Development of Multi-D.O.F. Master-Slave Arm with Bilateral Impedance Control for Telexistence

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Abstract

We developed the robotic arm for a master-slave system to support "mutual telexistence," which realizes close physical communication with other people using gestures and remote dexterous manipulation tasks. In this paper, we describe the specifications of the experimental setup of the master-slave arm for demonstration of the feasibility of the mutual telexistence concept. We developed the master arm of a telexistence robot for interpersonal communication. To facilitate smooth gestures of the operator, this arm has 6-degree-of-freedom structures to free the operator's elbow. The last degree of the 7-degree-of-freedom slave arm is resolved by placing a small orientation sensor on the operator's arm. Moreover, this master arm is made light and impedance control is applied in order to grant the operator as much freedom of movement as possible.

1. Introduction

It has long been a desire of human beings to project themselves in a remote environment, i.e., to have a sensation of presence in a remote place.

The concept of projecting ourselves by using robots is called telexistence (tele-existence) [1]. Telexistence is an advanced type of teleoperation system that enables an operator to perform remote manipulation tasks dexterously with the feeling that he or she exists in the remote environment where the robot is working in. The first telexistence master-slave system "Telesar (Telexistence Surrogate Anthropomophic Robot) I" is shown in Fig.1.

The second prototype of a telexistence master-slave system for remote manipulation experiments is being designed and developed with improved technology. The robot built for this system is called "Telesar II". We focus on producing human-like, realistic movement for Telesar II.

Fig. 1: The first telexistence master-slave system "Telesar I"

2. The mechanism of the master-slave arm of Telesar II

The slave arm of Telesar II is a 7 D.O.F. light weight arm [2]. The anthropomorphic slave arm is shown in Fig.2.

The master arm used in experiments of telexistence manipulation is shown in Fig.3 [3]. This master arm has force feedback.

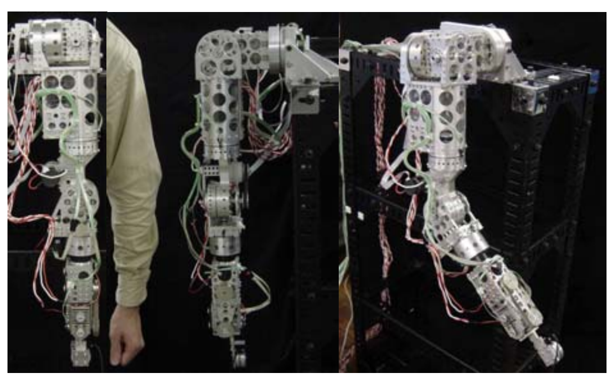


Fig. 2: The whole view of the slave arm of Telesar II

Fig. 3: The master arm of Telesar II

3. Control methods of master-slave system

Telesar I adapted unilateral control, but we adapted bilateral control for Telesar II because of the improvements in technology such as computational power.

Many types of bilateral systems are currently under development, but in this study we control the system based on the impedance control.

The basic principle of the impedance control type master-slave system is to give seemingly equivalent impedance to both master and slave. Furthermore, by minimizing its impedance, the master arm places only a slight load onto the operator's arm, and he or she can perform a wide variety of gestures and other body movement expressions without becoming hindered.

Another merit of bilateral impedance concerns operation safety. For contact operations of the slave arm with another person, the operator can feel the power from the person with a high sense of reality, so the potential danger of giving him or her superfluous power can be avoided.

If we control the master-slave system with a Dual Motion Transmission Method [4] that exchanges movement information between the master and the slave, the master's power is equal to the slave's, and exact power presentation can be performed in contact work.

In this control method, the control equations are as shown below.

$$F_0 = F_e = M_d\left(\ddot{X}_m - \ddot{X}_s\right) + B_d\left(\dot{X}_m - \dot{X}_s\right) + K_d\left(X_m - X_S\right) \quad (1)$$

Here, (M_d, B_d, K_d) mean the target impedance parameters of the master arm and the slave arm, F_0 means the operational force to the operator, F_e means the power that works from the object to the slave arm, X_m and X_s mean the posture vectors of the master and the slave.

In a state where the slave arm is moved without applying external power, since the master's power and the slave's are not equal, the operator receives the power by the product of target impedance and the posture error. However, making target impedance as small as possible can minimize undesirable load, unlike other control methods.

In order to verify the optimality of this bilateral impedance control system, we conducted simple comparison experiments with symmetry and force-feedback, which are general control method types.

The symmetry type is a control method in which the master and the slave transmit their posture information to each other, and apply a suitable gain according to the difference of their postures to produce a torque output.

