DEVELOPMENT OF A TELEOPERATION SYSTEM AND AN OPERATION ASSIST USER INTERFACE FOR A HUMANOID ROBOT

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Abstract: - This paper describes a humanoid robot teleoperation system through the Internet/LAN. The developed system is a server-client system based on Common Object Request Broker Architecture (CORBA). The main target is that a human operator can remotely control the humanoid robot arms by on-line as if own arms naturally. In order to achieve the operation, we have developed a user-friendly Virtual Reality (VR) user interface that is composed of ultrasonic 3D mouse system and a Head Mounted Display (HMD) with a gyro sensor. The preliminary experiments show that the system is available as a teleoperation tool for the humanoid robot.

Key-Words: - Humanoid Robot, Teleoperation, The Internet, CORBA, Virtual reality, Ultrasonic 3D mouse system, Motion trajectory generation

1. Introduction

The development of humanoid robot is a popular field in robotics. The shape of humanoid robot is so similar with human being that they can be adopted into human live spaces, for example, home, medical place, manufacturing factory, extreme environments, disaster sites and so on. Especially, it is so effective to replace human being with humanoid robot for operation in disaster site and/or extreme environment (ex. Atomic power plant). These environments might change at every moment, thus, an operator must remote control the robot by his/her determination.

Humanoid robot has a lot of degree of freedom arising from its shape. It provides the robot with many sophisticated motions holding the line against other mobile robots, for example, creeping, climbing/going down and so on. In order to remote control of humanoid robot, several user interfaces have been developed. For example, remote control cockpit system[1], and portable remote control device system[2] have force feedback master arms. By using it, the operator can give his/her desire arm motion to the robot viscerally. But such device is complex, and its cost is also expensive. On the other, simple master device system[3] has two joysticks as input master device. Although the joystick cost is low, the operator must have the usage all worked out to carry out some tasks with precision because it has only three degree of freedom. And it might imply that it is hard to deal with environmental variations like sudden accidents.

For developing humanoid robot teleoperation system, we think it necessary for the system that the user interface is simple and usable to reflect the operator's order, and the cost for development and running is minimum low. In this study, at first we focused on remote control of a humanoid robot's arms by on-line. To carry out the operation with ease, we developed an ultrasonic 3D mouse system as a master device for teleoperation system. And we also built a simple VR interface with it and a HMD equipped a gyro sensor. In this paper, we show the detail of our teleoperation system and its user interface, and experiment results.

The organization of this paper is as follow. Section 2 briefly describes the configuration of our teleoperation system. Section 3 describes the detail of operation assist user-interface. Section 4 presents experimental results. Finally, conclusions and future works are given in section 5.

2. Teleoperation System

Our teleoperation system is a server-client system through the internet/LAN based on CORBA [4][5]. There are two server PCs for control of communication and robot motion, and for live streaming CCD camera vision. And there are also two client PCs for control of communication and user interfaces, and for receiving live streaming vision. While an operator sends the server his/her order including task commands and/or planned motion based on robot vision, the robot implements the order and returns results to the client, that is, current robot status (standing or crouching and so on) and robot vision. For communication between an operator and a humanoid robot, TCP/IP with CORBA is used for motion operation, and UDP is used for live streaming. The schema of our teleoperation system is shown in Fig.1.

3. Operation Assist User Interface

When an operator watches robot vision monitor and gives a robot his/her order with simple input device like a joystick, he/she may feel some troubles to manipulate the input device and camera equipped on the robot at once. Because a joystick is not always suitable for quick 3D motion operation and the manipulating input device and camera is separated. In consideration of above case, we decided concepts of our user interface as follow; 1) take in the operator’s hand tip trajectory as order motion by a master device, 2) compose a VR interface with HMD equipped gyro sensor to share robot vision. The former needs to determine the space coordinates of operator’s hand tip. Considering the environment and the operator’s working area, and the precision of measurement, the cost for system development and running, we developed an ultrasonic 3D mouse system applied ultrasonic positioning system[6]. The latter is to reduce a workload of manipulating a robot camera. As synchronizing the robot head motion with the operator’s one, the operator can watch what he/she wants naturally.

