HRP: Humanoid Robotics Project of MITI

Hirochika Inoue[1], Susumu Tachi[2], Kazuo Tanie[3], Kazuhito Yokoi[3], Shigeoki Hirai[4], Hirohisa Hirukawa[4], Kazuo Hirai[5], Shigeto Nakayama[5], Kazuya Sawada[6], Takashi Nishiyama[6], Osamu Miki[7], Toshiyuki Itoko[7], Hajimu Inaba[8], and Masako Sudo[8]

[1] The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
inoue@jsk.t.u-tokyo.ac.jp
[2] The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
tachi@star.t.u-tokyo.ac.jp
[3] Mechanical Engineering Laboratory, MITI, 1-2 Namiki, Tsukuba 305-8564, Japan
{yokoi,tanie}@mel.go.jp
[4] Electrotechnical Laboratory, MITI, 1-1-4 Umezono, Tsukuba 305-8568, Japan
{hirukawa,hirai}@etl.go.jp
[5] Honda R&D Co. Ltd. Wako research Center, 1-4-1 Chuo Wako-shi, Saitama 351-0193, Japan
{Kazuo.Hirai, Shigeto.Nakayama}@f.rd.honda.co.jp
[6] Advanced Technology Research Laboratory, Matsushita Electric Works, Ltd.,
1048, Kadoma, Osaka 571-8686, Japan
{sawada, takashi}@ai.mew.co.jp
[7] Electronic & Control Technology Development Center, Kawasaki Heavy Industries, Ltd.
118 Futatsuzuka Noda, Chiba 278-8585, Japan
{miki, itoko}@tech.khi.co.jp
[8] Fanuc, Ltd. Oshino-mura, Yamanashi 401-0597, Japan
{Inaba.hajimu, Sudou.masako}@fanuc.co.jp

Abstract. AIST-MITI has launched a platform-based humanoid robotics project. The project has two phases: an initial phase of two years (FY1998-1999) and a latter phase of three years (FY2000-2002). In the initial phase, a platform for a research on the humanoid robotics was developed. The platform consists of a humanoid robot, a tele-existence cockpit to control the robot, and an equivalent virtual robot. This paper describes the objective and R&D basic plan of the project. The outline of the platform except the equivalent virtual robot is also reported.

1 Introduction

Agency of Industrial Science and Technology (AIST), Ministry of International Trade and Industry (MITI) of Japan has launched an R&D project on humanoid robotics from 1998FY. The project is run on a new scheme, called a platform-based approach, in which a platform is developed at an early stage and it is expected to be utilized by contributors of the project as an infrastructure for R&D. The approach is an antithesis of the ordinary way of robotics projects where elemental technologies are developed first and they are integrated at the final phase of the projects.

The platform consists of a humanoid robot, a tele-existence cockpit to control the robot and an equivalent virtual robot. AIST plans to develop the platform in the first two years of the project and its applications in the last three years.

Honda R&D Co. Ltd. has produced the humanoid robot platform. Kawasaki Heavy Industries, Ltd., Matsushita Electric Works, Ltd., Fanuc, Ltd., and the University of Tokyo have developed the tele-existence control cockpit system with which researchers can develop various element technologies in various applications. By using the developed cockpit system, we can obtain realistic kinesthetic sensation of a humanoid robot's motion. Fujitsu, Hitachi, the University of Tokyo, Electrotechnical Laboratory (ETL), and Mechanical Engineering Laboratory (MEL) have developed the virtual robot that is a software platform. It has the equivalent dynamics and geometric model to the humanoid robot with that of its working environment.

The rest of the paper is organized as follows: Section 2 reviews the objective of the project with related social background. Section 3 describes the overview of the project as well as the contributors of the project to develop the platform in the first two years. Section 4 shows the designed specifications of the humanoid robot. Section 5 gives the details of the tele-existence control cockpit system. The virtual robot is presented in the other paper presented in [11]. Section 6 shows the experiments with both the humanoid robot and the tele-existence control cockpit system. We conclude in Section 7.

2 Objective of the Project

The objective of the project is to develop a safe and reliable human friendly robot system capable of carrying out complicated tasks and supporting humans within the sphere of human lives and activities. This objective has been chosen from the following observations.

