Wearable Computing based on Multimodal Communication for Effective Teleoperation with Humanoids

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Abstract

This paper presents a new type of wearable teleoperation system that is applicable to a humanoid robot control. The proposed wearable teleoperation system consists of a self-contained computing hardware with a stereo HMD, a microphone, a headphone and a wireless LAN, an arm and head motion tracking mechanism using several types of sensors to get the motion data of an operator, and simple force reflection mechanism using vibration motors at proper joints. To achieve successful remote tasks, we adopt a new method that utilizes an intelligent self sensory feedback and autonomous behaviors such as automatic grasping and obstacle avoidance in a slave robot side, and the information feedback to an operator through the multimodal communication channel. Through this teleoperation system, we successfully demonstrated several teleoperation tasks including an object manipulation, a mobile platform control of the humanoid robot.

Key words: Teleoperation, Wearable Computer, Multimodal Communication, Humanoid Robot, Human-Robot Interaction

1. Introduction

The previous teleoperation research has focused on control performance of motion tracking and force reflection issues of master robotic arms. However, comfortableness and human wearability were easily ignored. As a result, most robotic arms are too heavy to wear and therefore give an operator excessive suffering during a teleoperation. These drawbacks have mainly restricted the range of teleoperation applications. To solve these weaknesses of conventional master system, the method of tracking the human arm motion have to be more convenient and flexible. In addition, it needs to be light enough to wear and be self-contained to operate in various environments.

Recently reported several telerobotic systems show us the possibility of this new teleoperation system. The robotic arm developed by KIST which is exoskeleton type can be applicable to various research areas because of its high wearability and force-reflection mechanism [1]. The wearable robot called 'Parasitic Humanoid' developed by University of Tokyo also gave us a good idea to develop a new type of teleoperation system [2]. These newly developed wearable robotic systems can be applicable to various areas including teleoperation in a hazardous environment, a human-robot interaction, a medical rehabilitation, a VR experience and so forth. In addition, In order to display more appropriate and intuitive information to the operator in an advanced teleoperation system, a multimodal sensory feedback based on a model of human perception was introduced recently [3].

The trend of the robot research is changing from the conventional industrial manipulator or the mobile robot to a more advanced robot such as a humanoid robot and a personal robot which has anthropomorphic shape, multimodal sensing and communication capability and intelligence such as a high-level task planning, a decision making, and a social interaction. In consideration of this new robot research paradigm, it is necessary for a type of teleoperation robot system to change to a more advanced type which is wearable, self-contained, easy operable with intelligent communication aid between a master system and a slave robot.

So far, we propose a new type of wearable teleoperation system which has the advantage of these new criterions and present its prototype. This paper describes the configuration of the proposed wearable teleoperation system, the prototype of the wearable master system, kinematics analysis of the developed system, multimodal communication with intelligent slave robot. Finally, in experimental result, some demonstrations that show the performance of the developed prototype are presented.

2. Configuration of the Proposed System

In remotely operated system, a main goal is to allow operator to accomplish the necessary tasks as efficiently and effectively as possible. At this point of view, operator-selective telerobotic modes of operation between a human master and a slave robot that allow automatic performance of subtasks that are either repetitive, require high precision, or involve extreme patience is a promising way to achieve increased remote work system efficiency [4].

As a master system, a wearable system which is light enough to wear, self-contained, easy operable with multimodal communication is a new direction of teleoperation research. This master system must have a human motion acquisition mechanism and an appropriate force feedback mechanism which are proper to be worn without user's discomfort.

An intelligent slave robot which has the high-level task execution capabilities including a 3D object detection, automatic object approaching and grasping, obstacle avoidance is a proper tool to interact with this new master system and examine the performance of developed teleoperation robotic system. As an intelligent slave robot, humanoid robot is suitable when we consider the above mentioned features of the slave robot. A humanoid robot is an autonomous robot in which a self-contained anthropomorphic physical body, intelligence that would give the robot some degree of autonomy, and environment sensing and expression capabilities.

