Development of Teleoperation Master System with a Kinesthetic Sensation of Presence

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Abstract

This paper describes a teleoperation master system with a kinesthetic sensation of presence which we have developed in the national project of "Humanoid and Human Friendly Robotics(HRP)". The system is to be used as a teleoperation platform system to investigate various application technologies with a humanoid and human friendly robot. The system has two exoskeleton type, 7 degrees of freedom(d.o.f.) master-arms which can provide an operator with reacting force sensation of slave robot arms, 2 d.o.f. gripping operation device installed on respective master-arms, which can provide him with gripping sensation, and a motion-base which can provide him with locomotive sensation of a humanoid robot. This system is expected to provide a sensation of telexistence when teleoperating a humanoid and human friendly robot.

Key words: Kinesthetic sensation, Telexistence, Teleoperation, Master-slave system, Motion-base, Motion Sense, Humanoid, Human friendly robot

1. Introduction

A humanoid robot has substantial advantages when working in surroundings where human beings usually live. The main advantage is that a humanoid robot can act as a human being in such a space without any previous works for the surroundings. On the other hand, human friendly and functional machinery is getting more strongly needed as robots are used closer towards human beings to care.

Based on the needs mentioned above, since 1998 fiscal year, Agency of Industrial Science and Technology (AIST)/Ministry of International Trade and Industry (MITI) has promoted the research and development project of "Humanoid and Human Friendly Robotics " as a project on the Industrial Science and Technology Frontier Program (ISTF).

In the first term, from 1998 to 1999 fiscal year, a platform as a common base of the research and development is to be developed. In the second term, from 2000 to 2002 fiscal year, various kinds of element technologies as for applications in which humanoid and human friendly robots are expected to be used will be developed by using the platform developed.

The platform consists of a virtual robot platform, three actual humanoid robots, and three telexistence control cockpit systems to operate each humanoid robot. A set of a humanoid robot and a telexistence control cockpit system can form an advanced remote control humanoid robot platform; an image of the platform is shown in Figure 1.

Figure 1 Advanced remote control humanoid robot

Telexistence Control Cockpit System
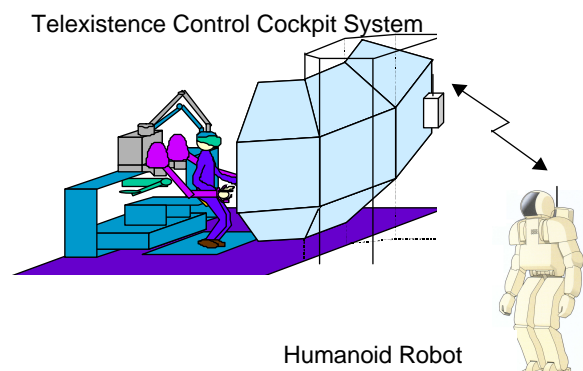
Humanoid Robot

platform

One of the most useful and realistic situations in which humanoid robots work is an operation in a case of disaster such as rescue operation in disaster field where human beings cannot enter because of remaining danger. In such a case the humanoid robots would be required to be remotely operated from a safe site with a sense of high

reality. Considering not only this kind of application but also other applications, Kawasaki Heavy Industries, Ltd., Matsushita Electric Works, Ltd., Fanuc, Ltd. and the University of Tokyo. have been developing the telexistence control cockpit system with which researchers can develop various element technologies in various applications; Kawasaki Heavy Industries, Ltd. takes part in this development as for master system with a kinesthetic sensation of presence.

There are many master systems[1] to operate remote slave manipulators, i.e. a 6 d.o.f. equi-inertia bilateral master-arm for underwater manipulators [2], 7 d.o.f. hydraulic SERCOS master-arm [3], 7 d.o.f. exoskeleton pneumatic Salford master-arm, 6 d.o.f. PHANToM master-arm, 7 d.o.f. unilateral master-arm [4], and so on. On the other hand, there are many motion-base systems to provide a person with motion sense on a vehicle; these are widely utilized in various kinds of simulators such as flight simulators and entertainment machines.

