2005 IEEE International Workshop on Robots and Human Interactive Communication

Marionette System for Operating and Displaying Whole-body Motion -Evaluation of Tele-manipulation Using Marionette Device-

Kazutoshi Nishii, Tomohito Takubo Kenji Inoue and Tatsuo Arai
Department of Systems Innovation
Graduate School of Engineering Science,
Osaka University
1-3 Machikaneyama, Toyonaka, Osaka 560-8531, Japan
Email: nishii@arai-lab.sys.es.osaka-u.ac.jp

***Abstract*— It is difficult to generate whole-body motion of a multi-joint robot and to observe its condition, since its structure is complicated. We propose Marionette System to provide an intuitive teleoperation system. Marionette system employs a small robot which is similar form to a target robot as an operating/displaying device. The device provides the operational feeling like handling a marionette, so we named it "Marionette Device." This system has several advantages: operation and presentation can be done simultaneously, all movable joints are operated intuitively, and the robot motion is displayed in the easy-to-understand way.**

We developed a similar humanoid robot as Marionette Device in order to operate HRP-2 and conducted the comparison experiment of presentation and operation. In this paper, we upgrade Marionette Device and develop a posture displaying device to verify the validity of the proposed system. We have carried out evaluation experiments on the remote control of upper body. Marionette System is compared with the conventional method using a joystick control and a CG display. The experimental results show Marionette System is more convenient operation and presentation environment.

***Index Terms*— Marionette System, Marionette Device, Master slave, Teleoperation, Humanoid**

I. Introduction

In the previous study of humanoid teleoperation, position and velocity commands were controlled by joysticks [1], [2] or a 3D mouse [3]. These devices have only small number of degree of freedom (DOF), so an operator can not control many joints easily. In another studies, motion capture [4], [5] and super-cockpit [6] system were developed to operate a humanoid robot by the motion of an operator's body. These control systems can operate the humanoid robot just like controlling his/her body. However, the installation of these systems is difficult since the size is big and cost is high.

Teleoperation systems for a humanoid robot also need displaying devices to know the state of the robot. The traditional presentation methods are displaying the enumeration of each of joint angles numerically, and rendering the CG model of the robot [7], [8]. Humanoid robots have complicated structure and a lot of points that should be checked; hence these methods do not change viewpoints smoothly.

For the operating problems, we consider the controlling device should have enough number of DOF and its design should be compactness. Therefore, we propose a small-sized humanoid robot as a suitable teleoperation device. The small-sized humanoid robot has tangible states and similar form, thus it presents a comprehensible display. We have proposed this humanoid type device as "Marionette Device," and teleoperation system that uses Marionette Device as "Marionette System" [9]. Marionette System is easy-to-use control system which can provide the operational feeling like handling a marionette, and realizes the operation and the display simultaneously.

II. Marionette System for Operating and Displaying

In this section, how to check and adjust the state of a control target in Marionette System is described. The aim of Marionette System is realizing the control environment in which operator can manipulate a control target smoothly and observe the state of the control target instantly. For the attainment of it, Marionette System is desired the quickness and the accuracy for the following two tasks.

Check if a task is carried out under a present situation.

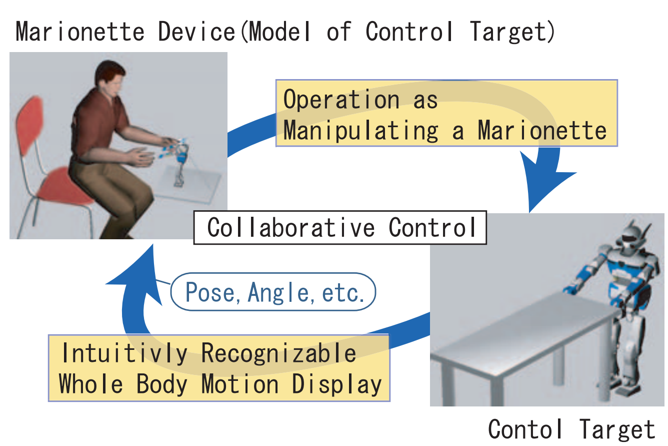

Fig. 1. Concept of Marionette System

Adjust a present state for execution of a task.

