Distributed virtual collaborative environments with Multitouch support: Implementation and Experiences

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ABSTRACT
In this paper, we present a new application framework aimed to support distributed synchronous collaboration using multi-touch interaction. The framework supports 2D and 3D virtual workspaces that enable two or more users to collaboratively or cooperatively manipulate shared objects with multi-touch interfaces. We present two applications developed with the aim to explore 2d/3d immersive collaborative environments with multi-touch interaction. We also present our experience and preliminary results in designing, developing and integrating these applications on educational settings.

Keywords
Multitouch interaction, Distributed environment, Collaboration, multi-touch collaborative environments

INTRODUCTION

Advances in multi-touch enabled hardware have led to the creation of a wide variety of applications. However, only few of them address remote collaborative environments (RCE). Although RCE is not a new topic and many researchers have addressed this problem before, advances in videoconferencing technologies and multi-touch technologies has allowed us to re-address RCE by integrating these two technologies.

We suggest that the growing interest in multi-touch can lead to the creation of collaborative immersive environments supported by multi-touch interaction that will offer everyday people new opportunities for collaboration only previously accessible on laboratory settings. We demonstrate that using today's technologies, and without the need for expensive hardware, it is possible to integrate videoconferencing with shared immersive spaces and multi-touch interaction. In this paper we present a Remote Multi-touch Collaborative Environment solution that supports 2D and 3D applications.

Motivation

Virtual environments have proved to be effective and emulate real-life settings. They support remote collaboration over a shared virtual space [10, 15]. However, they are limited to specialized scenarios and often require users to wear bulky and cumbersome equipment (HMD, Gloves, etc.). The cost to setup and maintain a VR environment has stopped it from going mainstream.

There is a gap between fully immersive collaborative environments (FICE) and videoconferencing environments. FICE focus on realistic shared spaces, while traditional video conferencing environments focus on providing a medium for communication. On one hand, FICE is especially valuable when the application requires a detailed representation of the world as a shared medium for collaborating over a common goal. These environments support direct feedback and offer a virtual representation of the participants. Videoconferencing environments, on the other hand, offer a communication channel for exchanging information, such as presentations, documents, and even shared desktop; with a special focus on visualizing the participant's presence. FICE often fail when the requirements are simple and the goal is to exchange information. Whereas videoconferencing systems fail when there is a need to collaborate on complex scenarios beyond document and desktop sharing.

Remote collaborative environments supported by Multi-touch interaction can fill the existing application gap and address a new set of applications. We believe that integrating videoconferencing systems with shared spaces and multi-touch interaction can overcome some of their individual limitations.

This paper starts by reviewing previous work and identifies several challenges for the development of Remote Multi-touch collaborative environments (RMCE). The paper later addresses these challenges and presents an application framework designed to support 2D/3D shared-space RMCE. Finally, the paper summarizes our experience and preliminary results in designing, developing and integrating RMCE, providing future directions and concluding remarks.

PREVIOUS WORK

Hiroshi Ishii et al. [3] proposed the ClearBoard system that allows participant to talk and draw as if they were in the two opposite sides of a transparent glass window. However this solution is only designed for 2D workspace, therefore restricts the possible application to drawing or manipulating

2D objects. Hauber et al. in [5] investigated the use of individual view in videoconferencing setting. They compared face-to-face condition to traditional 2D videoconferencing and to 'spatial local' and 'spatial remote' videoconferencing where each user is virtually located in different point of the workspace and therefore perceive the scene from different view points. Spatial interfaces were proved to support better gaze awareness, co-presence and sense of social presence than the 2D condition. However task performance was worst in spatial videoconferencing than in 2D condition. Moreover, in this study the virtual workspace was limited to a virtual table environment and users were forced to use mouse to rotate image in order to solve orientation problems. The authors commented that supporting a more natural manipulation of virtual object could lead to better task performance.

To our knowledge, no studies to date have investigated the impact of combining immersive 3D remote space and videoconferencing system using vertical multi-touch settings. Moreover, we believe that adding spatiality to the workspace could lead to explore new interaction techniques that support high level of cooperation.