Mechanical engineering has contributed to the improvements of industrial machinery as well as household goods, and made a great progress in recent years. Combined with the innovation in electronics and information processing technologies, various applications that have been considered impractical are expected to be feasible, including operations of power generation plants, tasks at construction sites and disaster relief mission.

Besides, the population of Japan is aging rapidly and people tend to have a fewer number of children. These facts imply that efficient and human friendly machinery has a great demand for supporting daily life and the activities of people, including helps for senior or handicapped people.

The objective of the project has been set to satisfy these demands, that is, to improve the efficiency and safety in industries and realize more convenient and comfortable life as well as to create new industries.

3 Overview of the Project

The project is run from 1998FY to 2002FY for five years, consisting of phase one for the first two years and phases two for the last three years. The platform is developed in phase one, and its applications in phase two. The total budget of the phase one is about 2 billion JPY.

The leader of the project is Hirochika Inoue from the University of Tokyo, and the sub-leader is Susumu Tachi also from the University of Tokyo. NEDO (The New Energy and Industrial Technology Development Organization) is responsible for the administration of the project with AIST, and MSTC (Manufacturing Science and Technology Center) is the secretary of the project.

As described above, the platform consists of a humanoid robot, a remote cockpit to control the robot and an equivalent virtual robot. The humanoid robot has been produced by Honda R&D. The remote cockpit has been developed by Matsushita Electric Works, Kawasaki Heavy Industries, Fanuc and the University of Tokyo, and the virtual robot by Fujitsu, Hitachi, MEL, ETL, and the University of Tokyo.

In phase two (FY2000-2002), research and development will be carried out on the application of humanoid robots with consideration given to the needs of industries in which such robots might be used. Improvement and addition of elemental technologies will be carried out using the platforms developed in phase one. The application research and development fields should conform with the purpose of the basic plan. Examples of relevant application fields include maintenance of plant, dangerous work in construction or disaster recovery, care service, security service. Proposals for research in other application fields have also been accepted. The budget of 2000FY is 840 million JPY. The budget will fluctuate for each year of the project. Several proposals for application research and development are to be accepted within the available budget after an evaluation of proposed fields for application research and development, specific research and development plans, and proposed research costs.

4 Humanoid Robot

The humanoid robot of the platform is a human type robot with two arms and two legs, which walks by biped locomotion. Figure 1 shows the humanoid robot.

Its specifications are shown in Table 1.

The robot has 1600 mm height, 600 mm width and 99kg weight excluding batteries. Honda R&D has done the implementation of the specifications on with their feasibility verification, and three copies of the robot have been provided.

The humanoid robot has the function shown in Table 2.

It is able to move on an uneven floor with bumps and dents of 20 mm or less by biped walking at a speed of 2 km/h or faster. The robot is also capable of going up and down steps of 200 mm or less in height at a speed of 1.5 sec/step. It can pick up an object from the floor with dual arms and carry out the two movements noted above at the stated speed when the object weighs less than 10 kg. The robot can operate for more than 30 minutes with batteries. The stereo cameras, that can pan and tilt, are mounted in the head and stereo microphone and speaker at the breast. The audio and visual information obtained by these devices can be sent to the remote computer.

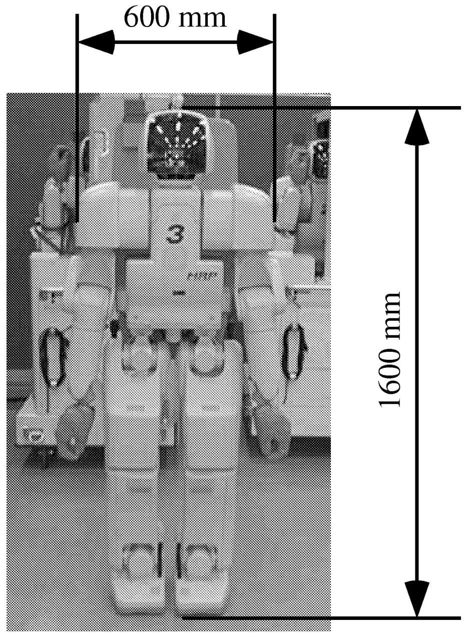

Fig. 1. Humanoid robot platform

The humanoid robot can be operated according to the command inputted from the remote computer such as the tele-existence control cockpit. The operating commands are listed in Table 3.

