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A Tele-operated Humanoid Robot Drives a Lift Truck

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Abstract

We have been developing new abilities of humanoid robot to realize proxy drives of a lift truck. Construction machines such as a lift truck play an important role in many tasks, but sometimes the environments are too hazardous for human operators. If a tele-operated humanoid robot can drive a construction machine, it can work at a dangerous place. This humanoid robot operator has two advantages than automated construction machine. It is much easier to carry the robot to a disaster site than moving the special construction machine. Besides, the robot may be less expensive than developing the special automated machine whose required number is relatively small. We have been developing new abilities of tele-operated humanoid robot HRP-1 to realize the application. This paper describes results of investigations and experiments as for proxy drives of a lift truck by HRP-1.

1 Introduction

A humanoid robot has substantial advantages when working in an environment where human beings usually live, because a humanoid robot can act as a human being in such a space without any previous reconstructions of the environment. In recent years, many universities [2][11] [12][17] and some companies [6][9] have produced humanoid robots. However the application area of the humanoid robots are still limited in the research, the amusement, and the entertainment.

Figure 1: Image Illustration of Application of Humanoid Robot for Tele-operation of Construction Machine

Since 1998 Japanese fiscal year (JPY), Ministry of Economy, Trade and Industry (METI) has promoted the research and development project of "Humanoid Robotics (HRP)." The aim of the projects is to find some suitable applications for the humanoid robots. In the first term of the project, from 1998 to 1999 JPY, humanoid robot platforms as common bases of the research and development have been developed [7][13]. In the second term, from 2000 to 2002 JPY, various kinds of element technologies as for applications in which humanoid robots are expected to be used are developing by using the platform developed[8].

Construction machines play an important role in

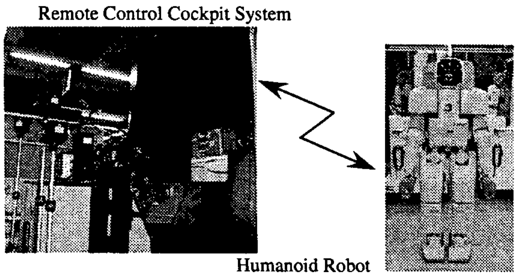

Figure 2: Tele-operated Humanoid Robot Platform

the many tasks, but sometimes the environments are too hazardous for human operators. If a humanoid robot can drive a construction machine and it can be operated from a remote site, the construction machine can work at a dangerous place. Figure 1 illustrated an image of a humanoid tele-driver. There are many trials to develop tele-operated construction machines [1][3][10][15][16]. However almost all of them are so special that it is not easy for human to drive them. This humanoid robot operator has two advantages than tele-operated construction machine. It is much easier to carry the robot to a disaster site than moving the special construction machine. Besides, the robot may be less expensive in the future than developing the special automated machine whose required number is relatively small.

We have been developing new abilities of humanoid robot to realize proxy drives of construction machines such as a lift truck or a backhoe in the second term of HRP. This paper shows the outline of the developed platform in the project and results of investigations and experiments as for a proxy drive of a lift truck by a tele-operated humanoid robot.

The rest of the paper is organized as follows. In Section 2, we present the humanoid robot platforms developed in HRP. The details of the proxy drive of a lift truck by a tele-operated humanoid robot are described in Section 3. We conclude the paper in Section 4.

2 Tele-operated Humanoid Robot Platform

The tele-operated humanoid robot platform consists of a humanoid robot, and a remote control cockpit system to operate the humanoid robot as shown in Fig. 2.

Table 1: Operating commands

Command	Parameters
Biped walking	Desired position x, y and orientation θ relative to the current position and orientation Walk up or down with the number of steps of the staircase. The width and height of each step must be unique and known.
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)

2.1 Humanoid Robot HRP-1

The humanoid robot of the platform is a human type robot with two arms and two legs, which walks by biped locomotion[7]. We call the robot HRP-1. It has 1600 [mm] height, 600 [mm] width, and 99 [kg] weight excluding batteries. It has 12 d.o.f. in two legs and 16 d.o.f. in two arms including hands with 1 d.o.f. grippers.

Each joint is actuated by a brushless DC servo motor with a harmonic-drive reduction gear. Brushless DC servo amplifiers, a Ni-Zn battery, a wireless ethernet modem are within the body.

The body is equipped with a inclination sensor which consists of gyroscopes and G-force sensors. Each foot and wrist is equipped with a force/torque sensor. In the head of the robot, there are two video cameras.

The humanoid robot can be operated according to the command inputted from the remote computer such as the remote control cockpit. The operating commands are listed in Table 1.

The orientation and acceleration of the body, the position and the orientation of the wrist, and the other measurements are output every 5 [msec]. The list of the output data is presented in Table 2.