In recent work on remote collaboration in tabletops, researchers have mainly focused in supporting awareness of the workspace and of the actions of remote collaborators. Most of these studies use representation of users arms shadow to convey the actions of distributed collaborators. In most of these systems, users cannot see each other [19], whereas in others [4, 12] they can see each other through video streaming showed in a separated display. In traditional videoconferencing system facial images and shared documents or applications are displayed in different windows on the same display. Some studies, as in [7], combine both approaches integrating participant's shadow arms and participant's video streams in two different windows on the same display.

However, in real situations, collaboration is situated in a physical environment where spatiality between collaborators, as well as awareness of actions of the others, takes an important role [2]. Previous studies on remote tabletop, constrain many of the rich cues available in face-to-face collaboration: workspace, spatiality, and individual point of view of the workspace. Few studies have investigated the impact of spatiality and individual view in remote collaborative environment.

CHALLENGES

We outline a number of technical challenges that must be considered in the design and implementation of RMCE.

Challenge 1: Distributed architecture

Remote and co-located immersive collaboration requires a distributed architecture to support real-time shared collaborative spaces and distributed multitouch interaction to attain an optimal user experience. Shared spaces have usually being implemented with client server architectures [8],[19] enabling the creation of shared spaces with co-located or remote users. In most of those system user interaction was performed with single input devices. Support for real-time multitouch interaction requires resource intensive mechanisms and can add delays, thus resulting in a poor users experience. This justifies the use of a fully decentralized distributed architecture.

Challenge 2: User awareness and connectness

Awareness of remote users' actions is needed to represent users' interactions to others in the shared space, being it a 2D shared space or a 3D shared space. Representing tabletops remote embodiments of distributed users has already been addressed in previous works [13, 17]. Telepointers and remote arm shadow have been mostly used as embodiment supports [13]. While remote arms representation are considered a more natural representation of the users [13], and they also convey informations about users gestures around and towards the shared artefacts [6], they obstruct most of the workspace and they are not practical if many users interact with the surface simultaneously. Moreover they can only be used in horizontal tables. Pointers are smaller and can easily support simultaneous users withouth obstuct the workspace. However, all these previous works are focused on applications that use 2D shared space. None of the previous studies have adressed the problem of represent remote embodiments of users interacting in a 3D shared space.

Challenge 3: Collaboration and cooperation levels

Different collaboration levels are required to control concurrent access to shared object either through turn taking techniques or simultaneous manipulation of the same object (cooperative techniques [9]). Previous studies of remote collaboration, the type of interaction allowed was mainly based on taking-turns behaviors or simultaneous manipulation of different objects [8]. In face-to-face situations, users can simultaneously control and manipulate the same object, for example holding the two sides of a long table. Using Margery's classification [9], this kind of interaction is the highest level of cooperation that can be achieved. We believe that adding the possibilities to cooperatively manipulate the same object in a shared 3D virtual environment will facilitate particular tasks and could result to be suitable for particular scenarios, such as gaming and learning.

Challenge 4: Mapping 2D to 3D

Users simultaneously manipulating a shared object require mapping of multi-user multi-touch 2D interaction to 3D space. Previous studies on remote cooperative interaction have been focused in using monitor displays [14], haptic device [1, 16] and immersive virtual environment with the support of head mounted display [8]. However, mapping simultaneous 2D fingers movement of different users to 3D object movements needs a new challenging approach that we plan to investigate.

COLLABORATION FRAMEWORK

We present an integrated Remote Multi-touch Collaborative application framework that supports 2D and 3D applications. The framework enables the development of applications requiring 2D and 3D shared spaces and facilitates the creation of shared objects that can be interacted by multiple remote users with multi-touch interfaces. This framework addresses the challenges for the development of RMCE described previously. The following table illustrates the different interaction behaviors supported by the application framework:

2D	3D	Functionality
Video streaming of the remote user	Video streaming of the remote user	Remote presence
Translation around x-y axis	Translation around x-y-z axis	Object manipulation
✓	✓	Grouping objects
identical	individual	Users point of view of the scene

Challenge 1: Distributed architecture

We have implemented a peer-to-peer distributed architecture where every node is a peer that behaves equally to all others. This architecture has no centralized node presents several advantages compared to client server architectures: firstly, there is no central point of failure, but most importantly, interactions events are not delayed in any server, being transmitted to all participating peer nodes as fast as the communication network allows.

