Proceedings of the 2009 IEEE International Conference on Systems, Man, and Cybernetics
San Antonio, TX, USA - October 2009

Spatial Faithful Display Groupware Model for Remote Design Collaboration

Wei Wang
Ph.D. Student, Design Lab,
Faculty of Architecture, Design and Planning
The University of Sydney
Sydney NSW 2006, Australia
Email address:
wwan9601@usyd.edu.au

Xiangyu Wang
Lecturer, Design Lab,
Faculty of Architecture, Design and Planning
The University of Sydney
Sydney NSW 2006, Australia
Email address:
x.wang@arch.usyd.edu.au

Jie Zhu
Ph.D. Candidate, Design Lab,
Faculty of Architecture, Design and Planning
The University of Sydney
Sydney NSW 2006, Australia
Email address:
jzhu0743@usyd.edu.au

***Abstract*—Traditional remote collaboration technologies and platforms are found restrained and cumbersome for supporting geographically dispersed design activities. This paper discusses some of these limitations and argues how these limitations could possibly impair efficient communication among designers. The paper also develops a model for supporting remote collaborative design among geographically distributed designers. This model is named Spatial Faithful Groupware (SFG), which is based on Single Display Groupware (SDG) model and Mixed Presence Groupware (MPG) model. The SFG model is also demonstrated with justified discussions in an urban design scenario, as compared with SDG and MPG.**

***Keywords*—spatial faithfulness, remote collaboration**

I. INTRODUCTION

Recent technology advances have dramatically changed the entire world, where human work and live. The days in which designers work face-to-face and rely on cartographical sketches for construction have become history now. An avalanche of new ideas and advanced tools has been introduced into designers' daily working routine by computer technology. A lot of CAD (Computer-aided Design) and 3D modeling software are developed to help designers realize their dreams. Latest cutting-edge technology like 3D printer [1] could further take design to reality in a matter of seconds. Distant communication and collaboration are empowered by network so that designers do not have to meet at the same time or location.

This paper starts with discussing certain typical issues involved in remote design collaboration and then comes up with a model called Spatial Faithful Groupware (SFG) to address some of these issues. This model is based on Single Display Groupware (SDG) [2] and Mixed Presence Groupware (MPG) [3]. The SFG model is also demonstrated with justified discussions in an urban design scenario, as compared with SDG and MPG.

II. ISSUES IN REMOTE COLLABORATION

Olson proposed five factors that were believed to lead to success in remote scientific collaboration from a study of 62 US National Science Foundation-sponsored projects [4]. Most of these factors are also applicable to remote design collaboration since they share remote collaboration features in general. These factors are: the nature of the work, common ground, collaboration readiness, management, and technology readiness.

This paper proposes six typical issues in the context of remote design collaboration, based to Olson's findings. They are: member embodiments, intentional communication, consequential communication, display disparity/orientation, perspective invariance, and tangible user interface.

Member embodiments afford clues for identities when several designers virtually meet through remote collaboration systems. Barsalou, Niedenthal, and Bardey [5] defined embodiments as "states of the body, such as postures, arm movements, and facial expressions, arise during social interaction and play central roles in social information processing". They also suggested four types of embodiment effects, which would eventually affect performance effectiveness. In addition to what were enumerated in this definition, there could be plenty of other things that can be used as embodiments, such as color, size and smell. However, due to specific design requirements and technique limitations, not all types of embodiments, which are easily perceived from face-to-face communication, could be implemented in remote collaboration systems. For instance, it is difficult to convey smells and flavors through computer network. Thus, careful consideration needs to be taken when determining what and how to embody remote members. Traditional remote collaboration platforms often choose a combination of text, portrait, and video to represent remote users or objects. This paper discusses the potentials of enriching user embodiments with spatial faithful clues. More details are discussed in a later section.

Intentional communication clues like gestures and other body languages would be perceived from those embodiments [6]. They are used ubiquitously in daily conversations to help express ideas clearly. For example, designers could use the 'OK' gesture to express their compliments. Sometimes these gestures and body languages could greatly improve the efficiency of communications, thus preserving intentional communication clues. Investigating these clues could improve the usability of computer-based remote collaboration systems.

