

## **NETWORK LATENCY EFFECT ON USER PERFORMANCE IN COLLABORATIVE VIRTUAL ENVIRONMENT USING TASK DISTRIBUTION MODEL**

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**ABSTRACT:** Collaborative Virtual Environments (CVEs) are used for training, education, tele-conferencing and assembly of synthetic objects. Network latency, loose coordination, no task distribution strategy and less awareness are the main factors that affect user performance in CVEs. The effect of network latency on user performance in CVE was analyzed. Visual and audio feedback was used for communication between the collaborators. Based on task distribution model, a simulated environment for collaborative assembly task was developed to conduct the experiments. The experiments were performed on different college students comprising of 20 virtual teams of 40 individuals using the latency from 0 to 5000 msec in LAN. The result showed that the user's performance was better in dynamic with audio with no latency, but whenever the lag was increased the task completion time increased than dynamic with textual based. At 1000 msec latency, the dynamic with audio and textual modality values were almost the same. Above 1000 msec of latency, the user performance in dynamic with textual was better as compared to dynamic with audio.

**Keywords:** Collaborative Virtual Environments, User Performance, Visual/Audio Feedback, Network Latency, Task Distribution Model.

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### **INTRODUCTION**

A Virtual Environment (VE) is the 3D representation of the real or imaginary data with which the user can interact in real time (Hachet, 2003). Based on the degree of immersion and the type of interfaces/components utilized in the system, Virtual Environments (VEs) can be classified into three major categories i.e. Non-Immersive Virtual Environment (NIVE), Semi-Immersive Virtual Environment (SIVE), Fully-Immersive could Virtual Environment (FIVE) (Kalawsky, 1996). Non-Immersive VR system is the least immersive and least expensive virtual environment generated without any specific use of hardware. The common components of NIVE are keyboard, data gloves, space ball, a stereo display monitor and glasses. Semi-Immersive VR system provides high level of immersion, while keeping the simplicity of the desktop VR. Fully-Immersive Virtual Environment provides highest level of immersion and is the most expansive VR systems. Its components include head mounted display, tracking devices, data gloves, (Bowman *et al.*, 2002).

Collaborative Virtual Environments (CVEs) are virtual reality systems that offer digital landscapes where individuals can share information through interaction with each other and through individual and collaborative interaction with data representation (Churchill and Snowdon, 1998). CVEs offer significant advantages for geographically located users. The users can work together

to achieve common objective while working on variety of applications like assembly task, training, computer aided design, tele-surgery, education and entertainment, (Wright, 2014; Lorenzo *et al.*, 2012; Garcés *et al.*, 2010; Giraldo *et al.*, 2007). However, the effective collaboration in VEs is strongly affected by the network latency. In CVEs, as the users are geographically distributed, a considerable amount of latency occurs in the collaborative work. Latency is the amount of time taken by a packet to transfer from one station to another in network connection (Christensson, 2016). However making improvement in the network design can sufficiently reduce it. In long distance collaboration, data transfer speed is imposed by congestion, bandwidth, protocols, consistency, storage devices, network architectures etc. That significantly increases network latency (Khalid *et al.*, 2016).

In this study, the effects of network latency in CVEs through various feedback based on task distribution model was thoroughly evaluated. The latency between 0 and 5000 msec for task acquisition using audio and visual/textual transformation to accomplish an assembly task was analyzed. Based on dynamic task distribution, the effect of network latency was analyzed in terms of task completion time, errors performed during task execution. The user's feedback was collected through questioners regarding various parameters that affect user performance.

## MATERIALS AND METHODS

An experimental study was carried out to check latency/delay effects on visual/textual and audio feedback based on task distribution mechanism on user performance in Collaborative Virtual Environments.

The study selected a “collaborative assembly completion task” of making the word “UNIVERSITY” from different objects scattered in VEs in different rooms as is shown in Fig- 1.