In addition, to send tele-commands to the slave robot intuitively and display more appropriate and intuitive information to the human operator in teleoperation system, multimodal tele-commands expression and multimodal sensory feedback, which we can call multimodal communication, are very important issues in an advanced teleoperation system

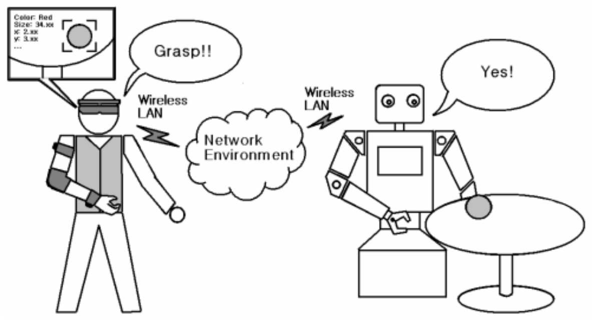

Fig. 1 Configuration of the Proposed Teleoperation System

In this study, we combined these ideas to solve real world teleoperation applications. In the proposed system, A human operator wearing the teleoperation system sends tele-commands through multimodal channel such as voice and arm and head motion. The tele-commands are delivered via wireless and wired network environments to the target slave robot. The intelligent slave robot can properly follow the human motion. When the operator want to make the slave robot do some subtasks, he can just say the voice commands through microphone attached on the wearable teleoperation system.

3. Prototype of the Wearable Master System

3.1. Wearable Master Platform

The proposed wearable master system consists of self-contained computer with a stereo HMD (head-mounted display), a microphone, a speaker, a wireless LAN, and hardware for tracking arm and head motion. The motion tracking hardware comprises magnetic based position and orientation trackers and several types of small, light sensors such as three-axis postural sensors and flex sensors; it also has a simple force reflection mechanism that uses vibration motors at wrist joints

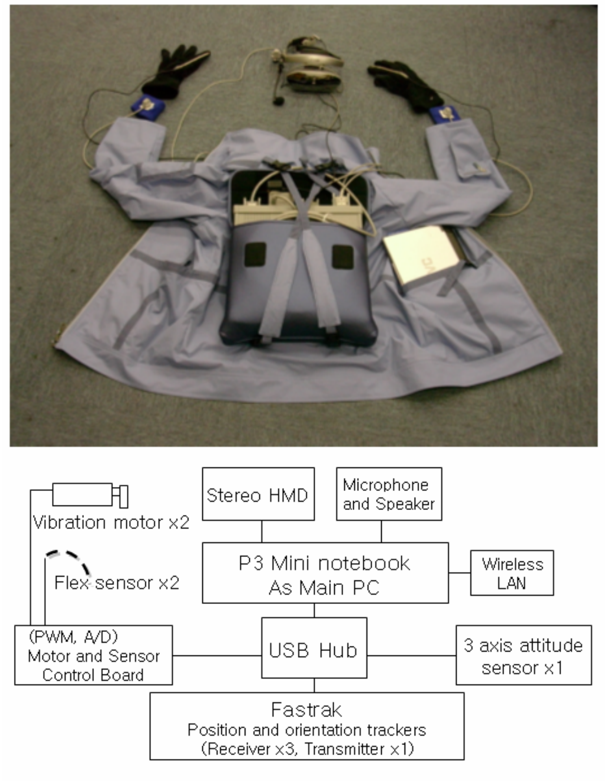

Fig. 2 Wearable Master Platform and Its Hardware Structure

The wearable master platform includes a mobile JVC Mini Note MP-XP7220 as the main computer for interacting with humans and communicating with the slave robot. The Mini Note PC has a Mobile P-III 866 MHz CPU, 256 MB memory and various peripheral interfaces such as a USB, IEEE1394 and PCMCIA. The control board and sensors for the master system are connected to this PC through the USB interface. Fig. 2 shows the appearance of the wearable telepresence platform and its hardware structure. Fig. 2 shows the outlook of wearable teleoperation platform and its hardware structure.