The orientation and acceleration of the body, the position and the orientation of the wrist, and the other measurements are output every 5 ms. The list of the output data is presented in Table 4.

By using these information, the operator can remotely command the robot to walk to the desired location and manipulate a certain object with monitoring the remote environment where the robot works in real-time.

The commands and the measurements are translated between the robot and the remote cockpit through the reflective memory system. There are two ways to read and write the data to the reflective memory of the robot. The one way is to connect the reflective memory of the remote cockpit to the one of the robot directly by the optical fiber. The other way is using wireless LAN and a communication CPU for the connection. The image from the stereo camera and the sound from the microphone and to the speaker are communicated by analog wireless data transmitter via AV connector. A possible configuration of the communication interface between the robot and the remote cockpit is illustrated in Fig. 2.

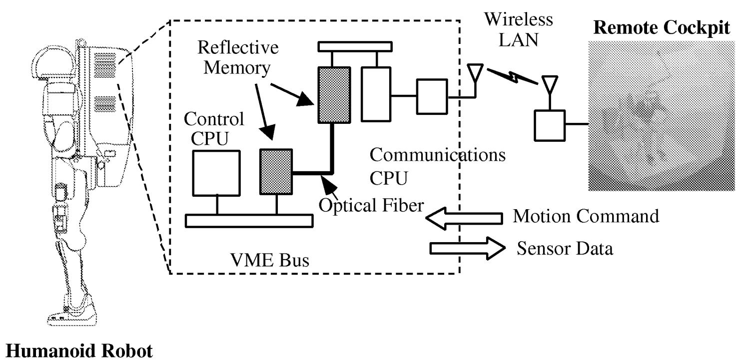

Fig. 2. Network interface

Table 1. Specification of the humanoid robot

Dimension	H 1600 mm x W 600 mm x D 595 mm
Weight	99 kg + 17 kg (battery)
Power supply	Line or battery, 136V, 50Amax, 1 kW when walking
Weight	99 kg + 17 kg (battery)
Working environment	Office/Laboratory, 10-35C
Head	Neck: 1 d.o.f., Pan +/-60 degrees Two color CCD camera: Stereo, 1 d.o.f. Tilt +85 degrees -15 degrees
Arms	7 d.o.f./arm, (Shoulder 3, Elbow 1, Wrist 3) Upper arm length 280mm, Lower arm length 280mm Wrist force/torque sensor Load 10kgf max by dual arms
Hands	Load 2 kgf max
Legs	6 d.o.f./leg (Hip 3, Knee 1, Ankle 2) Ankle force/torque sensor Walking speed 2km/h Robust walking for: floor roughness within 20mm, stairs of 200mm step height and, 200mm depth
Sensors	Gyroscope, Acceleration
Actuators	Brushless DC servo motor, Harmonic drive

Table 2. Function of the humanoid robot

Biped locomotion (Max. payload: 10 kg)	Walk forward/sideways/backward/obliquely, Turn on the spot, bend and stretch Walk up and down a staircase
Task execution by master/lave tele-operation	Carrying load up and down* Lift the lever up and down * Grasp load capacity 2 kg (single hand) * Load capacity 10 kg (dual arm)
Auditory/ Visual	Stereo vision with dual camera (pan, tilt, zoom) Stereo sound in/out

Table 3. Operating commands

Command	Parameters
Biped walking	Desired position x, y and orientation q relative to the current position and orientation Set x=y=0 and θ != 0, and the robot turn on the spot. Set x=θ=0 and small y, and the robot walk sideway.
hline Walk up and down the staircase	Walk up or down with the number of steps of the staircase. The width and height of each step must be unique and known.
Bend and stretch	The height of the hip joint
Move arm	Desired position and orientation of the wrist Desired position of the elbow joint
Grasp	Grasping force (+ Close, - Open)
Camera control	Pan / tilt angle, Zooming, Focus (Manual/Auto)