Fig. 1. Assembly Task Scenario

Where in first phase the assembly of multiple fundamental parts of a product was carried out and then they were combined to obtain the complete product in the second phase. The task distribution model suggested static and dynamic task distribution mechanism in this context (Fig-2) (Khalid *et al.*, 2016).

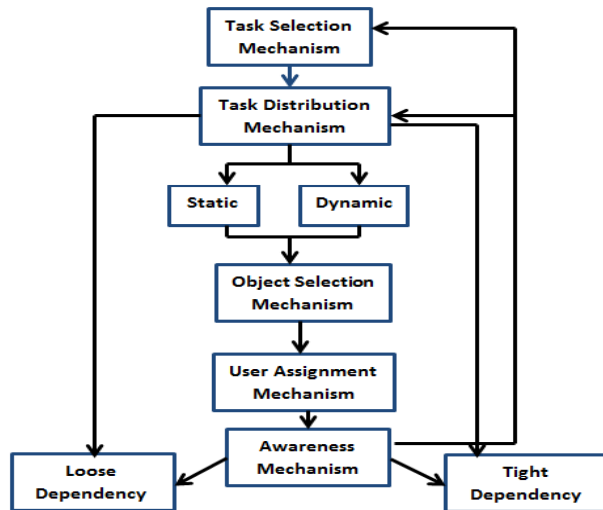


Fig-2. Task Distribution Model

In Static Task Distribution mechanism, the users knew in advance the task, subtask and objects which were manipulated. Communication was required to provide awareness among the collaborators during task execution.

In dynamic task distribution, task and sub tasks were not divided in advance. All users of the CVEs were

actively involved for task execution, to start task  $T_{i+1}$  all users were aware that  $T_i$  was completed and subtask  $T_{i+1}$  was going to start. All these information needs were communicated among the group users in real fashion. For this type of task, subtasks execution, high level of awareness are required among the collaborators (Khalid *et al.*, 2016). Awareness was actually the feeling of presence of other users in a VE (Greenhalgh, 2012). For awareness, communication was vital. For navigation, selection and manipulation of objects, Visual/textual, audio/oral and haptic communication modalities were used for awareness (Nguyen and Duval, 2014). In Dynamic task distribution the users and task were more dependent on each other.

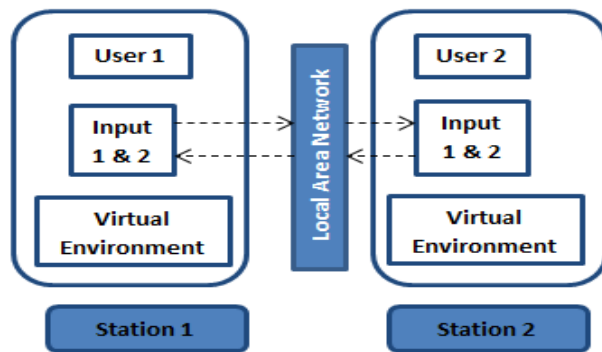
Thus to check the effects of network latency on awareness modality based on task distribution model, only consider the dynamic task distribution mechanism was considered

**Design:** For collaborative virtual assembly , experiments were conducted in which the participant’s search, picks and move, the scattered objects in VE to central room for acquisition of task based on dynamic task distribution on visual and audio modality were used (as explain in section 2). The study had a different cuboid objects of size 2 x 2 x 2 placed in different rooms in CVEs. The replicated shared collaborative virtual network environment was used for conducting the experiments. Visual and audio delay with dynamic task distribution mechanism and amount of delay (0, 1000, 2000, 3000, 4000 and 5000 msec) were used and implemented.

**Experimental setup:** WIIMOTE interactive device and TeamSpeak software for audio communication was used in the experiments. The system was powered by HP desktops with core i5 CPUs and an hplv1911 monitor, with a resolution of 1400 x 1050, on which textual data was displayed for visual feedback.

The virtual environment was constructed, using Microsoft visual studio 12 and updated at a rate of 60 frames per second.