By using the information, the operator can remotely command the robot to walk to the desired location and manipulate a certain object with monitor-

Table 2: 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

ing 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 images from the cameras and the sound from the microphone and to the speaker are communicated by analog wireless data transmitter via AV connectors.

2.2 Remote Control Cockpit

Figure 3 shows the configuration of the remote control cockpit system. It consists of an audio-visual display system and a tele-operation master system. The audio-visual display system includes surrounded projection display consiting of nine display screens, a head mount display (HMD) with a head tracker, and a 3D sound system[14]. The tele-operation master system includes right and left master-arm with two gripping operation devices, a motion-base, and a 3D mouse[4][5].

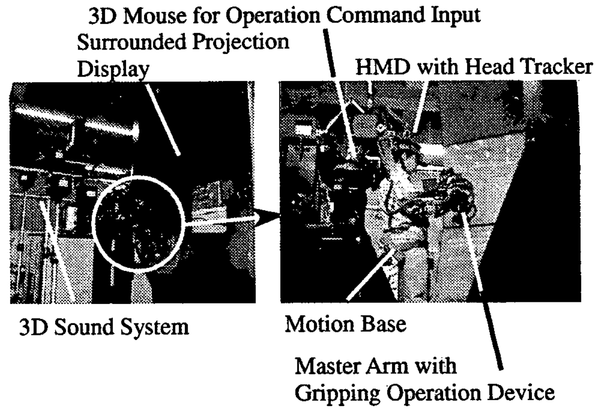

Figure 3: Configuration of Remote Control Cockpit System

Table 3: Specification of Master-arm

Interface type	Exoskeleton master-arms (Right and left arm)
Degrees of Freedom	7 d.o.f./arm
Output force	10 N (Maximum at a moment)
Maximum Speed	100 mm/sec at end-point of arm
Weight	75 kg / arm

The master arm is designed as an exoskeleton type and has seven degrees of freedom for each arm. Owing to this redundant d.o.f., the operator can instruct redundant posture of an arm of HRP-1 directly using its 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 wrist force sensor of HRP-1 so that the operator feels force and moment naturally. The specifications of the master-arm system are shown in Table 3.

Each master arm has a newly developed gripping operation device shown in Fig. 4. It is small and light enough to equip at the master-arm. The weight of the device is less than 0.3 [kg]. Using a gripping operation device, an operator can easily operate open-close motion to grip.

The motion-base system 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

Figure 4: Schematic diagram of gripping operation device

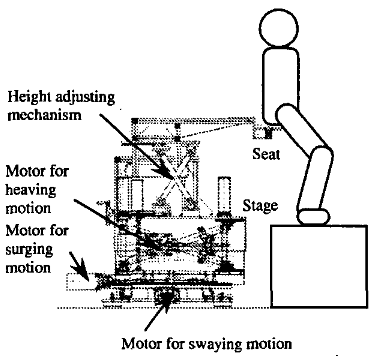

Figure 5: Motion-bae system

that we can measure on a humanoid robot. In order to present locomotive motion of the humanoid robot, a motion-base system which can present locomotive motion only by 3 d.o.f. translation; back and forth (surge), left and right (sway), and up and down (heave), have been developed. Because the system is used as a remote control humanoid robot platform, it is required to keep the displacement of an operator's eye point small enough for general purpose.

The developed system is shown in Fig. 5. Each stage is supported by linear guides. For surging motion with ± 75 [mm] and swaying motion with ± 100 [mm], the stages are actuated by 2 [kW] AC servomotors with ball screws. In heaving motion with ± 100 [mm], a pantograph mechanism is adopted to drive the stage. The pantograph mechanism is actuated by a 2 [kW] AC servomotor with a ball screw. There is another mechanism that can adjust a seat in up-down direction by manual operation in order to absorb any dimensional differences of operator's body.

The tele-operation 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 and hands, the operator manipulates by using master-arms and gripping operation devices, watching views on the HMD from the two video 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.

3 Remote Operation of an Electric Lift Truck by Tele-operated HRP-1

3.1 Experimental System

As a sample of construction machine for proxy drive experiments, we focused a lift truck because a it is one of the most popular construction machines in several fields. For the experiments, we introduced a standing operation type electric lift truck (Nichiyu FBR9-60) with 900 [kg] load capacity. Figure 6 shows the outlook of the lift truck driving by tele-operated HRP-1. HRP-1 has to control a fork (up-and-down, tilt, and reach), traveling speed and direction using the control levers and the steering wheel for proxy drives of the lift truck. Experiments of fork operations (lever operations), traveling operations (lever and steering wheel operations), and overall operation using levers and steering wheel were carried out. Through these experiments, we extracted points at issue and examined the measures. In these experiments, length of the levers and the dimensions of grips of the levers and the steering wheel were modified on purpose to suit the range and force needed to operate the levers and steering wheel to specifications of the remote control humanoid robot platform. HRP-1 grasps a lever or a handle of the lift truck loosely in order to avoid a lack of stability of the control system.

