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Applying an 'encounter-type' haptic display to telexistence

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Abstract

We have proposed an 'encounter-type' haptic display, which has many advantages over the 'mounting-type' in displaying a realistic sense of touch. However, it was difficult to use this type of display in telexistence. In this paper, we propose and discuss a method for applying encounter-type displays to telexistence in the real world. In addition, we report on prototype systems.

Key words: Telexistence, Encounter-type, Haptic display, Force display, Latency

1. Introduction

The 'mounting-type' haptic display, which always mounts or holds the end-effector of a system on an operator's body, is often used in telexistence systems. This type of haptic display generates a haptic sensation by changing its closed-loop rigidity according to the shape of the virtual object and the state of touch. The PHANToM[1] is classified as this type, but it is well known that this type of display has many disadvantages. For example,

1) It is difficult to display a real sense of collision with a virtual object. A sense of collision is considered to be a key sensation of touch.

2) Operators always have to always mount or hold actuators on their bodies, which restricts movement and feels unnatural.

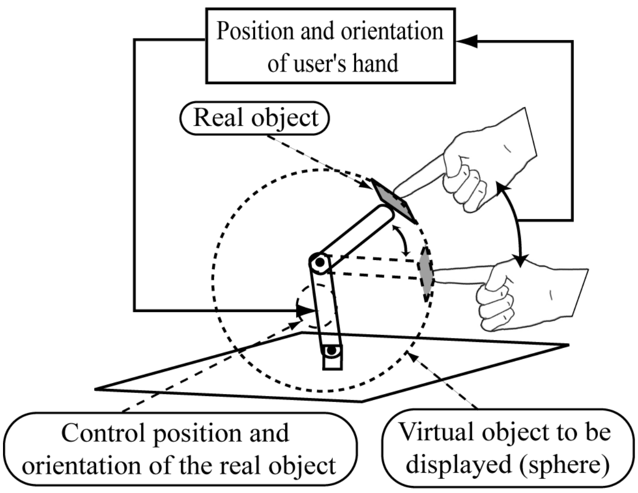

Fig. 1 The strategy of encounter-type haptic display (Tangent plane approximation)

In this research, we propose applying an 'encounter-type' haptic display to a telexistence system for solving these problems. In addition, we report another advantage of using the encounter-type haptic display.

2. The encounter-type haptic display

2.1. Characteristic of the encounter-type haptic display

Some researches have already developed encounter-type haptic displays. For example, K. Hirota et al. developed Surface Display[2] and S. Tachi et al. developed Active Environment Display (AED,[3]); however, their creations were haptic displays only for the virtual world. These displays could not use in telexistence in the real world. The general strategy of this type of display is shown in Fig. 1. First, move the real object (display unit) to approximate the surface around the contact point of the virtual object. Second, the display unit waits for the operator touches. Third, the display unit is controlled according to the operator movement and shape of the object, which enables the operator to experience a realistic sense of touch. We call it “tangent plane approximation”. Compared to mounting-type of display, the advantages of the encounter-type are summarized as follows.

- **Sense of collision:** When the user touches the virtual object, the collision has actually occurred. Hence, the operator experiences a real sense of collision.
- **Vertices and edges:** By using a real object, which has vertices and edges, as does a display unit, the operator experience a realistic sensation of touching vertices and edges [3].
- **If you do not touch anything, you do not feel any load:** The operator only has to mount or hold the passive system to measure, point and orientation of his/her finger. Hence, the operator is free from any extra load when he/she is not touching anything.