The two stations were connected with each other using client server replicated environment (Figure-3). Transmission control protocol (TCP) was used for data transmission between the stations. Both stations were connected in LAN via guided media. WIIMOTE was used for interaction with objects. Six levels of latency i.e. (0 to 5000 msec) were used in the experiments to check user,s performance in dynamic with audio and textual conditions.



**Fig. 3.**The network topology

**Procedure:** Forty participants consisted of twenty males and twenty females having ages between 26 and 32, took part in the study (n=40). To start a trial, the participants searched the objects in VE and were brought to central the room based on dynamic task acquisition mechanisms. Visual and audio feedback was provided when the objects were picked up by the collaborators. A Pre-trial and five test blocks were completed by each participant.

The cuboids objects, each containing separate alphabets on its faces, were placed in different room. The users searched and brought to the central room for making of the “UNIVERSITY” with dynamic with audio and dynamic with textual conditions collaboratively (Figure-1). The names of objects were communicated in real time in dynamic task distribution via audio/textual modalities. Whenever the user picked the object e.g. object ‘U’, then his/her collaborator was informed to search the next object ‘N’ and so on, up to the task completion. The communication between the collaborative partners was carried out in LAN under six levels of latency i.e. 0 msec, 1000, 2000, 3000, 4000 and 5000 msec for audio and textual data transmission. The quantitative measurements were allowed to assess that,

whether latency had different effects on visual and audio feedback, whether its significances varied according to the task completion and movement in CVE, and whether it affected users’ perceptions of latency in the same manner as their physical responses.

## RESULTS AND DISCUSSION

**Qualitative observations of user’s performance:** On visual/textual and audio feedback the effect of latency was negative. The way in which latency/delay effected user’s task completion time and errors based on awareness modality are shown in table-1 and table-2. From 0 to 1000 msec in LAN, latency/delay level, the users faced little trouble for task acquisition. After 1000 msec of latency/delay, it made it difficult to complete the assembly task. The latency/delay did not have a linear effect on user’s performance. Whenever the latency value reached to 5000 msec then it was clearly more disrupted. Performance gradually decreased when the latency level increased. Latency/delay had a much more serious effect on audio feedback (table-1). When latency/delay is zero, participants completed the task easily and had better coordination with each other, but whenever the latency increased from 2000 to 5000 msec, then task completion time and errors made by the users increased which severely affected the user’s performance in CVEs.

**Quantitative observations of user performance:** The mean task completion times using six levels of latency based on dynamic with audio and dynamic with textual conditions are given in table-1.

As estimated, the audio, visual/textual delay with dynamic task distribution had a significant effect on user’s performance, when the duration of lag increased, the task completion time also increased. A repeated measure ANOVA confirmed this, yielding a significant effect of audio and visual lags starting at 0 msec ( $F_{1,19} = 6.33$ ),  $p < 0.05$ ) up-to 5000 msec in LAN ( $F_{1,19} = 6.22$ ),  $p < 0.05$ ). The result showed that the user performance was better in dynamic with audio with no latency, but whenever the lag increased the task acquisition completion time increased than dynamic with textual based. At 1000 msec latency, the dynamic with audio and textual modality values were almost the same. Above 1000 msec of latency, the user’s performance in dynamic with textual were better as compared to dynamic with audio (table-1). The results concluded that, the user’s prefer dynamic with audio based task acquisition with low level of latency than dynamic with textual, but whenever the lag increased the user’s preferred dynamic with textual than dynamic with audio. The similar story provided the pattern of errors and difficulty ratings. Based on dynamic task mechanism with textual feedback using different level of latency, error rates increased significantly with latency ( $F_{1,19} = 7.84$ ),  $p < 0.05$ ). The

effects of audio feedback using different level of latency had also significant effect on user's error rates (table-2). Participants rated that textual feedback in dynamic nature of task distribution in term of network latency was easier

than the audio feedback (table-2). The results showed that the participants found the lag in visual/textual and audio feedback disrupting the task accomplishment in LAN.