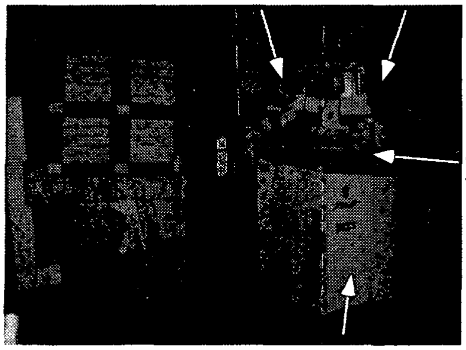

Figure 6: Tele-operated Electric Lift Truck with HRP-1

3.2 Experimental Results

First, lever operation experiments were carried out (Fig. 7). Figure 8 shows the force acting on the wrist of HRP-1 and the operation force of the master-arm. This figure shows the value of the force acting on the wrist of HRP-1 kept under 700 [gf] because HRP-1 cannot generate the force over 1 [kgf]. The time to operate the lifting lever by a tele-operated HRP-1 is about 20 [sec]. It took approximately 2.2 times longer than a human operator did. Also the time to operate the fork-reaching levers by a tele-operated HRP-1 is about 19 [sec]. It took approximately 2.8 times longer than a human operator did.

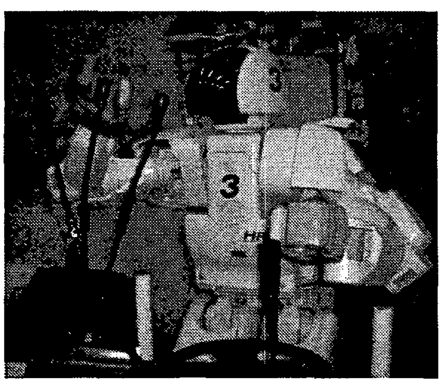

Figure 7: Lever operation experiment

Next, traveling forward and backward experiments were carried out. In these experiments, HRP-1 operated the forward/backward lever in standing posture.

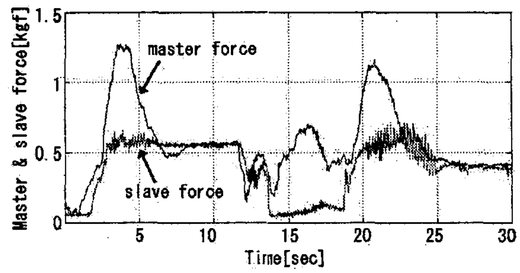

Figure 8: Results of lever operation experiments

Figure 9 shows the position of the west of HRP-1 as the lift truck traveled forward and backward. The maximum acceleration of the lift truck in the experiment was approximately 0.05 [G], and HRP-1 could keep the balance for standing. The influence of the acceleration of the lift truck on the lever operations using robot arms was negligibly small.

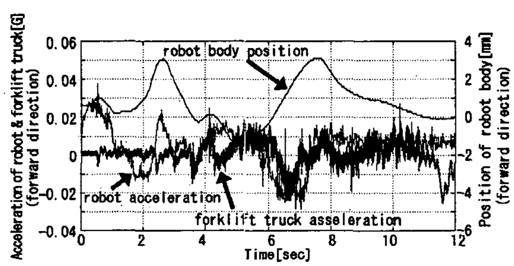

Figure 9: Results of forward/backward experiments

The steering wheel operation experiments were also carried out as shown in Fig. 10. Figure 11 shows the force acting on the master-arm, the operation force of HRP-1, and the two dimensional trajectory of the wrist of HRP-1. The position of the wrist at the start is different from the position at the end because HRP-1 needed to re-grasped the steering grip in order to avoid singularities. As the hand approach the nearest point to the west, the west moved by a balance control function of HRP-1. However, the movement was not influence to arm operations because the amount of the moving was very small (approximately 10 [mm]). Also we found that bilateral force control is essential to operate a steering wheel because an operator of HRP-1 detects the tangential direction of the steering wheel to rotate it while feeling the force acting on the wrist of HRP-1. The time to operate the steering wheel by