The concept of Marionette System for implementation of these function is illustrated in **Fig.1**.

A. Displaying by Marionette Device

When a control target is a humanoid robot, the information needs to convey to the operator is as follows.

- Manipulator tip postures, positions, and velocities.
- The end parts of feet postures, positions, and velocities.
- The link postures for obstacle avoidances.
- The direction of external sensors.
- The condition of the contact between an external world and the control target.
- The operating angle of each joint within its operating limits and non-interference areas.
- The body posture and the body altitude from the world coordinate.

A position information is produced an exact copy by the relative positioning which depending on the Marionette Device's scale. For example, if the size ratio of between the controlled target and Marionette Device is 1:5, Marionette Device's manipulator must move 1 cm when the control target's manipulator moved 5 cm. Velocity information does likewise; the relative position is replaced by a velocity vector. Posture/direction information is presented by the equalization of the inclinations of links to standard coordinates. From the reproducibility of above information, Marionette Device should have the numbers of joints same or more than the target robot has. In addition, a same link ratio is needed for displaying link postures. If the device can not have the same ratio, control methods are determined by the priority assignment between positioning control and posture control from the aspect of the purpose of a task. The interaction with environment express in the control force which is calculated based on the reaction force from an external world. Also, operating limits and non-interference areas are represented by same way (i.e., a powerful control force is needed when an operated joint goes over its limit).

Meanwhile, it is difficult that Marionette Device is designed for the equivalence of a mass and a dynamics balances. Therefore, correctable and stable presentations become compromised due to the necessity to a different posture control. Owing to this, we propose the posture displaying device for presentation of the remote robot's posture. The posture displaying device fixes Marionette Device in the air, and has the function to display the body posture from the world coordinate (**Fig.2**).

B. Operating by Marionette Device

Marionette Device has next three-functions to promote the facilitation of the operation, and the effective utilization of displaying methods which are described in preceding section.

1) An operation executed concurrently with a presentation.
2) All of joints can be controlled directly.
3) Several functionally-related movements are comprehended easily by a tangible visualization.

For the function 1), an operator can check the control target's motion on the action of Marionette Device and remediate troubled parts directly. This function decreases the imposition of operation, since these tasks are executed without switching from displaying to controlling. For the function 2), a smooth operation is effectuated even where the obstacle avoidance needs complicate orbital and frequently switching among control points. For the function 3), it is easy to understand that operating limits, the body posture, and what whole-body motion is generated by provided control. In particular, an operator manipulates hands and legs by considering a posture control and non-interference areas.

C. Comparison of a operation and presentation device

The comparative table of between Marionette Device and other control devices is shown in **Table I(a)**. Since Marionette Device is the scale-down model of a control target, there is the shortcoming of a fine operation. In case the fine operation is required, it is better able to respond to this issue that control methods diminish the relative sensitivity of the amount of displacement to the amount of operation.

The comparative table of between Marionette Device and other display devices is shown in **Table I(b)**. Marionette Device has a real body, thus it shows the performance advantage of the appearance of solidity. However, Marionette Device can provide only the information of remote robot. Therefore, environmental information is provided by other display devices in Marionette System.

III. Improvement in Marionette Device

In this section, the micro-controller unit (MCU) process for Marionette Device's control and the development of posture

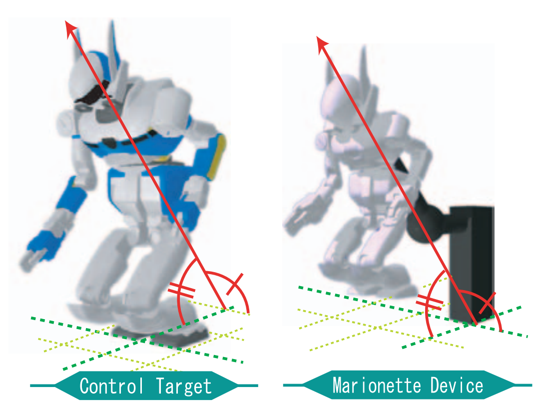

Fig. 2. Concept of posture device

TABLE I
COMPARATIVE CHART OF DEVICES

(a) Comparison of control

	Cost	DOF	Size	Plainly of Operation	Fine Operation
Keyboard	inexpensive	sufficient	small	bad	easy
Joystick	inexpensive	unsufficient	small	bad	difficult
Full Master Slave	expensive	sufficient	large	good	easy
Motion Capture	expensive	sufficient	large	good	easy
Marionette Device	rather expensive	sufficient	small	good	difficult