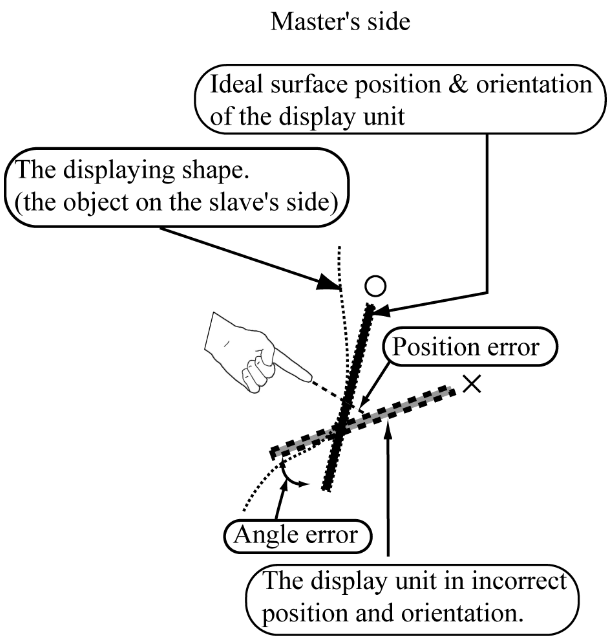

Fig. 2 The state before contact

Displaying a haptic sensation with a mounting-type haptic display should increase rigidity and torque of the actuators to display a sense of collision and edges. However, in such a case, the back-derivability of the system will decrease, and the operator will sense an unnatural feeling especially when the operator does not touch anything. Although when using the encounter-type display, we do not have to consider about this problem. Because, in this type of display, the actuators are separated from the operator’s body.

2.2. Applying the encounter-type haptic display to telexistence

Considering the use of an encounter-type haptic display in a telexistence system,

- **The environment (or the object) on the slave’s side must be measured before contact.**

The display unit has to be controlled to approximate the environment on the slave’s side before contact. To achieve an appropriate haptic sensation with an encounter-type haptic display, the surface of the display unit on the master’s side would have to be controlled to approximate the object on the slave’s side before contact. In other words, information about the environment on the slave’s side (relative position and relative orientation between the slave hand and slave environment) would be necessary before contact. To solve this problem, the following two methods are considered.

- Measure the slave environment around the contact point locally for every contact.
- Construct an environment model in advance.

In the case that we construct an environment model of the slave side in advance, it is known that we could use this method if the transmit latency is very big. But it lacks of flexibility in the variance of the environment. In addition, the dynamics of the object on the slave’s side are basically unknown, which presents another major problem if the model is to be constructed. On the other hand, when using the latter method, measuring the environment every contact time, we could not use it if the transmit latency is too big, but we could get flexibility against the variance of the environment, and we could measure the dynamics of the object. In this research, we choose the latter one to make a prototype system. If the problem about pre-measurement is solved, another advantage is gained.

- **Correctness against latency:** The system could display haptic sensation correctly in spite of the existence of transmit latency or control latency.

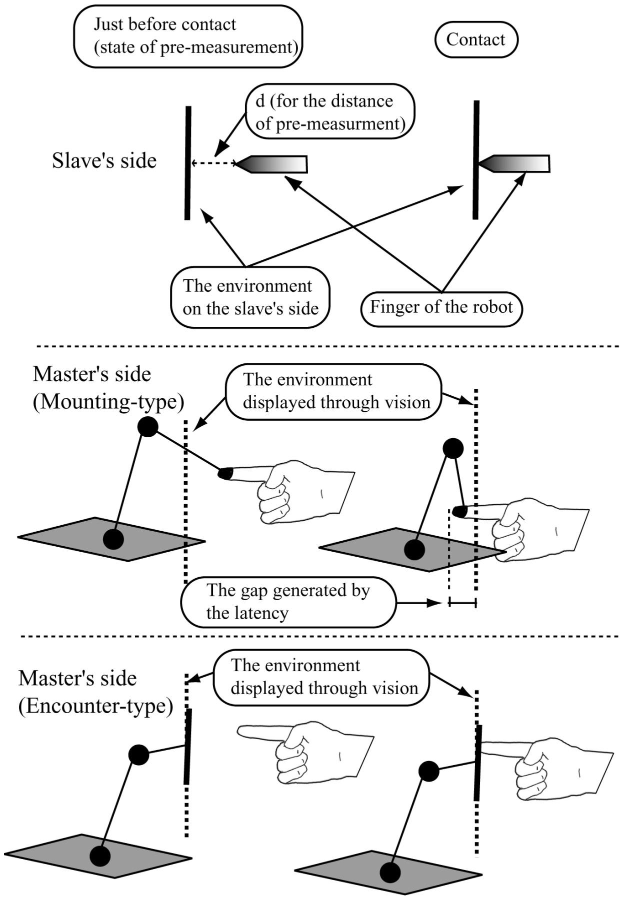

Fig. 3 About transmit latency

To use an encounter-type haptic display in a telexistence system, the information about the environment on the slave's side must be obtained before contact, which means that the slave's side environment must be pre-measured. On the other hand, the pre-measurement enables us to give haptic sensation correctly (Fig. 3). When we consider 1-dimensional situation, we can get the next inequality (1) as a condition for appropriate haptic presentation, where L[sec] for transmit latency,

