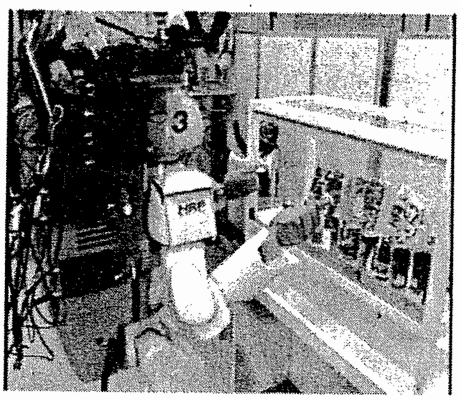

Fig.13 Photograph of Picking Up a Can

Fig.14 Photograph of Operator in the Cockpit

Fig.15 Robot Handing over a Can to a Child

4.2 Evaluation of Teleoperation Robot Hand

As an operator operates the attached master hand to his hand, he sees three-dimensional picture that is gotten from attached camera at the head of the fixed slave robot and can be given the feeling of grasping an object as shown in **Fig.16**. As the evaluation, we have tried to grasp variety of objects (difference is in shape, size and consistency) and to pack the objects in a box. **Fig.17** shows that the grasping operation is made possible by the function of the translation modules. **Fig.18** shows the robot carrying an object from hand to hand by robot arm control.

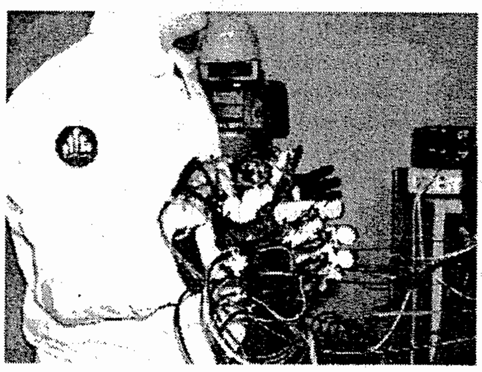

Fig.16 Initial Position of the Operator

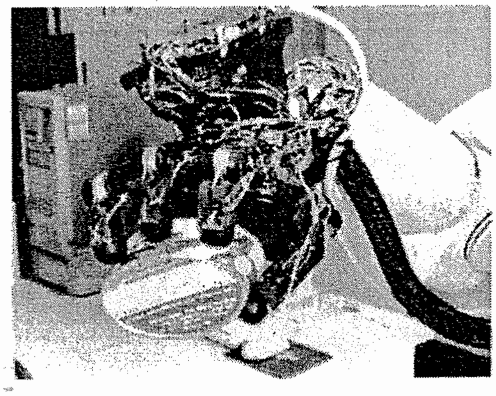

Fig.17 Grasping a Can

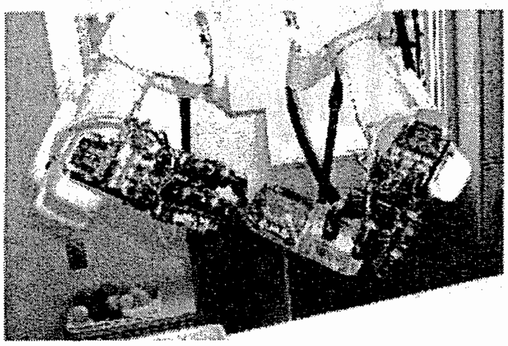

Fig.18 Carrying Object from Hand to Hand

5. Conclusions

A human operator in the developed telexistence cockpit can navigate and manipulate the humanoid robot as his surrogate as if he were just inside the robot, and can also expand his visual, audio and tactile abilities through the augmentation of visual, audio and force feedback.

The humanoid robotics project is now stepping up to the second phase of its development where the developed cockpit and the robot will be practiced and evaluated in the real application field mentioned in Section **1**. A human operator in the telexistence super cockpit can communicate with people around the humanoid robot by utilizing the robot as a communication tool or interface. That is, he or she in the cockpit can communicate with the people around the robot by sharing not only audio/visual information but also embodied information as shown in Fig.15

RCML (R-Cubed Manipulation Language) and RCTP (R-Cubed Transfer Protocol) [2] were implemented so that the super cockpit can be used as a server for the control of HRP robot through Internet by using RCML browser.

Telexistence super cockpit will be used as a human tool for the augmentation of human ability, especially expanding the limit of space and time.

Acknowledgement

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