GROUPWARE CONCEPTS FOR AUGMENTED REALITY MEDIATED HUMAN-TO-HUMAN COLLABORATION

Xiangyu Wang [1] and Phillip S. Dunston [2]

ABSTRACT

Augmented Reality (AR) technologies are suited for mediating human-to-human interactions for the entire life cycle of the engineered facility because the blending of the real (field conditions) and virtual (plans and other engineering information) and the attendant interaction metaphors can be tailored to facilitate group decision-making. To maximize the benefits of AR technology for various conditions, the concepts of computer-supported cooperative work (CSCW) and groupware must be utilized to design effective AR systems which are envisaged to mediate human-human collaborations for shared production tasks. This paper outlines principles and an investigation regarding how groupware principles and concepts are to be applied in prototyping effective AR systems for particular construction operations. Two case illustrations are also presented where two collaborative AR systems were closely examined through experimental observations. The results of the research presented in this paper could be useful to assist in designing AR systems for particular construction working scenarios.

KEY WORDS

Augmented Reality, computer-supported cooperative work (CSCW), groupware, mobility

INTRODUCTION

Production and service activities in the construction industry can generate great amounts of data, information, and documentation that must be accessed and utilized by numerous parties in varied locations and conditions. As the industry moves toward more digital information management, more IT tools need to be sought for storing, conveying, and accessing project information instead of relying on paper media.

Construction industry practitioners are looking increasingly toward varied computing devices to facilitate information retrieval and enhance performance of collaborative tasks. Computer-based collaborative tools support the transition from simple human-computer interfacing to more human-to-human interfacing mediated by computers. This emphasis on the mediation role of computers adds new technical challenges to the development of IT tools. Augmented Reality (AR) technologies are suited for mediating human-to-human interactions over the engineered facility life cycle because the combination of images and

[1] Lecturer, University of Sydney, Key Center of Design Computing and Cognition, School of Architecture, Design Science and Planning, Wilkinson Building (G04), Sydney NSW 2006, Australia.

[2] Asst. Prof., Purdue University, School of Civil Engrg., 550 Stadium Mall Dr., West Lafayette, IN 47907-2051, Phone 765-494-0640, FAX 765-494-0644, dunston@purdue.edu

information from the real (field conditions) and virtual (plans and other engineering information) sources and the attendant interaction metaphors can be tailored to enhance group decision-making processes. AR technology benefits can be maximized for various situations if the concepts of computer-supported cooperative work (CSCW) and groupware are incorporated into the design of AR systems envisaged to mediate human-human collaborations for shared production tasks. This paper presents principles and an investigation into how groupware principles and concepts should be applied in prototyping AR systems for particular construction project operations.

The goal of groupware is to assist a team of individuals in communicating, in collaborating, and in coordinating their activities. Groupware can be defined as: computer-based systems that support groups of people engaged in a common task (or goal) and that provide an interface to a shared environment (Ellis et al. 1991). Computer supported cooperative work requires the creation of groupware that supports interaction by multiple users. Many computer systems already support simultaneous interaction by more than one user. Simultaneous groupware concepts were applied in a study for Augmented Reality mediated human-to-human collaboration. The research results presented in this paper could be useful to assist in designing AR systems for particular construction working scenarios.

AUGMENTED REALITY TAXONOMY BASED ON GROUPWARE CONCEPT

Based on generic groupware concepts, three factors were identified for categorizing AR systems for construction use: *mobility, number of users and space*. Since the real object and/or its environment are augmented, the presumption of being classified as an AR system is that at least one user must be physically next to the augmented task. Otherwise the system is no longer an Augmented Reality case and falls into the collaborative teleoperation class.

MOBILITY

Most documented AR systems were designed for use in stationary or small local area environments. Progress made in wireless networks (RF, Radio Frequency and IR, InfraRed, signals) in terms of quality of services make it possible to build mobile AR systems (Kangas 1999). A mobile AR system is not simply a portable version of a stationary AR system, but one in which augmentation occurs through knowledge of the user's present location and therefore the surrounding environment (Renevier and Nigay 2001). The user's location and orientation are generally tracked by specialty trackers such as GPS and inertial measurment units. The construction domain can involve large distances, where mobile AR can play a crucial role for mobile work crews, bringing computer capabilities into the operational reality of various work locations. For example, Roberts et al. (2002) developed a mobile prototype AR system that allowed people to "look" into the ground and "see" underground features (e.g. geological structures, gas or water pipes, or zones of contaminated soil) by appropriating surveying and geodesy.

