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Mutual awareness in collaborative design: An Augmented Reality integrated telepresence system

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ABSTRACT

Remote collaboration has become increasingly important and common in designers' working routine. It is critical for geographically distributed designers to accurately perceive and comprehend other remote team members' intentions and activities with a high level of awareness and presence as if they were working in the same room. More specifically, distributed cognition places emphasis on the social aspects of cognition and asserts that knowledge is distributed by placing memories, facts, or knowledge on objects, individuals, and tools in the environment they work. This paper proposes a new computer-mediated remote collaborative design system, TeleAR, to enhance the distributed cognition among remote designers by integrating Augmented Reality and telepresence technologies. This system can afford a high level externalization of shared resources, which includes gestures, design tools, design elements, and design materials. This paper further investigates how this system may affect designers' communication and collaboration with focus on distributed cognition and mutual awareness. It also explores the critical communication-related issue addressed in the proposed system, including common ground and social capitals, perspective invariance, trust and spatial faithfulness.

1. Introduction

With recent developments and applications of computer-mediated design software tools that utilize the Internet, a plethora of opportunities and challenges have emerged that are able to accommodate communication and collaboration issues in remote collaborative design. Traditional *Face-to-Face* (*F2F*) interaction is being replaced by computer-mediated human interaction. This trend is providing new opportunities and tools to support Computer-Supported Collaborative Work (CSCW), especially for remote designers to work together virtually in a distributed environment. However, CSCW can hinder important features of F2F communication that people are used to and rely upon for enhanced perception and cognition. For instance this is limited support for gaze perception and awareness when using teleconferencing technologies.

Telepresence focuses on the interaction with live, real objects and places instead of virtual presence in a simulated environment. CSCW tools, for example, may be rejected by users if work processes and tasks subject to change. Thus, the higher degree of telepresence is provided, the closer feeling to what the designers have been familiar with will be achieved. This may increase users' acceptance toward adopting such technology into their regular design processes.

This paper presents a computer-mediated remote collaborative design system that can be used to enhance the distributed cognition among remote designers by integrating Augmented Reality and telepresence technologies. Traditionally, cognition has been explained in terms of information processing at the level of the localized individual. Distributed cognition emphasizes the distributed nature of cognition phenomena and focuses on the interaction of a person with tools, objects and other persons [13,28]. The proposed system has been named TeleAR system. Technologically, this system consists of a camera and a tabletop Augmented Reality component. The camera component is built with the focus on each individual's presence to others and tabletop is coupled with the camera component provides an Augmented Reality environment for remote collaboration. Augmented Reality has been extensively explored in collocated single user or collaborative context, for example, in the areas of individual design [36,37,39], collaborative design [38,40–42], collaborative learning [43], etc. The paper commences with a review of related

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work and then describes and discusses how the proposed *TeleAR* system can affect designers' communication and collaboration in remote locations.

2. Related work

There have been a number of studies that have examined the nature of collaborative work using technology. For example, Distributed Designers' Outpost [9] employs real Post-it notes as interactive media. The remote digital notes are synchronized with real local notes on a vertical display for collaboration. A novel approach of increasing efficiency in remote collaborative design in this system is the adoption of two mutual awareness mechanisms: (1) transient ink and (2) blue shadow [9]. The transient ink is used to convey position information of specific notes, which are added, removed or moved by a remote user while the blue shadow is used to provide simulated feedback of the approximated location of the remote user [9]. The simulated shadow is limited in its fidelity of approximation. For instance, it is difficult to distinguish shadows of two or more designers when they overlap. Tuddenham and Robinson [34] also developed a tabletop system, which supported remote and mixed-presence collaboration by visualizing distance designers' arms as shadows on the tabletop. In their experiments, three designers created poetry by moving and reorienting the words simultaneously.

