Cooperative Work in Virtual Environment with Force Feedback

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ABSTRACT

This paper describes a method of cooperative work in virtual environment with force feedback. There are many advantages in cooperative work. In this paper, we describe about teaching task in virtual environment. In the real world, instructors of sports teach by taking the trainee's hand. In order to teach something by taking trainee's hand in virtual environment, it is necessary to indicate reaction force from virtual environment. Most of virtual reality system, however, has no force feedback mechanism. In this research, we developed a system that enables two users to work simultaneously in virtual environment with force feedback. The system provides force to bind two user's hands. This function assists teaching task in common virtual environment. Through experiment to deform virtual object with force feedback, effectiveness of force feedback in cooperative work is tested.

When users collaborate via network, there would be time delay. It is difficult to teach any skill in such environment with force feedback, because of instability. We propose a haptic interface that enables user to teach skill even thought there is time delay. The most important point of teaching skill is to teach trainer's movement for trainee. In this system, pulling force toward the trainer is presented for the trainee. And in addition, force like viscosity or friction force is presented for the trainer. Through experiment to teach how to move the object in virtual environment, effectiveness of the interface is examined.

Keywords: haptic, cooperative work, virtual environment, force feedback, time delay

1. Introduction

There are many advantages in cooperative work, for example sharing work, instruction and so on. There have been several systems proposed to support cooperative work in computer generated 3D space. Takemura and Kishino built a cooperative work environment using virtual environment by combining head tracking stereoscopic displays and DataGloves[Takemura & Kishino, 1992]. Loeffler et al. have developed a system called "Networked Virtual Art Museum" which is shared with distributed users via telephone lines[Loeffler, 1993]. Sato and Ishii have developed a networked 3D virtual environment using force feedback device called "SPIDAR". It enables users to communicate face-to-face and hand over virtual object[Ishii et al, 1994]. When we practice penmanship or sports like tennis, trainers take trainee's hand and teach how to move it. Such trainer-trainee task is one of unique task for cooperative work as against for individual work. In order to teach something by taking trainee's hand in virtual environment, it is necessary to indicate reaction force from virtual environment. Most of virtual reality system, however, has no force feedback mechanism.