NUMBER OF USERS

AR systems can be classified as *single-user* AR and *multi-user* AR systems. Multi-user AR systems are regarded as collaborative systems that enable a group of users to perform a task in the real world. However, a multi-user AR system is not necessarily a collaborative AR system if the following definition is considered. Renevier and Nigay (2001) defined a collaborative AR system as one in which augmentation of the real environment of one user occurs through the actions of other users and does not merely rely on information previously stored in the computer. For example, a multi-user AR system that only provides human-human communication services should not be regarded as a collaborative AR system.

SPACE

The distance between users in a multi-user AR system should also be considered. Based on spatial relationships, single-user AR system apparently does not involve this consideration. AR systems with multiple users can be classified as either *collocated* systems or *distributed* systems. A collocated AR system is one wherein users are physically located in the same space and visible to one another. A distributed AR system is one wherein users are geographically separated and remotely collaborating with each other. Both cases could involve networking technology for communication and data transmission. Distributed AR systems can give each user the illusion that he or she is the only one using the system, thereby maintaining a "protective wall" hiding other users' activities. To support and encourage cooperation, distributed AR systems must allow users to be aware of the activities of others.

AUGMENTED REALITY IMPLEMENTATION MODES

Based on the different combinations of the three groupware factors, Table 1 illustrates categories of AR systems. Table 1 stresses the logical separation/combination between the three factors, and explains how the groupware concepts are implemented in order to allow different schemas of AR systems.

Table 1. Categories of AR Systems

<table>
<tr><th>Mobility / Number of users</th><th colspan="2">Stationary</th><th colspan="2">Mobile</th><th>Mobility / Space</th></tr>
<tr><td rowspan="2">Single</td><td colspan="2">1</td><td colspan="2">4</td><td>—</td></tr>
<tr><td colspan="2">—</td><td colspan="2">—</td><td>—</td></tr>
<tr><td rowspan="2">Collaborative</td><td colspan="2">2</td><td colspan="2">5</td><td>Collocated</td></tr>
<tr><td>3</td><td colspan="2">7, 8</td><td>6</td><td>Distributed</td></tr>
</table>

- 1 — Single Stationary AR System
- 2 — Collaborative Stationary Collocated AR System
- 3 — Collaborative Stationary Distributed AR System
- 4 — Single Mobile AR System
- 5 — Collaborative Mobile Collocated AR System
- 6 — Collaborative Mobile Distributed AR System
- Highlighted Square — Collaborative AR between one stationary user (office) and one mobile user (field):
  - § 7 — information flows from field to office where the AR task is undertaken
  - § 8 — information flows from office to field where the AR task is undertaken

The table illustrates the universe of feasible options from the three groupware factors, including even categories that do not constitute groupware. As an example to illustrate the notation of the Table 1, combination 6 refers to a collaborative mobile distributed AR system which combines the characteristics of mobile AR, collaborative AR, and distributed AR. Therefore a mobile collaborative distributed AR system is defined as one in which augmentation occurs through knowledge of where the user is and what the other remote users are doing. Table 2 presents the descriptions and noted examples for each implementation mode.

Table 2. Augmented Reality Implementation Modes

Mode	Descriptions	Noted AR Examples
1	Single stationary AR systems for one AR-supported task.	Augmented Reality computer-aided-drawing (AR CAD) (Dunston et al. 2002)
2	Systems that bring all the participants to one room for one common AR-supported task.	Mixed Reality-based face-to-face system (Wang et al. 2003) for mechanical contracting.
3	Systems that allow collaborations to happen among distributed personnel at stationary workstations. Limited social interaction is realized and social roles are hard to support under such conditions.	Billinghurst and Kato (1999) developed a distributed AR system that allows users to see each other as virtual images and the real world at the same time.
4	Single mobile AR systems for field use.	Roberts et al. (2002) developed an AR system that allows a single user to “look” into the ground and “see” buried infrastructure by surveying and geodesy.
5	Systems wherein all the mobile users are positioned together next to the object of the AR-supported task.	Reitmayr and Schmalstieg (2003) developed a Collaborative AR system to support a group of users for collaborative navigation and information browsing tasks in an urban environment.
6	Systems where there are several objects of the AR-supported tasks, remotely linked together and physically present in different sites. Each user performs actions on their own physical object.	Mobile AR systems worn by users distributed to inspect different but related portions of a constructed facility. The inspection executed by one user interleaves with the inspection by the other user. No documented examples.
7	Systems where the field crew collects information on the remote site and office personnel (e.g., designers, construction managers) employ AR visualization. The understanding of the proposed design can be augmented by the real world information provided by the field crew.	Field crew captures the real-scale as-built data of constructed structures using radar and laser scanning. Office personnel renders the data into a virtual counterpart in an AR environment and add a virtual design alternative of an extension unit onto the existing building. No documented examples.
8	Systems where the field crew is next to the AR-supported task and office personnel provide data remotely. The real environment/workspace of the crew is therefore augmented by information to facilitate the field operations.	Wang et al. (2004) presented the concept of an AR-based equipment management system (AR EMS) for maintenance and repair of heavy equipment fleets.