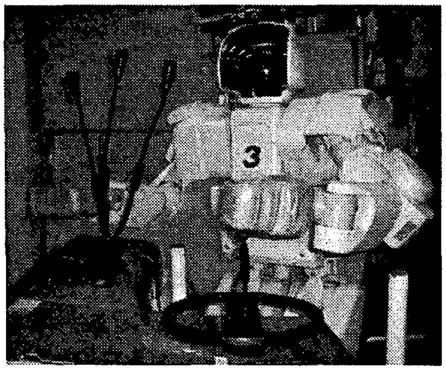

Figure 10: Steering wheel operation experiment

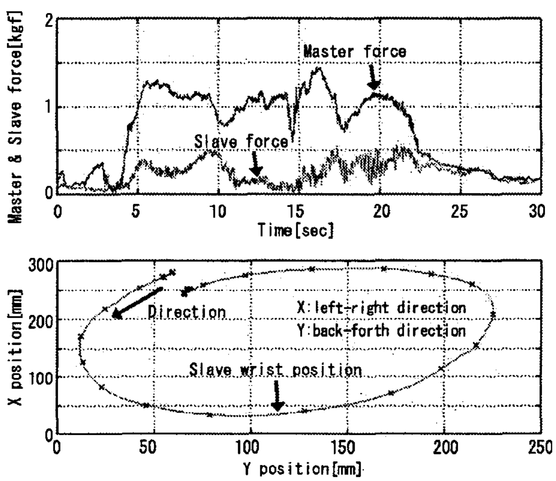

Figure 11: Results of steering wheel operation experiments

tele-operated HRP-1 is about 20 [sec]. It took approximately ten times longer than a human operator did because of the re-grasping of the grip.

Furthermore, we have examined performances as for remote operation tasks, which include the sequence of transferring a load on the palette. We have executed the following tasks using the tele-operated humanoid robot.

1. Lever operation: Inserting a fork under a palette after 3 [m] forward moving
2. Lever operation: lifting up a fork
3. Lever operation: tilting up a fork
4. Lever operation: 2 [m] backward traveling
5. Steering wheel and lever operation: 2 [m] forward traveling with a turn
6. Lever operation: lifting down a lift
7. Lever operation: tilt down a lift to the initial angle
8. Steering wheel and lever operation: 1 [m] backward traveling with a turn.

Several snapshots taken during the experiments are shown in Fig. 12.

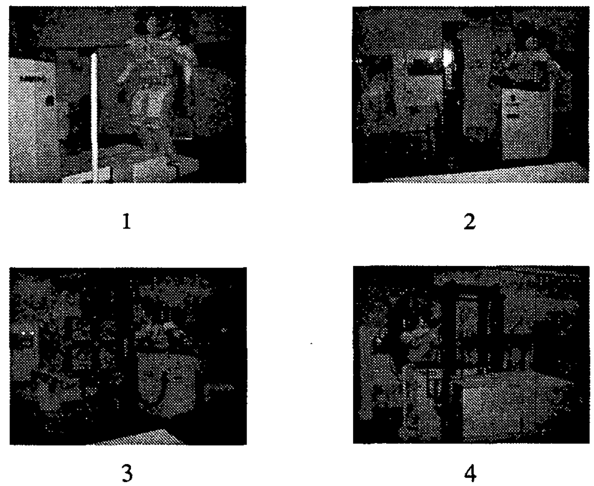

Figure 12: Sequence of transferring a load on the palette

The time to carry out these tasks is about 300 [sec]. It took approximately 3 times longer than the human operator did.

4 Conclusions and Discussions

This paper presented the current status of research and development on the application of the teleoperation of a construction machine by a tele-operated humanoid robot under going on HRP in Japan. We have succeeded in making the experiments as for the proxy drive of a forklift by the tele-operated humanoid robot HRP-1.

From the experiments, we found out several points to be improved as follow.

1. Software program for leg control at climbing will be modified to make commands corresponding to various shapes of stairs, which makes it easy to climb various types of construction machines.
2. The operator makes a walking command through visual information, so it is difficult for him to prevent a collision with the environment at the place

where the robot finishes a walk. This requires a function to measure distance between the robot and the environment and to check collisions. In the same way, it is difficult for the operator to check collisions between various parts of the arm and the environment only through visual information. This requires protective equipments to reduce damage caused by contact and a function to inform the operator of contact.

3. At camera operation, an operator had a difficulty with reading small words on a dashboard through onboard camera. This requires a function to adjust not only the direction of camera but also the zoom ratio. At the place where there is much amount of light, a function to adjust the aperture of the camera is needed.

In future, we are going to solve these problems and try to study the proxy drive of a construction machine which is operated in sitting posture such as a backhoe illustrated in Fig. 1.

At the end of the paper, we want to mention that not only construction machines but also almost all items are designed for humans. We believe a humanoid robot would have the most suitable shape for using them. For this characteristic, humanoid robot may expand its capability as human did.

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