3.1 Ultrasonic 3D Mouse System

This is a system to extract the operator’s hand tip trajectory. The configuration is as follow; an ultrasonic 3D mouse and an ultrasonic receiver net cage and the system control PC (Fig.2). The 3D mouse has 3 electrostatic transducers (transmitter) and 1 trigger switch and 3 mode select switches. The receiver net cage has 3 planes that ultrasonic receivers are allocated by 300[mm]×300[mm] regular interval on the frame of each plane, and its origin of coordinate is also shown in Fig.2. The electrostatic transducers used in this study are MA40E7S/R made by Murata Manufacturing Co. Ltd, Japan. The specifications are shown in Table 1.

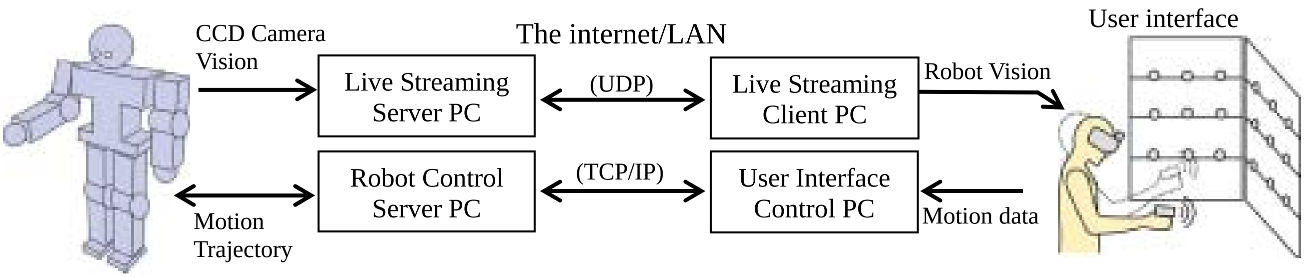


Fig.1 Schema of humanoid robot teleoperation system.

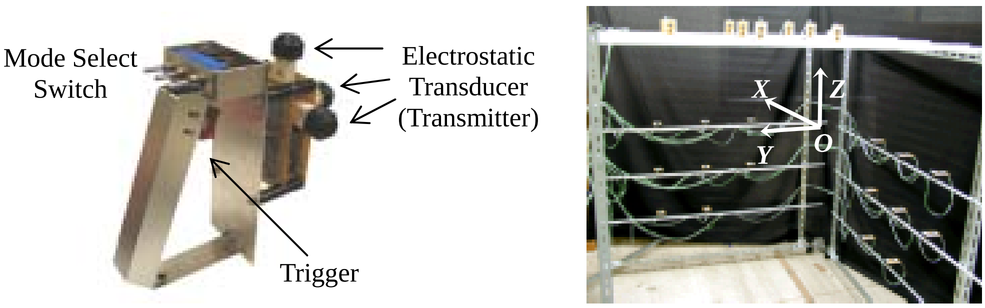


Fig.2 Ultrasonic 3D mouse and ultrasonic receiver net.

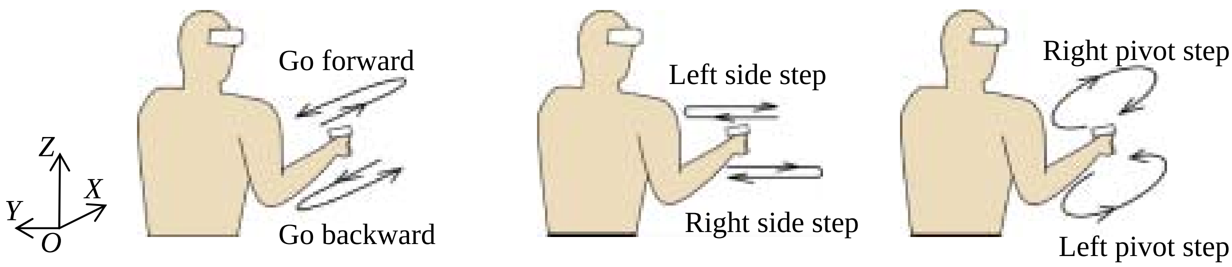


Fig.3 Gesture patterns corresponding to locomotion commands.

