ICAT 2003
December 3-5, Tokyo, JAPAN

Wearable Telepresence System using Multimodal Communication with Humanoid Robot

Yong-Ho Seo, Hun-Young Park, Taewoo Han, Hyun S. Yang

Artificial Intelligence and Media Laboratory,
Department of Electrical Engineering and Computer Science, KAIST
373-1, Guseong-dong, Yuseong-gu, Daejeon, 305-701, Republic of Korea
{yhseo, winds, hsyang}@paradise.kaist.ac.kr

Abstract

This paper presents a new type of wearable telepresence system that is applicable to the control of a humanoid robot. The system consists of self-contained computing hardware with a stereo HMD, a microphone, a headphone and a wireless LAN, an arm and head motion tracking mechanism that uses several types of sensors to get the motion data of an operator, and a simple force reflection mechanism that uses vibration motors at the proper joints.

To enable the robot to successfully accomplish remote tasks, we have adopted a new method that uses intelligent self-sensory feedback and autonomous behavior, such as automatic grasping and obstacle avoidance in a slave robot. The method also gives feedback to an operator through a multimodal communication channel.

Through this telepresence system, we have successfully demonstrated several teleoperation tasks including object manipulation and mobile platform control of the humanoid robot

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

1. Introduction

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

Several recently reported telerobotic systems have shown the possibility of this new kind of telepresence system. KIST developed an exoskeleton type of robotic arm that can be applied to various research areas because of its high wearability and force-reflection mechanism [1]. The University of Tokyo developed a wearable robot called Parasitic Humanoid, which also suggests a new type of telepresence system [2]. These newly developed wearable robotic systems can be applied to various areas including teleoperation in a hazardous environment, human-robot interaction, medical rehabilitation and VR experience. In addition, to display more appropriate and intuitive information to the operator in an advanced telepresence system, multimodal sensory feedback based on a model of human perception was recently introduced [3].

The trend in robotic research is changing. The focus has shifted from a conventional industrial manipulator or a mobile robot to a more advanced robot. Examples of advanced robots include humanoid and personal robots with anthropomorphic shape, multimodal sensing, communication capability and intelligence which includes high-level task planning, decision making and social interaction. In consideration of the new paradigm for robotic research, teleoperation systems need more advanced features. They should be wearable, self-contained, easy to operate and enable intelligent communication between a master system and a slave robot.

We now propose a new type of wearable telepresence system that has the advantage of these new criteria. This paper describes the configuration of the proposed system, presents a prototype of the wearable master system, discusses the kinematics analysis of the developed system, and examines multimodal communication with an intelligent slave robot. Finally, in the experimental results, the performance of the developed prototype is presented.

2. Configuration of the Proposed System

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

The new direction in teleoperation research involves a multimodal communication master system that is light enough to wear, self-contained and easy to operate. The system must have a mechanism for acquiring human motion and a feedback mechanism for using appropriate force. Moreover, such a system should be capable of being worn by the user without discomfort.

An intelligent slave robot with the capability of executing high-level tasks is a suitable tool for interacting with the new master system and for examining the performance of the developed telepresence robotic system. High-level tasks include the detection of 3-D objects, the ability to approach and grasp objects automatically, and the ability to avoid obstacles. As an intelligent slave robot, the humanoid robot is suitable when considered in conjunction with the features of the slave robot. The humanoid robot is an autonomous robot with a self-contained anthropomorphic body; it also has sufficient intelligence to give the robot some degree of autonomy, along with the capability of sensing the environment and expressing itself.

In an advanced telepresence system, multimodal communication is very important. This type of communication involves sending telecommands to the slave robot intuitively and displaying more appropriate and intuitive information to the human operator. It requires the expression of multimodal telecommands and multimodal sensory feedback.