Consequential communication, unlike intentional communication that transfers explicit messages, provides a huge amount of information [6, 7]. The information it carries is merely perceived by others and it is up to the perceivers to decide what to do and/or how to do with this type of information. Segal further suggested that movement is one important source of consequential communication due to the fact that motions are more attractive to human eyes. Traditional remote collaboration systems embed consequential communication clues into embodiments. More or less, these systems could inform local users of things that are happening at the remote site. Real-time mouse cursor tracking, and voice and video streams are the typical techniques that have been used to convey consequential communication.

Display disparity is another issue observed from the MPGSketch system [3]. In their system settings, designers at each individual site used heterogeneous displays. That in turn introduced orientation issues. Sharing the working environment with consistent table orientation and content orientation to each designer becomes a question that needs careful considerations.

Perspective invariance refers to the phenomenon that images and video stream of remote participants are taken from an inconsistent angle from which these images are perceived by the local participant(s) [8, 9]. Many remote collaboration systems are equipped with video recording capabilities to virtually connect two or more dispersed sites. This issue might lead to misunderstandings if not addressed properly. For example, if a person looks at the camera that is located in a position higher than his/her head, the audiences might think that they are taller than him/her. In addition, such setting might cause the audiences to have the feeling that they are being watched by this person, no matter where they are. It appears that this person is looking at each individual of the audiences. This is particularly true when over two remote sites are involved with only one camera per site. The perspective invariance issue would cause false impression to designers with distorted mental space of the working environment and hide certain factors that are essential to common ground.

Designers work together to design goods and products. The final results could be tangible, for instance, dresses, furniture, and buildings. In other cases they could be intangible, for instance, ideas, poetry, and music. Experiments showed that the use of Tangible User Interface (TUI) [10] could affect designers' spatial cognition and creative design processes in 3D design [11]. Thus, both forms of the final products could benefit from TUI.

For tangible products, designers could naturally create and manipulate 3D objects through gesture interactions powered by TUIs. This intuitive perception of the tangible products could help to reduce spatial cognition load and thus enhance design creativity. On the other hand, for intangible design tasks, TUIs could visualize design information and context so that designers could have some specific impression other than abstract concepts. For example, designers who write poetry might be able to move the words around to easily compose phrases and sentences through TUIs. Such interaction paradigm could facilitate brainstorming to generate new ideas.

III. TRADITIONAL COLLABORATIVE MODES

As mentioned above, systems for synchronous collaboration should support cooperation at the same time. However, locations might vary. That could be any of co-located collaboration, where all the designers work in the same real workspace, mixed presence collaboration, where some designers are co-located and others are geographically dispersed, and totally remote collaboration, where each designer stays in his/her individual site alone and joins a shared workspace with others. Single Display Groupware (SDG) model for co-located collaboration and Mixed Presence Groupware (MPG) model for mixed presence collaboration are referred here to help get better understanding of the essentials for remote design collaboration.

A. SINGLE DISPLAY GROUPWARE

Single Display Groupware was initiated by Stewart, Bederson, & Druin [2]. This model allows each co-located designer to interact with the system. It consists of two major components: an independent input channel for each designer (e.g., keyboards and mice) and a shared output channel (e.g., a single display) [2]. Typical systems like shared whiteboard and single tabletop applications fall into this category. The SDG model is one of the early attempts to create a framework that enables collaborative design for designers who are physically close to each other.

SDG is not an appropriate model for remote collaboration since it focuses on supporting users who are co-located. However, it points out several shortcomings with existing systems for co-located collaboration and some approaches that could be taken to tackle these shortcomings by new technologies. It is apparent that some of these shortcomings could be generalized to synchronous remote collaboration systems as well.

SDG adopts certain technologies to deal with these shortcomings, which could inspire the design and implementation of remote design collaboration systems. For example, it was suggested that traditional computer systems did little to encourage collaboration among multiple designers [2]. Apparently, this issue applies to remote design collaboration system as well as co-located collaboration. In order to solve this issue, SDG provides each designer with their individual keyboard and mouse as their separate input channel. Studies [12] showed that individual input device could improve children's learning collaboration, although simultaneous input was not supported. Having their own input devices made them feel they were involved and connected with the system, which encouraged them to learn. In remote design collaboration, certain improvements to these input channels might further encourage collaboration. TUI and simultaneous user interaction could be technological options for these improvements.