Real video streaming has been explored to bring richer experience as compared to voice only media such as telephone. For instance, ClearBoard [16,17] was one of the early implementations that leveraged real-time video textures for simulating traditional whiteboard-aided design. One of its key contributions was that it allowed eye contact through video by using a half mirror polarizing film projection screen. The screen can be rapidly switched between the transparent and light scattering state by varying the control voltage. Thus, during the design experiments, together with the collaborative digital whiteboard drawing, a user's reflected image was also captured by a camera behind the screen and transmitted to another. Blue-C [10] adopted and further investigated this idea of using half mirror projection screen, which was referred as "active panel" in their work. It introduced a spatially immersive environment for telepresence by combining simultaneous acquisition of multiple video streaming and 3D stereo projection. It provided a 3D portal that can facilitate collaborative design via body languages like gestures and movements. One limitation of the systems mentioned here is that they focused on one to one communication environment.

As compared against ClearBoard and Blue-C, which placed cameras behind the screens and manipulated the transparency of the screens to capture the images of the users, DigiTable [7] drilled a hole in the wood-screen and used a spy camera peeping through for video communication. Another important feature introduced by DigiTable was the masks of the detected objects, which can be hands, arms, or any object above the table. The masks were synchronized among geographically distributed users' tabletops to be the remote embodiments so that the local user can maintain an awareness of each other's actions.

These efforts mentioned above used various technologies to place the camera in a natural location, where the remote user can see and be seen by the local user as if they were communicating in a F2F manner. The location and orientation of the camera embody the eyes and the direction of gazes of the remote user. There is possible misalignment between the actual scene and the perceived one via projection screen (captured by the camera). Projection screen and camera are the intermediate components for externalizing one's presence, while in F2F, they are embodied into the human eyes, resulting in a seamless natural situation for others' perception. Therefore it is critical to understand the sensitivity of human eyes through quantitatively measuring the differences between the actual gaze and the camera-embodied one. In video auditorium research, Chen [6] conducted experiments to determine how accurately human perceive eye contact and adopted the results in the Video Auditorium design. He properly designed and designated areas to be just below the cameras, being as the "teleprompter", where the user can send his or her gaze to the intended students during a class.

3. Issues in remote collaboration

Tuddenham and Robinson [35] suggested that many remote tabletop projects have been inspired by co-located tabletop research including Single Display Groupware (SDG). Collaborative Virtual Environments (CVEs) tend to mimic physical F2F environments to reduce the cognitive load in a user's brains. For example, the artificial shadows mentioned above afforded information about illumination and approximated positions of others, which is akin to F2F communication. However, due to current technical limitations, not all sensible stimuli can be replicated by network devices and computers. Senses of smells and tastes are two examples that computers cannot directly support. Some issues and limitations arise due to these limitations, which leads to a gap between F2F collaboration, for example, Single Display Groupware (SDG) [33] and remote collaboration like Mixed Presence Groupware MPG [34].

Spatial faithfulness is a concept that may be used to plug this prevailing gap. Nguyen and Canny [25] defined three levels of spatial faithfulness:

- *Mutual spatial faithfulness*, which simultaneously enables each observer to know if they are receiving attention from other observers/objects or not;
- *Partial spatial faithfulness*, which provides a one-to-one mapping between the perceived direction and the actual direction (up, down, left or right) to the observers; and
- *Full spatial faithfulness*, which is an extension to partial spatial faithful systems. It provides a one-to-one mapping to both observers and objects.

As shown in Fig. 1, F2F collaboration provides *full* spatial faithfulness while most remote collaboration systems only support mutual or partial spatial faithfulness. Hence, these systems cannot precisely preserve clues like directions and orientations to each user. Consequently, perspective invariance [30,31] may arise which may interfere with the correct awareness of the environment. This phenomenon occurs when images and streaming videos of remote users are taken from inconsistent angles, from which the local users perceive these images or videos. Consequently, this might lead to misunderstandings as illustrated in Fig. 1(b).

Suppose three users are using remote collaboration groupware platforms for a design task. They would like to perceive each other as if they were talking F2F. Typically, a camera, which faces the local user, is used at each site to capture the streaming videos of the local user for both remote users. Additionally, two monitors or projection screens facing local user are used to display the videos received from the corresponding remote user. When A looks at their front direction, both audiences B and C will have the feeling that A is watching them even they have different virtual positions in the CVE. However, what they would expect and recognize in their brains is similar to that represented in Fig. 1(a), in which everyone perceives others' gaze correctly. The perspective invariance would cause a false impression to the users and lead to distorted mental space of the working environment. It requires additional cognitive process to map the direction faithfully in their minds.