3.2. Sensor, motor and Control hardware

The wearable master system has two kinds of sensors for detecting the user's arm and head motion. The sensors are attached to the operator to get relevant data for the system's usage. To measure the head movement of the operator, we use FASTRAK system from Polhemus Inc, FASTRAK is the solution for the position/orientation measuring requirements of applications and environments. It is suitable for head tracking, hand tracking, instrument tracking, biomechanical analysis, graphic and cursor control, sterotaxic localization, telerobotics, digitizing and pointing. head movement tracking is accomplished with the use of this magnetic based position and orientation tracker attached to the HMD. Other two magnetic trackers are located on the back of the operator's wrist, while a single transmitter and control box are attached to the back of the wearable suit. These sensors that measure the arm movement are fixed to elastic sports bands for the operator's comfort and convenient arm movement. In the Magnetic magnetic based tracker system, the transmitter is fixed generally. In this paper it is attached on the back of the user. So there are some noises by body movement. We attached 3-axis attitude sensor on the transmitter to compensate the error. By this attitude sensor, we compensate the position and the orientation of the 3 magnetic sensors on the head and the wrists.

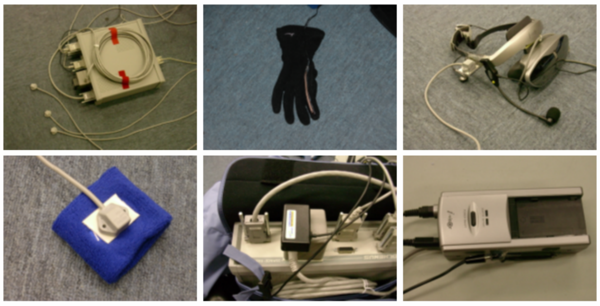

Fig. 3 Sensors and Control Hardware

Two flex sensors are attached to each glove of the operator. In addition, the master system has a simple force reflection mechanism that uses vibration motors at the finger and arm joints. The three-axis attitude sensor, MI-A3330LS from the MicroInfinity Co., Ltd., calculates the three rotation angles called the roll, pitch and yaw in the three axes. They also calculate the acceleration values for each axis and the output data via the RS232 interface. The flex sensors, FLX-01 from Abrams Gentile Inc., are used for measuring the bending angles of the elbow and finger. The vibration motors attached to the glove, elbow and the upper arm bands produce torque in accordance with the force feedback data.

To measure the analog data from the flex sensors and the speed control of the vibration motors, we built a customized control board. To develop the control board we used an ATmega163, an 8 bit microcontroller from Atmel Inc. The microcontroller has an 8 channel, 10 bit A/D converter and three 8 bit PWM timers for sensing and control. We converted the RS232 interfaces of the sensors and control board to USB interfaces by using special conversion cables. The conversion enabled easy connection with the mini-notebook.

3.3. Multi-modal Communication Hardware

This wearable master system offers the following communication interfaces to a user. Firstly, an operator wearing this system can see the stereo scene projected on stereo HMD (Head Mounted Display) captured from cameras of a slave robot in real-time. Secondly, by using a headphone, the operator can hear the voice and the sound information coming from the slave robot. In addition, the operator can send a voice commands by using a microphone in master system. Finally, the operator can use his arm and head motions to operate the slave robot intuitively while he feels the tactile sense and force feedback of the slave robot arm through the force reflection mechanism using vibration motors at his finger and arm joints. Through these multimodal interfaces, the operator can perform the necessary remote tasks as efficiently and effectively.

Fig. 4 Master System after Wearing

4. Kinematics Analysis

To operate a slave robot stably using this master system, it is necessary to analyze the kinematics of the system. The coordinates of master system are shown in Fig. 5.

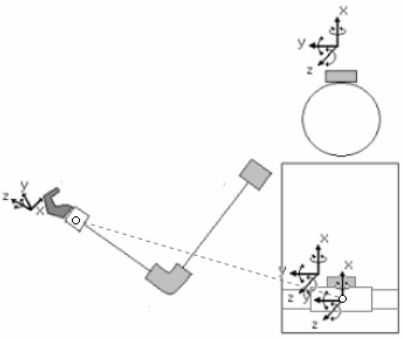

Fig. 5 Coordinates of Master Arm

The sensor of the head is to measure the motion of the head. The origin point of the positional sensors is attached to the waist of the master, and 3-axis sensor on the origin point measures the rotation of the body.