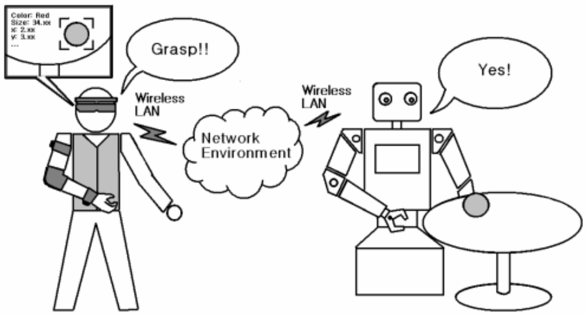


Fig. 1 Configuration of the Proposed Telepresence System

In this study, we combined these ideas to solve telepresence applications for the real world. In the proposed system, a human operator wearing the telepresence system sends telecommands through a multimodal channel that combines voice with arm and head motion. The telecommands are delivered to the target slave robot via the combination of a wireless and wired network. The intelligent slave robot can properly follow the human motion. The operator can make the slave robot perform some subtasks simply by saying the voice commands through a microphone attached to the wearable telepresence 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 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 each arm joint.

To power the sensors, motors, control hardware and HMD, a 7.2 V 2000 mAh NiMH battery was embedded in the developed suit. 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.

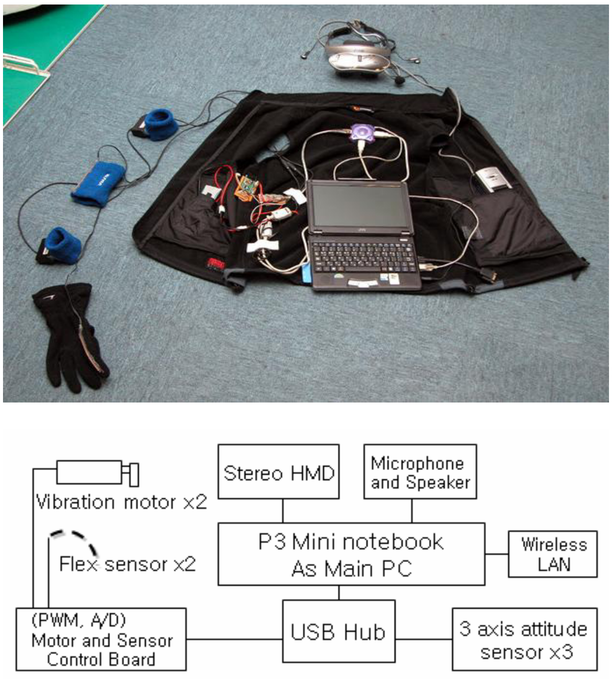


Fig. 2 Master Platform and its Hardware Structure

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, a three-axis attitude sensor is attached to the

HMD. Another three-axis sensor is located on the back of the operator's hand, while another is located on the operator's upper arm. Two flex sensors are attached to the glove and elbow of the operator. The sensors that measure the arm movement are fixed to elastic sports bands for the operator's comfort and convenient arm movement. 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 sensors, MI-A3330LS from the MicroInfinity Co., Ltd., calculate 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.

Fig. 3 Sensors and Control Hardware

3.3. Multi-modal Communication Hardware

The wearable master system offers the following communication interfaces to the user. Firstly, an operator wearing this system can see a stereo scene on the stereo HMD captured from the cameras of the slave robot in real time. Secondly, by using a headphone, the operator can hear the sound in a remote environment and a variety of voice information coming from the slave robot. In addition, the operator can send voice commands by using the microphone in the master system. Finally, the operator's arm and head movements are used to intuitively operate the slave robot while feeling the tactile sense and force feedback of the slave robot arm. These sensations are felt through the force reflection mechanism that uses vibration motors at the operator's finger and arm joints.

Through these multimodal interfaces, the operator can efficiently and effectively perform the necessary remote tasks.

Fig. 4 Wearing the Master System

4. Kinematics Analysis

For the master system to stably operate the slave robot, the kinematics of the master system and slave robot need to be analyzed. We first analyzed the forward kinematics of the master arm. Later, we calculated the desired joint angles of the slave robot by using the inverse kinematics. Fig. 5 shows the coordinates of the master arm.