Table.1 Technical specifications for MA40E7$^R/_S$ electrostatic transducer

	Transmitter	Receiver
	MA40E7S	MA40E7R
Nominal Frequency	40 [kHz]	
Minimum Receiving Sensitivity	-74 [dB]	--
Minimum Transmitting Sensitivity	--	106 [dB]
Beam Angle	100 [deg]	
Capacitance	2200±20% [pF]	
Maximum Voltage	85 [V_{p-p}]	
Operating Conditions Temperature	-30 ~ 85 [^oC]	
Measuring Range	0.2 ~ 3 [m]	
Resolving Power	9 [mm]	
Cover Size	18(D) x 12(H) [mm]	
Weight	4.5 [g]	
Character	Waterproof	

This system has two operating modes tomanipulate robot arms directly, "Direct Mode", and to operate locomotion by preset commands, "Command Mode" These modes can be selected by mode select switches on 3D mouse. Direct Mode is used to operate an odd arm (right / left mode), or both arms (symmetrical / synchronized mode). While the operator pulls the trigger, the system estimates 3D mouse position and extract the displacement vector of 3D mouse at every sampling. The vector is given to the robot as a reference motion data (reference motion vector). By using this system, the operator can operate robot's hand tip trajectory viscerally as if he/she dragged and dropped an icon on GUI desktop in real time. As deal with the displacement vector as order motion data, there is no need to consider the initial positioning between the 3D mouse and the robot hand tip at the start of operation, so the usability will become well. On the other, Command Mode is 3) gesture input mode for locomotion by walk. Here, the gesture means an identification of a 3D mouse trajectory pattern. Preset commands for locomotion correspond with gesture patterns as Fig.3.

3.2 Ultrasonic Positioning Estimation

We can know the speed of sonic wave at the air temperature and the propagation distance by measuring the wave propagation time. At least known 3 distances between 3D mouse and receivers, we can estimate the position of the 3D mouse in the sensor net by principle of triangulation. When the wave propagation time T_i [s] (i =1,2,3) is measured, the propagation distance L_i [m](i =1,2,3) is estimated by following.

$$L_i = (331.5+0.6t\,)\,T_i \qquad (1)$$

Here, t is room temperature [^oC].

Assuming that receiver positions R_i (x_i, y_i, z_i), (i =1,2,3) are known and exist on same plane (not on a straight line) in an arbitrary Cartesian coordinate, the position of 3D mouse P (x, y, z) is estimated by the following formulations (Fig.4).

$$\left.\begin{aligned}(x_1 - x)^2 + (y_1 - y)^2 + (z_1 - z)^2 &= L_1^2\\(x_2 - x)^2 + (y_2 - y)^2 + (z_2 - z)^2 &= L_2^2\\(x_3 - x)^2 + (y_3 - y)^2 + (z_3 - z)^2 &= L_3^2\end{aligned}\right\} \qquad (2)$$

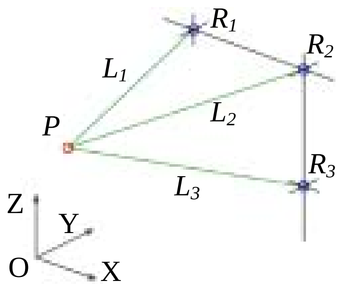


Fig.4 Position Estimation.

Fig.5 shows the diagram for the position estimation. As the ultrasonic positioning controller sends output signal to transmitter on 3D mouse, so it begins measuring the wave propagation time. When a receiver detects ultrasonic wave, it will return receiver signal to the controller and determine the time between 3D mouse and receiver. After sampling for 4[ms], the controller will calculate the distance between 3D mouse and receivers, and estimate the position of 3D mouse.

The control PC used in this study is DOS/V compatible PC with a Pentium III cpu (733MHz) and Linux OS (Red Hat 9). The time measuring process is executed by using cpu internal clock counter on the control PC. The precision for time measurement (the cpu frequency) depends on its operative conditions (power supply voltage, internal temperature and so on). But the sampling performance is about 250[kHz] on the average, and the theoretical resolution for distance measurement is about 1.3[mm] at room temperature 20[^oC]. The total processing time is set 10[ms].