By using means mentioned above, we cannot obtain realistic kinesthetic sensation of a humanoid robot's motion. The reason is that existing means are only suited to slave robots whose shoulder positions are fixed as for inclination of upper body and to simulated or presented motions which are obtained only on a vehicle without any legs' kinesthetic sensation. In case of walking, only moving the seat without any legs motion is inadequate to show kinesthetic and realistic sensations, and in case of motion with inclination of upper body, a master-arm which has extra d.o.f. or other device to display inclination has to be designed.

In order to solve the problems above we have developed a master system with a kinesthetic sensation of presence of a humanoid and human friendly robot. In this paper we will describe the master system and our future works.

2. Telexistence Control Cockpit System

2.1 System Concept and Configuration

We have developed a telexistence 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, kinesthetic sensation, and audio-visual information.

Figure 2 shows the system configuration. It consists of an audio-visual display system and a teleoperation master system; the audio-visual display system includes nine display screens, a head mount display (HMD) with a head tracker, and a 3D sound system, and the teleoperation master system includes right and left master-arm with two gripping operation devices, a motion-base, and a 3D mouse. The teleoperation master system is used to provide an operator with kinesthetic sensation as for robot's acting force and moment and upper body's motion, while the audio-visual display system is used to provide with realistic information as for robot's surrounding views and sounds.

When traveling, an operator sends a command by using a display screen with the 3D mouse as a command input device; surrounding scenery from the robot is displayed on the other screens with some auxiliary information, and kinesthetic sensation is displayed by moving the motion-base. When working on a dexterous task with arms, an operator manipulates by using master-arms and gripping operation devices, watching views on the HMD from robot eye cameras; kinesthetic sensation of inclination of robot upper body is displayed with the motion-base, and force and torque at wrists of robot and gripping force can be fed back to the operator through the master-arms and the gripping operation devices.
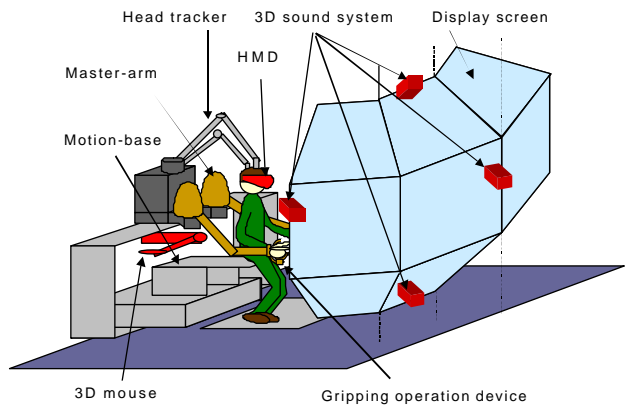

Figure 2 Configuration of telexistence control cockpit system

In use of the teleoperation master system, an operator leans on a seat of the motion-base and pushes his hands in attachments of the master-arms and the gripping operation devices. Then, 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.

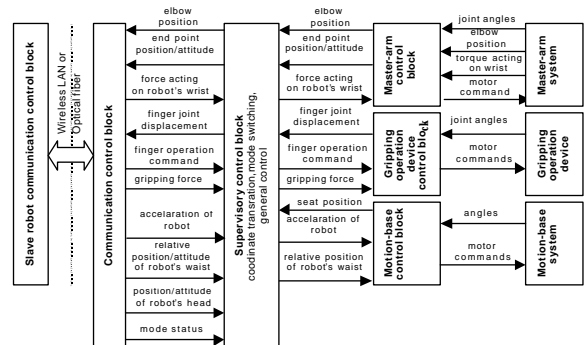Figure 3 Functional block diagram of teleoperation master system

Figure 3 shows a functional block diagram of the teleoperation master system. Each of the master-arm system, the gripping operation device, and the motion-base system has a control block. These control blocks are connected to a supervisory control block which translates

data according to coordinate systems and switches modes of the system. The supervisory control block is connected to the communication control block which communicates with the slave robot through wireless LAN or optical fibers.

We will describe the functions as to kinesthetic sensation of presence using the master-arm, the gripping operation device, and the motion-base in the following sections.

