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Research Article

Task Distribution Mechanism for Effective Collaboration in Virtual Environments

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Abstract: Collaborative Virtual Environments (CVEs) are computer generated worlds where two or more users can simultaneously interact with synthetic objects to perform a task. User performance is one of the main issues caused by either loose coordination, less awareness or communication among collaborating users. In this paper, a new model for task distribution is proposed, in which task distribution strategy among multiple users in CVEs is defined. The model assigns the task to collaborating users in CVEs either on static or dynamic basis. In static distribution there exists loose dependency and requires less communication during task realization whereas in dynamic distribution users are more dependent on each other and thus require more communication. In order to study the effect of static and dynamic task distribution strategies on user's performance in CVEs, a collaborative virtual environment is developed where twenty four (24) teams (each consists of two users) perform a task in collaboration under both strategies (static and dynamic). Results reveal that static distribution is more effective and increases users' performance in CVEs. The outcome of this work will help the development of effective CVEs in the field of virtual assembly, repair, education and entertainment.

Keywords: - 3D interaction, virtual reality, awareness, collaborative virtual environment, user performance.

1. INTRODUCTION

The advent of powerful personnel computers with realistic 3D graphics capabilities and real time processing of 3D trackers data have caused the immersions of virtual environment where two or more user can co-exist and perform a task,. These environments are called Collaborative Virtual Environments (CVEs) [1]. Some of the CVEs application are education, assembly, entertainment, engineering design, military training, tele-presence and virtual surgery [2]. More advanced CVEs, which support complex, real time and haptic collaboration have been suggested for numerous applications, mainly in the area of training [3-5]. Avatars (ball, simple virtual hand, sphere, circles and humanoid avatars etc.), Data in the form of audio, video and textual, are the main requirements for CVEs. Audio data is used in teleconferencing application while video data is used in video conferencing application. The audio, visual and haptic awareness virtual modalities are used for better communication and user's assistance in CVE to increase user performance [7, 8].

In CVEs interaction with objects may take synchronous or asynchronous form [6]. In synchronous type interaction concurrent manipulation of separate or the same attributes of

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an object are carried out. For example one person holds an object and the other paints it or suppose two or many peoples displace or lift a weighty object together. While in asynchronous type of interaction in CVE the sequential manipulation will be carried out with the distinct or with same attributes of the objects. For example one person changes the object position and another person changes it further. To perform collaborative task in CVEs either synchronously or asynchronously awareness is important to achieve better performance. The awareness concept in CVEs as defined by [1] mainly concerns the presence and activities of other users. Awareness is the knowledge of a user about the actions, intensions and status of other users in collaborative virtual environment. The awareness measures the degree, nature or quality of interaction between two objects or users [9]. Communication among the users is an essential factor for better awareness. The communication may be verbal such as audio or nonverbal such as visual, gestures based, pointing to or even facial expressions [10].

Various models have been presented by Benford and Fahlen [11], Sandor et al. [12], Ullah et al. [19], Otmane et al. [18] and Rodden et al. [14] to increase user performance in collaborative virtual environments. In CVEs as multiple users are involved for task execution. So either all the users will work on a single task or the task is divided into subtasks and users work on it in groups. Very little work has been done in literature on how to distribute the task among groups and subtasks among the members of a particular group? In this paper we present a novel task distribution model according to which task assignment to collaborative users can be made either statically or dynamically. In addition, the effect of each task distribution type (static and dynamic) on user's performance is studied in a collaborative virtual environment. Similarly the communication coordination and awareness requirements of the static and dynamic distribution are also investigated. Our investigation will help in the development of effective CVEs (ensuring increased user performance) in the field of virtual assembly and repair, virtual environment for education and entertainment and tele-operation systems.

This section is followed by the related work. In Section 3 the proposed model is described. In Section 4 the experiments and their results are shown. In section 5 conclusion and future work are given.

