Usability Issues of an Augmented Virtuality Environment for Design

Xiangyu Wang[1] and Irene Rui Chen[2]

[1] Lecturer; [2] Ph.D. Candidate
Design Lab, Faculty of Architecture, Design and Planning, The University of Sydney, Australia
x.wang@arch.usyd.edu.au, IreneRui.Chen@gmail.com

Abstract. This paper presents a usability evaluation of an Augmented Virtuality (AV)-based system dedicated for design. The philosophy behind the concept of the system is discussed based on the dimensions of transportation and artificiality in shared-space technologies. This system is introduced as a method that allows users to experience the real remote environment without the need of physically visiting the actual place. Such experience is realized by using AV technology to enrich the virtual counterparts of the place with captured real images from the real environment. The combination of the physicality reality and virtual reality provides key landmarks or features of the to-be-visited place, live video streams of the remote participants, and 3D virtual design geometry. The focus of this paper describes the implementation and a usability evaluation of the system in its current state and also discusses the limitations, issues and challenges of this AV system.

Keywords: Augmented Virtuality, Mixed Reality, Virtual Environments.

1 Introduction

Augmented Virtuality (AV), similar to Augmented Reality (AR), is a type of Mixed Reality user-interface. The taxonomy of Mixed Reality interfaces, introduced by Milgram [1][2] describes methods of combining real-world and computer-generated data. While Augmented Reality involves adding computer generated data to primarily real-world data, Augmented Virtuality deals with predominantly real-world data being added to a computer-generated virtual environment. Augmented Reality was investigated as one solution for displaying preoperative images related to the neurosurgeon's view of the operative field. In some neuro-navigation systems, selected information from preoperative images is displayed as two-dimensional (2D) monochromatic contours on the right ocular of the surgical microscope [3]. This solution has certain limitations. For instance, multimodal and preoperative three-dimensional (3D) images are only displayed as 2D monochromatic contours on microscope oculars, with a resulting information loss [4].

A system has been presented for creating 3D AV scenes for multimodal image-guided neurosurgery [4]. An AV scene includes a 3D surface mesh of the operative field which is reconstructed from a pair of stereoscopic images. This process acquired through surgical microscope, and 3D surfaces segmented from preoperative

F. Lehmann-Grube and J. Sablatnig (Eds.): FaVE 2009, LNICST 33, pp. 151–164, 2010.

multi-modal images of the patient [5]. The performance evaluation of this system is used for a physical phantom and report the results of six surgical patients where AV was used in conjunction with AR. The clinical advantages of this visualization approach are highlighted in the context of brain surgery, mainly surgery of cortical lesions located in eloquent areas where multimodal preoperative images are needed [6]. Therefore, it seems that AV systems have some advantages over AR systems in certain application circumstances.

2 Mixed Reality Boundaries Theory

Benford [7] introduces the three dimensions of transportation, artificiality, and spatiality as a means of classifying shared-space technologies. There are three motivations behind this means [7]. It allows people to design trade-offs involved in determining the costs and benefits of supporting different spatial properties such as containment, topology, movement, and shared coordinate systems. Secondly, the gaps in the technology can be identified where new approaches might be developed so the insights can be provided to new directions of research [7]. The final motivation is to produce a simple and inclusive taxonomy that can help people to summary out the key principles in order to understand the primary distinctions between them [7]. This study reflects on the relationship between dimensions of transportation and artificiality according to the classification from shared-space technologies.

2.1 Transportation

The concept of transportation is comparable to the concept of immersion from virtual reality. Both are in relation to an interface technology that has been designed to introduce a participant into a new environment while at the same time excluding sensory stimuli from the local environment [8]. However, there are two aspects which are different from transportation to immersion. Firstly, transportation is unlike immersion, it includes the possibility of introducing remote participants and objects into the local environment that then becomes augmented rather than excluded. This is the main trend in Augmented Reality and ubiquitous computing and may be an important first point for designing technologies that need to be integrated with existing tools as part of the daily working environment. Another difference is that transportation considers how groups of participants and possibly other objects such as physical documents might be transported together. Immersion has typically been paying attention to individual participants [9]. Even where sharable interfaces such as projected displays have been used, the effects on and role of local objects have not been considered.

