The Design of Internet-Based RobotPHONE

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Abstract

RobotPHONE is a Robotic User Interface (RUI) that uses robots as physical avatars for interpersonal communication. The shape and motion of RobotPHONE is continuously synchronized by a bilateral control method. Using RobotPHONE, users in remote locations can communicate shapes and motion with each other. In this paper, we will present the design of an Internet-Based RobotPHONE. To use RobotPHONE via the Internet, we developed a time delay compensation control method. In this paper we also discuss this new control method.

Key words: Robotic User Interface, Bilateral Control Method, Internet, Communication Device

1. Introduction

RobotPHONE is a communication device based on the concept of a Robotic User Interface (RUI). In contrast to a Graphical User Interface (GUI), which uses the combination of WIMP (Window, Icon, Menu, Pointing Device), RUI utilizes a robot as an interface for a human being. The concept of a GUI that originated from NLS (On-Line System) by Douglas C. Engelbart [1] and Alto by Alan Key [2] changed the way computers are used. GUI simplified the use of a computer and played an important role in the spread of computers for public use. However, because GUI is based on WIMP, recently the interaction method used by GUIs has been recognized as limited when interacting with our real world situations.

NaviCam [3] and Tangible Bits [4] are attempts to overcome such GUI limitations; by using a physical object that exists in the real world as the interface. Many of these attempts use a see-through head mounted display (HMD) or a projector to output information to the user. Therefore, considering that direct interaction with such outputted information is still limited, we believe that an output method that makes use of a real object hasn't yet been established.

On the other hand, personal robots such as pet robots [5] are a good example of utilizing a real object. Contrary to a computer graphics (CG) character on a computer display, these robots have a physical body and that existence attracts people. A robot can be regarded as a computer with a physical body that enables it to interact with the real world. Hence, considering its strong capability to interact with the real world, a robot would be efficient interface having an input and an output method for the real world. As well, if we regard the robot as a general-purpose machine, it is possible to consider that it is a universal interface. Robotic User Interface (RUI) is the terminology for this type of interface. That is, the concept of using a robot as an interface between the real world and the information world can be referred to as a RUI. An intelligent robot as a physical entity for an Artificial Intelligence agent or a haptic feedback robot arm used in virtual reality (VR) systems are good examples of a RUI.

RobotPHONE [6] is a RUI system for interpersonal exchanges that uses robots as agents for physical communication. The RobotPHONE system employs robots that are called shape-sharing device. The shape and motion of remote shape-sharing devices are always synchronized. Operations to the robot, such as modification of posture, or input of motion, are reflected to the remote robot in real-time. Therefore, users of RobotPHONE can communicate and interact with each other by exchanging the shape and motion of the robot.

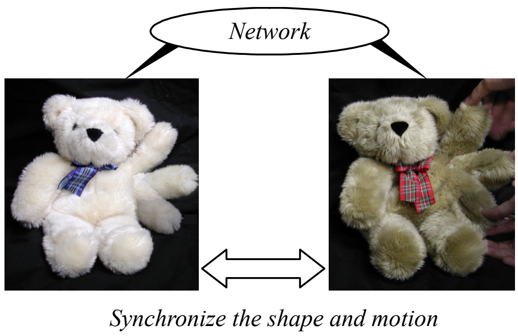

Fig.1 The concept of RobotPHONE

If an ordinary telephone is considered to be a device for transferring voice, RobotPHONE is a device for transferring motion. Further, because RobotPHONE uses a physically existing robot as the input and output interfaces, a user of the RobotPHONE system can directly feel the force of a user at the other side of the system. Therefore, users of RobotPHONE can get motion information not only as a visual sensation but also as a tactile sensation; it is thus possible to say that RobotPHONE is a new type of telephone that can simultaneously transfer visual, haptic and auditory information. It can also be said that RobotPHONE is a system that makes it possible to have an object exist virtually in a remote place on behalf of a user. RobotPHONE transfers the existence of the user not by attempting to transmit the user them self but to transmit the user's substitute. Consider a mother giving a child a stuffed animal to keep the child company at night. This is a form of communication aided by a physical entity. RobotPHONE can facilitate this kind of communication.