2. RELATED WORK

The best-known work performed for the management of interactions in the CVEs is the spatial model of interactions proposed by Benford and Fahlen in 1993 [11]. Basically it is used to control data transmission in CVEs. The main theme of this model is to use the space properties as a base to start and allow interaction and communication among the objects of CVEs. In this model the virtual space is breakdown to metric spaces, to measure different objects directions and positions. For orientations and positions settings, objects of the CVEs have the capability to change their interaction and communication. Interaction between objects occur via combination of media transmission like text or visual, audio and video through specific interfaces. According to Benford model, interaction between two objects becomes possible whenever their auras collide or overlap. In this model only modalities are described to increase the user awareness for better performance. The spatial model has limited support for contextual factors in interaction (being in a room compared to being in an open park) [9].

Sendor et al. [12] extended the Benford model of interaction during the years. Uses nimbus, focus and awareness ideas on semantic networks objects and their relations. In this method structure of the deleted or updated objects history and relations are built. As this model maintain the history of objects which is very difficult task in CVEs and create an extra overhead.

Greenhalgh et al. [13] used the method of third-party objects integration. The "third-party objects" provide provision for awareness calculation by using the appropriate factors, which increase scalability. Third party objects may represent features of interaction context, such as crowds, common objects, rooms/ buildings or more abstract factors such as control of the chair or membership of a group. These objects are defined in terms of their activation and effects. It means that what they do and when they do it. There are two classes of effects used in "third-party objects". The first one is the adaptation, which is used to modify existing awareness relationships i.e. suppression or amplification. In second one "the secondary sourcing" concepts of new indirectly forms of awareness are used. The combine effects of adaptation and secondary sourcing is mainly useful to realize the group effects. The group effects include abstraction and aggregation of the whole group [9, 13]. In "third-party objects" among the communicating bodies, simultaneous interactions are required, which create extra overhead. Also in this approach the interaction will change dynamically.

Rodden in 1996 proposed a model of presence for cooperative and/or collaborative applications [14]. This model basically describe the shared nature of the pool of different objects. In this mechanism the objects which are shared and relationship between them form a common space. The users of the virtual environment project their action onto this common space and their action is available publically to all objects which form the common space. Basically the presence model allow a shared workspace of collaborative and/or cooperative applications which based on presence and awareness notions.

The model of dynamic management of interests [15] deals with the problem of presence management in collaborative virtual environments between different users. This model mainly defines user's behaviors and actions taken based on their common of interest. Changes occurs in their center of interest over the passage of time. Main problem in this approach is that when all users of the environment take a common interest i.e. all users interested in a single object, then no interaction will occurs to the remaining objects of the environment. Due to this problem the task will not be completed. Another major problem in this approach is that when the user change their common of interest then the user's performance will be affected.

Bharadwaj et al. [16] proposed a model based on Benford spatial model of interaction that ensure awareness in heterogeneous environments. The model allows the easy choice of sources to users to make interaction with objects in CVEs. For sources provision access rules are used.

A model for three dimension interactions in CVEs was proposed by Otmane et al. [17]. This model gives information to user's assessment to make interaction in CVEs and gives knowledge to users about the system state.

To make help the users to interact in CVEs, workflow based model is used. This model basically provide assistance to users of the environment to improve performance of the users in a single-user interaction (to navigate and select) as well as in multiuser setup (in the case of more users manipulate the same object). This model consists of motor and shared component. The shared component is presented as the shared data space that symbolizes the behavior of users and sources in the CVE. The motor component is presented as a set of assistance functions that deals with data processing from the shared space and provides tools to assist the users during the 3D interaction process. It uses the shared data and applies them via assistance functions (navigation, selection and manipulation functions) on particular sources (focus, aura, nimbus, assistant and avatar) in the CVE [18]. Similarly, Ullah et al. [19] proposed a model for cooperative and/or collaborative tasks in CVEs which is based on the Benford spatial model of interaction [11]. According to this model two users succeed for interaction if their auras collide with same object. In this concept the user awareness is increased and eventually rises the user's performance in CVEs.

3. PROPOSED TASK DISTRIBUTION MODEL

CVE is a computer generated world where two or more user can simultaneously interact with synthetic objects to perform a task. This can be represented in the following way:

$CVE = \{T, O, U\}$
$T = \{T_1, T_2, T_3....T_i\}$ Equation. (1)
$O = \{O_1, O_2, O_3....O_J\}$ Equation. (2)
$U = \{U_1, U_2, U_3....U_m\}$ Equation. (3)

Where T, U and O represent the set of Tasks, Objects and Users as shown in equation 1, 2 and 3.respectively. In order to explain the concept of task distribution model, we consider the scenario of a CVE where the assembly of multiple constituent parts of a product (a complex machine for example) is carried out in the first phase and then they are integrated (assembled) to get the final product in the second phase. This task can be realized in the following two ways.