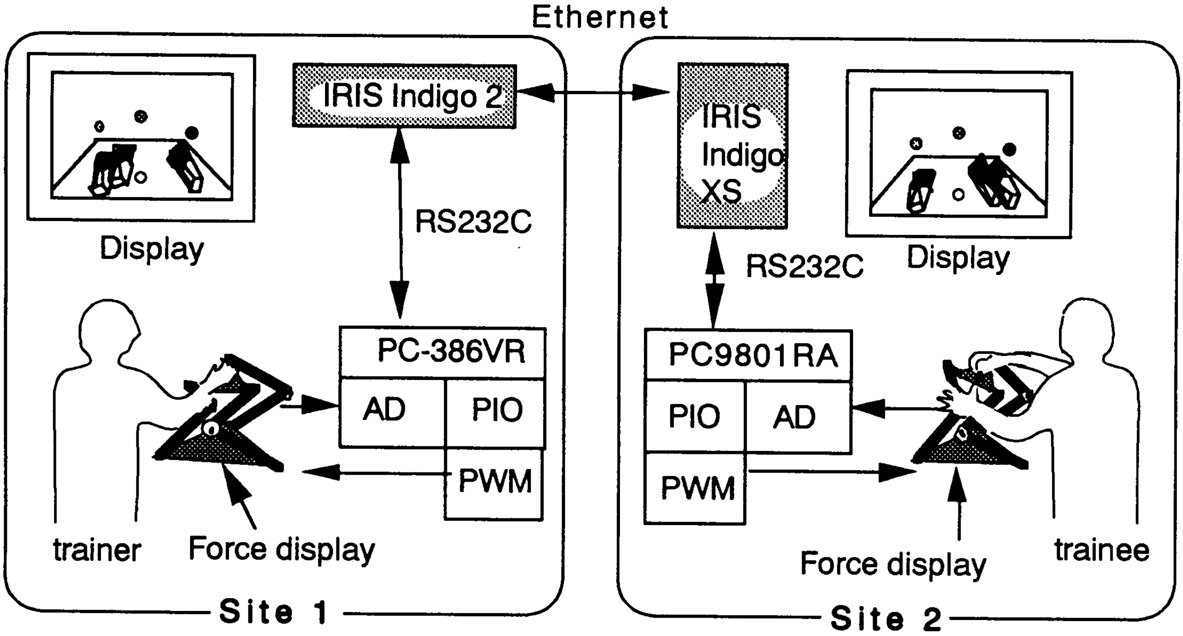


Figure 1. Hardware configuration of the system

In this paper, we describe about a method of teaching task in virtual environment with force feedback. We have developed a software tool for programmers of haptic virtual environment called VECS(Virtual Environment Construction System). Using the system, we developed a program that enables two users to work simultaneously in virtual environment with force feedback. The program provides force to bind two user's hands. This function assists teaching task in common virtual environment.

VECS has a network capability by using Ethernet. Recently, it is easy to get a large quantity of information via network such as Internet. If we use such network, there is large time delay among users. The time delay imposed by limits on the speed of light(radio transmission) and computer processing at sending and receiving signals. It is unacceptable to feed resolved force continuously back to the same hand that is operating the control. This is because the delayed feed back imposes an unexpected disturbance on the hand that the operator can't ignore and which, in turn, forces an instability on the process. We propose a haptic interface that enables user to teach skill even thought there is time delay.

2. System Configuration

2.1 Hardware

The hardware configuration of two sites of the system is indicated in Figure 1. Force feedback for each user is realized by a 6 degree-of-freedom master manipulator. Visual information is displayed by visual display device. The one site of the system employs two computers: a graphics computer for real-time monocular image of virtual space, and an I/O computer that supervises sensors and actuators. The I/O computer is equipped with analog-to-digital(A/D) converters and a parallel input/output unit. The graphics and I/O computers are connected by a serial(RS-232C) communication line. The graphics computer are IRIS Indigo2 and IRIS IndigoXS; the I/O computer are NEC PC-9801.

Those sites communicate each other via TCP/IP socket connection. Hand position data and a flag which indicates grasping object are transmitted to the other site. At the same time each graphic workstations updates the database of virtual world.

In this system, net transmission delay via ethernet is about 0.1 sec.
Overall view of the system is shown in Figure 2.

(1)Desktop force display

A 6 degree-of-freedom manipulator was developed as a force display. The manipulator applies reaction forces to the fingers of the operator. The manipulator employs parallel mechanism. The typical design feature of parallel manipulators is an octahedron called "Stewart platform." In this mechanism, a top triangle and a base triangle are connected by six length-controllable cylinders. This compact hardware has the ability to carry a large payload. The structure, however, has some practical disadvantages in its small working volume and its lack of backdrivability (reduction of friction) of the mechanism.

In our system, three sets of parallelogram linkages(pantograph) are employed instead of linear actuators. Each pantograph is driven by three DC motors. Each motor is powered by a PWM(Pulse Width Modulation) amplifier. The top end of pantograph is connected with a vertex of the top platform by a spherical joint. This mechanical configuration has the same advantages as an octahedron mechanism has. The pantograph mechanism improves the working volume and backdrivability of the parallel manipulator. The inertia of motion parts of the manipulator is so small that compensation is not needed.