As represented in figure 1, in every node a multitouch hardware interface converts input events to TUIO protocol datagrams which are sent to all participating nodes. Each local application receives TUIO messages from all nodes. The application uses those messages to represent in the application the visualization of "touch" events of all users. But only input events from the local user are applied to the application data and objects. So that interactions with objects at each node are visualized in other nodes, we have implemented an update protocol that transmits object changes at each node to other peers. This update protocol is implemented with datagram messages for fastest transmission.

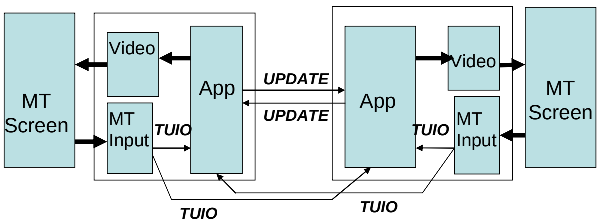

Figure 1. Distributed peer-to-peer architecture

Challenge 2: User awareness and connectedness

The framework supports the use of colored "fingerprints" to represent the point of contact (or area of work). These fingerprints act as a natural visual representation of each participant's fingers, as they interact in the space. Connectedness is addressed by incorporating a video conferencing link into the shared space itself. It shows to each participant the video image of the other participant in the area of the shared space where he is interacting.

Participants can see each other through the shared space, which allows them to be aware of the other participant's intentions by tracking their eye gaze (spatial interfaces support better gaze awareness that signals intention and indicates the area of the space being use [5]).

Challenge 3: Collaboration level

The framework addresses concurrent access to shared objects by using a flexible mapping of the user interaction based on the application needs. The framework allows for the creation of synchronous multi-touch applications by means of the update mechanisms made possible by the distributed architecture.

The framework supports synchronous communication by a assigning behaviors to objects in a shared space and allowing them to be controlled by any user; whereas a local or remote. If two users in different nodes interact simultaneously with an object, events of both users are sent to both application instances, where interactions can be processed in different order at each end. However, this mechanism is only valid for operations that do not change the state of the application.

The framework allows objects to be manipulated by one or many fingers, and by one or many users. That is, it is possible to map the user multi-touch interaction to various behaviors. For example, in multi-touch collaborative environments, fingers from participants at opposite ends can scale an object that is typically scaled by one single user. In a more complex example, one participant could define the rotation axis using one finger, and the other participant could rotate it at a given speed. Moving the axis would cause the rotation to change as well.

Challenge 4: Mapping 2D to 3D

Currently the framework supports 2D and 3D shared spaces that enable two users to collaboratively or cooperatively manipulate several shared 2D/3D objects with multi-touch interfaces. A 3D application developed within the RMCE framework maps 2D fingers to 3D by using a finger-ray objects and limiting actions on shared objects.

2D Shared Collaboration Space

In a 2D shared space users select and move objects in two directions: up/down and left/right. Every user can interact with multiple fingers simultaneously. Touch events of each user are represented on every multitouch screen with "fingerprints" that show to other users where each user is trying to interact. Fingertips of each user are shown in

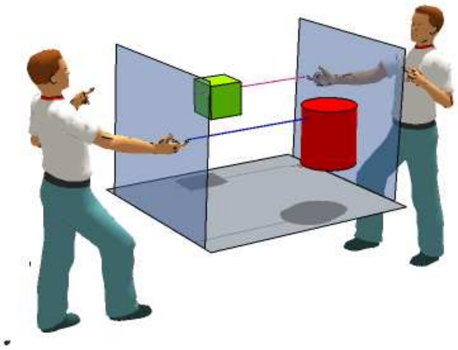

Figure 2. Collaboration environment: A 2D/3D shared space enables users with multi-touch interfaces to interact with objects simultaneously.

different colour. Fingerprints images are a bit larger than the diameter of fingers tips. We have implemented a shared space where all users will access the same space from the same perspective, thus every user sees the objects in the same position on their screen (this is not a transparent wall where a user will see objects from one side and the other user from the other side), we think that 2D shared spaces must be viewed from the same perspective by both users even though it can provoke some confusion in some situations.