B. MIXED PRESENCE GROUPWARE

Mixed Presence Groupware, on the other hand, follows distributed groupware theories and extends SDG, which, in turn supports distributed user interactions. Both distributed and co-located designers could work together over a shared visual workspace at the same time [3]. It is achieved by mixing shared CVEs with the physical/real environment and reflecting collaborators' actions on all displays through network technology. Some systems use conventional PC monitors for displays and they are considered to be insufficient to maintain awareness for collaboration [6, 13]. Others provide large displays, such as tabletops and projections, for each collaborator [14, 15, 16].

Tang identified two major disparities in MPG as compared to co-located collaboration groupware, which were display disparity and presence disparity [3]. As discussed in common ground issues, display disparity refers to the discontinuity of the virtual space and uncertainty of the orientation when horizontal tabletops are connected with vertical displays; while presence disparity refers to the different perception of others one could have when others were remote or co-located. In order to address these two issues, different technologies were implemented to support interactions and collaboration in various MPG systems. Some of these technologies are discussed in the following section.

Tuddenham and Robinson [16] also suggested that these remote tabletop projects were inspired by co-located tabletop research (including SDG). Elements of co-located collaboration were selectively adopted in these systems, so as to compensate the features that are not available in remote collaboration.

After discussing SDG and MPG for supporting synchronous collaboration, it is believed that many conditions/elements in SDG are challenged by distance. These conditions/elements afford many functions and features, which designers are used to and rely on. However, they are not always accessible after they become remote in CVEs. This brings certain problems for remote collaboration, which includes the six issues discussed above. MPG systems focus on the issue of presence and target to mitigate these threatens to promote presence. Through various technologies, these systems could ensure the accessibility of these conditions/elements as well. They could be recorded or captured at the physical environments, taken through the boundary, and then being replicated in virtual working environments. As a result, geographically dispersed designers can still access and benefit from these conditions/elements in remote collaboration. For example, TUI enables natural interactions as it is in SDG.

IV. SPATIAL FAITHFUL GROUPWARE

Spatial Faithful Groupware (SFG) model developed in this paper extends the concept of MPG and focuses on a higher level of presence. Nguyen and Canny (2004) defined spatial faithfulness as the extent to which a system could preserve spatial relationships such as up, down, left, and right. They also identified three levels of spatial faithfulness, which are adapted into this paper to measure the presence in remote design collaboration systems. They are mutual, partial, and full spatial faithfulness.

According to their definition [17], (1) Mutual spatial faithful system simultaneously enables each observer to know if he/she is receiving attention from other observers/objects or not; (2) Partial spatial faithful system provides a one-to-one mapping between the perceived direction and the actual direction (up, down, left or right) to the observers; (3) Full spatial faithful system is an extension to partial spatial faithful systems. It provides this one-to-one mapping to both observers and objects.

Some examples may help to understand these definitions. Considering the case of mobile phones, when someone's phone is ringing, the user can realize that someone else is trying to get in touch with him/her. Otherwise, if the phone is not ringing, it indicates that no one wants to talk to him/her. Thus, the ringing mechanism provides each mobile phone holder mutual spatial faithful awareness of the calling attentions from others. Next, 3G phones with webcams could enable partial spatial faithfulness, since perceived directions from the video can be mapped to the actual directions. However, full spatial faithfulness has not been accomplished yet. When the video is watched by the third person with a different angle, things get changed. Both the user of the phone and this third person will have the same mapping in their mind due to the fact that they are watching the exactly same video. Both of them will have the illusion that the person over the other end of the phone is looking at him/her. Apparently, the two mappings are not consistent and one single camera cannot provide full spatial faithfulness for three of them.

Co-located collaboration groupware is considered as full spatial faithful system. However, most current MPG systems (including those mentioned above) cannot preserve this element/condition for remote design collaboration. Thus, SFG model further extends MPG model with its own interests in providing a full spatial faithful environment, which is another important feature threatened by distance. This SFG model is a descriptive approach to analyze the benefits and effectiveness of spatial faithful environment settings. Each user will be able to perceive consistent spatial information of the shared work environment. This spatial relationship information is individually mapped to each designer's own view angles no matter whether they are co-located or remotely distributed.