As a sub-mode of Mixed Reality (MR), Augmented Virtuality (AV) technology can insert real contents into a predominantly virtual environment [16] and AV technology provides a means to merge a richly layered, multi-modal, 3D real experience into a virtual environment [13]. The study we represent later is an Augmented Virtuality-based system which provides the ability for a remote architect to explore a virtual counterpart of a remote place that needs to be inspected for defects. The system actually provides an experience of exploring a virtual representation of a real place. Therefore, in this case, it characterizes the essential difference between the concepts of local and remote.

2.2 Artificiality

The dimension of artificiality focuses on the extent to which a space is either synthetic or is based on the physical world. This bridges the extremes from wholly synthetic to wholly physical environment such as between the total synthesis of an environment, independent of all external reality from nothing but bits in a computer to the electronically mediated delivery of a physical place and firmly based in everyday reality [9]. Different technologies can be located along this dimension according to the ratio of physical to synthetic.

In the study presented here, the counterpart space explored is created to contain real-world images as object textures by mapping certain real elements extracted from the real space onto a virtual environment for richness. In this way, participants can have a strong sense of involvement in the remote sense since the scene contains real images. Especially, the photos have been taken under similar positions lighting conditions. Therefore, participants can have a feeling of realism through navigating the virtual environment.

The relationship between the transportation and artificiality can be explained in the Fig. 1, which describes the broad classification of shared spaces according to transportation and artificiality [9]. The black contour highlights the connection between the physical reality and virtual reality for this study.

As described before, the textures can be taken from landmarks/feature objects existing in the real space and which have dual (mirror) objects in the virtual world. This offers the advantage of making a virtual world appear as the real world and the augmented virtual world could be viewed as a mirrored version of the real place as show in Fig. 2.

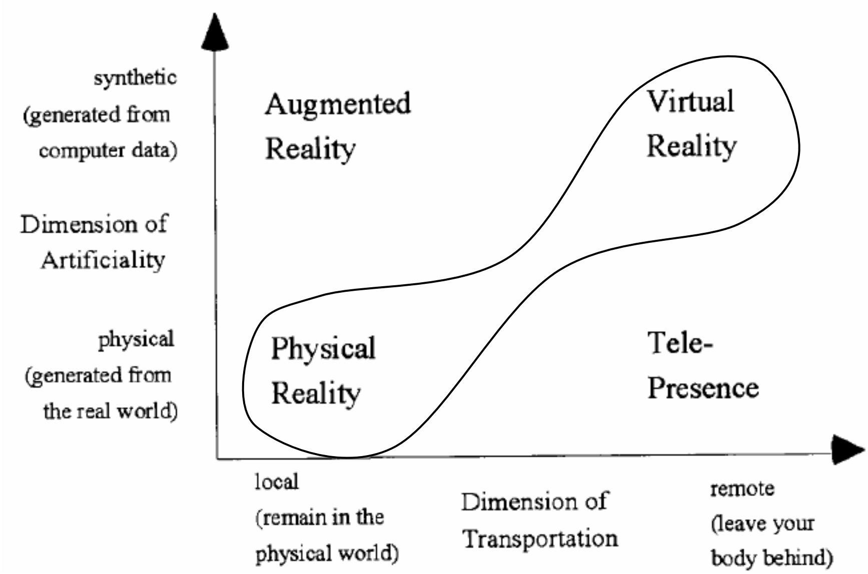

Fig. 1. Broad classification of shared spaces according to transportation and artificiality adapted from [9]