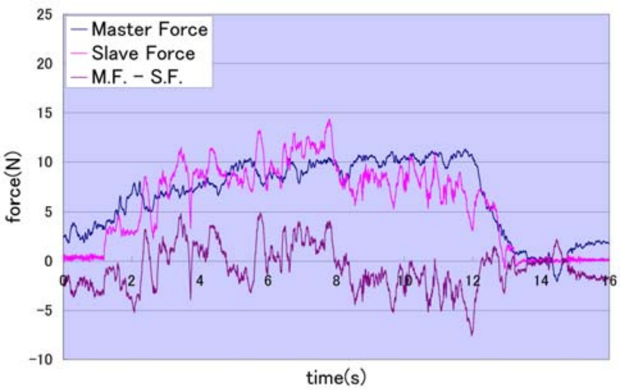
The force-feedback type is a control method in which the master transmits posture information to the slave, and the slave transmits power information to the master. The master receives the torque command value from the product of the suitable gain and the difference of the master's power and the slave's, and the slave receives the torque command value from the product of the gain and the difference between the master's posture and the slave's.

For the fundamental experiment, we compared symmetry, force feedback, and impedance control types. At first, we used the left arm of the master system as the virtual slave arm, and used the right arm of the master system as the master arm to eliminate mechanical difference between the master and the slave, and compare the control methods themselves.

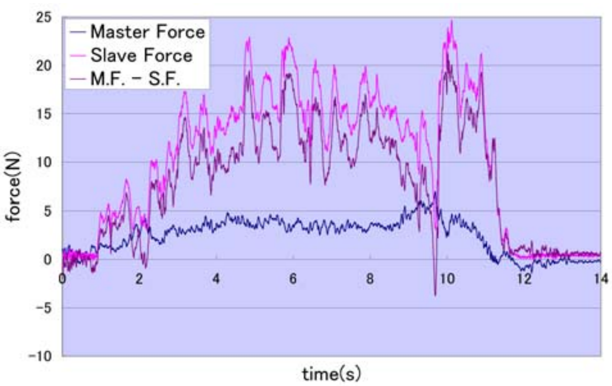
In this experiment, we activated all 6 axes of the master arm and the virtual slave arm. Results of this experiment are shown in Fig.4.

In symmetry type, the operational force is large because the operation itself needs large power. In force feedback type, the virtual slave arm pushes the wall with superfluous power, and the operator can't feel it. In impedance control type, tracing with stable power was realized.

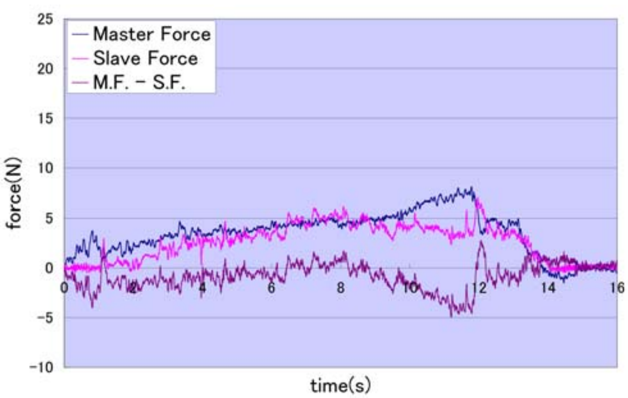
In the second experiment, we checked the influence of different inertia with comparison of symmetry and impedance control type. We attached a weight to the virtual slave arm to increase its inertia, and measured the operational force. The result of this experiment is shown in Fig.5. Compared with the increase of the operational force in symmetry type (from 7.4N to 9.3N), the increase of the operational force in impedance control type is very small (from 3.7N to 3.9N).