(b) Comparison of display

	Cost	Size	Appearance of Solidity	Environmental Display
Flat Display	inexpensive	small	bad	possible
3D Display	rather expensive	small	good	possible
Head Mounted Display	rather expensive	small	good	possible
Immersive Projection Display	expensive	large	good	possible
Marionette Device	rather expensive	small	very good	impossible

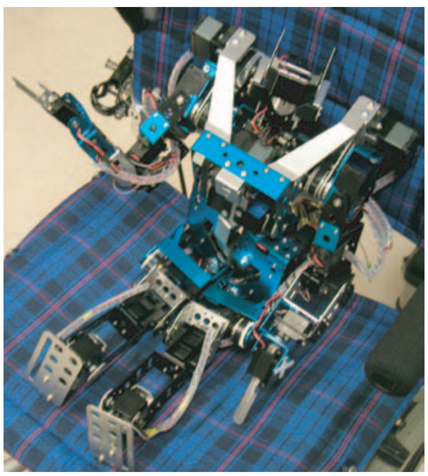

Fig. 3. View of Marionette device

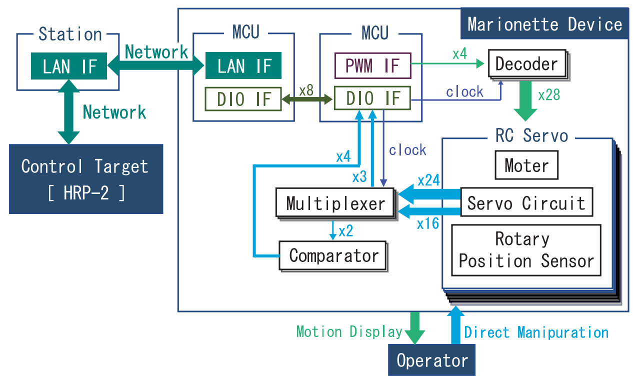

Fig. 4. Marionette device controller

displaying device are described. The Marionette Device used in this paper is shown in **Fig. 3**. The device was designed based on the structure of HRP-2 [10], which was control target, and control/display HRP-2's 28 DOF not involving a hands closing motion.

A. Segregation of MCU processing

The flow of the Marionette Device's control signals is shown in **Fig. 4**. The Marionette Device used the servo motors which were controlled by pulse-width modulation (PWM) signals. The interface for connection between the Marionette Device and HRP-2 was a LAN connect interface. We appropriated the two dedicated MCUs for a PWM signals generation and a network communication, since the load growth of MCU was gained by a whole-body control.

Moreover, these functions had the execution priority for a more stable control. The PWM signal generation required sec order controls, thus this function had the highest execution priority. A MCU-MCU communication function had the second execution priority, and the network communication had the lowest priority. These priority settings made the stable servo motor control without the influence exerted by network traffic variations. In addition, we selected UDP as a transport protocol for a high-speed data transport.

B. Necessary functions of posture displaying device

Control target's postures are an upright posture, a resupine posture, a prone posture, a side toppling, and the intermediate state of these postures. Accordingly, a posture displaying device needs 2 DOF for roll axis and pitch axis. In addition, the mechanism of the posture displaying device is not desired to take away from the operationality of Marionette Device. The CAD model of the posture displaying device based on the above-mentioned demand is shown in **Fig. 5**.