Table 4. Output data

Output data	Parameter
Position of the heel	Position: x, y Orientation: θ
Position of the wrist	Position: x, y, z Orientation: Quaternion: QX, QY, QZ, QW
Position of the hip	Position: x, y, z Orientation: Quaternion: QX, QY, QZ, QW
Acceleration of the body	Linear Acceleration: ax, ay, az
Ground reaction force	Only Fz is available among 6 axis force / torque at the ankle
Griper	Opening angle of the gripper
Wrist force / torque	Force: Fx, Fy, Fz Moment: Mx, My, Mz
Camera	Pan / tile angle, Zooming position

If needed, some extra equipment, whose total weight is less than 10 kg, could be mount on the flanges located on the both sides of the backpack of the robot. The main parts of the robots have a mechanically and electronically modular structure that can be changed to add and/or modify functions.

The multi-fingered hand has also been developed by Honda R&D for the part of the hardware platform. A picture of the hand is shown in Fig. 3.

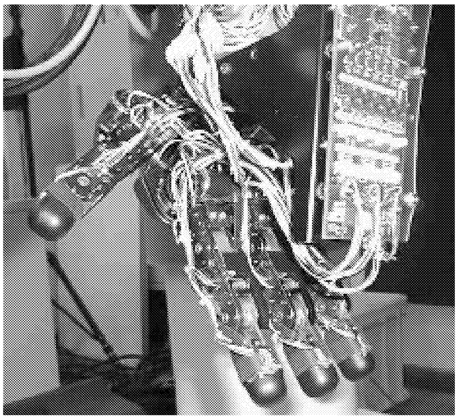

Fig. 3. Multi-fingered hand

The hand has four fingers with 3 d.o.f.. Although all actuators are mounted in the hand itself, the size of the hand maintains a similar size of human hand. The specification of the hand is described in Table 5.

A 3-axis force sensor is mounted at the tip of each finger and a small pressure sensor is attached at the first cushion of each finger. By using the measurements from these sensors, it can control the grasping force according to an object.

The dual arm system with the multi-fingered hands is constructed in order to examine the performance of the hands. Unfortunately, the current version of the humanoid robot has not enough payload for mounting the hand controller, so we used only upper body of the humanoid robot. The both of the hand and the arm can also be tele-operated by using the master hand system developed by Fanuc as shown in Fig. 4.

5 Tele-existence Control Cockpit System

We have developed a tele-existence control cockpit system by which an operator can command basic motions as to arm manipulation and traveling to a robot under being displayed force and moment,

Table 5. Specification of Hand

Weight	0.806 kg
Length	185 mm
Width	95 mm
DOF	12 (3 per finger)
Sensor	3 axis F/T, Tactile
Actuator	DC motor + Special planetary gear

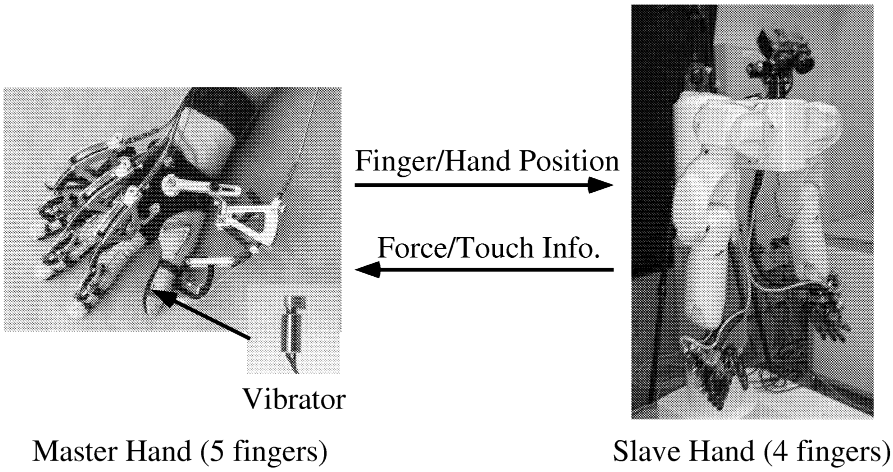

Fig. 4. Tele-operation system of the multi-fingered hand

kinesthetic sensation, and audio-visual information. Figure 5 shows an outlook of the system. The system is composed of a surrounded audio-visual display system [6] and a teleoperation master system [7]. We will introduce the features of the surrounded audio-visual display system and the teleoperation master system in the following sections.