V. CASE ILLUSTRATION: REMOTE URBAN DESIGN SCENARIO

In order to better explain the concept of SFG, an urban design task is chosen here as a case illustration. The scenario is described as following: three geographically dispersed designers from different areas are creating a blueprint for a block of residential area, containing facilities such as shopping malls, cinemas and hospitals, etc. Lots of spatial data needs to be dealt with during the design work, which makes this scenario an ideal candidate for demonstration purpose. A full spatial faithful display groupware system is conceptualized in this section. Then this paper will continue to discuss how design collaboration could be influenced by this SFG system in terms of the five issues presented above, as compared against SDG and MPG.

Fig. 1 briefly illustrates typical setups for SDG, MPG, and SFG. As shown in Fig. 1(a), three co-located designers are seated around a table, which can be regarded as a tabletop. They can simultaneously manipulate physical objects on the table to express their opinions. For example, they can pinpoint a wooden model of a shopping mall on a map and then propose the location and orientation of how it should be built. Others instantly pick up the location and orientation information on the same tabletop and may discuss their suggestions accordingly. Fig. 2(b) shows a typical remote collaboration system with single camera setup in MPG. Each designer can see the same blueprint from his or her individual display. Any change made by any designer will be synchronized to all the tabletops to ensure consistency.

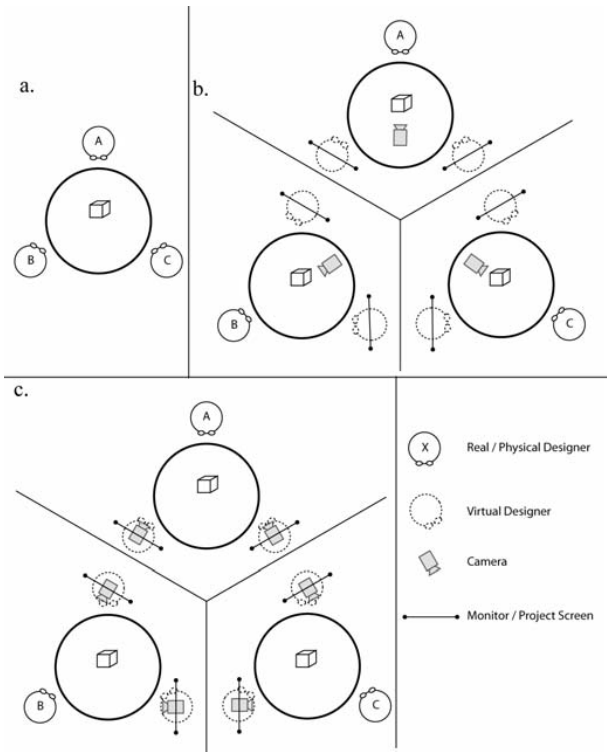

Figure 1. Overview of various collaboration system setups: a) co-located environment, b) MPG system, c) SFG system.

The perspective invariance issue can be easily identified from Fig. 1(b) and Fig. 1(c). Single camera is not enough for conveying accurate spatial information for both users. When A looks at the building block on the tabletop, both B and C might incorrectly perceive A's gaze as shown in Fig. 1(b). According to the definition, this kind of setting cannot provide full spatial faithfulness.

VI. Comparisons among SDG, MPG, and SFG

As illustrated in Fig. 1(c), multiple cameras are used to preserve the information of location and gaze direction of the remote designers. They are located and orientated where the remote virtual designers would be seated and facing. SFG model is still MPG in a sense that all the distributed designers see via his or her own display. However, with the help of multiple cameras, the level of presence is promoted to full spatial faithfulness. That is to say, the full spatial faithfulness feature in SDG can be somehow regenerated for designers that are geographically dispersed. They can directly talk to each other and precisely perceive others' facial expressions, body movements, gaze directions and gestures, as they were facing each other. In that sense, SFG is therefore an extension of MPG because it provides better immersive experience of the working environment.