Each joint had ± 90 deg operating angle, so the posture displaying device duplicated all inclination from the ground of a control target. For the operationality problem, Marionette Device's mount point was located in the dead space of a working area. On the other hand, the bosom parts of the Marionette Device can not use for operation because it was fixed on the posture displaying device. In case of humanoid

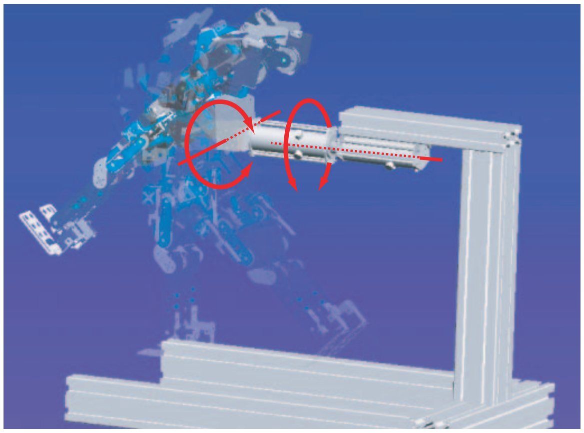

Fig. 5. Support mechanism

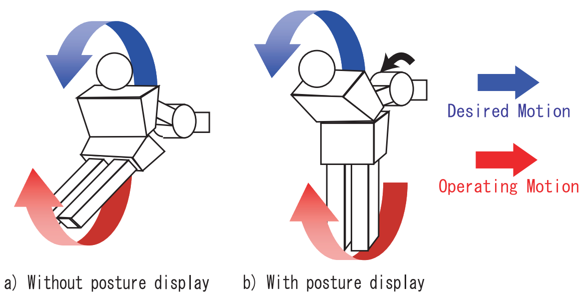

Fig. 6. Directions of posture control

robot controls, generally, humanoid's legs are imagined touch on the ground. Therefore, bending a upper body is perfectly natural control if chest joints are wanted to bend. In contrast, the design of posture displaying device did not provide natural control, since it need to control a lower body if chest joints are wanted to bend (**Fig. 6 (a)**).

For the natural control problem, we developed that a lower body can control the posture with checking an alteration in the posture (**Fig. 6 (b)**). An operator gains the understanding of a posture movement without the muddle of operation, since the operator can control the posture with the verification of operation's results. This operation method was realized by motion of the posture displaying device which balanced out a lumbar axial displacement.

C. Operating of posture displaying device

The network communication program between the Marionette Device and HRP-2, and the control program of the posture displaying device are implemented as multithread. The control system configuration based on the information of angles is shown in **Fig. 7**. A Communication relaying was done by two TCP/IP-based client programs which connected with a Marionette Device's server and a HRP-2's server respectively. Whole-body angles were commuted among clients

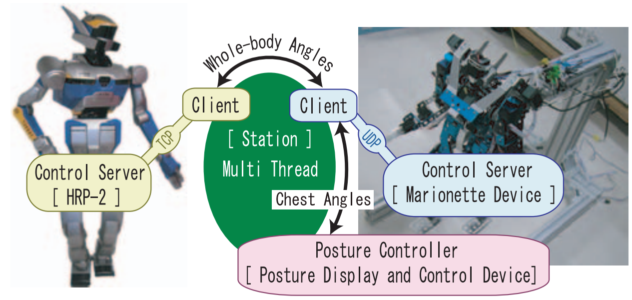

Fig. 7. Flow of Control Signals

and servers. The control program of the posture displaying device commuted only chest angles. However, the plantar surface's slope of a control target also changes the posture of the control target. Therefore, we add the information about lower body angles and attitude sensors in a future work.

IV. Experimental Evaluation

A. Task setting for remote-controlled upper body

To estimate of the operational performance and the visual effects of the Marionette Device, we conducted an experimental evaluation for a teleoperation with generally devices: a joystick and a flat display. The experiment assumed the remote control of HRP-2's upper body parts, and set the task of approaching target objects by HRP-2's hands. During carried out the task, an operator can not check the state of HRP-2 with eyes directly and by an environmental monitor. The information of HRP-2 was presented by 3DCG displayed on flat display or the Marionette Device for whole-body angles. In addition, a flat display used for displaying head camera images.