In this paper, we present the system design of our RobotPHONE, which can stably communicate over communication links, such as the Internet, with time varying delays.

2. System overview

Fig. 2 shows an overview of the Internet-based RobotPHONE system.

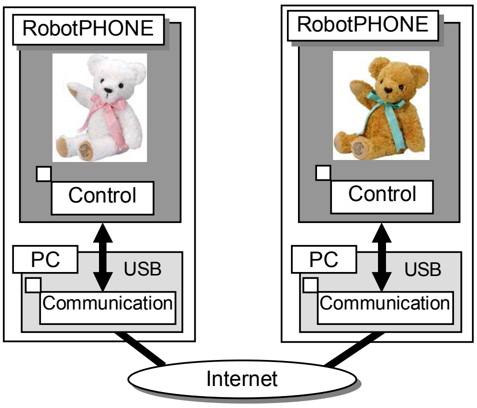

Fig.2 System overview

As shown in Fig.2, this system uses two teddy bear-like robots (RobotPHONE) as a shape-sharing device. This humanoid type robot has 2 degrees of freedom at each arm, 2 degrees of freedom for the head for 6 degrees of freedom in total (Fig. 3). All DC motors of the RobotPHONE are controlled by microcontroller inside the device. The RobotPHONE onboard controller has a USB connector that is used to connect it to a PC. For voice communication, the RobotPHONE has a microphone and a speaker, which can be linked to the PC's sound device.

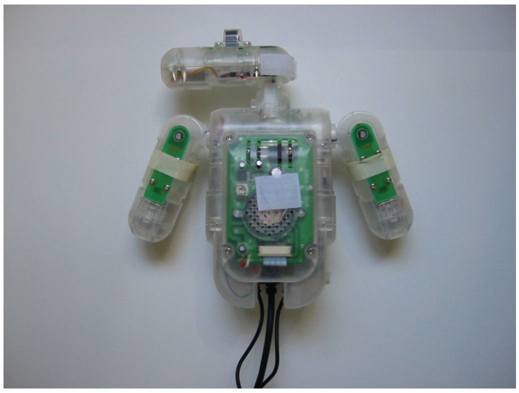

Fig.3 The mechanism of the RobotPHONE

RobotPHONE software running on each PC controls the RobotPHONE through the USB connection and synchronizes the motion of two RobotPHONEs in distant places by exchanging data over the Internet. The RobotPHONE software also transfers voice data in addition to motion data. Therefore a user can communicate using motion and voice. The RobotPHONE software uses the RCTP 2.0 protocol [7] for transferring motion data. Fig.4 shows the screen image of the RobotPHONE software.

Fig.4 RobotPHONE software

3. Bilateral control with time delay

In this section, we explain the control method, used in the Internet-based RobotPHONE system for synchronizing the motion of the RobotPHONE.

Ordinarily, to synchronize motion between distant places, as the RobotPHONE does, the bilateral control method would be used. However, if there is a time delay in the communication line, it is well known that such a communication delay will destabilize the system if a conventional control method like a symmetrical bilateral control method is used. This will especially be a major problem when the RobotPHONE is used over a communication line, such as the Internet, with time varying delays. To overcome this problem, several methods have been proposed. Anderson and Spong [8] proposed a time delay compensating bilateral control law based on scattering theory. Oboe and Fiorini [9] proposed a PD-type controller. However, these methods are relatively complex schemes; therefore, if these methods are applied to the RobotPHONE, it will be a more complex system than necessary. In addition, as the time delay becomes longer, these methods tend to increase the equivalent damping and inertia of the system for system stability, and so the system becomes sticky and heavy as a result.

As described earlier, the goal of the RobotPHONE is to be a communication device that can be used like an ordinary telephone; thus, a user should be able to always manipulate the RobotPHONE in the same manner regardless of any communication line time delay. Hence, it is difficult to apply the above methods to RobotPHONE. We therefore decided to use a new method that would be the most suitable for the RobotPHONE.