1. A single group of users performs the assembly of constituent parts sequentially i.e. task T is completed by completing subtasks $T_1, T_2....T_i$ one after another.
2. There are multiple groups of users and each one is assigned a specific task (T_i). In both cases the first step is to select a particular task as shown in Fig. 1. The next step is to determine that how the group members will realize the task? The model proposes two ways in this context.

1. Static task distribution
2. Dynamic task distribution

3.1. Static Task Distribution

In static task distribution, when a task is selected by a group of users then each user in the group will know in advance that which subtask he/she is going to carry out. It means that the user will know about the object he/she will manipulate. For example if the task set T consist of subtasks $T_1, T_2, T_3....T_i$ and the users set U consists of $U_1, U_2, U_3....U_m$, then according to static distribution, T_1 is assigned to U_1 and T_2 is assigned to U_2 of the same group and so on. The respective users will execute their subtasks. Communication and awareness among users in a group during task execution depends on task/subtasks dependency. If the tasks are loosely coupled having less dependency then low awareness will be required and less communication. Similarly if they are tightly coupled with more dependency then high level awareness will be required for which more and frequent communication is needed.

3.2. Dynamic Task Distribution

In dynamic task distribution, no division is carried out in advanced i.e. at start level. Here all users will be actively involved to first complete subtask T_1 then subtask T_2 and so on up-to T_i. In dynamic task distribution starting subtask T_{i+1} all users must be aware that T_i is completed and subtask T_{i+1} is going to start, these information must be communicated to all users of the environments in real fashion The same dynamic task distribution mechanism in CVEs will be followed for subtasks if they consist of sub-subtasks For dynamic task distribution high communication and strong awareness are required during task execution. For dynamic task distribution in CVEs the users as described by equation 3 are divided into Free Users (*UF*) and Busy Users (UB) sets as given in the following:

$U = \{UF + UB\}$
$UF = \{UF_1, UF_2, UF_3....UF_k\}$
$UB = \{UB_1, UB_2, UB_3....UB_l\}$

Objects will be selected from objects set as described by equation 2. If object O_j is selected by a user then he/she is included in the busy user set (*UB*). The rest of free (*UF*) users will be candidates for the selection of remaining objects $O_j - 1$. Similarly if a busy user releases the object or completes his task then he/she is included back in the free user set. This process is depicted in Fig. 2.

The dynamic task distribution is explained with the help of following procedure.

