# The Effect of Audio and Visual Aids on Task Performance in Distributed Collaborative Virtual Environments

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**Abstract:** Collaborative virtual environments (CVE) has recently gained the attention of many researchers due to its numerous potential application domains. Cooperative virtual environments, where users simultaneously manipulate objects, is one of the subfields of CVEs. In this paper we present a framework that enables two users to cooperatively manipulate objects in virtual environment, while setting on two separate machines connected through local network. In addition the article presents the use of sensory feedback ( audio and visual) and investigates their effects on the cooperation and user's performance. Six volunteers subject had to cooperatively perform a peg-in-hole task. Results revealed that visual and auditory aid increase users' performance. However majority of the users preferred visual feedback to audio. We hope this framework will greatly help in the development of CAD systems that allow the designers to collaboratively design while being distant. Similarly other application domains may be cooperative assembly,surgical training and rehabilitation systems.

Keywords: CVEs, Cooperative manipulation, Framework, Human performance, Multimodal feedback.

## 1. INTRODUCTION

THe successful advancements in the field of high quality computer graphics and the capability of inexpensive personal computers to render high-end 3D graphics in a more realistic manner has made virtual reality feasible to be used in many areas such as industrial design, data visualization, training etc. Similarly there are other domains of VR application such as medical [5], [4], assembling, repairing and education [3], [1] etc.

Human beings often perform their work (from simple to complex ones) in a collaborative manner, that is why virtual reality (VR) scientists initiated the development of virtual environments (VEs) supporting collaborative work. A CVE is a computer generated world that enables people in local/remote locations to interact with synthetic objects and representations of other participants within it. The applications of such environments are in military training, telepresence, collaborative design and engineering, distance training, entertainment, and many other personal and industrial applications [8]. Interaction in CVE may take one of the following form [6, 9]:

(1) Asynchronous : Sequential manipulation of distinct object attributes, for example a person changes an object's position, then another person paints it,
(2) Asynchronous : Sequential manipulation of the same attributes of an object, for example a person moves an object to a place, then another person moves it further,
(3) Synchronous : Concurrent manipulation of distinct attributes of an object, for example a person is holding an object while another person is painting it,
(4) Synchronous : Concurrent manipulation of the same attributes of the same object, for example when several people lift or displace a heavy object together. The concurrent manipulation is also termed as Cooperative Manipulation or Cooperative Work about which the paper is concerned.

In order to carry out a cooperative task efficiently, the participants need to feel the presence of others and have means of communication with each other. The communication may be verbal or non verbal such as pointing to, looking at or even through gestures or facial expressions. Similarly the participants must have a common protocol for task execution. The design and implementation of a system with these capabilities specially for distant users has really been a challenging job for the researchers. For example the architecture of the virtual world may be client server or a replicated one [7]. In case of client server architecture the known problems of network load and latency arise.

Similarly in replicated solution the consistency of two or more sites need to be addressed. We implement the VE designed for cooperative work in replicated architecture and seek solution to network load/latency and consistency in unique way. Similarly to impart the user feels the presence of others and to make cooperative work easier and more intuitive we augment the environment with audio and visual aids. Moreover we investigate the effect of these sensory feedback on user performance in a peg-in-hole task.

⋆ Sponsor and financial support acknowledgment goes here

This section is followed by the related work, section 3 describes the proposed architecture that facilitates the cooperative manipulation of objects in VE. The effect of audio and visual aids on cooperation and the hardware platform used for the experiments. Section 4 discusses the experimental protocol and result's analysis. Section 5 is dedicated to conclusion and gives some track for future work.

## 2. RELATED WORK

A lot of work has already been done in the field of CVE, for example Emmanuel et al. have designed a virtual room, where the users can virtually meet, present, discuss and share documents and files [10]. The objective is to facilitate a meeting among geographically distant users. Similarly MASSIVE provides a collaborative environment for teleconferencing [11]. Most of this collaborative work is pertinent to the general software sketch and the underlying network architecture [16, 17].