$$d \geq \int_{\tau}^{\tau+L+C_m} v(t)dt \quad (1)$$

Cm[sec] for control latency of the display system on the master's side, $v(t)$[m/sec] for the speed of the operator's arm/finger and d[m] for the distance of the pre-measurement, that is, the maximum value of the distance between the finger of the slave arm and the slave environment during the pre-measurement state(Fig. 3). The τ is for the time when starts pre-measurement. If it is mounting-type system, d in the condition would be zero, so the condition may not be completed.

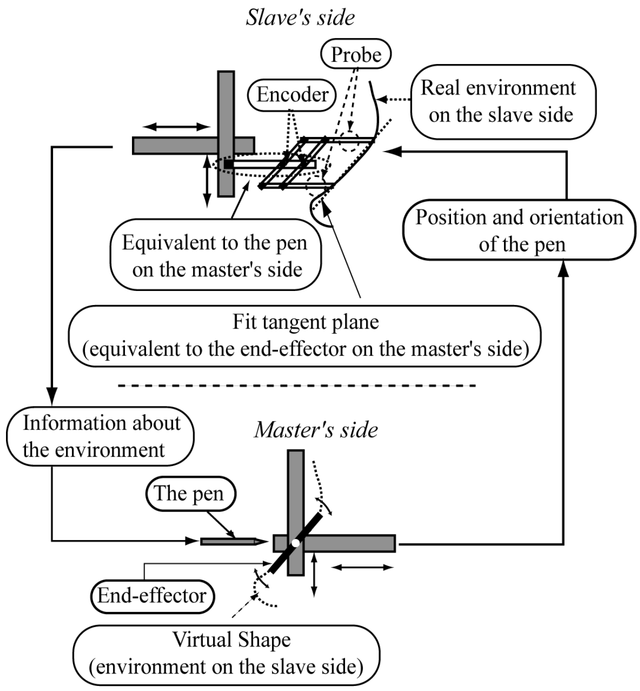

Fig. 4 Implementation of the system

3. System design

When displaying haptic sensation in a telexistence system, the information about the slave arm and environment on the slave's side should be displayed through visual and haptic sensation to the operator on the master's side. However if the difference between visual and haptic sensation about position and orientation of the arm became larger, the operator would feel an unnatural sensation (Fig. 2). Therefore, some consideration must be given to these problems. Here, we consider about the accuracy of position and the gradient of the line on the fingertip. Some researches have examined about human's position recognition of the fingertip[4] and curve recognition[5][6]. When considering the presentation of haptic sensation with the encounter-type haptic display, first, it will be the problem that the gap between the position and orientation of the surface of the display unit around the contact point and the same of the shape of the object which presenting. We could consider that if the gap is under the threshold, the haptic display could make haptic sensation appropriately (Fig. 2). The positioning accuracy of the human fingertip without visual feedback is about 1[cm][4]. The resolution about the angle of the line of the fingertip without visual feedback is about 4-6[deg][5]. These are the assumptions used as conditions of the system.