The target objects, which were a basket ball and a soccer ball, were putted on the ninety-centimeter-high poles. The experiment measured the time required for slapping away the balls from the pole. The target objects were allocated on four points which is shown in **Fig. 8**. Target 2 and Target 3 could touch with not only the nearer arm, but also the farther arm with swirled a lumbar part around. For Target 1 and Target 4, only the nearer arm could approach. Also, the head camera could not find any target in initial state. Therefore, in first, an operator had to control a cephalic part and/or a lumbar part toward the target object. After find the ball, the operator must operate an arm part in a head camera's field of view. In case of Target 1 and Target 4, due to limitation of the head camera's field of view and the head joint's range of movement, the head camera could find the targets only by operation of both the cephalic part and the lumbar part. Since the level turn of the lumbar part get the arm which use approach away from the target in the head camera images, the forward flexion was needed to touch the targets with HRP-2's hand.

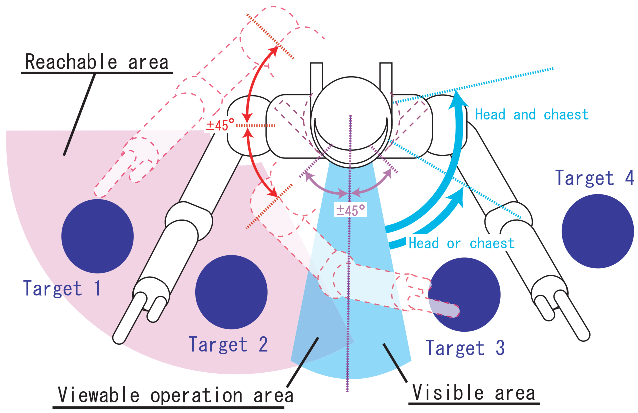

Fig. 8. Targets Layout

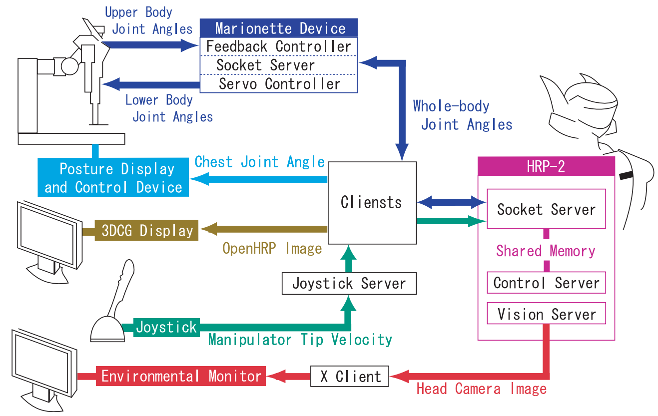

Fig. 9. System configuration

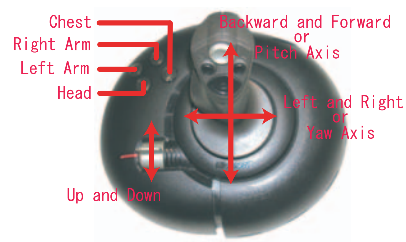

Fig. 10. Control stick and button layout of joystick

B. Comparison experiments of remote control and presentation

Fig. 9 shows the system configuration of the devices for experiments. The joystick had two levers, which had 2 DOF and 1 DOF, and four buttons (**Fig. 10**). An arm control was a tip velocity control: the 2 DOF lever was assigned a horizontal direction control, and 1 DOF lever was assigned vertical direction control. A head and a lumbar control was an angular speed control, using only the 2 DOF lever which was assigned roll axis and pitch axis. The four buttons corresponded to a left arm, a right arm, a head, and a chest, respectively. An operator must push any one of the buttons which was assigned a desired control part with a lever control. A 3DCG model was VRML model made from OpenHRP [11]. This model system had a controllable, free view point by dragging a screen with a mouse.

The joint angles of the Marionette Device's upper body, which are arms (6 DOF 2), head (2 DOF), and lumbar (2 DOF), corresponded one-to-one with HRP-2' joint angles. The Marionette Device's lower body, which not used operating device, was controlled as a displaying device. An operator could control each joint directly, and several joints at the same instant. In this regard, however, the upper body of the Marionette Device did not feed-back the information on the actual location of HRP-2. Besides, a HRP-2's control method set the speed limit which was comparable with the speed limit for joystick control. Therefore, with large controlled variable by the Marionette Device, HRP-2 could not follow position control lead. That means the slippage of joint angles arose between the Marionette Device and HRP-2.