2.2 Master-arm system

A manipulator of a humanoid robot, a "slave-arm" in the following sections, has redundancy and can execute not only a position tracking task with a desired position and orientation of the end point, but also an obstacle avoidance task by using the redundant d.o.f. of the arm. Therefore, to control such a slave-arm, we need to constrain the redundant d.o.f. besides commanding a desired position and orientation of the end point. To meet the needs, we have developed a master-arm system which is a haptic device to control a slave-arm. We defined "elbow angle" as an index of the redundant d.o.f., and utilized it as a part of command inputs to a slave arm. Then, in order to expand work space of the master-arm, we designed it to avoid interference with a human operator.

In general, joint arrangement of human arms is described as a simple model with two ball joints at a shoulder and a wrist, and one revolute joint at an elbow. One of the most popular way to avoid interference of a master-arm with a human operator is to design a master-arm with a joint arrangement similar to human, that is to design it as an exoskeleton type. We took the same design, and furthermore a position of a shoulder joint of the designed master-arm was carefully examined to avoid interference with a human operator. This designing concept resulted in a compact mechanism of our master-arm system.

Since this master-arm system has a joint arrangement similar to human, it can rotate its elbow around a line segment between the wrist joint and the shoulder joint, keeping a position and orientation of the wrist joint fixed. We defined an angle, called "elbow angle" (Figure 4), to depict this rotational motion of the arm, and utilized it as a constraint condition of the master-arm.

By controlling the elbow angle of the master-arm according to operator's elbow motion, the master-arm can avoid interference with a human operator. At the same time, by using the elbow angle with a position and orientation of the end point, we can generate an input command for a redundant slave-arm.
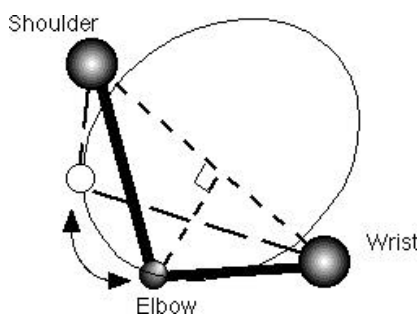
Figure 4 Definition of "elbow angle"

We implemented seven actuators for seven joints of the master-arm for force feedback. In this case, we control six of them to perform force feedback control to a human operator, and the other to adjust the elbow angle.

The elbow angle is derived from a moving direction of an operator's arm which is measured by sensors on the master-arm. Several optical sensors are located on a lower link of the master-arm. By using information from the sensors, the elbow angle is controlled so that it roughly keeps a relative distance between a human operator's arm and the master-arm.

Figure 5 shows a schematic diagram of the master-arm control system. In this control system, the elbow angle is generated by "elbow angle generator" as described above. And also a position and orientation of the end point of the master-arm is generated by "end point generator". These outputs, the elbow angle and the end point's position and orientation, are put into "joint motion generator" in order to generate input commands for each joint actuators. To realize force feedback function, force information of the master-arm and the slave-arm is put into "end point generator".
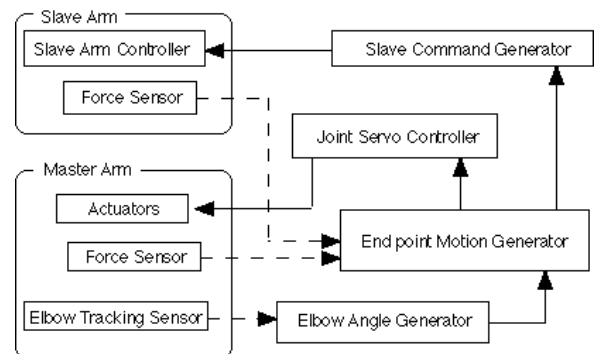
Figure 5 Schematic diagram of master-arm control system

The joint arrangement of the master-arm is shown in Figure 6. Actuators are put for each joint, and a 6-axis force/torque sensor is put on the wrist joint to measure forces and torques generated by a human operator.