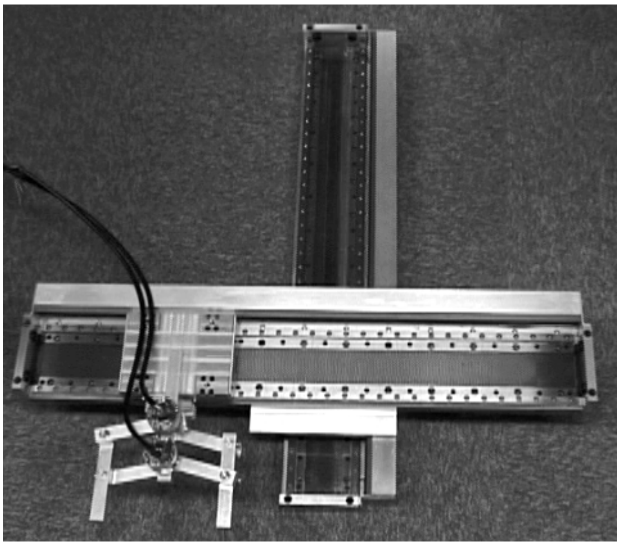

Fig. 5 The system of the slave's side

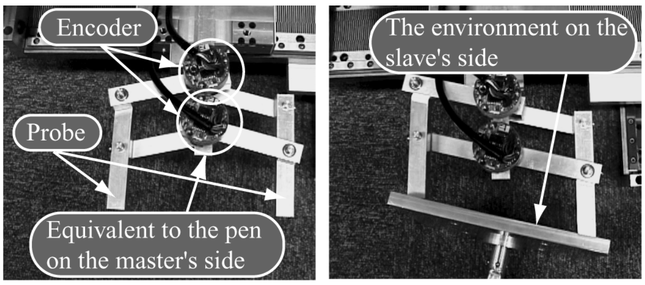

Fig. 6 Left: The sensor on the slave's side (normal)
Right: The sensor on the slave's side (just before contact)

4.Implementation of the system

As a slave system, we made a 2-DOF system because it was easy to make. It moves in a horizontal plane. The operator holds a pen-like device to measure his/her movement. For accuracy of the measurement, we use probe-like system to pre-measure the environment on the slave's side. In this case, the information that we need is the relative position and orientation between the pen and the tangent plane around the contact point. The overview of the system is shown in Fig. 4. The system on the slave side is shown in Fig. 5. We used a linear servo actuator for the movement in the horizontal plane. Its resolution about the position is 0.5[μm]. For pre-measurement, we used a probe-like system shown in Fig. 6. The probe makes contact with the environment on the slave's side before the pen contacts. We use the gradient between two probes as the gradient of the pen against the environment. The probes are kept parallel with the pen by using a parallel link system. The encoder in the probe is 3000[pulse/round] unit. In this system, the accuracy of the position of the pen of the slave's side is 1[mm], and the accuracy of the orientation of the probe on the slave's side is 0.12[deg](Table 1). They satisfy the condition we refer to. Here, if we assume that L=20[ms], Cm=40[ms] and v=20-60[cm/sec], the d would be about 1.2-3.6[cm].

Table 1 System specifications

Degree of Freedom	2-DOF in the horizontal plane
Range	50[cm] for each DOF
Accuracy	1[mm]
The range measured by the probe	21.60[deg]～157.02[deg]
Resolution of the probe	0.12[deg]
The distance of pre-measurement	3.7[cm]

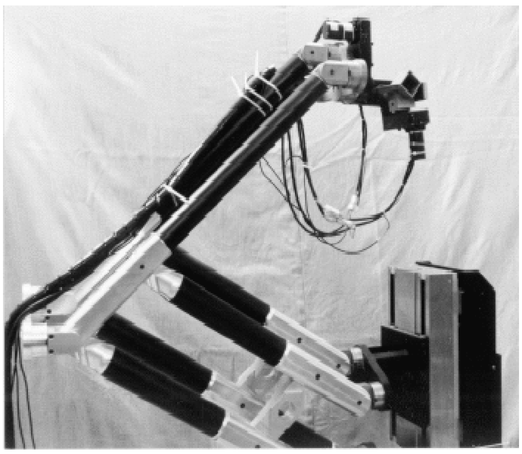

Fig. 7 The AED

In this situation, the distance of pre-measurement 3.7[cm] is almost sufficient. As a master system, we use AED ([3],Fig. 7). The AED has 6-DOF, but we restrict its DOF according to the DOF of the slave system.

5. Conclusion

In this research, we have proposed to use an encounter-type haptic display to telexistence and examined the conditions to be considered. We have made a prototype system according to the conditions. In the future, we will conduct research regarding direct haptic presentation to the human finger without using a pen device.

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