4. External force transferring bilateral control method

To create a suitable bilateral control method for the RobotPHONE, we first focused on the fact that previous approaches were mainly designed for a teleoperation system. In a teleoperation system, the operator performs some tasks like grasping some object at the slave side at a place distant from the master side. Hence, in a teleoperation system it is very important to match as much as possible both position and force between the master and the slave. On the other hand, the RobotPHONE is a communication device, which transfers motion to each other, and is not intended to do some complex task at a distant place. Thus, it can be said that the precise reflection of the position between the master and the slave is not so important with the RobotPHONE. Therefore, we thought that we could use a new bilateral control scheme, which transfers motion and force to each other but does not actively match positions between the master and the slave. Our basic idea is as follows:

> *Each device only sends information caused by external force.*

By following this scheme, only movement information caused by an applied force is sent to the opposite device and, the opponent device does not send back any information caused by the received information. Therefore, this control system can be basically regarded as a pair of two independent control systems and it can be said that communication line time delay does not affect the system. A similar kind of idea can be seen in a voice echo canceller.

Based on this idea, we developed a new control method referred to as the external force transferring bilateral control method for the Internet-based RobotPHONE. An impedance representation of the external force transferring bilateral control method is as follows.

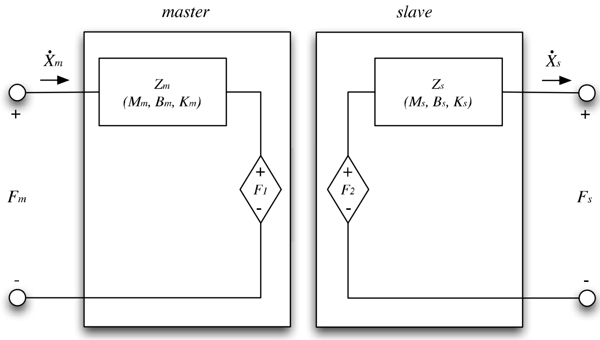

Fig.5 Impedance representation of the external force transferring bilateral control method

In Fig.5, the dynamics of the master and the slave systems are described as follows:

$$F_m - F_1 = M_m\ddot{X}_m + B_m\dot{X}_m + K_mX_m \quad (1)$$

$$F_2 - F_s = M_s\ddot{X}_s + B_s\dot{X}_s + K_sX_s \quad (2)$$

Where X_m and X_s are the respective positions of the master and slave arms, M_m and M_s are the respective inertias, B_m and B_s are the respective dampings, K_m and K_s are the respective elasticities, F_1 and F_2 are the respective motor torques, F_m is the master input torque and F_s is the slave output torque.

In addition, we consider the following impedance representation of the operator, master-slave system and environment.

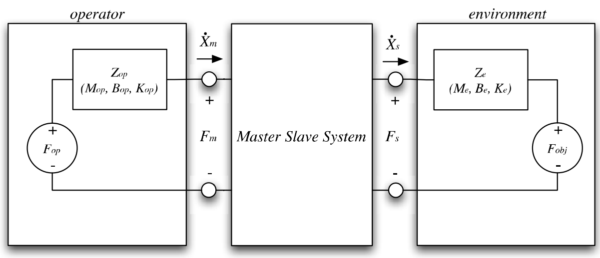

Fig. 6 Impedance representation of the operator, master-slave system and environment

In Fig. 6, the dynamics of the operator and the environment are given as follows:

$$F_{op} - F_m = M_{op}\ddot{X}_m + B_{op}\dot{X}_m + K_{op}X_m \quad (3)$$

$$F_s - F_{obj} = M_e\ddot{X}_s + B_e\dot{X}_s + K_eX_s \quad (4)$$

Where M_{op} and M_e are the respective inertias of the operator and the environment, B_{op} and B_e are the respective dampings, K_{op} and K_e are the respective elasticities, F_{op} is the operator applied torque and F_e is the torque from the environment.