3D Shared Cooperation Space

In a 3D shared space users select and move objects in a 3D space; every users can interact with multiple fingers simultaneously. All users access the same space from different perspectives, each user sees each object in different position in their screen. In a very basic configuration, one user sees the front view of a 3D scene while another user sees the same 3D scene from its back as in figure 2.

To support object selection we adapted the ray-casting technique used in virtual environment [11], to multi-touch interaction. Touch event of each users are represented on the screens of every user with "finger-rays" which are lines starting in a point inside a rectangular area in the 3D space which represents the multitouch surface of one user, and growing perpendicular towards the space which is being visualized by the corresponding user. In the basic configuration in figure 2 rectangular areas of both users are positioned in front of each other so that each user sees the other exactly in front of him, but both rectangular areas can be position anywhere in the 3D space in our framework. To move objects back and forth users have to touch them with two "finger-rays" and pull or push the object by approaching finger-rays or pulling them apart.

PRELIMINARY EVALUATION

The work discussed in this paper is part of an ongoing consortium-led research work towards interactive educational experiences in remote settings. The work is aimed developing 2D and 3D virtual and mirror worlds embedded in learning applications. Our investigation of remote multi-touch collaborative environments to support 3D scenarios for learning is still at an early stage, and our findings are preliminary. Nevertheless, we present our experience in developing immersive collaborative environment with multi-touch interaction *for education.*

Early observations

We tested the system with 8 participants performing two collaborative tasks in groups of two. In one task participants played a letter writing game, in the other task participants created a storyline by selecting and moving objects on a shared space. Participants also accomplished the same tasks over a non-virtual space, sitting around a table. Each task had to be completed within 5 minutes.

Most participants immediately understood the interactions possible with the multitouch interface. Only a few complained that it was a bit of work to understand the task and the multitouch interaction simultaneously. All participants agreed that they needed to communicate and coordinate with each partner to complete the task. All participants completed the task satisfactorily; interestingly, some decided to extend their time to follow-on creating more stories than required.

Experience with a 2D shared space application

Distributed interaction awareness

A "fingerprint" represented user interaction within the shared space. It appeared at the position where each user touched the screen and lasted a few second or indefinitely depending on the task configuration. In all sessions users agreed that fingerprints helped them to interact with objects. Most users commented that "fingerprints" confirmed that the system was receiving their actions. It helped users to know where the interaction point was. Several users commented that fingerprints helped them to know what their partner was doing. However some users commented that objects in the shared space did not move as fast as their fingerprints.

Video-conferencing connectedness

Users could see each other behind the 2D shared space using a video link. In the tasks involving several large objects, the user complained that they could almost never see the face or expressions of their partner. We have not implemented a minimize object functionality which could overcome this problem. The other letter-drawing task, participants commented that they felt they were fully connected to their partner.

Distributed collaboration

The 2D shared space with multitouch interaction facilitated collaboration among remote users. Users saw objects in the 2D space with the same perspective though they were in different places, objects appeared in the same position to both participants. This disposition of the elements could have caused difficulties when discussing the position of objects relative to the other users, especially when indicating "left/right position" since the left of one user is


Figure 3. Users collaborating in a 3D shared space with video conferencing. The users interact as if they were located in two opposite sides of the same virtual space. Both multi-touch areas are transparent so each participant sees each other behind the shared 3D space.

not the right of the other. However no participant commented this to be a problem. Participants said that when they needed to indicate an object to the other participant they simply pointed to an object and their partner would notice the fingerprint on top of the object. Some participants complained that some objects covered other objects making them difficult to select. When both users tried to move the same object at the same time the system responded to both users. Objects could move to one direction when both partners interacted with it, or stand still when dragging them to opposite directions. This was surprising to some users, but since the objects ended in the same position for both users, the task continued without trouble.