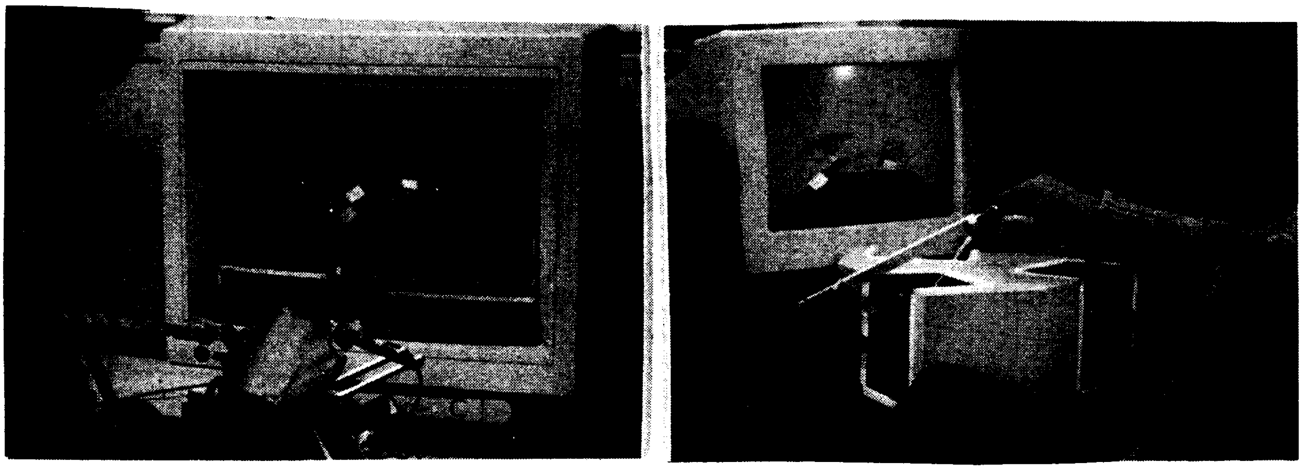
The working space of the center of the top platform is a spherical volume whose diameter is approximately 40 cm. Each joint angle of the manipulator is measured by potentiometers. Linearity of the potentiometers is 0.5%. The maximum payload of the manipulator is more than 700gf, which is more than a typical hand.

(2) Graphic computer

Image of the virtual space is generated by graphics work stations, IRIS Indigo2 Extreme and IRIS Indigo XS. The CPU are R4000(100MHz) and R3000(33MHz), which manage virtual space and haptic representation.

2.2 VECS

Virtual world technology usually employs various types of input/output devices. Manipulation of virtual objects essentially requires force feedback. However, methods for force feedback are at a fumbling stage. We have developed several kinds of force



Site 1 **Site 2**

Figure 2. Overall view of the system

displays. Software of virtual environment has been tightly connected to control program of force displays. This problem is a hazard for development of further application of haptic virtual environment. Therefore, we developed a software tool for programmers of haptic virtual environment, in which control programs of force display, description of virtual space, and user application are divided into modules. The system is called VECS(Virtual Environment Construction System). VECS is developed by C language on UNIX. Various types of force displays can be plugged into VECS. The system supports two force displays. Two users can simultaneously interact in the same virtual environment. This function enables easy construction of groupware program.

Physical laws for the virtual world are contained in VECS. Gravity, elasticity and viscosity are currently implemented. Collisions between virtual objects are detected in real time. Shapes and attributes of virtual objects are defined in the user application module. User of VECS programs the methods for interaction between virtual objects and operators.

VECS is composed of following three programs (Figure 4):

(1)Program for object data

Supervising behavior of virtual objects.

(2)Program for device data

Communication with force display.

(3)Program for application data

Detection of user intention and updating virtual environment.

Dividing into these programs, force displays and physical laws in virtual environment are easily reconfigured. Moreover, this system defines "time" of virtual environment. Time of virtual environment increases independently from the user. This function enables autonomous growth of virtual objects.[Yano & Iwata, 1995]

VECS is composed of two processes: kernel and user application. Kernel of VECS determines behavior of virtual objects and generates graphic image of virtual environment. This process runs autonomously. User application determines the methods for interaction between virtual objects and operators. Shared memory is used for communication between these processes.

VECS is currently implemented on SGI IRIS Indigo. Exchanging graphics library, the system can be ported to other graphics work stations. In our laboratory, it also runs on HP9000/425t with personal VRX graphics engine.