Basdogan et al. have investigated the role of touch (force feedback) in cooperative task. They connected two monitors and haptic devices to a single machine [2]. Similarly, Eva-lotta et al. have reported the effect of force feedback over presence, awareness and task performance in a CVE. Similarly, they connected two monitors and haptic devices to a single host [12]. A heterogeneous scalable architecture has been given, which supports haptic interactions in collaborative tasks [18]. Other important works that support the cooperative manipulation of objects in a VE include [15, 14, 13, 23] but all theses systems require heavy data exchange between two nodes to keep them consistent.

## 3. PROPOSED COOPERATIVE SYSTEM

In this section we present our work that enables two users, connected through Local Area Network (LAN), to cooperatively manipulate objects in the VE. Secondly we will show how to use sound and visual aids to help increase and facilitate the cooperative manipulation of objects between the two users.

The VE we used for cooperative manipulation has a cubic structure, consisting of three walls, floor and ceiling. Furthermore the VE contains four cylinders each with a distinct color and standing lengthwise in a line. In front of each cylinder at some distance there is a torus which similar in color (see figure 1.

One of the important task related to collaborative/cooperative system is the representation of users in the virtual world. This is normally carried out using avatars [6, 19, 10, 14] or some other representations like virtual hands or balls [16, 1, 13, 20]. We use two spheres which are identic in size but different in colors (one is red and the other is green) so that the users may not only feel the presence of others but can also make a difference between the two pointers. The software was developed using C++ and OpenGL Libraries.

### *3.1 Augmenting cooperative work with Audio/visual aids*

Cooperative work is really a challenging research area, specially when the users are connected through LAN or Wide Area Network (WAN ), because there are a number points to be treated, for example to sense the presence of others and to have awareness of where is and what is the status of the other partner, is essential and may have profound effects on the degree of cooperation. Similarly the cooperating persons should also have some feedback to know, when they can start together, can leave each other (when task is finished), or if there is some interruption in the middle. For this we exploit audio and visual channels.

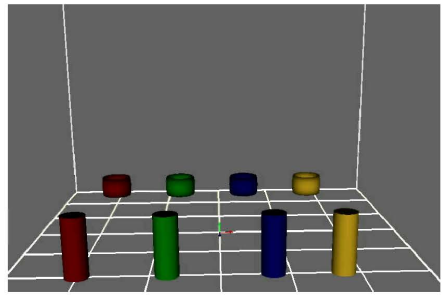

Fig. 1. Snapshot of the collaborative virtual environment.

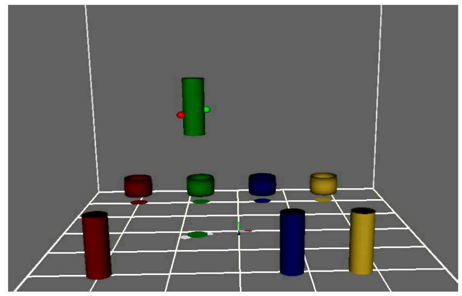

Fig. 2. Illustration of the cooperative peg-in-hole task

When visual aid is active and if any user moves to touch a cylinder, it takes the color of the corresponding sphere. This color will be transparent indicating that the second user is not yet colliding with this cylinder. If the second user collides his/her sphere with the same cylinder then it will acquire the color of the second sphere. At this time the user can cooperatively move the cylinder anywhere in the VE, under the conditions defined in equations 1 and 2. In short if a single sphere collides with the cylinder then the later will acquire the color of the former but will look a little transparent showing the absence of the second sphere. If both spheres are attached to the same cylinder then the later will show the exact color(no transparency) of the sphere that collided it last.

If one of the user detaches (due to his slow or speedy movement compared to the other) during the cooperative task, the cylinder will stop moving and gains the color( with transparency) of the sphere still attached. This will show the user that his partner is no longer in contact with the cylinder. In this application users are required to move the cylinder, put it in the torus so that its bottom touches the floor of the VE. When the users successfully place the cylinder on its final position, the corresponding torus changes color which indicates that the task has completed.

As our current system is installed on desktop environments that do not support stereoscopic display. In order to have the knowledge of perspective positions of various objects in the VE, we make use of shading (see figure 2) for all objects in the environment.