Features of the master-arm are the following:

1) Instruction for redundant posture of a slave-arm by tracking elbow motion of an operator
2) Detection of operator's elbow motion without contact
3) Force feedback from a slave-arm
4) Mechanical balancing with counter weights

The specifications of the master-arm system are shown in Table 1.
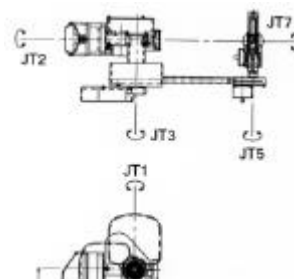
arm's forces. Through such experiments, we have designed the master-arm system for the platform.

Figure 6 Joint arrangement of master-arm

Table 1 Specifications of master-arm

Interface type	Exoskeleton master-arms (Right and left arm)
Degrees of freedom	7 (each arm)
Output force	10N (Maximum at a moment)
Max speed at end point	100 mm/sec
Weight	75kg (each arm)
Joint angle range	JT1: -60 – 80 [deg]
	JT2: -15 – 50 [deg]
	JT3: -30 – 90 [deg]
	JT4: -50 – 55 [deg]
	JT5: -70 – 70 [deg]
	JT6: -70 – 70 [deg]
	JT7: -70 – 70 [deg]

Figure 7 Prototype master-arm

We have developed a prototype master-arm to evaluate the design concept. The prototype master-arm is shown in Figure 7.

An example of the experimental results using the prototype master-arm and a slave-arm is shown in Figure 8; FS-06, an industrial robot made by Kawasaki Heavy Industries, was used as a slave-arm in this experiment. A six-axis force/torque sensor is implemented on the wrist of the slave-arm. In this case, an operator operated the slave-arm to push a rigid wall with constant force. Figure 8 shows a trend data of the master-arm's and the slave-

Figure 8 An example of experimental results

2.3 Gripping operation device

We have been developing a gripping operation device with which an operator can easily operate open-close motion to grip in his thumb and index finger's work space, feeling gripping force of a slave robot. The most difficult design issue is how to realize a small and light mechanisms equipped at a master-arm. Figure 9 shows a schematic diagram of the designed gripping operation device. We took a wire tension mechanism to display gripping force in small size and light weight[5]. There are two motors to independently display forces of a thumb and an index finger; the mechanism for thumb has another degree of freedom to allow thumb's radial abduction and ulnar adduction to keep wide work space.
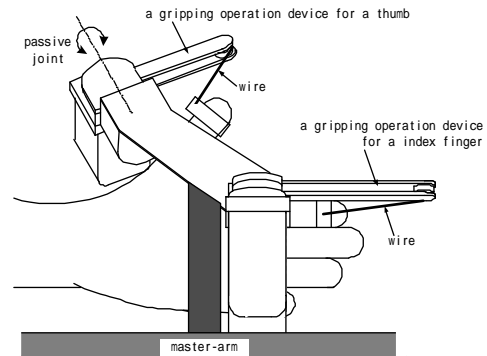
Figure 9 Schematic diagram of gripping operation device

As for gripping operation, an operator can operate open-close motion of slave hands; commands are generated according to lengths of wires which are pulled without any looseness by keeping wire tensions constant.

The specifications of the gripping operation device are shown in Table 2.

Table 2 Specifications of gripping operation device

Degrees of freedom	active 2
	passive 1

Display method	wire tension
Max display force	5N (instantaneous)
Weight	620g (prototype)

The features of the gripping operation device are the followings:

1) Gripping force display by wire tension
2) Open-close command according to two wire lengths
3) Wide sphere of motion with a passive joint

We have developed a prototype device to evaluate the designed concept. Figure 10 shows a photograph of a test bed of the device.

Figure 10 Test bed of gripping operation device

By using the test bed we could obtain various design data to suit for open-close operation with realistic sensation of gripping; for example, more than 0.5 N change in wire tension can be distinguished by an operator.

2.4 Motion-base system

We have developed a motion-base system which 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 which we can measure on a humanoid robot.   In order to present locomotive motion by a motion-base system, there are two methods in general, i.e., presentation by rotational motion, and presentation by translational motion.