**Table 1. Mean completion time and stand deviation (STD) with different latency lag.**

Conditions	Mean Task Completion Time and Mean Standard Deviation (STD) With different Latency Lag (Mille Seconds)					
	0	1000	2000	3000	4000	5000
Dynamic Task via Audio	3.77	4.43	4.80	5.06	5.59	6.05
Dynamic Task via Textual	4.00	4.30	4.50	4.70	5.00	5.45
Dynamic Task via Audio Mean (STD)	0.50	0.67	0.46	0.49	0.71	0.75
Dynamic Task via Textual Mean (STD)	0.55	0.72	0.53	0.59	0.87	0.83

**Table 2: Mean errors and standard deviation (STD) with different latency lag.**

Conditions	Mean Errors and Mean Standard Deviation (STD) With different Latency Lag (Mille Seconds)					
	0	1000	2000	3000	4000	5000
Dynamic Task via Audio	0.88	1.55	1.845	2.17	2.54	2.91
Dynamic Task via Textual	0.92	1.65	1.99	2.4	2.71	3.2
Dynamic Task via Audio Mean (STD)	0.50	0.51	0.61	0.60	0.55	0.46
Dynamic Task via Textual Mean (STD)	0.35	0.30	0.38	0.40	0.33	0.26

## DISCUSSION

The effect of network latency due to sensory feedback was investigated by various psychologists via oscilloscopes, master slave robotic arms and handwriting analyzers (Jay *et al.*, 2007; and Heyde *et al.*, 2001;). Outcomes of these studies showed that delay in visual feedback increased errors and task completion time. Analysis of handwriting analyzer tells that whenever the users in the VE wrote on a tele-scriber, the letter formed slowly and also varied in shape due to delay between the pen movement and its resulting marks (Heyde *et al.*, 2001). The study also showed that the association between the latency level and performance deterioration was linear. It means that whenever the latency level became high the writing speed and its replication marks decreased, which showed that the delay and writing marks, had indirect proportion (Jay *et al.*, 2007). In a study MacKenzie and Ware (1993), conducted quantitative research for analyzing the effect of visual latency in computer-based environment. The users moved the mouse from initial/starting position to the final/target position with latency between 25 msec and 225 msec to see the cursor movement. The study showed that, the relationship between latency and time of users to accomplish the task was linear.

A model of performance degradation due to visual feedback delay was proposed by (Ware and Balakrishnan, 1994). To account the reaching movement in 3D environment of the CVEs MacKenzie and Ware,

(1993) proposed their model. The effects of longer time delay was explained i.e. in seconds instead of msec while conducting remote driving experiment in terms of memory disturbance (Day *et al.*, 1999). The study of (Ferrell, 1966), showed that haptic the feedback was much better than in terms of performance, time and errors improvement instead of visual feedback, to perform a positioning task.

Many studies have been conducted to observe the visual, audio and haptic collaboration in CVEs reported by (Gunn *et al.*, 2005; Kim *et al.*, 2004; Sallnäs and Zhai, 2003; and Hubbard, 2002). However, in all these studies no one has measured the effect of network latency on task performance based on task distribution.

In this study analyzed the effect of latency based on task distribution mechanism i.e. dynamic with audio and dynamic with textual analyzed. It was observed that collaborators perform well in dynamic with audio, whenever, the latency was below 1000 msec in LAN. Latency from 1000 msec to 5000 msec affected user performance deterioration to rise more sharply in audio than visual/textual feedback in dynamic task distribution. Errors analysis also showed that user's performance degraded with increase in latency. In future the effect of latency based on task distribution model for different network media be checked and analyzed.

**Conclusion:** The effect of latency lag was analyzed for better user's performance in CVEs. Latency lags of 1000, 2000, 3000, 4000 and 5000 were used to perform the assembly task in CVEs using dynamic task distribution

mechanism. It was observed that collaborators performed well in dynamic with audio, whenever the latency was below 1000 msec in LAN. Latency from 1000 msec to 5000 msec affects user performance deterioration to rise more sharply in audio than visual/textual feedback in dynamic task distribution.

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