The control law of the posture displaying device and the Marionette Device's pitch axis of a lumbar part was **Fig. 6 (b)**. In contrast, since the posture displaying device did not have a yaw axis, the Marionette Device's yaw axis of the lumbar part was not balanced out. Thus, we made the comparison of the operational feeling of the lumbar axes to make clear the effect of the improved of an operational feeling by the posture displaying device.

Targets were selected from Target 1/Target 2 and Target 3/Target 4. An operator knew that a one target located each side of HRP-2, but not knowing a concrete layout. We conduct the experimentation about the four combinations of two targets by six subjects. An experimental view is shown in **Fig. 11**.

C. Results and discussion

The results shown in **Table II**. The average time of Marionette System's cases was nearly two times shorter than traditional environment's cases. This time was 45% of hours of work in the traditional teleoperation system. Besides, the number of cases that was confirmed effect of shorter hours is 87.5% in all cases. Thus, Marionette System was more convenient operating environment than the operating environment which use the joystick and the 3DCG.

The following items were singled out as factors causing the differences time by the comment of subjects and the experimental view.

1) When joint angles reached operating limits, an operator spend much time thinking of where the joint has a problem and what the operation is needed for an improved situation in the traditional teleoperation environment. Marionette System not only shortened the amount of

Fig. 11. Approach to the targets

TABLE II
REACHING TIME

(a) Traditional Environment (joystick and 3DCG)

Target No.		1 & 3	1 & 4	2 & 3	2 & 4	Average
Operator	A	3'16"	5'23"	3'08"	6'35"	4'36"
	B	5'59"	6'58"	7'16"	5'57"	6'33"
	C	3'29"	10'26"	6'40"	5'23"	6'30"
	D	5'19"	5'40"	6'14"	7'34"	6'12"
	E	2'48"	4'27"	2'39"	5'00"	3'44"
	F	1'36"	3'54"	4'25"	2'35"	3'08"
Average		3'45"	6'08"	5'04"	5'31"	5'07"

(b) Marionette System

Target No.		1 & 3	1 & 4	2 & 3	2 & 4	Average
Operator	A	3'44"	4'15"	3'08"	3'36"	3'41"
	B	2'48"	2'58"	3'23"	3'53"	3'15"
	C	3'09"	1'18"	4'31"	3'23"	3'05"
	D	2'56"	2'46"	2'42"	3'16"	2'55"
	E	1'44"	1'02"	1'23"	1'40"	1'27"
	F	2'05"	3'51"	1'38"	2'13"	2'26"
Average		2'44"	2'42"	2'47"	3'00"	2'48"

this time, but also reduced the frequency of reaching limits.

2) Since the layout of the joystick's buttons was not correspond to layout of the body parts sensuously, an operator sometimes required affirmation of the layout when the operator select the button.
3) The simultaneous operation of several joints of Marionette Device could carry out the task effectively.

The reason of item 1 was caused by two advantages of Marionette Device. First, Marionette Device had the better expressiveness than 3DCG, so that the operator got the good results of specifying the location of the limited joint and decrease in the frequency of the operation with reaching limits. Secondly, since the joints of Marionette Device could be controlled directly, problematic state was modified promptly. Furthermore, Marionette Device did not need the extra task which is declared in item 2 as well as the particular operation for changing control points, Item 3 is attributed to paucity of the number of the joystick's DOF. In particular, this results in the differences time on the task which needs multiple joint control like we conducted in this paper.

For the operation with the joystick, combination of Target 1 and Target 4 took the longest time for the task. This combination was the farthest target pair from HRP-2, thus an operator spent much time to change control points. Additionally, the operation with the joystick tended to draw rougher trajectories than the operation with the Marionette Device. This fact denote that the longer trajectory needed the longer time for operation, showing that time differences were attributed to target combinations, as well. In fact, the time for the tasks was not due to target combinations in the operation with the Marionette Device.

In addition, we got the other comments of subjects as follows.