5.1 Surrounded Audio-Visual Display System

This section describes the developed surrounded audio-visual display system embedded in a tele-existence control cockpit.

The audio-visual display system developed in this project consists of a surrounded visual display system, a HMD system with a head-tracking function, and a surrounded audio display system. In order to solve the problem of HMD's narrow visual field that has been pointed out, the surrounded visual display, such an immersive projection type as is adopted in CAVE [8], has been newly developed [9]. The surrounded visual display widely presents the real image which are captured by a stereo multi-camera system for a wide field of view mounted on the robot. The presented images allow the operator to get a feeling of moving around on the robot when he controls the robot to walk around[1] . On the other hand, when the human operator controls the robot to manipulate an object in a robot site, he needs an image associated with his head motion rather than an image of wide view. In the project, the HMD system with a head-tracking function has been developed to meet these needs. Since a binocular camera platform is originally installed, the real image captured by the binocular camera is presented on the HMD. And the camera platform moves to track the operator's head motion. The augmented reality technique [10] is utilized to support the operation of the operator and finally a virtual environment is supplemented to the real images captured by the robot cameras. Also, the surrounded audio display system is embedded in this cockpit to make the operator listen to the sound captured by the mike mounted on the robot.

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

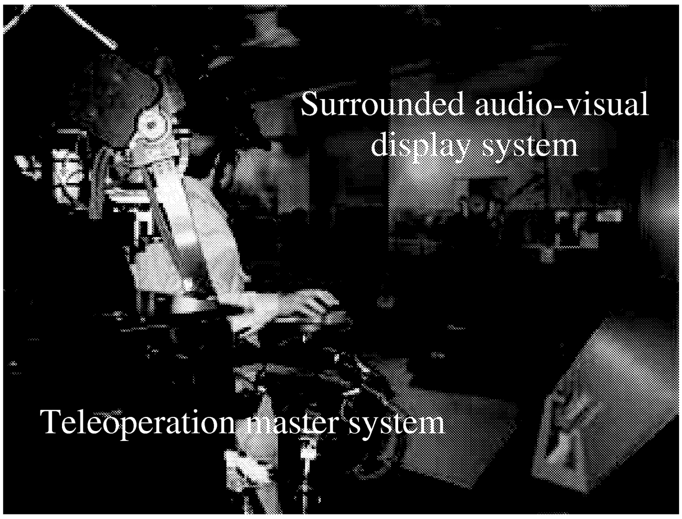

Fig. 5. Outlook of tele-existence control cockpit system

Surrounded Visual Display System The surrounded visual display is composed of 9 pieces of screens. Each screen has 60 inches for the diagonal distance. On the 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[2] is shown in Fig. 6. There are two sets of 4 small cameras: each set corresponds to each eye, allocating the distance of 65 mm from each other. Each camera corresponds to each screen. The real images captured by the multi-camera system are presented on such 4 screens of the surrounded visual display as the left, right, center and bottom. Thus, the vision field is set at 150 degrees in the horizontal, 19 degrees in the upper vertical and 58 degrees in the lower vertical directions.

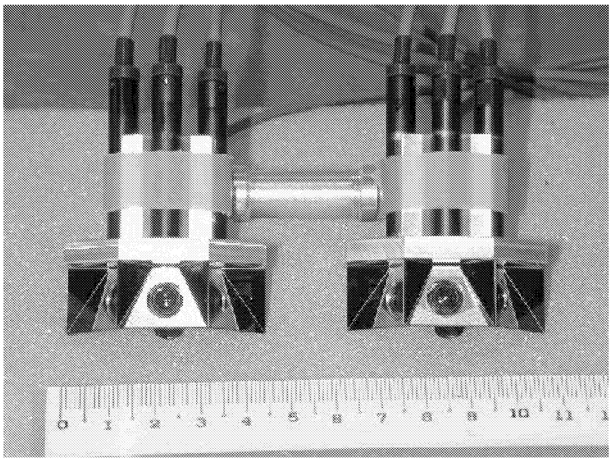

Fig. 6. Photograph of the developed stereo-multi-camera system for a wide field of view

[2] In the current stage of development, we have not installed the multi-camera system on a platform that can be tele-operated. Thus, we have not developed a function that moves the multi-camera system according to the operator's head motion.