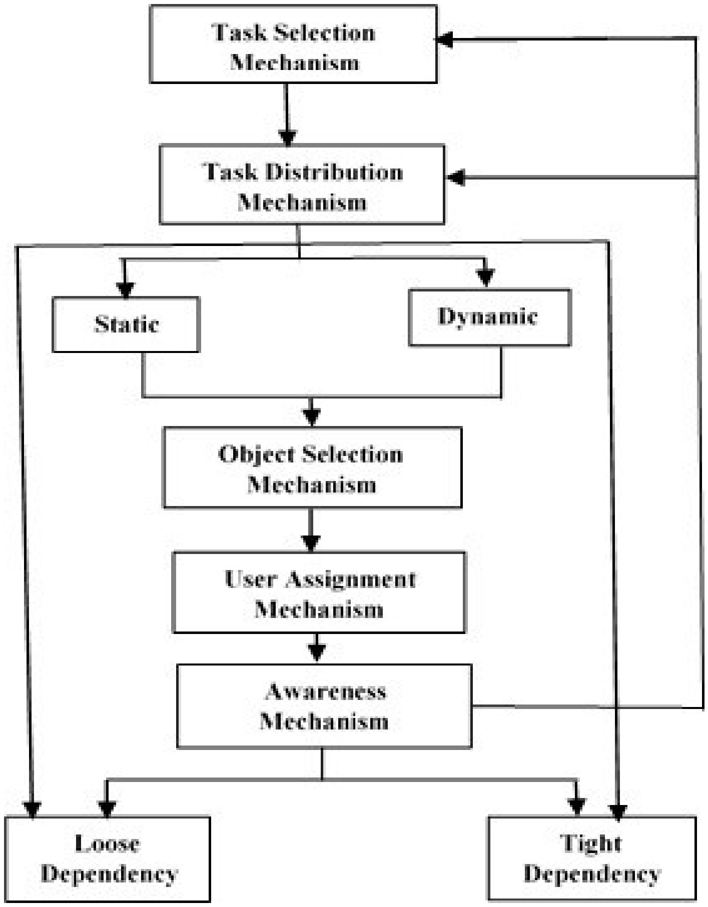

Fig. 1. Task distribution model.

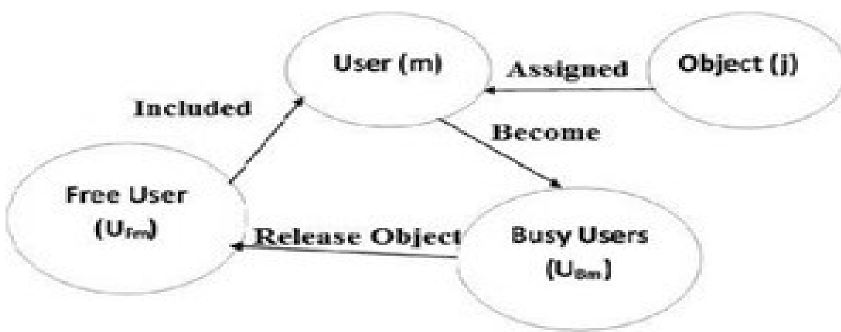

Fig. 2. Objects assignment.

DY NAMIC TASK (*T, O, U*)

[1] For each Task i

[2] Repeat step 3 to 9 for (j=1; $j \leq i$; j++)

[3] Assign O[j] to one of free user from free user set (*UF*)

[4] *UF* become *UB*

[5] Inform user via user awareness modalities i.e. audio, textual

[6] $UF - 1 \leftarrow O_{i-j}$

[7] If O[j] released by *UB* then

[8] $UF + 1 \leftarrow O_{i-j}$

[End of if structure]

[9] Continue

[End of inner Loop]
[10] Task Completed
[End of outer Loop]
[11] Return

3.3. Awareness

It is the knowledge of a user about the presence of other users in the CVEs It deals with the degree, nature or quality of interaction between two objects or users [9]. Communication is required among the users of the CVEs to provide awareness. Various communication modalities are used for awareness like audio, visual and haptic.

3.3.1 Audio Modality

To accomplish a collaborative task in VEs in more realistic manner and to achieve high performance and increase co-presence of users, oral/audio communication is used. It allows users to negotiate and exchange information on various tasks, such as selection/manipulation of objects etc.

3.3.2 Textual/Visual Modality

Various visual modalities like shadow, change of colors, arrows and lightning are used in CVEs to increases user awareness [20]. Textual communication allows users to exchange information on various tasks (releasing and picking of objects), which increases performance and co-presence of collaborative users in CVEs. Targeted and global awareness are the two main types of awareness used in CVEs.

3.3.3 Targeted Awareness

Whenever the selective users inform each other about theirs activities in CVEs, this type of awareness is called targeted awareness. For example if there are more than two groups of users involved in collaborative work. Suppose group 1 is responsible for task T_1 and group 2 for T_2, where the latter is dependent on the former. In this case if group 1 completes its task, then there should be a mechanism to inform group 2 only, so this kind of awareness is called targeted awareness.

3.3. 4 Global Awareness

In global awareness process the users of the CVEs are aware of each other individual activities. When all groups are executing their assigned task then they should be aware of each other activities whenever they want from any location. This kind of awareness mechanism is called global awareness [21].

3.4. Task Dependency

Coupling refers to the degree to which task in CVEs are dependent upon each other. In this regard we defined three type of tasks. (1) tightly-coupled task (2) loosely coupled tasks (3) decoupled tasks. In tightly coupled tasks there exist a strong relationship between two or more tasks/subtasks and hence the dependency will increase due to which high awareness is required during the accomplishment of such tasks/subtasks. In a loosely coupled task/subtasks there exist weak relationship between two or more tasks/subtasks having low dependency. Loosely coupled task/subtasks require low degree of awareness and hence less communication is used. In a decoupled tasks/subtasks, operations on the objects can be performed separately and independently. In static distribution there exist loose dependency and required less communication during task realization whilst in dynamic distribution users are more dependent on each other and thus require more communication.