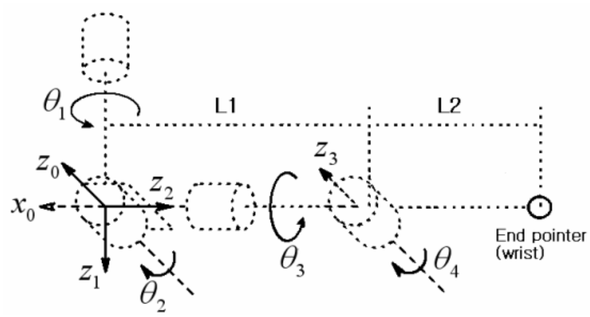

Fig. 6 Kinematics Parameters of Slave Arm

Because we use the positional sensors, we know the position of the master hand. So we can calculate the desired joint angles of the slave robot by using the inverse kinematics. Under the assumption that the position of the master robot's end pointer is identical with that of the slave arm's , Θ_4 is calculated as follows.

$$\theta_4 = \cos^{-1}(\frac{L1^2 + L2^2 - dist^2}{2*L1*L2})$$

(dist = distance of master arm's end pointer , L1 = length of slave's upper arm, L2 = length of slave's lower arm)

There are many solutions of the inverse kinematics. So we restricted the solution by the 3-axis sensor on the wrist.

Since we know the position of the wrist and the direction of the wrist, we can get the position of the master arm's elbow as follows.

$$P_e = \begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} x_w - L2*a \\ y_w - L2*b \\ z_w - L2*c \end{pmatrix}$$

([a b c] = unit vector of the direction of the master's wrist, [x_w, y_w, z_w]= the position of the master's wrist)

Then, we can get the plane that has three points, origin, elbow and wrist. We let the position of the slave's elbow be on this plane. Because We know the length of three sides and the positions of two position – the origin and the wrist -, we can get the position of the slave's elbow. Let the position of the slave's elbow be [x',y',z'].

Because the position of the elbow is determined only by Θ_1 and Θ_2. we can calculate Θ_1 and Θ_2 as follows

$$\theta_2 = \sin^{-1}(\frac{x'}{L1})$$

$$\theta_1 = \sin^{-1}(\frac{y'}{L1\cos\theta_2})$$

At last we assume that Θ_3 is zero, and calculate the position of the slave robot arm's end pointer. Let p be the distance between this position and the goal position, then we can get Θ_3 by following equations.

$$\theta_3 = \cos^{1}(\frac{L2^2 + L2^2 - p^2}{2L2^2})$$

5. Multimodal Communication with Intelligent Slave Robot

In order to interact more intuitively and efficiently with a remote robot in a teleoperation system, multimodal communication interfaces based on human perception and expression are essential requirements [3]

Many researches on teleoperation has concentrated on more precise tracking of master arm and force feedback which reduce the gap between master and slave robot for the operator to feel more realistic. However, we choose an alternative method that utilizes an intelligent self sensory feedback and a context based behaviors in a slave robot side and gives the information feedback to an operator through the voice and visual communication channel with a simple force refection mechanism using vibration motors rather than using precise control with high force reflection.

In this system, for the intelligent self sensory feedback and the context based behaviors in a slave robot, we developed two subsystem, master and slave system. In the Master system the user can communicate by various channels like vision, voice, and motion. User can get the visual information by vision channel. By voice channel users can give order or get information. Through motion channel, motion tracking and gesture commands are activated, and Users can get force feedback by force feedback channel. Fig. 7 shows the configuration of the Master system.

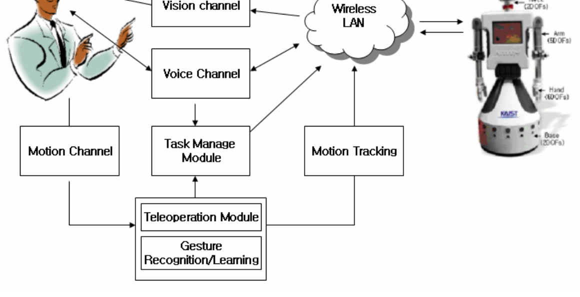

Fig. 7 Configuration of the Master System

In the slave system of Fig. 8, various functions for the intelligent self sensory feedback are implemented. The slave robot transfer the visual information to the master system through CCD camera, and communicate by voice channel. The slave can avoid obstacles automatically by ultrasonic sensors. By haptic sensor, the slave measure the pressure of the hand and transfer the force feedback information to the master system. And for the context based behaviors, behavior manger choose the right behavior under the conditions.