HMD System with Head-Tracking Function The HMD system with the head-tracking function is shown in Fig. 7. The operator looks at the real images presented on the HMD, and controls the arms and hands of the robot. As is shown in the same figure, the system has a counter-balancing mechanism so that the operator is not bothered to feel a weight of the HMD he is wearing. Three axes are installed on the top portion of a head, the left and right portions of ears, and the top portion of the head, respectively. These axes enable the operator to move his head in pan, tilt, and roll directions.

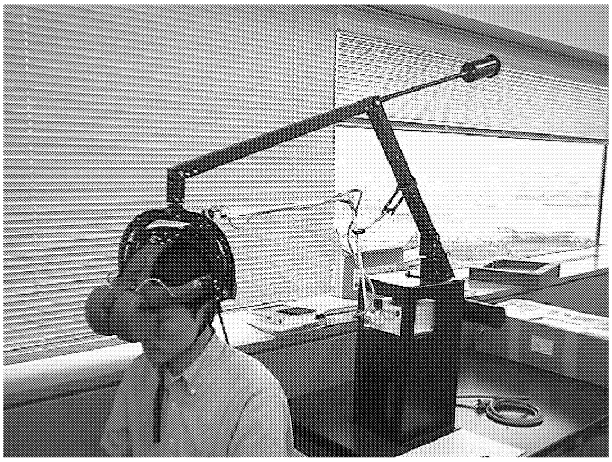

Fig. 7. Developed HMD system with head-tracking

Visual User Interface System with Augmented Reality Technique If a visual user interface provides the operator with only camera image during tele-operation of the robot, it might happen the operator gets lost and then he is not able to navigate the location or orientation of the robot. Thus, we have introduced the novel system of augmenting camera images with certain information that supports the operator to navigate the robot. Here, we have constructed a computer-based graphical (CG) model of the humanoid robot operating in the virtual environment (VE) using the VRML, and we have both the CG model in the VE and camera images presented on the surrounded visual display. The CG model of the robot in the VE is presented on the right-bottom screen of the surrounded visual display. Also, an operational menu for the operator is presented on the left-bottom screen of the surrounded display[3] .

Surrounded Audio Display System The surrounded audio display system consists of 8 speakers and a headphone the human operator is wearing. The 3-dimensional microphone system mounted on the robot detects a sound signal around the robot. The sound signal is displayed on the 8 speakers and the headphone.

5.2 Teleoperation Master System

The teleoperation master system consists of a right and left master-arm with a gripping operation device for each arm, a motion-base, and a 3D mouse. Figure 8 shows an outlook of the teleoperation master system.

When using the teleoperation master system, an 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 and hands. The motion-base can display vibration, shock, and acceleration acting on the robot and upper body's inclination to the operator.

[3] In the current stage of development, we have used 6 pieces of screens for the visual user interface for navigation of the robot. The rest 3 pieces of screens can be used for displaying a certain image necessary to be presented.