3.3 Live Streaming System

To transmit robot camera vision to the operator, a live streaming system is applied. The robot camera vision is captured and software-encoded to mpeg4 format data (QVGA (320x240 pixels)) on the live streaming server PC in almost real time, then transmitted to the client PC by UDP (Fig.6). For the server and client application, we applied multicast application "FocusShare"[7], which is distributed at

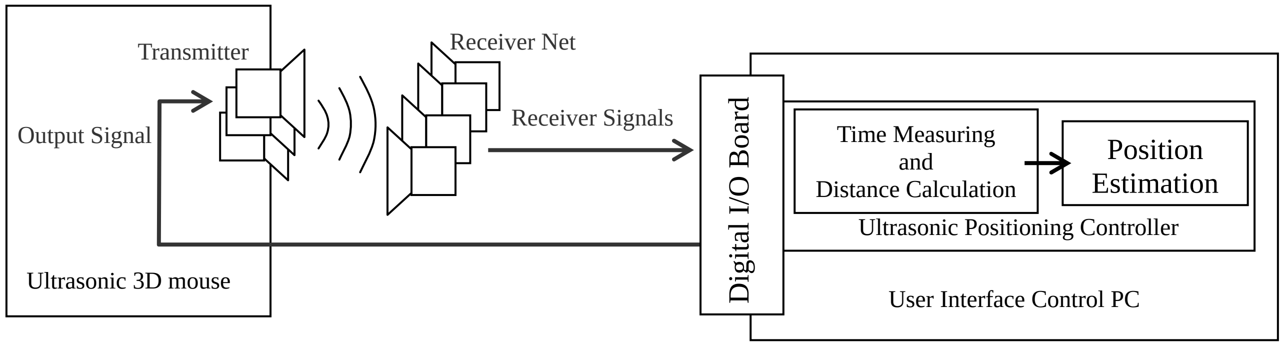


Fig.5 Diagram for position estimation.

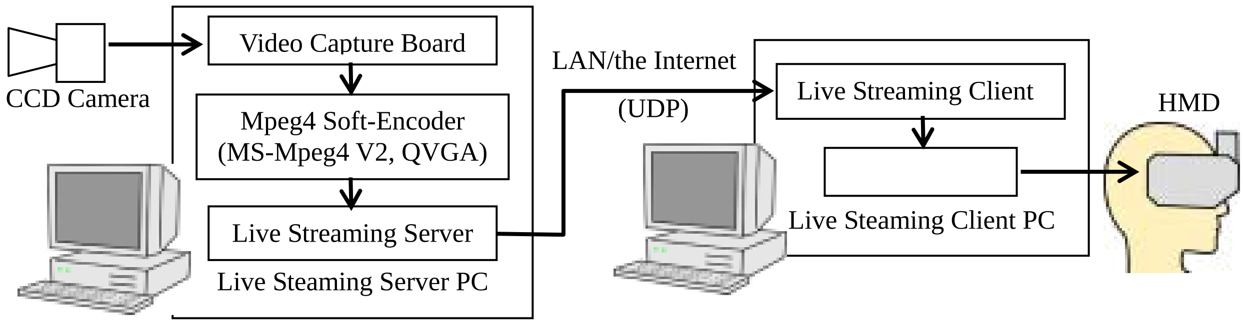


Fig.6 Live Streaming System.

OpenNIME web site[8]. The server PC used in this system is DOS/V compatible PC with a Pentium IV cpu (2.53GHz) and Windows OS (Windows XP SP2). The live streaming data is decoded on the client PC (Notebook PC with Pentium M (900MHz) and Windows 2000 SP4), and projected on HMD. HMD used is i-Visor DH-4400VP made by Personal Display Systems, Inc., USA, and it has two 0.49inch, 1.44 million pixels LCD, and supports SVGA graphic mode. And, gyro sensor used is InterTrax^2 made by InterSense Inc. of USA, which can track roll, pitch, yaw direction angles (except for angular speed and acceleration), and its minimum resolution is 0.02 [deg] (relative).

3.4 Motion Trajectory Generation

The motion trajectory generation method is as follows; at first, adding a reference motion vector given by 3D mouse to current robot hand tip position, the reference robot hand tip position is set. And by linear interpolating the position and current robot hand, the reference hand tip trajectory is pre-released based on given a reference motion time (here, 10[ms]). At this moment, the trajectory is checked about collision and workspace of hand tip.

If there are any errors, a new reference hand tip position will be set again, and a new reference hand tip trajectory will be released. Finally, it will be converted to reference arm joint angle trajectory by inverse kinematics. In Direct Mode, the reference motion vector is essentially handled as data for right arm. Both reference hand tip positions are determined by adding same reference motion vector to each current robot hand tip position. But if symmetrical mode, left reference hand tip position will be determined by adding a reference motion vector that its Y direction element will be reversed.

4. Experiments

This section describes experiment results about performance evaluation using developed system. Experimental humanoid robot “Bonten-Maru II” was used.