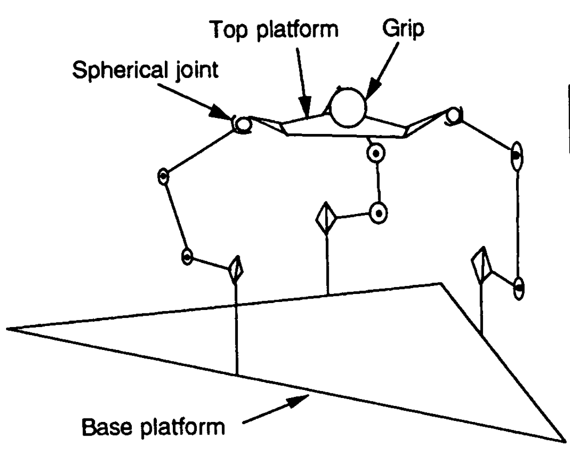


Figure 3. Mechanical configuration of the force display

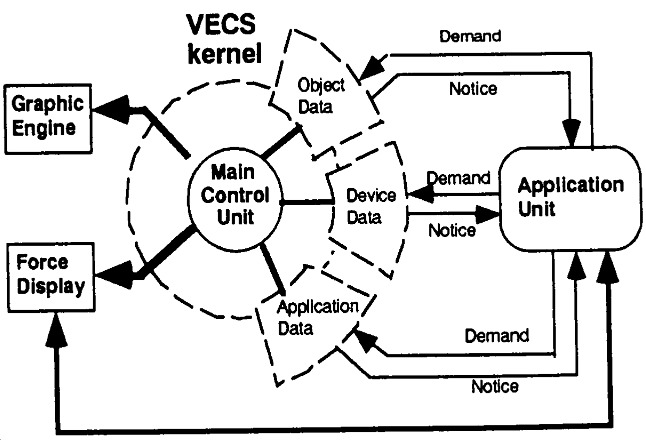


Figure 4. Software configuration of VECS

2.3 User Interface of VECS

Visual image of user interface of VECS is shown in Figure 5. The user of the system sees his/her virtual hand, virtual objects and virtual control panels. Virtual control panels include buttons and slide bars. Command input and parameter setting are done through these devices. If the virtual hand comes close to these buttons, the hand is pulled toward the center of the buttons by force display. This applied force assists the user to operate control panels. If the user grasps the button, the color of the button changes and command is input. VECS supports two force displays, and two users can simultaneously interact in the same work space as shown in Figure 5.

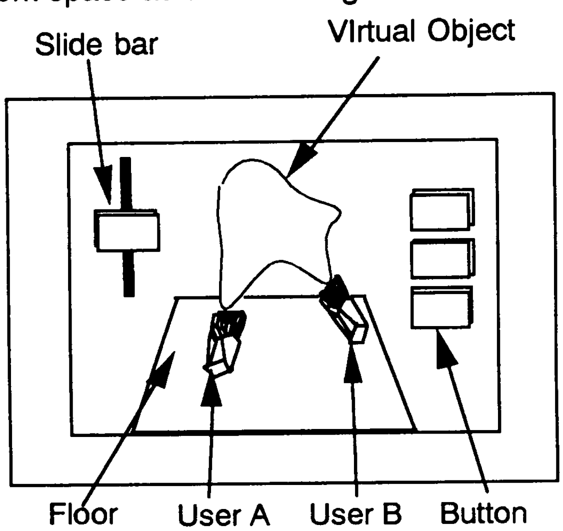


Figure 5. User Interface of VECS

3. Performance Test of Cooperative Work with Force Feedback

3.1 The Environment of Experiment

We consider one of the application of cooperative work is 3D shape design. Therefore, the effectiveness of cooperative work in virtual environment with force feedback has been demonstrated by simple deforming task.