Suitable points of contact are those points along the height of the cylinder that allow its selection and manipulation. In order to keep the cooperative work realistic we allow the cylinder's

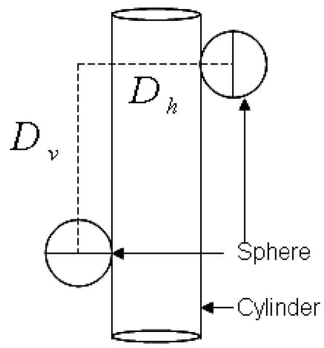


Fig. 3. Illustration of conditions and way of cooperative manipulation

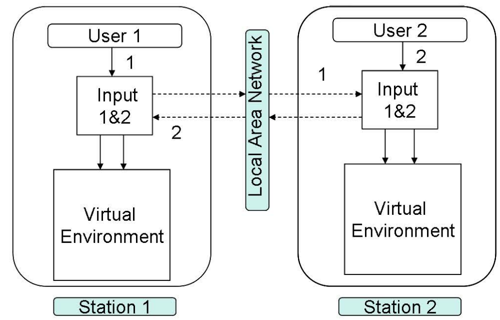


Fig. 4. Illustration of the framework of cooperative virtual environment

selection along its height and not through its top or bottom. Similarly the following conditions are also checked once the two sphere are in contact with a cylinder ( Fig. 3.

$$D_h \geq 2R_c - K \tag{1}$$

$$D_v \leq T \tag{2}$$

In equation 1, $D_h$ represents the horizontal distance between the centers of the two spheres, $R_c$ is the radius of the cylinder and $K$ is a positive constant. This check ensures that the spheres must not completely penetrate in the cylinder and should remain visible during the task. In equation 2, $D_v$ represents the vertical distance between the centers of the two spheres that must be less then or equal to a threshold $T$. When conditions in equation 1 and equation 2 are both satisfied then users can cooperatively move the cylinder.

Similarly when the audio aid is active, then the collision (at a suitable point) of each sphere with a cylinder will generate a distinct sound. The detachment of a sphere during the cooperative task will also create a specific sound as an indication of interruption in the task and at the same time the single user will not be able to move it further. In the same way there is a special sound, whenever the cylinder is positioned on the desired location inside the torus. This sound is a sign of subtask completion.

### *3.2 Framework for Cooperative VE*

The framework plays a very important role in the success of collaborative and/or cooperative VEs. It is pertinent to, how different users will have access to the same virtual world and data (i.e centralized, distributed or replicated), what protocol (TCP ,UDP, etc) to be used and what kind of data should flow through network to keep consistency as well. A lot of work has been done on the framework/arhitecture of collaborative systems (as discussed in the related work) but there is very little significant work on the framework of cooperative systems [21].

We use a complete replicated approach and install the same copy of the VE on two different machines. As the figure 4 depicts each station has a module which acquires the input from the local user. This input is not only applied to the local copy of the VE, but is also sent to the remote station where it is applied to same VE in the same manner. The same module receives the input from the remote station which is applied to the local copy of the VE. It means that a single user simultaneously controls the movement of two pointers (in our case a sphere) at two different stations, so if this pointer triggers any event at one station, it is also simultaneously applied at other station because the code is exactly the same on two machines.

Here it is also worth mentioning that the only data that is exchanged between the two stations is the position and orientation of the two pointers each controlled by a single user. In order to have reliable and continuous bilateral streaming between the two stations, we use a peer-to-peer connection over TCP protocol.

### *3.3 Hardware Setup*

We installed the software on two pentium 4 type personal computers connected through Local network. Each machine had processor of 2GHZ and 1GB memory. Each system is equipped with standard graphic and sound cards. The first system used 17 inch CRT type monitor to display the virtual world, while a 24 inch plate LCD tv screen was attached to the second system.

Similarly each VR system is equipped with a patriot polhemus [22] as input device. It consists of a controller to which a source and one or two sensors (we use one at each station) are attached. The controller uses a standard USB for connection with computer. The workspace that polhemus support is a half sphere of 50cm radius.