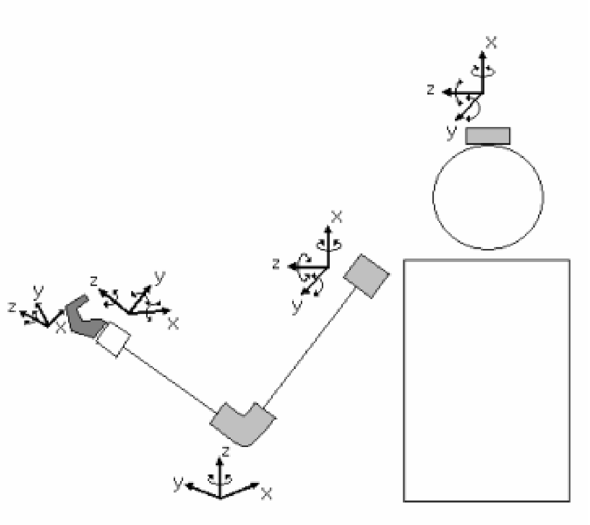


Fig. 5 Coordinates of Master Arm

4.1. Forward Kinematics

In this paper, we assumed different lengths for the master arm and the arm of the slave robot arm. We also assumed identical positions for the position of the end pointer of the master and the slave. The kinematical process is divided into two sub-processes. Firstly, we applied the position of the master arm's end pointer (the wrist) to that of the slave arm. Secondly, we applied the direction of the master hand to that of the slave hand.

The position and direction of master arm's end pointer were applied to the slave arm. We used Denavit-Hartenberg notations to describe the position of the end pointer.

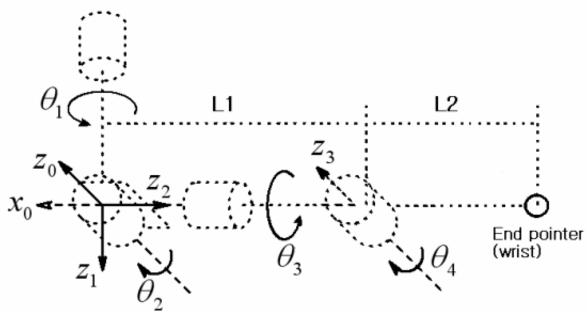


Fig. 6 Kinematics Parameters of Master Arm

The D-H table of the transform matrix $\mathbf{T_p}$ calculating the position of the end pointer is represented as table 1.

Table 1. Link Parameters

Link	a_i	α_i	d_i	θ_i
1	0	90	0	θ_1
2	0	90	0	θ_2
3	L1	90	0	θ_3
4	0	-90	L2	θ_4

The position of the end pointer calculated by **Tp** is expressed by equations (1) to (3).

$$\begin{aligned} x = {} & -L1\cos(\theta_1)\cos(\theta_2) - L2\cos(\theta_1)\cos(\theta_2)\cos(\theta_4) \\ & - L2(-\cos(\theta_3)\sin(\theta_1) \\ & - \cos(\theta_1)\sin(\theta_2)\sin(\theta_3))\sin(\theta_4) \end{aligned} \tag{1}$$

$$\begin{aligned} y = {} & -L1\cos(\theta_2)\sin(\theta_1) - L2\cos(\theta_2)\cos(\theta_4)\sin(\theta_1) \\ & - L2(\cos(\theta_1)\cos(\theta_3) \\ & - \sin(\theta_1)\sin(\theta_2)\sin(\theta_3))\sin(\theta_4) \end{aligned} \tag{2}$$

$$\begin{aligned} z = {} & L1\sin(\theta_2) + L2\cos(\theta_4)\sin(\theta_2) \\ & + L2\cos(\theta_2)\sin(\theta_3)\sin(\theta_4) \end{aligned} \tag{3}$$

(θ_i: angle of ith joint, L1: length of master's upper arm, L2: length of master's lower arm)

4.2. 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 by equation (4).

The parameters θ_1, θ_2, and θ_3 are calculated by using equations (1) to (3).

$$\theta_4 = \mathrm{Acos}((\mathrm{distance}^2 - SL1^2 - SL2^2)/(2*SL1*SL2)) \tag{4}$$

(distance = *distance of master arm's end pointer; SL1 = length of slave's upper arm; SL2 = length of slave's lower arm)*

Finally, the master arm and the slave arm have the same hand direction in the absolute coordinates system. The hand direction $\mathbf{T_d}$ of the master arm is calculated as an absolute angle. The coordinates system of the slave hand is represented by equation (5).

$$\mathrm{T_{ds}} = \mathrm{T_d} \cdot \mathrm{T_{d'}^{-1}} \tag{5}$$

5. Multimodal Communication with Intelligent Slave Robot

To interact more intuitively and efficiently with a remote robot through a telepresence system, multimodal communication interfaces based on human perception and expression are essential requirements [3].