The interface for this test is shown in Figure 7. The subjects deform a flat surface by

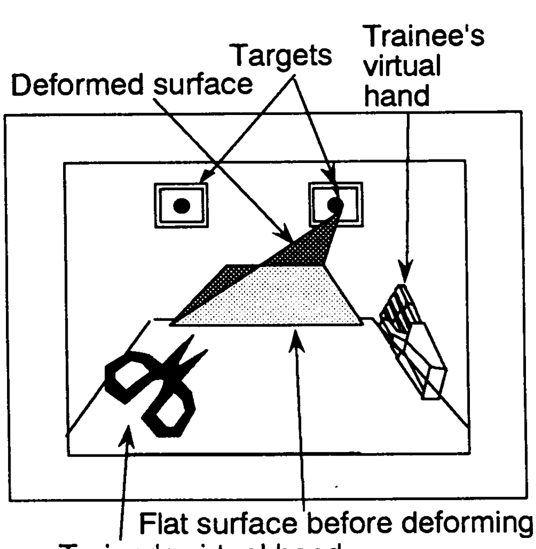


Figure 7. User interface of deforming task

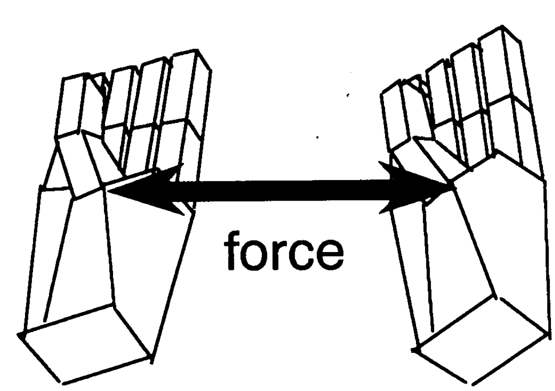


Figure 6. Applied force between users

repositioning its vertexes.

Users can only move the vertex when both trainer and trainee grasp it. Then the vertex is fixed to the middle point between trainer's hand and trainee's hand. The task is to move the vertexes to the targets which are located at their upper position.

Two conditions are set for the experiment:

(1) With force feedback.

The subjects collaborate each other in deforming with force feedback. When the trainer grasp trainee's hand, the system provides force to bind their hands by force displays.(Figure 6)

(2) Without force feedback.

The subjects deformed object without force feedback, only by visual information.

We took 6 volunteer subjects from the students of our university. We examined average completion time. Figure 8 shows the result of the experiment. Horizontal axis indicates two conditions. The completion time are indicated by bar chart. The data includes error bars which indicates standard deviation. The time with force feedback is 30% faster than without force feedback (t= 6.07;critical value= 2.03).

We also examined mean distance between users (Figure 9). Horizontal axis indicates two conditions. The mean distance between users are indicated by bar chart. The data includes error bars which indicates standard deviation. The mean distance between users with force feedback is 40% smaller than without force feedback (t= 6.09;critical value= 2.03).

These results indicate the effectiveness of force feedback.

4. Method of Cooperative Work in Time Delay.

We selected a trainer-trainee task in which an instructor teaches a beginner how to move virtual object. In such case, trainer takes trainee's hand. Our system provides force to bind two user's hand (Figure 6). In case there is time delay between them, the task is fairly difficult. The trainer's hand is pulled toward delayed trainee's hand and the trainee's hand is pulled toward delayed trainer's hand. That causes instability.

The most important point of teaching task is to teach trainer's movement to trainee.

We propose following force presentation for compensation of time delay (Figure. 10).

(1) For the trainee, pulling force toward delayed trainer's hand is presented.