From (1) and (3), we get

$$F_1 = F_{op} - \left(M_{op}\ddot{X}_m + B_{op}\dot{X}_m + K_{op}X_m\right) - \left(M_m\ddot{X}_m + B_m\dot{X}_m + K_mX_m\right) \quad (5)$$

From (2) and (4), we get

$$F_2 = F_{obj} + \left(M_e\ddot{X}_s + B_e\dot{X}_s + K_eX_s\right) + \left(M_s\ddot{X}_s + B_s\dot{X}_s + K_sX_s\right) \quad (6)$$

Let us consider the situation where external force is applied to the master and this information is transferred to the slave without load. In this case, the equation (5) becomes

$$F_{op} = M_m\ddot{X}_m + B_m\dot{X}_m + K_mX_m \quad (7)$$

Where F_1 is 0 and M_{op}, B_{op} and K_{op} is 0. Then, the equation (6) becomes

$$F_2 = M_s\ddot{X}_s + B_s\dot{X}_s + K_sX_s \quad (8)$$

Where F_{obj} is 0 and M_e, B_e and K_e is 0. A simple control scheme for the external force transferring bilateral control method is then given by

$$F_1 = F_s \quad (9)$$

$$F_2 = F_m \quad (10)$$

Thus the motion information of the master and slave arms are described as follows

$$M_m\ddot{X}_m + B_m\dot{X}_m + K_mX_m = M_s\ddot{X}_s + B_s\dot{X}_s + K_sX_s \quad (11)$$

Where F_{op} is F_m. This equation shows that the impedance parameters must be equal between the master and slave arms for synchronizing positions and motions of the master and slave arms. In addition, if another parameters like the impedance parameters of the operator or the environment are not 0, unlike the above assumptions, this also leads to position inconsistency between the master and the slave.

However, we think that it is possible to minimize difference of positions and motions between the master and the slave by matching the impedance parameters between them as much as possible. If the impedance parameters are sufficiently matched between the master and the slave, temporal impedance mismatch between the operator and the environment, or the existence of an external force (F_{obj}) are accumulated as position deviation between the master and the slave, and act as a position offset to the transferred motion.

As noted, we intend to apply this control method to the RobotPHONE communication device. Thus, we think that this position inconsistency would be negligible. Furthermore, in an actual situation using the RobotPHONE, users will send motions to each other not continuously but intermittently. Therefore, by introducing a method that moves each arm to the default position in a motionless period, we can periodically reset position inconsistencies between master and the slave.

5. Experimental Results

The following diagram shows the control scheme of our experimental system for verifying the external force transferring bilateral control method.

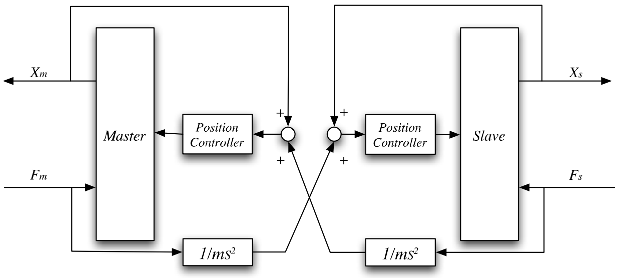

Fig.7 The bock diagram of the experimental system

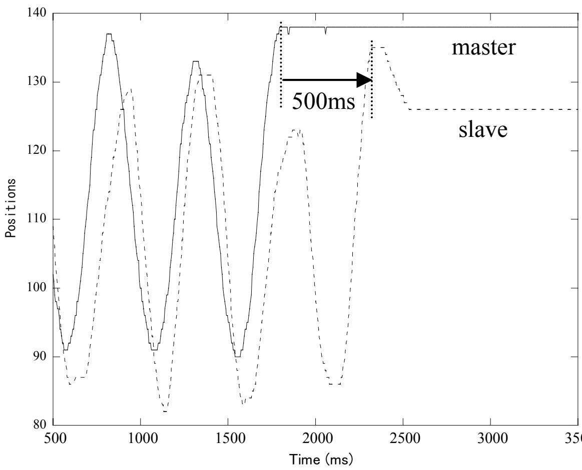

Fig.8 The external force transferring bilateral control method with 500ms time delay

Fig. 8 shows the experimental results of the external force transferring bilateral control method with 500ms time delay. As seen in Fig.8, the slave arm successfully traced the motion of the master arm, and at the end of each arm motion, a 500ms gap, which corresponds to the time delay, is observed. After this gap, each arm remained in the same position and no oscillation was observed. We performed this experiment with up to 5 seconds time delay. Through all experiments, this system showed no unstable behavior under all the time delay conditions we tested.