4.1 Humanoid Robot “Bonten-Maru II”

We have developed “Bonten-Maru Ⅱ” humanoid robot system, have proposed a Humanoid Robot Control Architecture (HRCA) based on CORBA and implemented as an integration of many humanoid robot control modules, which correspond to CORBA servers and clients.

The robot has two 3-DOF arms, two 6-DOF legs, a 2-DOF neck and a joint to twist the body at the humanoid robot control modules, which correspond to CORBA servers and clients (Fig.7). The height and total mass of the robot are 1.25[m] and 32[kg], respectively. Every joint of the robot is driven by a DC servomotor with a rotary encoder and harmonic drive reduction system, and PC with Linux (CPU: Celeron 2.4GHz) is utilized for control. The motor driver, the PC and the power supply of the robot are placed outside of the robot. The sampling frequency is 200 [Hz]. Also, two monochrome CCD cameras (542x492 pixels) are quipped on its face.

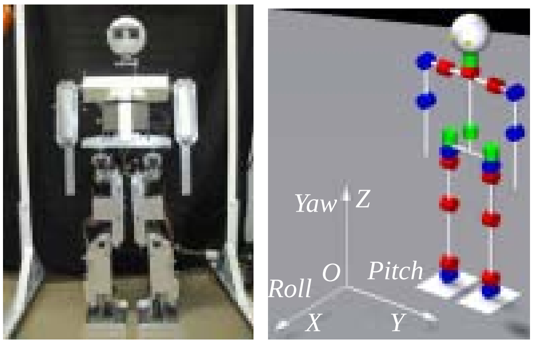
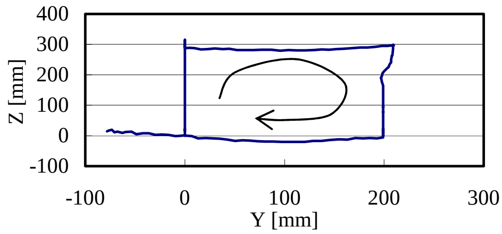


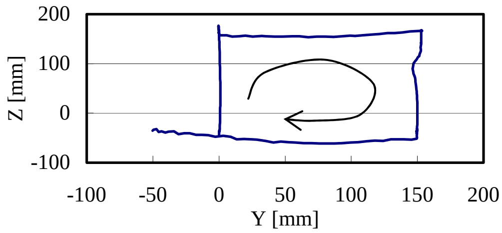
Fig.7 Humanoid “Robot Bonten-Maru II” and its joint configuration.

4.2 Results of Teleoperation experiments

We performed a right arm teleoperation experiment in a LAN environment as a follow; the operator drew a simple quadrilateral hand tip trajectory on Y-Z plane in the ultrasonic receiver net with 3D mouse. Fig.8 (a) and (b) show an order trajectory given by 3D mouse and a motion trajectory of right robot hand tip. Note, in this experiment, the room temperature was 24[^{o}C], and Fig.8 (b) is viewed from the origin of right arm coordinates (it corresponds to the right shoulder). Although there is a difference in scaling that it is caused by feedback errors, each motion pattern matches well. And also, in Fig.9 is shown the operation time in every communication. The horizontal axis is the number of communication



(a) Order trajectory given by 3D mouse.



(b) Right robot hand tip trajectory.

Fig.8 Results of teleoperation experiment.

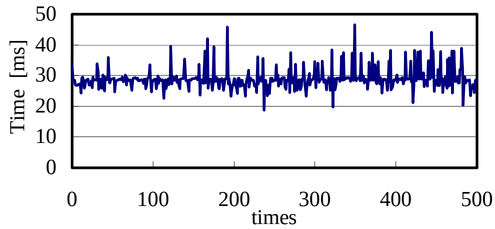


Fig.9 Operation time.

times. There are some data spreads due to network traffics, but the operator could carry out the experiment without serious time delay errors in real time.