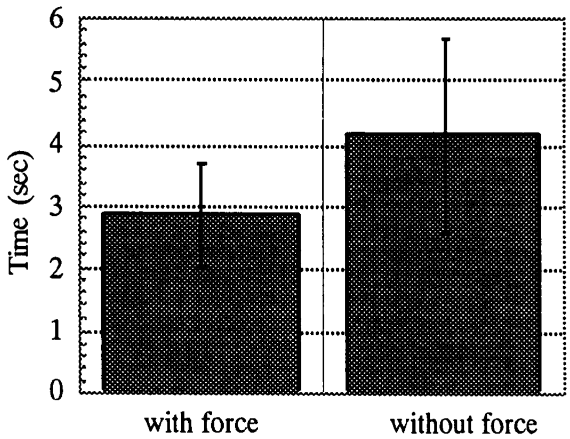


Figure 8. Completion time of the test

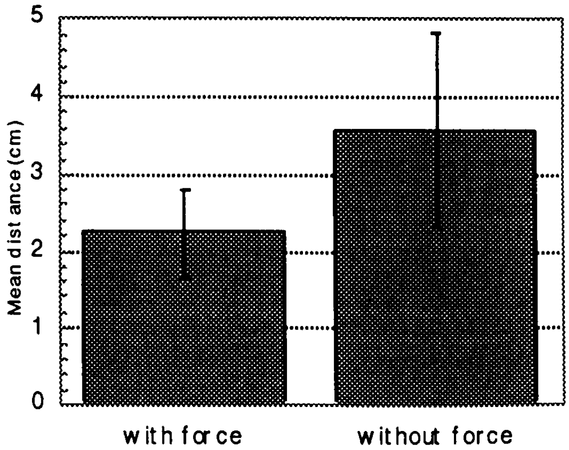


Figure 9. Mean distance between users

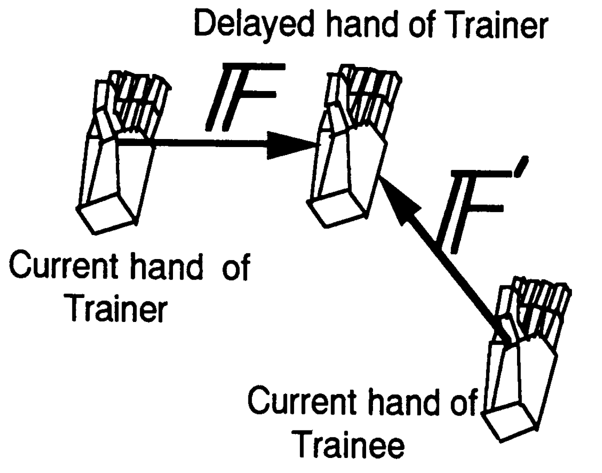


Figure 10. Applied force for compensation of time delay

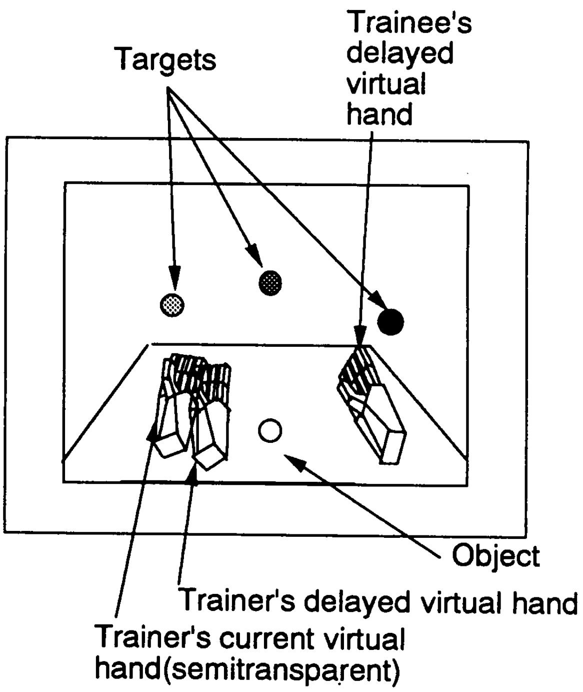


Figure 11. User interface in case of time delay

Trainee feels like his/her hand is bound to the trainer's hand and is pulled by trainer.

(2) For the trainer, We present pulling force toward delayed his/her own hand.

Trainer can check trainee's movement by visual feedback. However the trainer must keep in mind that there is time delay. If the trainer forgets the time delay and he/she reacts quickly to trainee's delayed movement, they are confused and that causes instability.