Usually, a motion-base system mainly employs rotational motion by generating acceleration or impressing a feeling of acceleration with an inclination in the gravity field. However, the rotational motion is not suitable for our case, because our system is used as a advanced remote control humanoid robot platform so that it is required to keep the displacement of an operator's eye point small enough for general purpose. Therefore, we have developed a motion-base system which can present

locomotive motion only by translational 3 d.o.f.; three motions are back and forth (surge), left and right (sway), and up and down (heave).

The developed system is shown in Figure 11. Each stage is supported by linear guides. For surging motion and swaying motion, the stages are actuated by servo motors with ball screws. In heaving motion, a pantograph mechanism is adopted to drive the stage. The pantograph mechanism is actuated by an electric servo motor with a ball screw. There is another mechanism which can adjust a seat in up-down direction by manual operation in order to absorb any dimensional differences of operator's body.
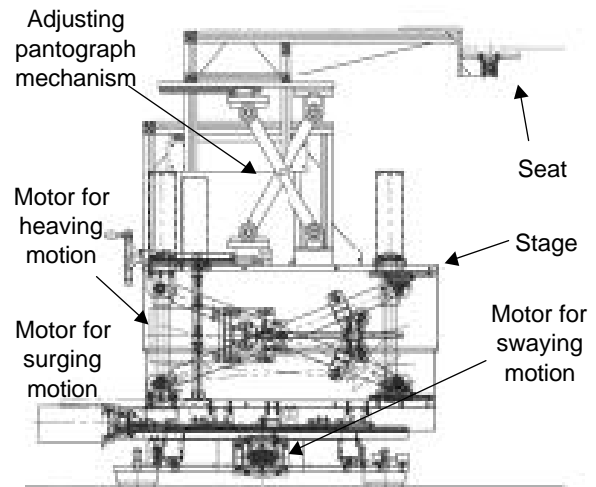

Figure 11 Motion-base system

We have developed a prototype motion-base system in 1999 fiscal year in order to evaluate the design concept of the platform motion-base system. The specifications are shown in Table 3. A photograph of the prototype motion-base system is shown in Figure 12.

A walking motion, the basic motion of a humanoid slave robot, was examined through carrying out an experiment to evaluate this system. Acceleration data of walking were acquired from an acceleration sensor on the waist of a person who actually walked.

Table 3 Specifications of prototype motion display system

-axis Left-Right direction	
Stroke range	± 75mm 150mm
Actuator	AC servo motor 2kw
Ball screw	20, Lead 20mm
Mechanism	Linear guides
-axis Back-Forth direction	
Stroke range	± 100mm 200mm
Actuator	AC servo motor 2kw
Ball screw	20, Lead 20mm
Mechanism	Linear guides

| -axis Up-Down direction	
Stroke range	± 100mm 200mm
Actuator	AC servo motor 5kw with break
Ball screw	20, Lead 20mm
Mechanism	Linear guides and a pantograph mechanism

Figure 12 Prototype motion-base system

Then the measured data were displayed by this motion-base system after signal processing; acceleration data were integrated twice to generate position reference input, and a high pass filter was utilized to cancel an influence of drift.

Figure 13(a) shows actual walking acceleration data, and Figure 13(b) shows the reproduced acceleration data displayed by the developed motion-base system. For the latter one, we multiplied 1/4 to the calculated position reference input, because vibration with "faithfully" reproduced acceleration was too radical for human when using this motion-base system.