Experience with a 3D shared space application

Distributed interaction awareness

In the shared 3D space users interactions were represented by “finger-rays”, lines starting in a point inside a rectangular area and growing towards the space which is being visualized by the corresponding user. When a user touches the screen the “finger-ray” starts to grow to indicate the direction where it is going to interact. “Finger-rays” end in an object if the line intersects with the object, else they grow towards infinity or until a wall is reached. In the experience “finger-rays” enable each participant to see what the other participant is doing. However several participants complained it was not obvious how to select an object. Especially those participants that had performed the task in a 2D space expected that putting their finger on top of an object in the screen would enable them to touch it. Some users commented that “finger-rays” made it possible to see the object they were interacting without covering it up with their finger (but only in some areas of the screen). Users reported it was easier for them to move objects which are nearer to them because it was easy to intersect their finger-rays with nearer objects. Objects could be moved from the back towards the front of the viewing user by selecting them with two “finger-rays” and separating those finger-rays. However some participants have difficulties separating their fingers while keeping their finger-rays interacting with the object.

Video-conferencing Connectedness

In the 3D space video of the other participant were shown at the other end of a virtual tunnel, as seen in figure 3. Users also complained that they hardly seen each other since shared objects were covering large parts of their vision space. Some participants observed that sometimes "finger-rays" seem to grow from the other participant eyes. This is due to video cameras being located just above the screen, thus hands of each participant were never shown to the other participant.

Distributed collaboration

Users saw the shared space from different view points. Some users commented that it took them some time to realize this, some even needed to tell its partner what they were seen to explain it, however after these initial hesitations they proceeded with their assigned task. When a participant had trouble moving an object from the back to the front, he asked the other participant to move the object towards him by pushing the object, which seemed to be an easier interaction. Although users could move objects in three axes, unfortunately in the proposed tasks there was very little need to move objects backward or forward. Some users move objects in those directions because they were instructed to put objects in a personal space which they agree that it was the space that was near to each participant. If two users interacted with one finger each in the same object it move first in one direction then in the opposite as in the 2D space; if both users tried to push or pull the object simultaneously the object would move first back and then forward, but ended in the same position for both users so users did not complaint.

CONCLUSIONS AND FUTURE WORK

We have identified and addressed the challenges of distributed virtual collaborative environments with multitouch support through a framework that supports 2D and 3D virtual workspaces. We have also presented two applications that enable two or more users to cooperatively manipulate shared objects with multi-touch interfaces.

Preliminary results indicate that after adjusting to the virtual shared space, users are able to cooperatively manipulate shared objects with multi-touch interfaces. And that communication is natural through the embedded videoconferencing channel despite occlusion problems.

Future work will focus on re-addressing alternatives ways to interact with objects in the 3D space using multi-touch interfaces. The work will explore interactive 2D and 3D virtual and mirror worlds as educational experiences to support distance learning and cultural exchange.