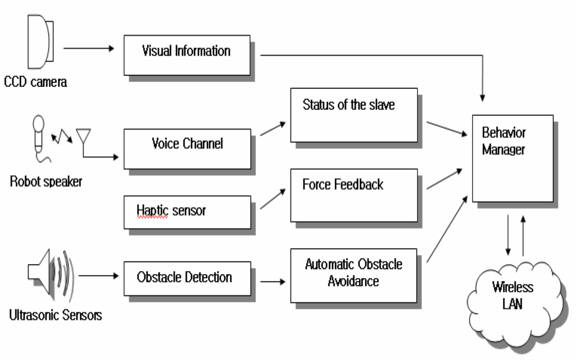

Fig. 8 Configuration of the Slave System

For example, when the slave robot picks some object in this system, It can send the operator the contact force information using voice expressions and information through a headphone and HMD respectively. Besides, when an operator want to control the slave robot more precisely, he can also send predefined voice commands to the slave robot using a microphone of this master system even while he are using arm and head motion in teleoperation to do given task. We named this system a wearable teleoperation system with multimodal communication aid.

5-1. Voice Communication Channel

Speech synthesis and recognition have been an important technology for human-robot interaction. This is aloso an important technology for future teleoperation system.

In the proposed teleoperation system, using speech synthesis, a slave robot can send a remote environment information to an human operator and express its internal status immediately. Also, speech recognition is a way for the operator to command the slave robot intuitively.

For speech synthesis, the proposed system has a TTS (Text to Speech) program that can produce natural korean and english sentences developed by Cowon Systems, Inc. For the speech recognition, it has an HMM speech recognition program developed in our laboratory that can recognize about 50 words

5-2. Visual Communication Channel

Through visual communication channel, the view of the remote slave system is transferred to an operator wearing the master system. This view is displayed on stereo HMD screen of the wearable master system after being augmented with textual and graphical information. It is useful and helpful for the operator to understand the status of the slave system and the environment around the slave system.

5-3. Gesture Recognition

For more effective communication, our new system can recognize the gesture. By gesture recognition technique, we can improve the functionality of the system. In general case, the system tracks users' motion. But If a gesture is detected, the system performs predefined commands. For example, when users let the robot move, in the previous system, users speak 'turn left' command, robot asks the degrees, and users answer '30 degree' by speech communication. Users must know the degree of the direction. If users use gesture commands, users can make robot move by pointing the direction, and changing the direction is also easy. Users can communicate with the robot by speech, vision, motion, and predefined gesture now.

In our system, , the system tracks users' motion usually. but If a gesture is detected, the system performs predefined commands. If users want to use the gesture recognition mode, users have to wait 3 seconds, then users can use the gesture recognition mode. If no gesture is recognized, the system would be changed to the motion tracking mode.

The framework has also gesture learning module. Users can use this module by saying “Gesture Learning Start”. After gesturing, users have to say “Gesture Learning End”, and Users can match this gesture with pre-defined functions by verbal communication.

We do this learning and recognition by neural network method. The main features are the coordinates and the shape of the hand each time.

5-4. Task manager

We also focused on the behaviors of the robot. We assumed that robot is so intelligent that it can exactly do what users want and react to all environments. But it is the last goal, not practical one. Users have to make behaviors and reactions for tasks. So we implemented a communication framework that users can configure tasks and behaviors easily.

Our task manager has two functions. First function is a task managing. The robot has current states and user-defined task and behaviors. It is too hard to make all behaviors. We produce interface that user can use predefined behaviors in behavior Database. For example, if we want the robot to bring a baseball to us, we can make a 'baseball' task that consists of selecting, finding, approaching, and grapping behavior, and simply say "baseball!!".

Second function is behavior development of behaviors. Users need to teach robot to do right thing in environments. If users repeat same behavior again and again, user must be tired. Behaviors are created by direct motion tracking and learning algorithms.

5-5. Automatic Behaviors in Slave Robot

In this study, we are suggesting a prototype of a "human-computer-remote sensing-interactive" telerobotic system which will be dominant in near future [3].