(a) Acceleration of a human body in walking
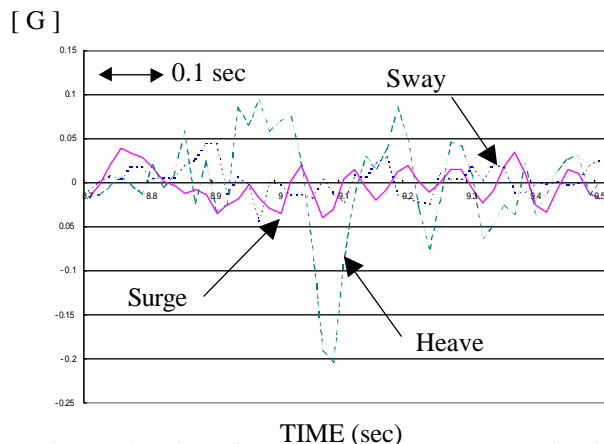
(b) Acceleration displayed by the prototype motion-base

Figure13 An example of the results in investigation tests

It was also found that the seat shape on which an operator only can "lean" is better than the shape of a usual chair from the view point of kinesthetic presentation. The reason is that our "lean" type seat forces the operator to stand on one's feet, and this allows the operator to feel adequate kinesthetic sensation as ground reaction. Furthermore, it was confirmed through the experiments that presenting a recorded visual image with acceleration greatly improves operator's feeling of walking.

3. Future Works with the Platform System

The telexistence control cockpit system developed is now under building up to test the designed functions and performances. Then the system will be used to investigate various application technologies as for a humanoid and human friendly robot. This telexistence control cockpit can be met with not only a humanoid robot but also a non-humanoid and human friendly robot; in case of remote operation of a non-humanoid robot such as a wheel type mobile robot, we can set a foot operation device on a foot step, and an operator can sit in a seat like when driving a car.

A layout of the system is shown in Figure 14. Eye positions of operators approximately from 155 cm to 185 cm tall can be leveled on the center of the display screen by adjusting the seat position and the foot step.
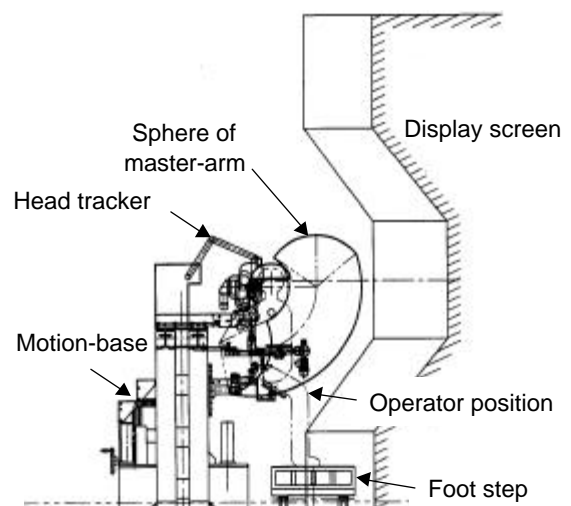
(drawings)

Figure 14 Layout of telexistence control cockpit system

By using the advanced remote control humanoid robot platform, various tasks can be achieved such as traveling place to place, going up and down stairs, bringing, picking up, clamping, handling an object, and so on.

The other more complicated tasks will be expected to be achieved by using the developed telexistence control cockpit after further progress in slave robot's functions. The system will be very useful for researchers to investigate such further technologies and technologies as for various kinds of applications of humanoid and human friendly robots in the second term of the project.

4. Conclusions

There are many master-arm systems and many motion-base systems, but we cannot feel realistic kinesthetic sensation of a humanoid robot's motion because existing means are only suited to limited slave robot motions and not to inclination and movement of upper body.

In order to solve the problems we have developed a master system with a kinesthetic sensation of presence of a humanoid and human friendly robot in the first term of the research and development project of "Humanoid and Human Friendly Robotics System" promoted by AIST/MITI.

The master system consists of two exoskeleton type 7 d.o.f. master-arms, two 2 d.o.f. gripping operation devices, and a motion-base. The master-arm can provide an operator with kinesthetic sensation of slave robot arms by feedback of force and torque at a slave robot's wrist. The gripping operation device is installed on each master-arm and can provide him with gripping sensation. 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.

All these elements have been evaluated by prototype

devices to design a advanced remote control cockpit platform system. The system is now under building up to validate designed functions and performances. Then the system will be used to investigate various application technologies as for a humanoid and human friendly robot in the second term of the project.

We expect that the system can provide a sensation of telexistence when tele-operating a humanoid and human friendly robot in the near future.

5. Acknowledgement

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