REFERENCES

1. Basdogan, C., Ho, C.-H., Srinivasan, M. A., & Slater, M. (2000). An experimental study on the role of touch in shared virtual environments. ACM Transactions on Computer Human Interaction, 7(4), 443–460.
2. Gaver, W. W. 1992. The affordances of media spaces for collaboration. In *Proceedings of the 1992 ACM Conference on Computer-Supported Cooperative Work* (Toronto, Ontario, Canada, November 01 - 04, 1992). CSCW '92. ACM, New York, NY, 17-24.
3. Ishii, H. and M. Kobayashi (1992): ClearBoard: A Seamless Medium for Shared Drawing and Conversation with Eye Contact. *Proceedings of the Conference on Human Factors in Computing Systems*. Monterey, CA, pp. 525–532.
4. Izadi, S., and Agarwal, A. C-Slate: Exploring Remote Collaboration on Horizontal Multi-touch Surfaces. *Proc. TABLETOP 2007*, 3-10.
5. Hauber, J., Regenbrecht, H., Billinghurst, M., Cockburn, A. Spatiality in videoconferencing: trade-offs between efficiency and social presence, *Proceedings of the 2006 20th anniversary conference on Computer supported cooperative work*, November 04-08, 2006, Banff, Alberta, Canada
6. Kirk, D. *Turn It This Way:Remote gesturing in VideoMediated Communication.* PhD. Thesis, University of Nottingham, 2007.
7. Li, J., Wessels, A., Alem, L., and Stitzlein, C. 2007. Exploring interface with representation of gesture for remote collaboration. In *Proceedings of the 19th Australasian Conference on Computer-Human interaction: Entertaining User interfaces* (Adelaide, Australia, November 28 - 30, 2007). OZCHI '07, vol. 251. ACM, New York, NY, 179-182.
8. Márcio S. Pinho, Doug A. Bowman, Carla M.D.S. Freitas, Cooperative object manipulation in immersive virtual environments: framework and techniques, *Proceedings of the ACM symposium on Virtual reality software and technology*, November 11-13, 2002, Hong Kong, China
9. Margery D. M., Arnaldi B., and Plouzeau N. 1999. A general framework for cooperative manipulation in virtual environments. *In Proceedings of EGVE 99: Eurographics Workshop on Virtual Environments*. Springer, New York, N.Y., 169--178.
10. Minatani, S., Kitahara, I., Kameda, Y., and Ohta, Y. 2007. Face-to-Face Tabletop Remote Collaboration in Mixed Reality. In *Proceedings of the 2007 6th IEEE and ACM international Symposium on Mixed and Augmented Reality* (November 13 - 16, 2007). Symposium on Mixed and Augmented Reality. IEEE Computer Society, Washington, DC, 1-4.
11. Mine, M. R. 1995 *Virtual Environment Interaction Techniques*. Technical Report. UMI Order Number: TR95-018., University of North Carolina at Chapel Hill.
12. Pauchet, A., Coldefy, F., Lefebvre, L., Louis dit Picard, S., Perron, L., Guérin, J. Tabletops: Worthwhile Experience of Collocated and Remote Collaboration. *Proc. TABLETOP 2007*, 27-34.
13. Pinelle, D., Nacenta, M., Gutwin, C., and Stach, T. 2008. The effects of co-present embodiments on awareness and collaboration in tabletop groupware. In *Proceedings of Graphics interface 2008*, 1-8.
14. Roy A. Ruddle, Justin C. D. Savage, Dylan M. Jones, Symmetric and asymmetric action integration during cooperative object manipulation in virtual environments, *ACM Transactions on Computer-Human Interaction (TOCHI)*, v.9 n.4, p.285-308, December 2002
15. Sakong, K. and Nam, T. 2006. Supporting telepresence by visual and physical cues in distributed 3D collaborative design environments. In *CHI '06 Extended Abstracts on Human Factors in Computing Systems* (Montréal, Québec, Canada, April 22 - 27, 2006). CHI '06. ACM, New York, NY, 1283-1288.
16. Sallnas, E., Rassmus-grohn, K., & Sjöström, C. (2000). Supporting presence in collaborative environments by haptic force feedback. *AMC Transactions on human-computer interaction, 7,* 461–476.
17. Tang, A., Boyle, M., and Greenberg, S. 2004. Display and presence disparity in Mixed Presence Groupware. In *Proceedings of the Fifth Conference on Australasian User interface - Volume 28,* 73-82.
18. Tang, A., Neustaedter, C. and Greenberg, S. VideoArms: Embodiments for Mixed Presence Groupware. *Proc. HCI 2006,* 85-102.
19. Tuddenham, P., Robinson P. 2007 Distributed Tabletops: Supporting Remote and Mixed-Presence Tabletop Collaboration. *Second Annual IEEE International Workshop on Horizontal Interactive Human-Computer System*, pp 19-26.