4. EXPERIMENTATION AND EVALUATION

4.1. Environment

In order to investigate the effect of static and dynamic task distribution. We developed a CVE as shown in Fig. 3. The environment consists of multiple rooms. Each room contains a 3D (cube) object on which a character is displayed as shown in Fig. 3. Users are represented by virtual hands. There is a central room which is different in color from other rooms. The user will search the objects

Fig. 3. Virtual reality scenario.

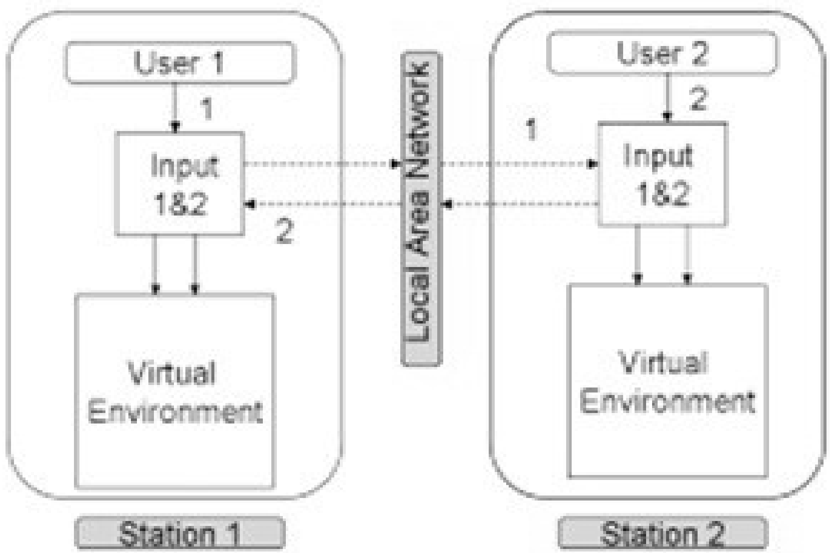

Fig. 4. Experimental setup.

in both static and dynamic task distribution and will bring it to the central room for placement in order to get a meaningful word from the characters displayed on the objects.

4.2. Experimental Setup

Two core i3 laptops having 2GB RAM and NVIDIA graphic cards were used for experimentation. The client server replicated environment is used as shown in Fig. 4. Transmission control protocol (TCP) is are used data transmission between the stations. Server is running on one station and on the other end the client is installed. The stations are connected via LAN using Un-shielded twisted pair cables. The user uses WIIMOTE for interaction with objects. In both VR stations there is a mechanism for getting input from the local as well as remote user. It means that a single user concurrently controls the movement of two pointers (in our case a hand) in the replicated environment connected stations. So if a pointer triggers any event at one station, it is also simultaneously applied at other station. The objects and user position are changed which is exchanged in real time between two stations. The whole CVE is developed in C++ and OpenGL Library.

4.2.1 Procedure

In order to examine the effect of static and dynamic task distribution on user performance, we carried out the experimentation on different students. Twenty four (24) groups of students voluntarily participated. Most of them were PhD and master having ages from 23 to 34. Each group consists of two students. Before starting the experiment a short briefing and pre-trial about the environment and experiment was given to student in order to make them familiar with the scenario, objects and awareness modalities. All the twenty four groups performed the experiment in five trials each for static and dynamic task distribution. The experiment was carried out under the following four awareness modalities condition.

C1= Dynamic via audio

C2= Static via audio

C3= Dynamic via textual

C4= Static via textual

We recorded the task completion time for each experiment. The time counter started for static and dynamic task when the scenario was loaded to perform the task in CVE and ended when the task was completed. After task completion we gave each user a questionnaire in order to have the subjective feedback.