As indicated by Table 1, full spatial faithfulness enabled by SFG could benefit remote design collaboration by addressing perspective invariance issue. As a consequence, some other issues could be mitigated accordingly since these issues are not independent or isolated. Instead, they are interrelated and might be affected consequently. They could discuss things naturally as if they were co-located. Intentional and consequential communication clues behind them as well as their unintentional communication ones would be perceived accurately and naturally. Gaze direction and other communication clues are perceived so they could just nod to someone without worrying about being misunderstood. In this urban design scenario, such improvements could enable remote designers to perceive better awareness of other designers and objects. That would further improve design performance with increased efficiency. The following section details certain remote collaboration issues in SDG, MPG, and SFG.

A. Member Identity Embodiments

As discussed above, embodiments afford clues for identifying other designers. Some of these clues, which could be one's on face, voice, and even smell, are directly gathered

TABLE 1. Comparison among three groupware models

Factors/Issues	SDG	MPG	SFG
Member embodiments	plenty of resources for identification	limited by technology	support most SDG resources, better than MPG due to the improved perception of other designers and the environment
Intentional and consequential communication	ubiquitous and handy	limited by embodiments	supported by precise video taken from remote site
Display disparity/Orientation	N/A	hard to connect heterogeneous displays	homologous displays provide a unified and immersive environment to every single designer as in SDG
Shared awareness	face-to-face	impeded by presence and perspective invariance issue	improved by full spatial faithfulness
Design activities	real physical objects	TUI with shared virtual objects	same as MPG, but with spatial faithful perspective of the objects

by human sensational organs such as eyes, ears, and nose. Kock proposed the psychobiological model to explain why human favor face-to-face co-located communication based on Darwinian evolution theory [18]. He stated that human developed many types of organs including sensory and motor organs primarily for face-to-face communication. According to this theory, it can be inferred that SDG, as a form of face-to-face platform, would provide plenty of resources to feed to human sensory organs. With these resources, human brain can then process these resources and obtain accurate results for identification.

Both MPG and SFG could provide clues that are sufficient for identification. For example, a name list of all the designers or the arm shadows would easily clarify who is participating and what roughly are the designers doing. However, neither MPG nor SFG could afford as many sensing clues as those in SDG due to the limitation of current technologies. This lack of naturalness might cause higher cognitive load in the brain. Following the arm shadow example discussed above, one has to imagine what it would be like for the remote designers to have such arm shadow effects. On the other hand, SFG supports more clues compared to MPG because it adds full spatial faithfulness in the video for all the designers. Therefore, this would contribute to higher degree of naturalness, which demands less cognitive load for identification according to this psychobiological model.

Furthermore, indirect clues such as intentional and consequential communication clues can further benefit member identification by providing supplementary evidence from the embodiments. This is further discussed in the next section.

B. INTENTIONAL AND CONSEQUENTIAL COMMUNICATION

Intentional communication and consequential communication are another two communication channels that are more naturally perceived in SDG. They have been extensively used in collaborative design and they work very well for expressing concepts [19]. Similarly, limitations of current technologies restrict the full potentials of these two communication channels.

The embodiment in MPG is one of the issues that lead to this situation, which is clearly depicted in the Fig. 1(b). Both designer B and designer C could see the same video of designer A. Thus, A could not differentiate whom he/she is talking to. When A intends to talk to B, for instance, who might work for transportation bureau for designing highways in a city, A just looks at the camera in front of him/her and talks directly to it. A's intentions will be perceived by C as well as B, who is not the one A intends to talk to. C would not realize A's original intentions without A's explicitly telling who he/she is talking to. This is not as natural as SDG, which could cause confusions and misunderstanding.

MPG, on the other hand, could support natural intentional and consequential communication through multiple cameras as shown in Fig. 1(c). A could look at B's embodiment on the display and talk to B as if they are co-located. Thus, A only communicates his/her intentions to B without confusing C. In addition, A's consequential communication information is also selectively relayed to B and C in consistent with the seating plan. The precise video taken from remote site is the key feature for supporting such natural communication.