These force plays role like viscosity or friction force to the trainer. The trainer can't move the hand so quickly.

5. Performance Test of Cooperative Work in Time Delay.

5.1 The Environment of Experiment

As a usability test of this method, we examined repositioning task of virtual objects. The interface of this test is shown in Figure 11. We put three targets at similar distance from the start point. There is a virtual ball at the start point. Users can only move it when both trainer and trainee grasp it. The ball is located at the middle point between trainer's hand and trainee's hand during it is grasped. Through the experiment, predictor display[Sheridan, 1993] is used. It displays current user's hand as semitransparent and delayed hand as solid. We can recognize what will be doing by predictor display.

In this experiment, we use virtual balls in stead of flat surface. The reason why we don't use the same environment as previous experiment is that subjects can easily recognize whether they grasp the object or not.

The experiment was conducted to estimate this technique under two conditions: with and without force feedback, through 0-s time delay, 1-s and 3-s respectively. Each condition contains 2 trials.

We took 6 volunteer subjects from the student of our university. We examined accuracy of tracing the trainer's trajectory. Mean distance between trainer's hand and trainee's is calculated at each program cycle. Figure 12 shows mean distance of the each condition. Horizontal axis indicates time delay. The mean distances between the trainer and trainee are indicated by bar chart. The data includes error bars which indicates standard deviation. Each value of condition with force feedback is 50% smaller than without force feedback in the same time delay (t=5.9882155, t=6.5586435, t=5.7867037 respectively, and critical value= 2.20098627).

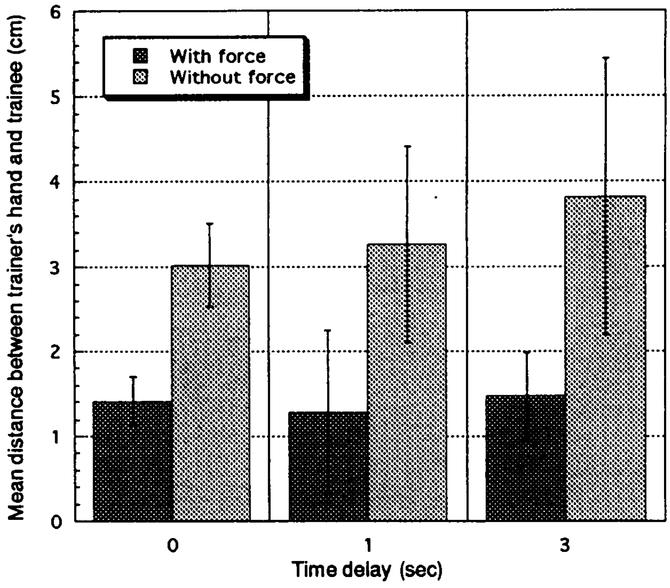


Figure 12. Mean distance between trainer's hand and trainee.

5.2 Discussion

We can not find significant difference between two conditions from average completion time. Force feedback actually assisted the task, although resistance applied to the trainers required time to complete the task. However, we can find qualitative differences from mean distance. All subjects reported that force feedback is very useful. The trainee could feel his hand was pulled by the trainer. The trainer could feel the viscosity and reported that they could easily realize the distance between trainer's current hand and trainer's delayed hand. It suggests the trainer doesn't have to keep in mind the time delay.

6. Conclusion

We have developed the system which enables us cooperative work in virtual environment with force feedback. Through the experiment of deforming task, the effectiveness of teaching task with force feedback was demonstrated. In case that there is time delay between users, we propose a technique in which pulling force toward trainer's hand is presented for the trainee. And pulling force toward trainer's delayed hand is presented for the trainer. Through experiment of repositioning task, the effectiveness of the technique was demonstrated.

In our current system, only the instructor can control the trainee. In order to support more interactive communication, however, the system should support bi-directional communication. Future work of our research will be development of bi-directional communication method.

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