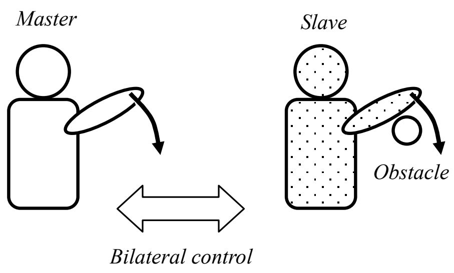

Fig. 9 Experimental setup with obstacle

Fig. 9 shows the next experimental setup. In this experiment, an obstacle was placed under the slave arm to be hit by the operation from the master arm.

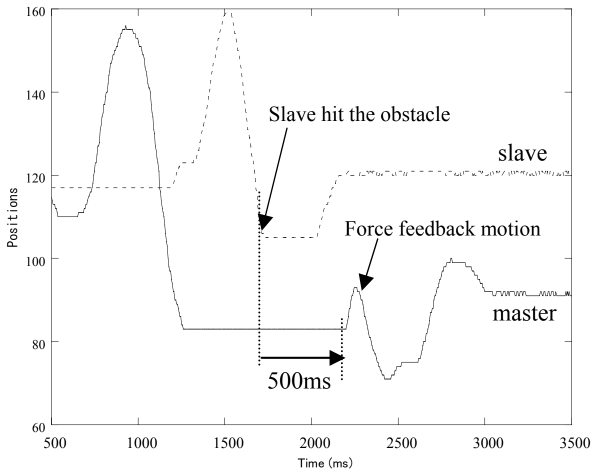

Fig.9 The slave hit the obstacle with 500ms time delay

Fig. 9 shows these results. At first, the slave arm followed the motion of the master arm with 500ms delay. Then, the slave arm hit the obstacle, halted its motion, and sent back the external force information to the master. At the same time, the master already stopped its motion; the information from the slave took 500ms to reach the master because of communication line time delay between the master and the slave. 500ms after the time of the hit on the obstacle, the external force information reached the master and the master output force according to the information from the slave. As shown in Fig.9, this force output from the master generated a counter motion to the inputted motion by the operator and becomes force feedback to the operator. Through a series of such events as above, both master and the slave showed no oscillation. This experiment was also conducted with up to 5 seconds time delay; very stable behavior was observed under all time delay conditions we tested.

We implanted an external force transferring bilateral control system and experimentally confirmed that this control method is stable under various time delay conditions.

6. Related work

There are several works that share haptic sensation or the position of the object for interpersonal communication. Ishii's inTouch [10] synchronizes the rotation of rollers under the hand. Fogg's HandJive [11] synchronizes the movement of a balloon and a stick gripped in the user's hand. PsyBech(Physically Synchronized Bench) by Ishii [12] synchronizes the position of an object on the workbench. However, these works synchronized only the motion or position of the object. We think that the combination of shape and motion is especially important, and this combination results in the embodiment of realistic communication.

inTouch was tested with Internet connection [12], using motion prediction and control parameter tuning for time delay compensation; the method seemed to be sensitive to increases of the time delay.

7. Conclusion

In this paper we briefly explained our concept of RUI and showed our design for the Internet-based RobotPHONE. To compensate for the communication line time delay observed in the Internet, we proposed a new bilateral control method called the external force transferring bilateral control method for the Internet-based RobotPHONE. We discussed this control method and implemented it in an experimental system. Through the implementation, we experimentally confirmed its stability under various time delay conditions, and we demonstrated the feasibility of our Internet-based RobotPHONE design.

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