4.2.2 Task

The users will search the cuboid objects which are placed randomly in CVE and bring the objects to the central room for making the word "UNIVERSITY" under the given conditions C1, C2, C3 and C4 collaboratively as depicted in Fig. 3. In dynamic task distribution the objects' names are communicated to the users via audio/textual modalities in each conditions i.e. C1, C2, C3 and C4. When the object 'U' is picked up by any user then his/her collaborator should be informed to search the next object 'N' and so on, till the task is completed. This type of task distribution is dynamic task distribution. While in static task distribution five objects i.e. 'U', 'N', 'I', 'V' and 'E' are assigned to user1 and the remaining 'R', 'S', 'I', 'T' and 'Y' to user2. Here the task is divided in a way that there exist loose coupling and no dependency during task execution. Each user can independently complete his/her assigned task. Therefore, there will be less communication during task realization.

In the subsections given below the results of task completion time and errors made by the students are analyzed during the accomplishment of the task. Similarly the feedback collected from students through questionnaire are also thoroughly examined and discussed.

4.3. Analysis/ Results

4.3.1 Task Completion Time

For task completion time the ANOVA ($F(3, 23) = 4.06$, $p < 0.05$) is significant. Comparing the task completion time of conditions C1, C2, C3 and C4, we have 185.7 sec mean (standard deviation 40.24), 156.76 sec (with 39.41 standard deviation), 192.45 sec (with 40.75 standard deviation) and 166.23 with (41.03 standard deviation) respectively.

The results show that C2 (Static via Audio) and C4 (static via textual) have an effect and increase users performance in CVE. Finally it can be concluded that static task distribution have an influence and increase user's performance in CVE as shown in Fig.5.

4.3.2 Errors in Task Completion Time

Selection of a wrong object or its wrong placement (releasing in a room other than the central room) is considered is an errors. The number of errors made during task accomplishment under each conditions were recorded, analysis of which is presented in Fig. 6. The results show that C2

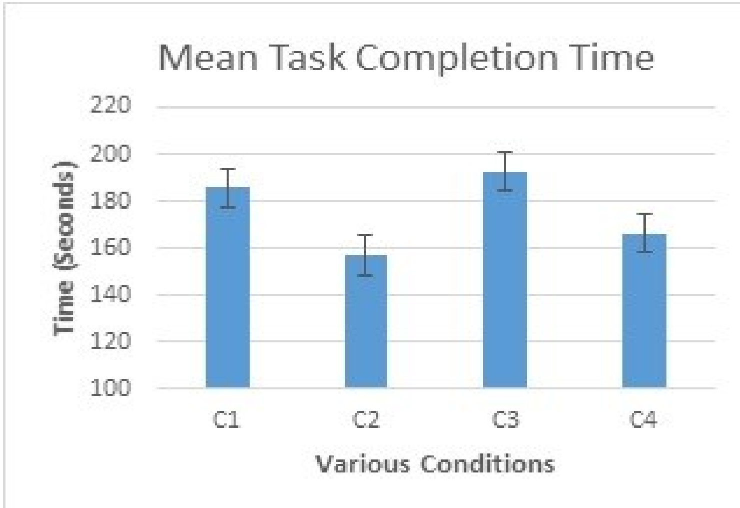

Fig. 5. Mean task completion time.

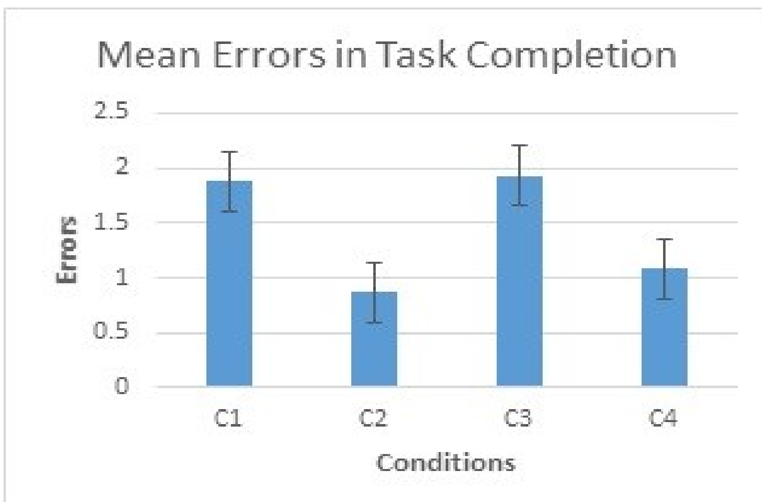

Fig. 6. Mean errors.