CASE ILLUSTRATIONS

Two AR systems were investigated regarding the groupware issues through observations of experimental trials and post experiment questionning of the engineering student subjects. System descriptions and groupware issues are presented in this section regarding the evaluation.

CASE 1: MIXED REALITY-BASED FACE-TO-FACE SYSTEM

This Mixed Reality-based face-to-face system is a collaborative virtual environment wherein collocated users are supported in a mechanical design review collaboration. The collaborators can each see the same spatially aligned 3D virtual model but can control their viewpoints independently through their head mounted displays (HMDs). Since users are not immersed in HMDs, normal words, gestures, etc. are visible in the augmented environment, where the work group can communicate and collaborate naturally with each other in real time. More details can be found in Wang (2005).

Groupware Issues

- *Gain in social interaction:* face-to-face working session tends to be less serious. Since there is more interchange about non-task-related topics, people tend to be distracted frequently from the main task. The effect is a possible gain from a social aspect and a possible loss in efficiency from time wasted. However, because of the ability to look directly at other participants and communicate, the subjects tend to accomplish more work in less time when they are focused. Even though group members rarely look directly at each other during face-to-face sessions, being in the same room seems to increase the awareness of other individuals' activities to the point where highly cooperative work can be done.
- *More distraction issues:* The face-to-face session seems to be overly distracting. For example, in the face-to-face session, when one subject moved the tracking marker — the real-world anchor for the virtual model — to get a view from another perspective, the other user sometimes became distracted and confused about the orientation of the virtual model. This event highlights a fundamental difference between single-user and multi-user interfaces. With single-user interfaces, users usually have the mental context to interpret any display changes that result from their own actions. Sudden rotation of the virtual model is therefore acceptable. In contrast, with group interfaces, users are generally not as aware of others' contexts and intentions and can less easily interpret sudden display changes resulting from others' actions. A simple solution is a protocol to audibly announce users' intentions prior to taking action — suitable in some situations but often a burdensome discipline.

CASE 2: MIXED REALITY-BASED VIRTUAL SPACE SYSTEM

This system is a distributed virtual environment that enables remote collaborators to review the same design across the Internet in a real-time manner. Collaborators can verbally communicate with each other and evaluate a design solution in a common context of discussion by sharing perspectives. Distributed sessions have a noticeably different communication pattern from face-to-face sessions. With current communications technology, transmission times and rates for wide-area networks tend to be slower than for local area networks. The possible impact on response time must therefore be considered. More details can be found in Wang (2005).

Groupware Issues

- *Discussion is made more difficult:* Because most of the voice communication technology via network is not full-duplex, only one subject's voice is transmitted at a time. Consequently, the subjects tend to take turns and are unusually polite.
- *Group focus is more difficult, requiring greater concentration:* Distributed collaboration seems to require more concentration and is more tiring. Since discussion is more difficult when some of the group members are distributed, the subjects feel that they are working harder to get and give feedback.
- *Social interaction is decreased:* Distributed sessions tend to be more serious. Since there is less interchange about non-task-related topics, the subjects tend to focus on the immediate task. The effect is a possible efficiency gain from time saved and a possible loss in regard to social needs.

CONCLUSIONS

This paper introduced the concepts of computer-supported cooperative work (CSCW) and groupware into the design of effective AR systems, which are envisaged to mediate human-human collaboration for shared production tasks. Two case illustrations were also presented in the paper where the groupware issues involved in two collaborative AR systems were explored through experimental observations. The future work will incorporate emerging and evolving groupware and collaboration strategies, and testing of the performance of collaborative systems for particular AR implementation modes.

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