C. DISPLAY DISPARITY/ORIENTATION

MPG model points out the display disparity issue, which related to the difficulties in connecting heterogeneous displays. SDG, as implied by its name, uses one single display for all the designers so that display disparity is not applicable. MPGSketch [3] leveraged transformed mouse cursors to deal with this issue. If the same mechanism is applied in Fig. 1(b), for example, the mouse cursor of the local designer remains unchanged while the other two cursors will be rotated for 120 degrees and 240 degrees respectively. This mechanism could afford each local designer with a brief notion of the directions where the other two designers are facing. However, it has nothing to do with the orientation of the contents/objects that the designers are working on. Therefore, Tang introduced heuristic seating methods [3]. This heuristic seating method assigns the designers, who use conventional vertical displays, on the same side of the virtual table and the rest of the sides of the table to those who use horizontal displays. Through this way, the majority of the designers could be served well. However, it could not always guarantee proper sides for all designers since there are just four sides of a normal table.

In contrast, SFG adopts another approach. Since all the designers are individually dispersed, a round horizontal tabletop is chosen. No side is applicable and designers are evenly distributed around the virtual tabletop in this case. Each designer uses the same tabletop to avoid heterogeneous displays. Controversially, this kind of set up might introduce certain inconvenience since round displays are quite rare. On the other hand, designers might need to adapt themselves to this setup and get used to it.

D. SHARED AWARENESS

SDG maintains full spatial faithful awareness and each designer is aware of other designers (who are they, what do they do) and artifacts or objects (who is making this, who wants to grab that) in the workspace [20]. On the other hand, issues like presence disparity, display disparity, and perspective invariance interfere with designer-designer and designer-object awareness in MPG. The designer-designer awareness is about the extent to which each designer knows about others, as well as the extent to which one can afford to be known by others. The designer-object awareness deals with the extent to which designers comprehend the meaning of the objects.

Unlike partial spatial faithfulness found in MPG, SFG employs multiple cameras for full spatial faithfulness. Similar to SDG, precise spatial information can be naturally perceived for better awareness. The perspective invariance example discussed above shows that designer-designer awareness is well maintained by persevering gaze direction and other intentional or consequential communication clues in SFG. For designer-object awareness, as shown in Fig. 1(c), suppose A is talking about designing an entrance for a building, which is represented by a wooden cube on the tabletop. Both B and C could see A's movements and gestures from their individual perspective and then roughly tell which face of the cube is being referred to. This enables efficient communication since A does not need to explicitly say something like "east or west of the building" to the other two designers. Instead, A could just use his/her fingers to point to it, saying "how about this side?" The other two would instantly be aware of the referred object and get better comprehension of the A's idea.

E. Design Activities

Models such as wooden blocks of the buildings are often used to intuitively illustrate an urban design plan from a bird's-eye view. Urban designers could manipulate these blocks to see how it promotes or interferes with other conditions. Due to the creativity and dynamic nature in design, one cannot expect a series of deterministic procedures to be taken for design tasks. Each design task should have some uniqueness in its final product. In SDG, by the easy manipulation of these artifacts and objects, designers might inspire design creativity. For example, when a designer unintentionally moves a skyscraper from one spot to another in order to find a suitable location, another designer might find out that the original location would be good for a park. Such naïve manipulation could possibly promote design creativity.

Therefore, in MPG and SFG, Tangible User Interface is utilized to encourage this type of design activity in remote collaboration. Those artifacts might be digitalized or equipped with various sensors so that they can be virtually shared by all the designers. When coupled with full spatial faithfulness support in SFG, these virtually shared artifacts could afford better designer-object awareness. Same manipulation effects could be perceived as those in SDG. Furthermore, digitalization of the artifacts could make design process efficient and effective. For example, enlargement or shortening can be easily accomplished without starting all over again. Thus, one can randomly resize the object until the best effect is achieved. Otherwise, many objects with various sizes need to be tried out one by one, which can be time-consuming and cumbersome.

VII. Conclusion

This paper discusses certain groupware issues in traditional remote collaboration systems. A model for remote collaboration named Spatial Faithful Groupware (SFG) is developed based on Single Display Groupware and Mixed Presence Groupware. This SFG model enables both intentional and consequential communication cues, like facial expressions, body languages, gaze directions and gestures, to be transmitted with embedded spatial information that could be properly perceived by remote designers. An urban design scenario is also presented as a case illustration to demonstrate the details of this model. Spatial faithfulness and its effects on remote design collaboration are the two major issues discussed in this paper. However, the model is not limited to this specific scenario. The SFG model and the findings from the paper could be generalized in other similar design tasks that demand remote collaborative efforts.