## 4. EXPERIMENTAL STUDY

### *4.1 Method*

In order to evaluate the system and the effect of visual and auditory feedback on user performance in cooperative object manipulation, we carried out a user experimentation. For this purpose we took six persons and divided them into three groups (G1,G2 and G3). All the participants were male, right handed and had ages from 22 to 45. Half of the users were experts in the field of virtual reality while the other half had the basic knowledge of the domain.

Each group was given a short briefing about the experiment and to get familiar with the system. They were also given a pretrial in which they experienced all feedbacks. For each trial the users needed to start the application on their respective machines. After starting the application on both computers and successful network connection they could see the two spheres (red and green) on their screens. Seeing the two spheres they were required to bring and place their corresponding sphere on the origin(0,0,0). Once both spheres were placed on the said position, after five seconds each of them saw a message on their screens saying "you can start the task". This was done in order to have a protocol for "when and how to start". The origin of the VE is indicated by the three 3D arrows of the frame of reference. The experiment was carried out under the following three conditions.

- C1= No aid
- C2= visual aid
- C3= audio aid

The three groups performed in the three conditions according to the following order.

- G1: C1, C2, C3
- G2: C2, C1, C3
- G3: C3, C2, C1

We recorded the completion time for each trial. After task completion we gave each user a questionnaire in order to have the subjective feedback. Apart from the name, sex, age and expertise in VE, the questionnaire had the following questions.

(1) What condition you preferred?
(1) C1 (2) C2 (3) C3
(2) What feedback you found the most pertinent ?
(1) C2 (2) C3
(3) Which part of the task was the most difficult ?
(1) To pick up objects (2) To move objects (3) To place objects
(4) Under which condition you better perceived the actions of your partner.
(1) C1 (2) C2 (3) C3

### 4.2 *Task*

The experiment for the users was to cooperatively pick up a cylinder and put it into the torus whose color matches with the cylinder. The users were required to place all the cylinders in their corresponding toruses in a single trial. Each group performed exactly four trials under each condition. The order of selection of the cylinders was also the same for all groups i.e to start from the red, go on sequentially and finish at yellow.

### 4.3 *Results and Analysis*

In this section we present and analyze the results based on both task completion time and user responses collected through questionnaire.

*Task completion time* The general ANOVA for task completion time is (F(2,2)= 35.34, $P < 0.005$) significative. The mean of task completion time under C1 is 218.33 seconds with std as 25.65. Similarly for C2 it is 140.5 seconds with std 43.13, and C3 gives a mean of 109.33 sec with std as 14.63 (see figure 5). Comparing the task completion time of C1 with that of C2 and C3, we got statistical significance. It means that both visual and audio cues ameliorated the users' performance. In contrast, comparing the task completion time of C2 and C3 did not show any statical difference. It means that they provided almost the same level of guidance.

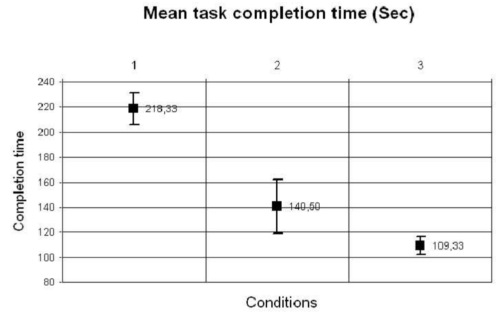


Fig. 5. Task completion time.

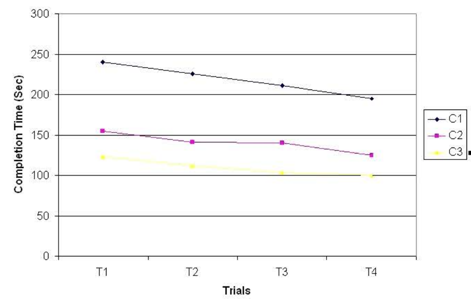


Fig. 6. Illustration of user learning process.

*Learning process* Learning is defined here by the improvement of group performance during task repetitions. We asked each group to repeat 4 times the previously defined task. The results show that applying condition C1, the subjects achieved the task in 240 seconds (std = 22.91) during the first trial and in 195 seconds (std = 27.83) during the last trial. In the same way they completed the task under condition C2 in a mean time of 155 seconds (std=42.64) in the first trial, while took 125 seconds (std = 33.08) in the fourth trial. At last we have the group mean time of 123 seconds (std =18.02) under condition C3 for the first trial and 100 seconds (std =21.63) for the last trial (see figure 6).