Next, we performed a total teleoperation experiment as follows; the operator will give locomotion commands by gesture input, and move

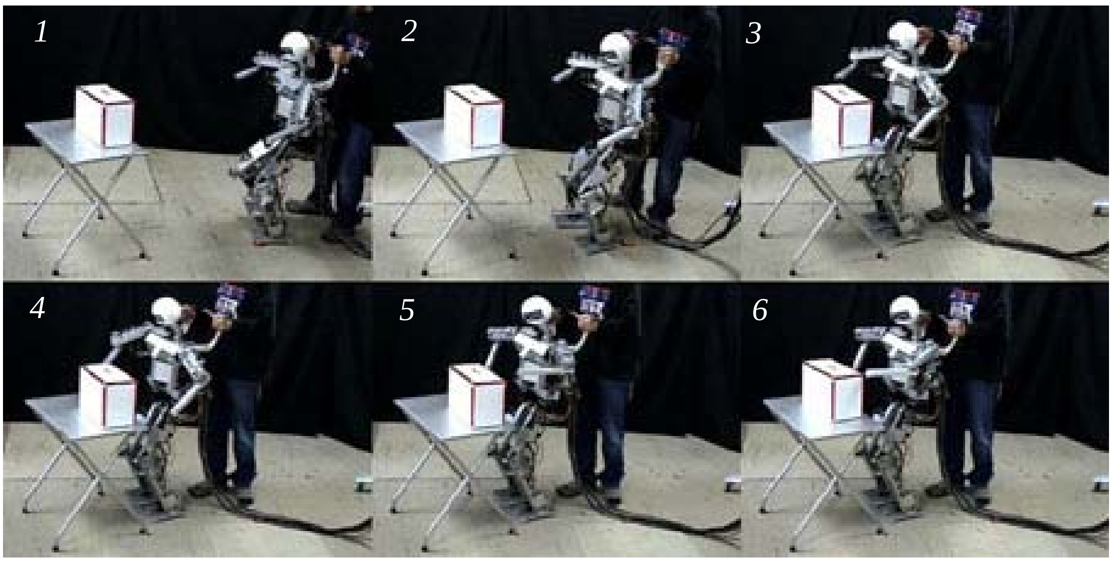
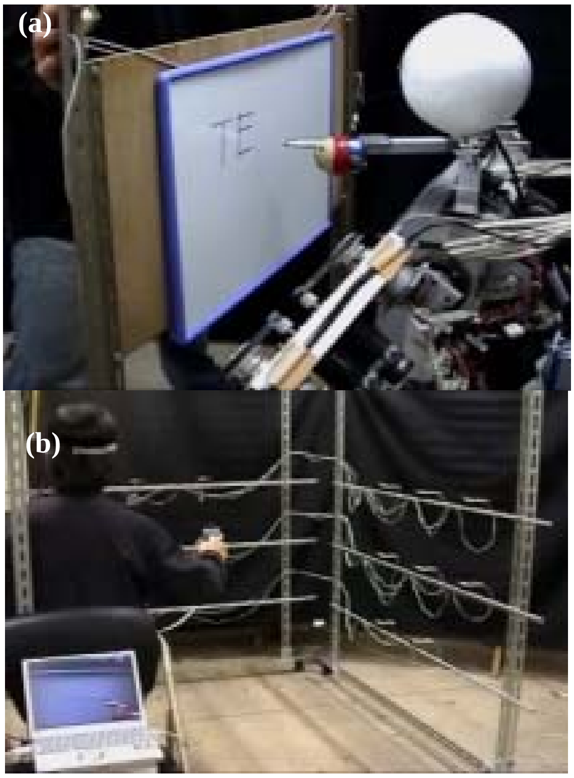


Fig.10 Video capture of teleoperation experiment.



(a) Drawing simple characters.

(b) Operator with the 3D mouse.

Fig. 11 Demonstration test of the 3D mouse.

the robot to a target box. Then he/she will give the order robot arm motions to touch the box. In Fig.10 is shown a video capture of the experiment, and it indicates that our system is available for humanoid robot teleoperation. Fig. 11 shows a teleoperation demonstration. Using the 3D mouse, the operator tried to draw simple characters.

5. Conclusions and future works

In this paper, we presented the teleoperation system for a humanoid robot and the operation assist user interface. We developed an ultrasonic 3D mouse system for the user interface. And we performed some teleoperation experiments to evaluate the system performance with humanoid robot “Bonten-Maru II”. The results show that our system is available for humanoid robot teleoperation system.

However, now, there are some problems that the live streaming system cannot communicate beyond network rooters, and the 3D mouse cannot operate robot hand postures and so on. In the future, we are going to improve these problems, and to develop more effective and user-friendly interfaces. And also, we will develop a whole body remote control system with them.

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