Many teleoperation researches have concentrated on more precise tracking of the master arm and force feedback. These factors help reduce the gap between the master and the slave robot with respect to the operator's sense of realism. However, we chose an alternative method that uses intelligent self-sensory feedback and context-based behavior in the slave robot. This method gives feedback to an operator through the voice and visual communication channel; it employs a simple force refection mechanism that uses vibration motors rather than precise control with a high force reflection.

In this system, for example, when the slave robot picks an object, it sends the operator information on the contact force; the operater hears vocal expressions through the headphones and reads information through the HMD. Furthermore, to control the slave robot more precisely, the operator can send predefined voice commands to the slave robot. During teleoperation, the operator can even use the master system's microphone while using arm and head motion to do given task. We named the system a wearable telepresence system with multimodal communication.

5-1. Voice Communication Channel

Speech synthesis and recognition are important for human-robot interaction. The technology is also important for future telepresence systems.

In our telepresence system, the slave robot uses speech synthesis to send information from a remote environment to a human operator. It immediately expresses its internal status. Speech recognition also enables the operator to intuitively command the slave robot.

For speech synthesis, the proposed system has a text-to-speech program developed by Cowon Systems, Inc., that can produce natural Korean and English sentences. For speech recognition, the system has an HMM speech recognition program that can recognize about fifty words; this program was developed in our laboratory.

5-2. Visual Communication Channel

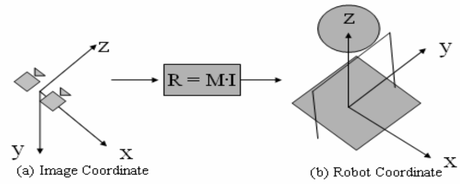
Through a visual communication channel, the view of the remote slave system is transferred to an operator wearing the master system. This view is displayed on the master system's stereo HMD screen after being augmented with textual and graphical information. for the information on the screen helps the operator to understand the status of the slave system and the environment around the slave system. Fig. 7 shows an example of the HMD screen.


Lobj area=841 mcx=123,mcy=82
Robj area=840 mcx=101,mcy=84
rx=75.958865
ry=14.545455
rz=-4.641363

Fig. 7 Information Visualization

5-3. Automatic Behaviors in Slave Robot

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



(a) Image Coordinate

(b) Robot Coordinate

$$M = \begin{pmatrix} \sin\phi & -\sin\theta\cos\phi & \cos\theta\cos\phi & \cos\phi(r\cos\theta + h\sin\theta) \\ -\cos\phi & -\sin\theta\sin\phi & \cos\theta\sin\phi & \sin\phi(r\cos\theta + h\sin\theta) \\ 0 & -\cos\theta & -\sin\theta & -r\sin\theta + h\cos\theta + H \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

r,h,H,θ,ϕ = distance between center and lens in cm, height of camera from motor, height of motor from ground, rotation of camera on y axis, rotation of camera on z axis

Fig. 8 Data Conversion from Image Coordinate to Robot Coordinate

For the automation of subtasks in the slave robot, the autonomous representation of objects into 3-D geometrical data is needed in the remote task space. To get the 3-D data of an object after image filtering and segmentation for the detection of color objects, a conventional two parallel stereo camera model was implemented in the slave robot. We can then get the 3-D position of the focused object by converting the image coordinate to the robot coordinate as shown in Fig. 8.

For automatic avoidance of obstacles, a mobile slave robot must have proper sensors such as ultrasonic and infra-LED sensors to detect obstacles and to measure the distance from those obstacles. It also needs an avoidance algorithm. As shown in Fig. 9, for the parameters of the automatic avoidance algorithm in the slave robot, we used the safe movement measurements surrounding the mobile base.