This results in performance improvement of 18.75, 19.35 and 18.69 percent for conditions C1,C2 and C3 respectively. We noted that there was a considerable learning process in the sequence of trials under each condition, but on the other hand we have not noticed any significant difference among the learning processes of various conditions.

*Subjective evaluation* In this section we analyze the response collected through questionnaire. As it is clear from the figure 7 that option A has zero percent response for all the questions and it is evident. Taking the response for question 1, we observed that 83.33 percent users have preference for condition C2 and only 16.66 percent liked condition C3. Similarly the 2nd question which is related to the two feedbacks, 66.66 and 33.33 percent users responded for C2 and C3 respectively. The third question which is about the difficulty of different parts of the cooperative work, half of the users reported the cooperative

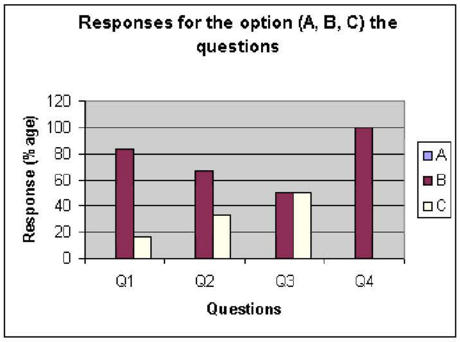


Fig. 7. Percentage of the user responses

transportation of the object more difficult while for the rest half the placement was more difficult. For the 4th question all the users are agree that they could better perceive the actions of their partner under condition C2 (visual).

### *4.4 Discussion*

Keeping in view the results of the task completion time, responses of the questionnaire and users' comments, we observed that the addition of visual and audio cues greatly helped users in cooperative manipulation of objects in the VE. Secondly the addition of visual and audio aids, also increased the users' performance and enabled them to perceive each other's actions. Although users were able to complete the task in lesser time under C3, but statistically there is no significant difference between C2 and C3.

The lesser task completion time in condition C3 is because of the different sound created under different events which acted as alarms and consequently users responded quickly as compared to that of condition C2. Some of the users also complained that generating unique sounds for different events some time created a noisy situation, specially when these events occurred frequently. For example the frequent collision and detachment of spheres with cylinder during its transportation. On the other hand majority of the users preferred the aid provided by C2, and they all reported a better perception of their partner's action using this condition.

## 5. CONCLUSION AND FUTURE WORK

Collaborative virtual environments(CVE) is a very challenging research area due to various crucial problems to be treated before getting a system that support collaboration, but researchers are continuously trying to remove these difficulties and pave the way for its perspective commercial and scientific use in various domains.

Cooperative virtual environments, where users simultaneously manipulate objects, is one of the subfields of CVEs has not been investigated too much. In this paper we present a framework that enables two users to cooperatively manipulate objects in the virtual environment, while setting on two separate machines in two different rooms connected through local network. We use replicated approach based on our frame work to implement the environment for cooperative work. In addition the article presents the use of audio and visual aids in the virtual world and investigates their effects on the cooperation and user's performance.

In order to check the efficiency of the proposed framework and see the effects of visual and audio aids for cooperation and perception of each other's actions we carried out user experimentations. Based on users' task completion (in various conditions) and the responses collected via questionnaire, we concluded that the exploitation of the two sensory modalities may greatly help in cooperative manipulation of object in the VE.

We hope this framework will greatly help in the development of CAD systems that allow the designers to collaboratively design while being distant. Similarly other application domains may be cooperative assembly,surgical training and rehabilitation systems.

In future we are planning to work in many directions. First we will test the same experiment on distance network (i.e over internet). Secondly we will shift the system from desktop to large scale semi immersive VE and replace the polhemus by the human scale SPIDAR (Space Interface Device for Artificial Reality ) in order to include the modality of force feedback.

Similarly we will implement the proposed framework for the cooperative teleoperation of robot(s) over a local network and also over the internet.

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