1) Since the Marionette Device's control had a time delay, its trajectories were not ideal.
2) For a manipulator tip within head camera images, the operation with the joystick was especially difficult.
3) On displaying by 3DCG, the moment at which a manipulator tip enters head camera's field of view was hard to make out.
4) An operator addled because the Marionette Device's yaw axis of the lumbar part needs to revolve a lower body to inverse direction from what the operator wanted to revolve an upper body. However, its pitch axis control which needed same operation had no confusion.

The solution for item 1 was the improvement in the ability to pick up working speed of HRP-2. Actually, after head camera found the manipulator tip, there is no problem because the subjects only needed the adjustment which speed is enough slow to be synchronized with HRP-2. Item 2 resulted from discord among coordinate systems, that is, the subjects did not control on vision coordinate system because the task coordinate system conformed to body coordinate system. For Marionette Device, the positional relation of HRP-2's parts was grasped readily, so the subjects did not have this type problem. Item 3 also indicate this Marionette Device's advantage. The fact of item 4, the control law of the posture displaying device and the Marionette Device's pitch axis of the lumbar part had the effect for the improvement of the operation feeling.

V. Conclusion and Future Work

In this paper, we developed a new control environment "Marionette System" which uses a small-size humanoid robot as a control/display interface "Marionette Device." In order to verify availability of Marionette System, we developed Marionette Device and conducted the comparison experiment with the system using a joystick and a flat display. The experimental result showed that Marionette System provided more convenient operation and presentation environment. In operation, Marionette Device shortened the time for an experiment task because an operator controlled several parts at once without cumbersome changeover. In presentation, an operator got the good results of specifying the location of the limited joint and decrease in the frequency of the operation with reaching limits. In addition, the positional relation of remote robot parts was grasped readily by Marionette Device.

It is considered as our future works which are lower body control and its evaluation with Marionette Device.

REFERENCES

[1] H. Hasunuma, et al, "A Tele-operated Humanoid Robot Drives a Backhoe," Proc. of the IEEE Int. Conf. on Robotics and Automation, pp.2998-3004, 2003.

[2] E. S. Neo, et al, "Whole Body Teleoperation of a Humanoid Robot -A Method Integrating Operator's Intention and Robot's Autonomy-," Proc. IEEE Int.Conf. Robotics and Automation, pp.1613-1619, 2003.

[3] Takashi Nishiyama, et al, "Development of User Interface for Humanoid Service Robot System," Proceedings of the IEEE Int. Conf. on Robotics and Automation, pp 2979-2984, 2003.

[4] K. Kurihara, S. Hoshino, K. Yamane, Y. Nakamura, "Optical Motion Caputure System with Pan-Tilt Camera Tracking and Realtime Data Processing," Proc. of the IEEE Int. Conf. on Robotics and Automation, pp.1241-1248, 2002.

[5] A. J. Ijspeert, J. Nakanishi, S. Schaal, "Movement Imitation with Nonlinear Dynamical Systems in Humanoid Robots," Proc. of the IEEE Int. Conf. on Robotics and Automation, pp.1398-1403, 2002.

[6] H. Hasunuma, et al, "Teleoperation master arm system with gripping operation devices," Proc. of Int. Conf. on Machine Automation, pp.567-572, 2000.

[7] J.J. Kuffner, S. Kagami, M. Inaba, H. Inoue, "Graphical simulation and high-level control of humanoid robots," In Proc. IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, pp.1943-1948, 2000.

[8] N. Sawasaki, et al, "Application of humanoid robots to building and home management services," Proc. of the IEEE Int. Conf. on Robotics and Automation, pp.2992-2997, 2003.

[9] T. Takubo, et al, "Marionette System for Operating and Displaying Robot Whole-Body Motion -Development of Similar Humanoid-Type Device-," Proc. IEEE/RSJ Int. Conf. Intelligent Robots and Sytems, pp.509-514, 2004.

[10] K. Kaneko, et al, "Design of Prototype Humanoid Robotics Platform for HRP," Proc. IEEE/RSJ Int. Conf. Intelligent Robots and Sytems, pp.2431-2436, 2002.

[11] H. Hirukawa, F. Kanehiro, S. Kajita, "OpenHRP: Open Architecture Humanoid Robotics Platform," The International Journal of Robotics Research, 2004.