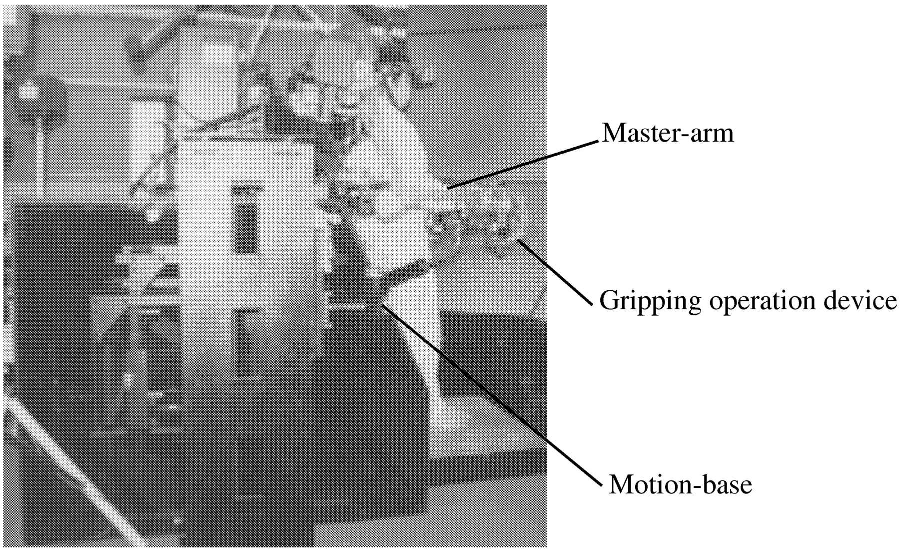

Fig. 8. Outlook of the teleoperation master system

The master-arm is designed as an exoskeleton type and has seven degrees of freedom for each arm, so the operator can instruct redundant posture of a slave-arm being tracked his elbow motion by using a joint motor of the master-arm and optical sensors located on the lower link of the master-arm. The other joint motors can generate force up to 10 N fed back from a slave-arm for an operator to feel force and moment.

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

The motion-base system developed makes an operator experience locomotive motion of a humanoid robot. The system can present acceleration, posture and motion with high reality by using acceleration and posture that we can measure on a humanoid robot. The motion-base can provide an operator with sensation of walking and inclination of upper body by driving the seat position under an operator ' s standing posture. In order to keep the displacement of an operator's eye point small enough for general purpose, the motion-base system is designed to present locomotive motion only by 3 d.o.f. translation; three motions are back and forth (surge), left and right (sway), and up and down (heave).

6 Experiments with the Developed Platform Robot System

In order to evaluate the usability of the developed platform robot system, we have carried out experiments that allow an operator to navigate and manipulate the robot in a real environment whose size is 3.5 m (D) by 6.0 m (W).

An operator operates a remote robot by using the left-bottom screen of the surrounded visual display, in which the operational menu for the operator is presented, as shown in Fig. 9.

The menu includes a 2-dimensinal map of the environment and a series of operational commands to the robot. When the operator indicates a location and orientation of a goal where the robot should reach, the user I/F 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 4 pieces of screens of the surrounded visual display. This makes the operator feel as if he is on the robot walking around the robot site.

In order to evaluate the usability of the developed platform robot system during the manipulation, we have carried out some experiments that allow an operator to perform various tasks: open-closing a slide door to pick up a can, assembling blocks, pushing a cart, and so on. A scene of performing the tower of Hanoi is shown in Fig. 10 as an example. The operator looks at the binocular camera images presented