(static via audio) and C4 (static via textual) have significantly low errors as compared to C1 (dynamic via audio) and C3 (dynamic via textual) respectively.

4.3.3 Subjective Evolution

In subjective evaluation section the responses collected through questionnaire are analyzed. The questionnaire has five questions, each question contains three to four options for response. The user/subjects select an option for each question.

Question 1: Which task distribution do you prefer?

(a) Static (b) Dynamic

For this question 70% students preferred static while 20% opted for dynamic.

Question 2: Which feedback is the most relevant that you find?

(a) Audio (b) Textual

To this question, conditions audio, textual obtained the preference of 70%, 30% respectively.

Question 3: Task completion is the most difficult under which condition?

(a) C1 b) C2 c) C3 d) C4

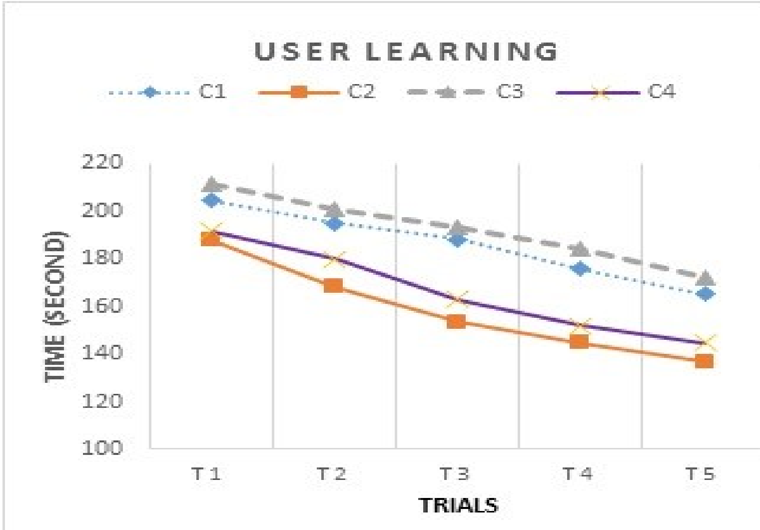

Fig. 7. User learning.

For question no.3, 65% of the students choose condition C3.

Question 4: In which condition do you feel more the presence of your collaborator?

(a) C1 b) C2 c) C3 d) C4

Here 50% of the students opted for C1 while the view of remaining 50% was distributed equally for condition C2, C3 and C4.

Question 5: Which feedback is more helpful in dynamic task distribution accomplishment?

(a) Audio b) Textual

The response of 90% students was in favor of audio feedback and 10% selected textual feedback.

According to the students feedback collected through questionnaire and remarks we observed that static task distribution significantly enhanced user's performance.

4.3.4 User/Subject Learning

Learning is the improvement of group performance during task repetitions. In our experimental setup and execution of the experiment we asked each student of the group to repeat 5 times the previously defined task under each condition. The results show better performance of user in next trial because of the user learning from the environment.

This results of performance improvement is 19%, 24%, 18% and 24% for conditions C1, C2, C3 and C4 (from trials t_1 to $t_{5)}$ respectively as shown in Fig. 7 which means that task learning was more under static distribution.

5. CONCLUSIONS

In this paper, a new model for task distribution was proposed, in which task distribution strategy among multiple users in CVEs was defined. The model assigns the task to collaborating users in CVEs either on static or dynamic basis. In static distribution there exists loose dependency and requires less communication during task realization whereas in dynamic distribution users are more dependent on each other and thus require more communication. In order to study the effect of static and dynamic task distribution strategies on user's performance in CVEs, a collaborative virtual environment was developed where twenty four (24) teams (each consists of two users) performed a task in collaboration under both strategies (static and dynamic). Results revealed that static distribution was more effective and increases users' performance in CVEs. The outcome of this work will help the development of effective CVEs in the field of virtual assembly, repair, education and entertainment. In future the effect of task distribution model on learning virtual environments and network latency will be investigated.

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