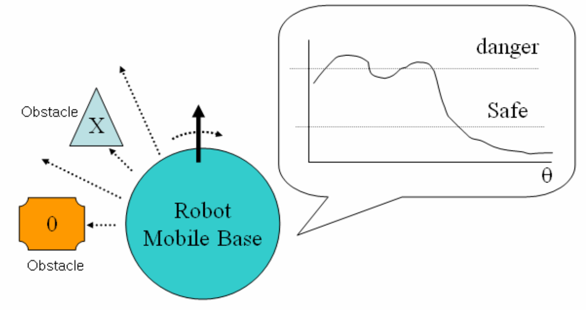


Fig. 9 Automatic Obstacle Avoidance

5-4. 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 (1*2 DOF) equipped with two CCD cameras for stereo vision, a mouth for speaking motion (1 DOF) and a neck (2 DOF) that tracks a moving target for gazing control. Its body has two arms (5*2 DOF), two hands (6*2 DOF), a waist (1 DOF) and a mobile platform with two wheel motors (1*2 DOF). 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].

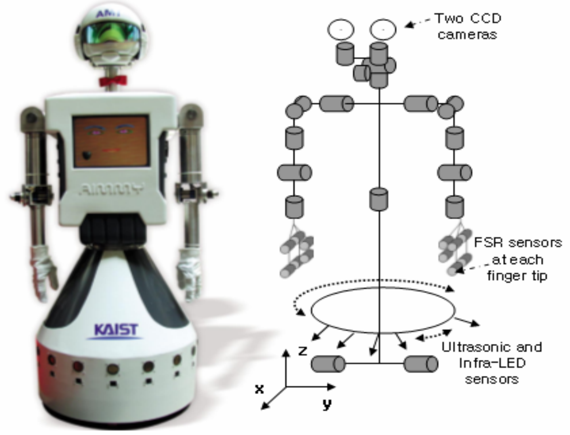


Fig. 10 Humanoid Robot, AMI and its DOF Structure

6. Experimental Result

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

First, to verify the basic function, we performed an experiment in which the robot followed the movement of the user's arm and head. In this experiment, the system showed the same exactness and precision as previous systems but with greater convenience for users.

Second, we conducted an experiment in which the user let the remote slave robot pick up one of the objects on a table to confirm the overall effectiveness and performance of the system. In this experiment, the user used only a voice command to make the robot approach the table. Once it had moved near the table, the robot used the voice channel to inform the user of the distance from its current position to the table. The user then used a voice command to make the robot approach the table within the given distance. The user's arm movements were used to operate the robot's arm as the user watched the HMD. Finally, after moving the robot's arm closely over the object, the user used a voice command to make the robot pick up the object. Figures 11 and 12 show the two experiments.

We are currently developing the proposed force reflection mechanism with the aid of vibration motors. After developing the mechanism, we will conduct experiments to show its performance.

Fig. 11 Experiment 1, Gesture Following

7. Conclusion

This paper proposes a wearable telepresence system and explains the implementation of the prototype. We conducted 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 gesture mimicking, mobile platform control of the humanoid robot and object manipulation. We also showed the performance and efficiency of our wearable telepresence system.

In the future, we will implement the suggested force reflection method and then prove the performance by experiments with the robot. Furthermore, to enhance the master system, we will research the use of more advanced visualization by AR technology, along with the use of two arms.

Fig. 12 Experiment 2, Tele-Manipulation

8. Acknowledgement

This work was partly supported by the Korea Ministry of Commerce, Industry and Energy through the Personal Robot Project and by the Digital Media Lab Project in Korea.

References

1. Younkoo Jeong, Dongjoon Lee, Kyunghwan Kim, Jong Oh Park: "A wearable robotic arm with high force-reflection capability," *proceedings of IEEE RO-MAN 2000*, pp.411-416 (2000).
2. Taro MAEDA, Hideyuki ANDO, Make SUGIMOTO, Junji WATANABE, Takeshi MIKI: "Wearable Robotics as a Behavioral Interface-The Study of the Parasitic Humanoid-," *proceedings of IEEE ISWC '02*, pp.145-151 (2002).
3. Kammermeier, P., Buss, M.: "A human perception model for multi-modal feedback in telepresence systems," *proceedings of IEEE SMC '99*, pp.1020-1025 (1999).
4. William R. Hamel: "Fundamental Issues in Telerobotics," *proceedings of IEEE-RAS HUMANOIDS 2003*, pp.66 (2003).
5. Yong-Ho Seo, Ho-Yeon Choi, Il-Woong Jeong, and Hyun S. Yang, "Design and Development of Humanoid Robot AMI for Emotional Communication and Intelligent Housework," *Proceedings of IEEE-RAS HUMANDOIS 2003*, pp.42 (2003)