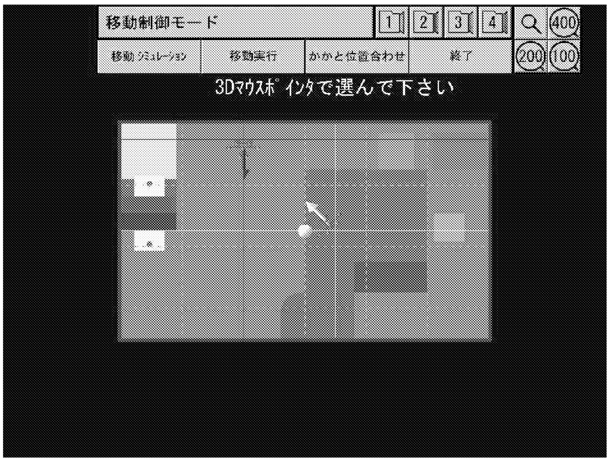

Fig. 9. One example of the operational menu

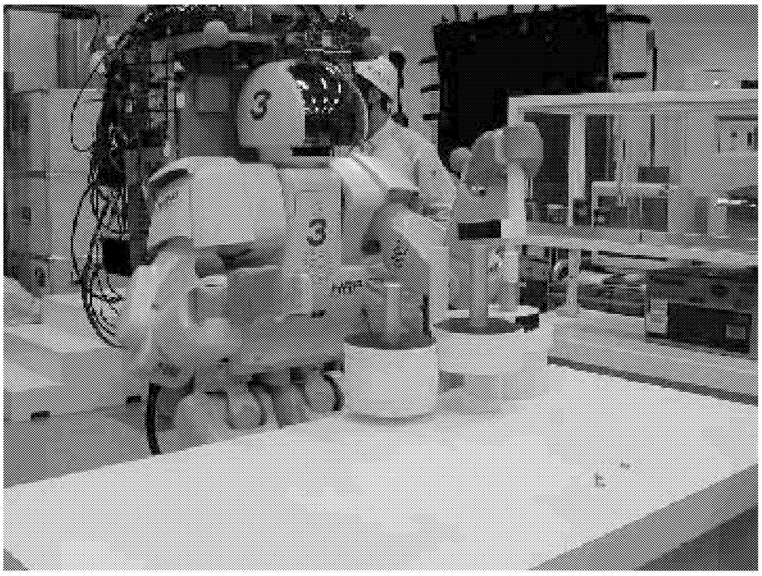

Fig. 10. Scene of the platform robot's performing the tower of Hanoi

on the HMD, and moves his head to watch a ring of the tower. He can easily catch and handle the rings through the remote site humanoid robot ' s arms and hands by using the tele-existence control cockpit system under a reality of presence.

7 Conclusions

Now, we have the platforms to research the humanoid robotics. In the phase two of the project, development of application systems using robot platforms will be conducted. Before the Humanoid 2000 conference, NEDO will select applications from organizations interested in participating in the project and the phase two will be launched.

A same question has been queried to the project again and again; "Why a humanoid robot?" The main mission of the project is to answer the question positively and clearly, and show promising applications of humanoid robots.

Acknoledgements

We thank Manufacturing Science and Technology Center (MSTC), New Energy and Industrial Technology Development Organization (NEDO), Agency of Industrial Science and Technology (AIST) for their entrusting development of the project "Humanoid Robotics", and the members cooperating in the project for their constructive support.

We also thank Prof. Yokokohji of the Kyoto University for his various instructive advice.

References

1. Report of Humanoid Robotics, NEDO-PR-010013756, NEDO (1998). (In Japanese)
2. ditto, NEDO-PR-010013757, NEDO (1998). (In Japanese)
3. Tanie, K.: FNR: Platform Based Humanoid Project, Proc. ISRR (1997).
4. Inoue, H.: A Platform-based Humanoid Robotics Project, Proc. IARP First Int. Workshop on Humanoid and Human Friendly Robotics (1998) I-1-1-4.
5. Tanie, K.: MITI ' s Humanoid Robotics Project, Proc. Second Int. Symposium on Humanoid Robots (1999) 71-76.
6. Nishiyama, T., Hoshino, H., et al.: Development of Surrounded Audio-Visual Display System for Humanoid Robot Control, Proc. Of the 9th International Conference on Artificial Reality and Telexistence (ICAT ' 99) (1999) 60-67.
7. Hasunuma, H., Kagaya, H., et al.: Development of Teleoperation Master System with a Kinesthetic Sensation of Presence, Proc. Of the 9th International Conference on Artificial Reality and Telexistence (ICAT ' 99) (1999) 53-59.
8. Cruz-Neira, C. et al., Surrounded-Screen Projection-Based Virtual Reality, Proc. of SIGGRAPH ' 93 (1993) 135-142.
9. Hoshino, H., Nishiyama, T., Nakajima, R., Sawada, K.: Development of Surrounded Projection Based Display, Proc. of the Virtual Reality Society of Japan, 4th Annual Conference (1999) 147-148 (in Japanese).
10. Rekimoto, J.: A Tutorial Introduction to Computer Augmented Environments, Computer Software, Vol.13, No.3 (1996) 4-18 (in Japanese).
11. Nakamura,Y., et al., V-HRP: Virtual Humanoid Robot Platform, submitted to this conference.