Symmetry type

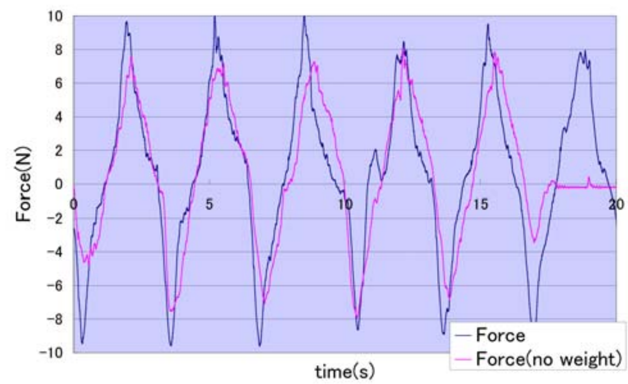


Force feedback type

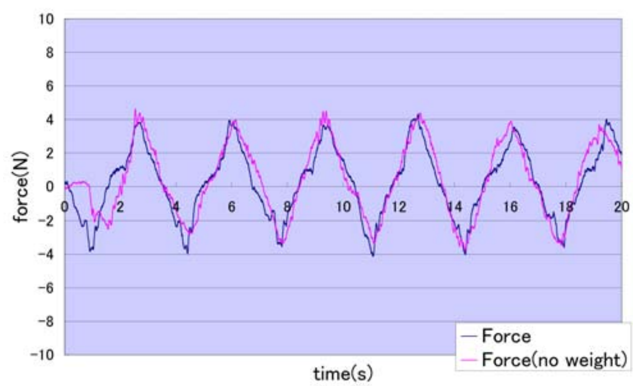


Impedance control type

Fig. 4: Result of the first experiment of comparison



Symmetry type



Impedance control type

Fig. 5: Result of the second experiment of comparison

In the third experiment, we used the actual slave arm of Telesar II to confirm the validity of bilateral impedance control for master-slave system with different mechanical structure. The overall view of the experimental setup is shown in Fig.6. In this experiment, the slave arm moved in free space, and we checked the accuracy of following ability in three axes of the universal coordinate. The results of this experiments is shown in Fig.7. As shown in these three graphs, sufficient accuracy for gestures and communication was confirmed in this experiment.

In the fourth experiment, we checked the accuracy of force presentation of this system. The slave arm traced the wall, and we measured the operational force and the opposing force from the wall applied to the slave arm. The result of this experiment is shown in Fig.8. Small operational force is realized, forces on the master arm and the slave arm are comparatively close, and the stable trace is also realized. Namely, impedance control type is also effective in this system.

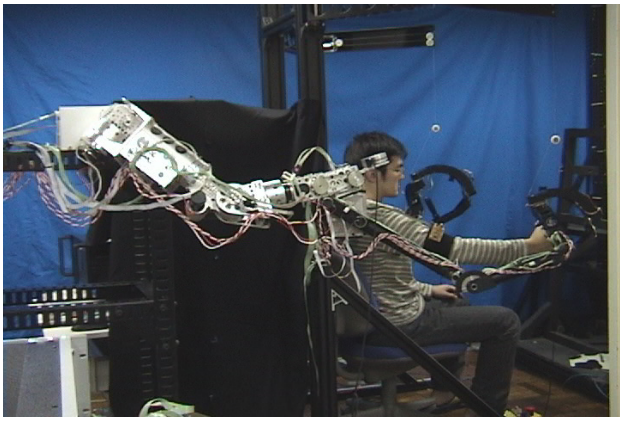


Fig. 6: The overall view of the experimental setup using the actual slave arm of Telesar II

Through all the experiments shown above, the features that must be realized in good master-slave system for telexistence were actually realized in impedance control type, so the validity of impedance control type was confirmed. The features were as follows:

- Reproduction of the operator's work
- Precise force feedback
- Stable contact
- Gesture is enabled
- Smooth Operation
- Sufficient accuracy of following ability
- Safe for humans
- Precise force feedback
- Stable contact operation (for shaking hands, etc.)

4. Head mechanism

Now we are developing the head mechanism with vision system of Telesar II for more efficient experiments of telexistence with vision feedback. The overall view of the head mechanism is shown in Fig.9, and its all components designed in the virtual environment of Pro/Engineer, the three dimensional CAD system, are shown in Fig.10. It has the screw mechanism to adjust the distance between two cameras to the distance between two eyes of the operator.

In the presentation, we will show the additional experiments using vision feedback of the head mechanism of Telesar II to demonstrate the feasibility of the mutual telexistence concept.