References

[1] ThinkLab. (n.d.) Retrieved January 15, 2008, from http://www.thinklab.co.uk

[2] J. Stewart, B. Bederson, and A. Druin: Single display groupware: a model for co-present collaboration, *Human Factors in Computing Systems: CHI 99* (pp. 286-293). ACM Press. 1999

[3] A. Tang, M. Boyle and S. Greenberg, Display and presence disparity in Mixed Presence Groupware. *JRPIT*, 37:2, 71-88 2005

[4] G.M. Olson: 2008. The challenges of remote scientific collaboration. Retrived Feb 1, 2009 from National e-Science Centre Website: http://www.nesc.ac.uk/talks/745/GaryOlson.pdf

[5] LW. Barsalou, PM. Niedenthal, AK. Barbey, and JA. Ruppert, Social embodiment. In B. H. Ross (Ed.), *The psychology of learning and motivation,* Vol. 43 (pp. 43-92). San Diego, CA: Academic Press. 2003

[6] C. Gutwin, and S. Greenberg , A Descriptive Framework of Workspace Awareness for Real-Time Groupware. *Comput. Supported Coop. Work* 11, 3 (Nov. 2002), 411-446. 2002

[7] L. Segal, Effects of checklist interface on non-verbal crew communications, NASA Ames Research Center, Contractor Report 177639. 1994

[8] J. Cerella, Pigeon pattern perception: limits on perspective invariance, *Perception* 19(2) 141 – 159. 1990

[9] D. Vishwanath, AR. Girshick, and MS. Banks, Why pictures look right when viewed from the wrong place. *Nature Neuroscience* 8, 10, p1401-1410. 2005

[10] Tangible User Interface. (2008, November 25). In Wikipedia, The Free Encyclopedia. Retrieved 15:10, February 2, 2009, from http://en.wikipedia.org/w/index.php?title=Tangible_User_Interface&oldid=253954038

[11] M. Kim and L. Maher, The impact of tangible user interfaces on spatial cognition during collaborative design, *Design Studies*, Volume 29, Issue 3, Pages 222-25 2008

[12] K. Inkpen, K.S. Booth, M. Klawe, & J. McGrenere, The Effect of Turn-Taking Protocols on Children's Learning in Mouse-Driven Collaborative Environments. *In Proceedings of Graphics Interface (GI 97) Canadian Information Processing Society*, pp. 138-145. 1997

[13] C. Gutwin, and S. Greenberg, Design for individuals, design for groups: tradeoffs between power and workspace awareness. *In Proc. CSCW*, 207-216. 1998

[14] JC. Tang, and S. Minneman, VideoWhiteboard: video shadows to support remote collaboration. *In Proc. CHI*, 315–322 1991

[15] H. Ishii. and M. Kobayashi, 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. 1992

[16] P. Tuddenham and P. Robinson, Distributed Tabletops: Supporting Remote and Mixed-Presence Tabletop Collaboration, *Horizontal Interactive Human-Computer Systems*, 2007. TABLETOP '07. Second Annual IEEE International Workshop, pp.19-26, 10-12. 2007

[17] D. Nguyen, and J. Canny, Multiview: Spatially Faithful Group Video Conferncing. *Proc. CHI 2004*, ACM Press (2004), p512-521 2004

[18] N. Kock, The Psychobiological Model: Towards a New Theory of Computer-Mediated Communication Based on Darwinian Evolution. *Organization Science* 15, 3 (Jun. 2004), 327-348. 2004

[19] A. Tang, C. Neustaedter, and S. Greenberg, Embodiments for Mixed Presence Groupware. *Research Report* 2004-769-34, Department of Computer Science, University of Calgary, Calgary, Alberta, Canada. December 21. 2004

[20] G. Mcewan, M. Rittenbruch, and T. Mansfield,. Understanding awareness in mixed presence collaboration. *In Proceedings of the 19th Australasian Conference on Computer-Human interaction: Entertaining User interfaces,* 2007