For the subtask automation in a slave robot, It is necessary to represent the objects into a 3-D geometry data in the remote task space autonomously. To get the 3D data of an object after image filtering and segmentation process for color objects detection, a conventional two parallel stereo camera model is implemented in a slave robot. And then we can get the 3D position of the focused object by coordinate converting from image coordinate to robot coordinate.

For the automatic obstacle avoidance, a slave robot which has moving capability must have proper sensors such as ultrasonic and infra-LED sensors to detect obstacles and to measure distances from those, and avoidance algorithm. We implemented automatic avoidance algorithm in the slave robot using safe movement measurement parameters surrounding mobile base as shown in Fig. 9.

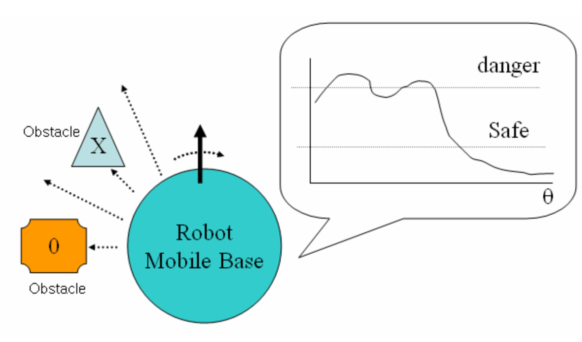

Fig. 9 Automatic Obstacle Avoidance of Slave Robot

5-6. Humanoid Robot, AMI as an Intelligent Slave Robot

To show the performance of this system, we chose the humanoid robot AMI as the target slave robot. AMI has two eyes equipped with two CCD cameras for stereo vision, a mouth for speaking motion and a neck that tracks a moving target for gazing control. Its body has two arms, two hands, a waist and a mobile platform with two wheel motors. In addition, AMI has various sensors such as 16 ultrasonic sensors and 12 infra-LED switches for detecting obstacles and measuring distances; it also has six force-sensing registers at the end of the fingers [5].

Mechanical Specification of AMI

AMI is 1550[mm] tall. The breadth of shoulder is 650[mm] and the total weight is about 100[kg]. The shape and the DOFs arrangement of the assembled robot are shown in Fig 10. Mechanical specification of the developed AMI is shown in Table 1. in appendix

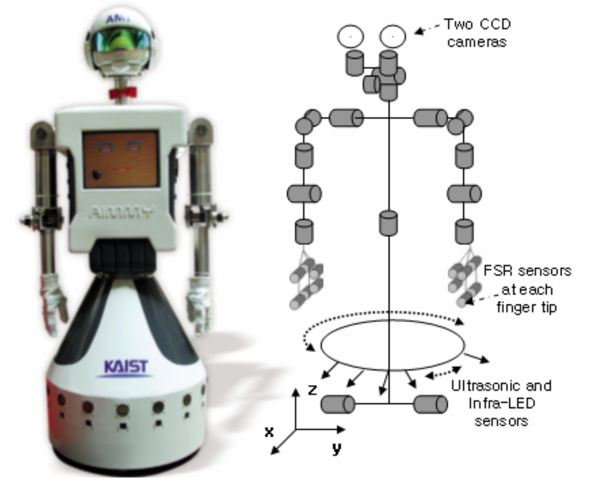

Fig. 10 Humanoid Robot, AMI and its DOF Structure

Hardware Specification of AMI

Computing power of the main computer system is very important for the processing of real time vision, motion planning, voice recognition, high-level control algorithms, and so on. In addition, the ability to integrate the framegrabber, the sound processor, and other various pheriperals for operation of a humanoid robot is also needed for the main computer. Therfore, we chose a commertial PentiumIII-1GHz(133FSB) PC system as the main computer system of our humanoid robot.

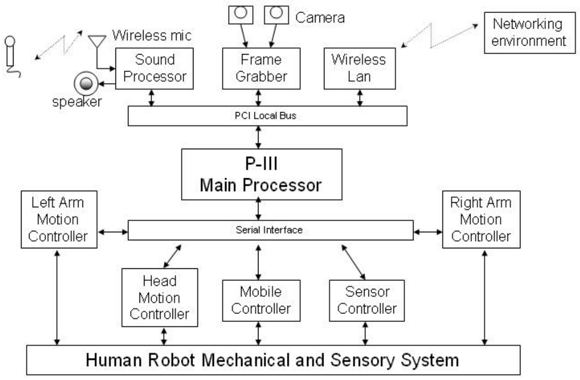

Fig. 11 Hardware Structure of AMI

Multi-channel framgrabbers for image capturing from two CCD cameras, sound cards for voice synthesis and recognition, wireless LAN cards for tele-operation and monitoring, and LCD screens to visualize the internal status and emotional expressions are integrated with this main computer system.