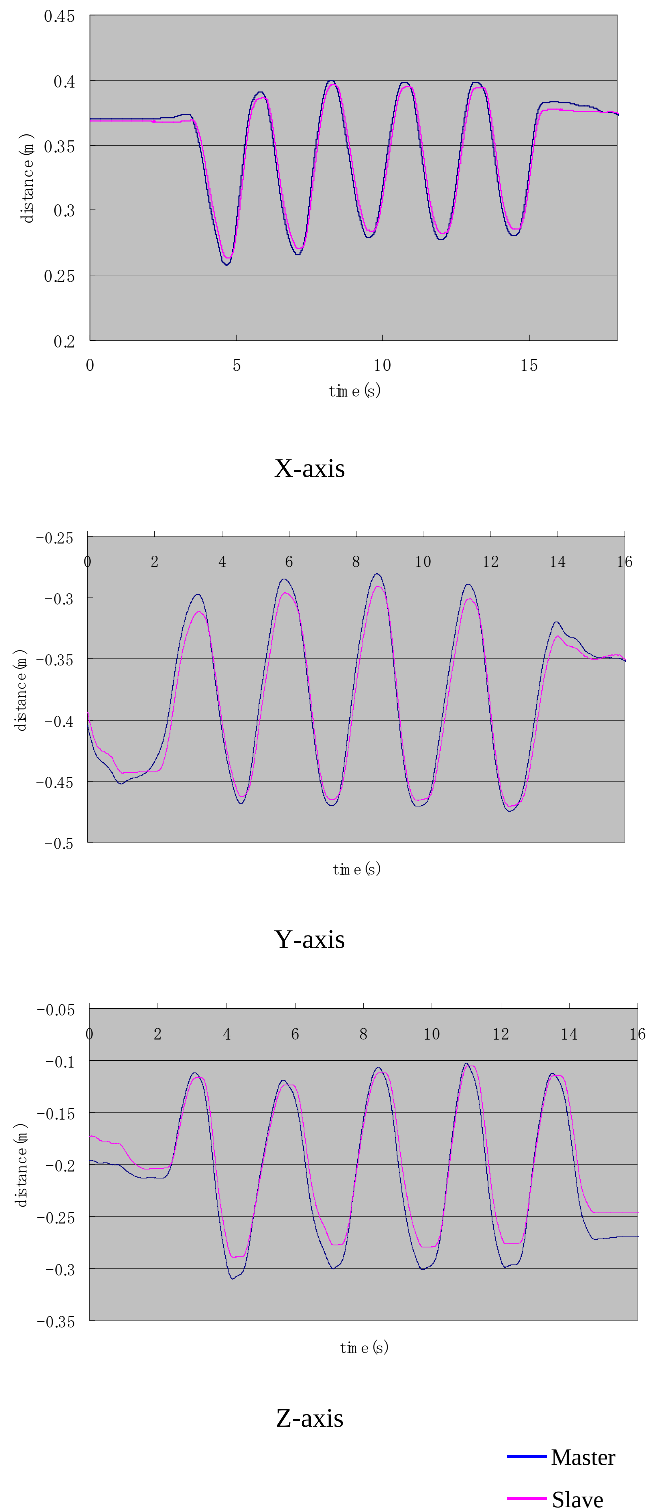


Fig. 7: Results of experiments to check the accuracy of following ability

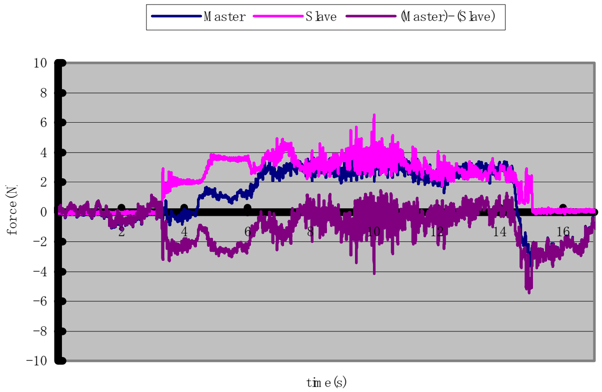


Fig. 8: The result of the experiment using the slave arm

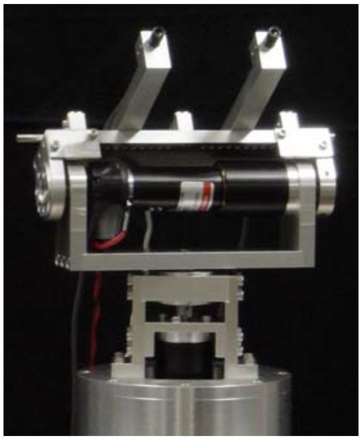


Fig. 9: The overall view of the head mechanism

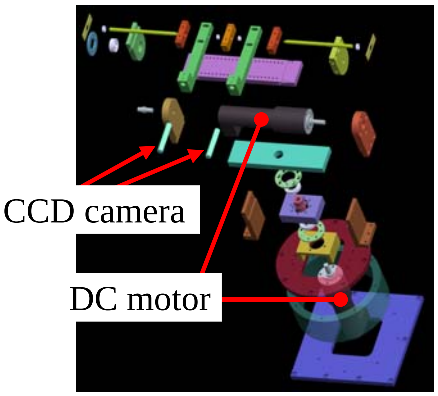


Fig. 10: The all components of the slave head

5. Conclusions

This paper described the mechanical design and development of the new master-slave arm for mutual telexistence. The validity of the bilateral impedance control was confirmed in fundamental experiments. With this system, the operator will be able to move the slave robot in a remote location very smoothly with a high sense of presence.

6. Acknowledgments

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7. References

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