All controllers of the head, arms, and sensors are directly connected to the main computer via multi port serial interfaces (RS-232). Each controller has both 8bit and 16bit microprocessors to process real time jobs such as motor control and sensor data interpretation. Therefore, the hardware controllers of AMI are distributed and controlled by the P-III main computer using a high-level pre-defined protocol.

6. Experimental Result

To verify performance of the wearable teleoperation system, we conducted the following experiments.

First, in order to verify the basic function, we performed the experiment that the robot followed the movement of the user's arm and head. In this experiment, the system showed the same exactness and precision as the previous systems, as well as the improved convenience for users.

Second, we conducted the experiment that the user let the remote slave robot pick up one of the objects on the table in order to confirm the overall system performance and effectiveness. In this experiment, the user made the robot approach to the table only by voice command. Once moved near the table, the robot let the user know the distance from the current position to the table through voice channel, and then user made the robot to approach to the table in the given distance by voice command. The user moved his arm to operate the robot's arm with looking at the HMD. Finally, the user made the robot pick up the object through voice command after he moved the robot's arm closely over the object.

Third, we performed the experiment that the user command the pre-defined function by gesture. While the robot is tracking the motion of the master arm, the user stop and express gesture, then the robot do the pre-defined job instead of the motion tracking.

At last, while the robot is grasping, the haptic sensor of the slave robot hand measure the pressure of the hand, and the slave give the information to the master system. The master system represents the pressure information by the vibration motor. If the pressure is getting high, the intensity of the vibration will be strong.

7. Conclusion

This paper proposed the wearable teleoperation system and explained the implementation of the prototype.

Furthermore, we conducted the experiments using the humanoid robot, AMI as a slave robot to confirm the system performance and effectiveness. Through these teleoperation experiments, we successfully demonstrated several teleoperation tasks including a motion tracking, a mobile platform control of the humanoid robot, an object manipulation, a gesture command, and a force reflection, and showed the performance and the efficiency of the developed wearable teleoperation system.

Furthermore, we'll do research on the enlargement of the master system so as to utilize the more advanced visualization by AR technology.

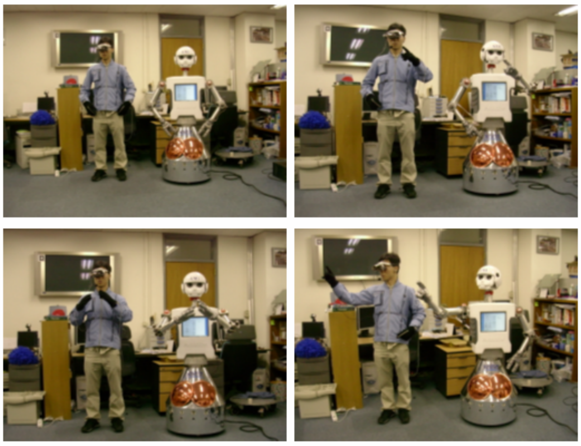

Fig. 12 Experiment Result

8. Acknowledgement

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Appendix

Table 1. Mechanical Specification of AMI

DOF	Head	Eye	2
		Mouth Neck	1 2
	Arm	Arm	5x2
		Hand	6x2
	Body	Waist	1
		Vehicle	2
	Total		32
Weight	Total		About 100[kg]
Dimension [mm]	Height		1550
	Breadth of Shoulder		650
	Arm		750
Motor	Arm	Maxon DC Servo	150W/24V
	Hand, Eye and Mouth	Hitec R/C Servo	HS-77BB HS-81MG
	Waist	HD DC servo	RH-20
	Vehicle	Rockland DC servo	DX-6-25
Gear and Ratio	All Planetary gear except Hand, Mouth, Eye: R/C servo module and Waist: Harmonic Drive		1/100, 1/150, 1/50