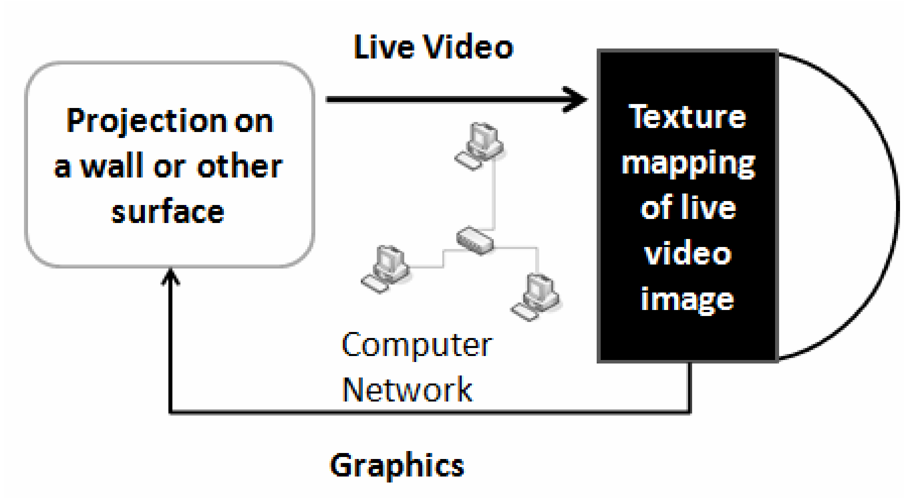

Fig. 2. Creating a simple mixed-reality boundary adapted from [8]

3 Research Issues for Experimentation

The prototype and implementation of the AV system has been completed as an interface which enables the user to inspect remotely. It also provides a mean for distant collaboration as well as an improved presentation of the AV space. The experimentation stage involves the controlled usability experiment to validate the concept of AV as an intuitive interface paradigm capable of supporting remote inspection.

One usability study is devised to investigate how AV space might provide perceptual and cognitive support and augmentation, for individual designers interacting within a virtual environment which contains real entities that can be potentially exploited in useful ways. Experiments should be devised in a way to study the effects of the merging of real entities into a virtual environment on the nature of a person's perceptual and cognitive performance as compared with a purely real environment. The test task(s) would be specifically designed to address issues of designer's comprehension and retention of spatial information. Furthermore, usability engineering approaches would be adopted to perform meaningful usability evaluation of the AV spaces. For example, special usability questionnaires and associated data collection strategies would be developed in order to assess certain features of AV space, such as extent of presence. The authors will base the development of the questionnaires on the authors' previous work [14] and widely accepted theoretical models such as the model of presence [15] that can be easily generalized to the AV case.

4 Methods

The prototype implementation of the AV system has been completed currently as an interface for users to collaborate remotely. The experimentation stage is to validate the concept of AV as an effective interface paradigm capable of supporting remote collaboration. The AV system is customized as the experimental facility used as the vehicle for experimentation presented in the next section.

4.1 Experiment Setup

The steps for setting up the AV system have been described as follows:

1) Make sure all three computers are running Max/Msp with Jitter properly.
2) Make sure all three computers are on the network, and obtain the IP address
3) Install a web cam, better to be DirectX compatible
4) Connect each computer to the corresponding projection screen.
5) The three computers are arranged in a master – slaves' structure (one master and two slaves). There are three different version called "projects' in the program folder. You should run the appropriate corresponding "project" program file. Also, the IP address should be adjusted to the corresponding position of computer. Therefore, the multi –projection system has been built for the AV environment (See Fig. 3 for details).
6) The computer controlling the middle computer is the "master". The input to this computer controls the movement in the AV environment (forward, backward, turn right, turn left)
7) The sensors are also connected to the middle computer via USB. The port number is fixed so don't change it to other USB socket.

After everything is setup, when you step on the sensors, in the program (the "project" file), the corresponding objects would flash as you step. Then the program is ready to run.

This empirical study is devised to investigate how AV environment might provide perceptual and cognitive support and augmentation, for designers interacting within a virtual environment which contains real entities that can be potentially exploited in useful ways. This study involves individual usage of the AV environment to explore the potential usability issues involved in the system. The purpose of the study is to investigate whether human's capability of comprehending the spatial information and

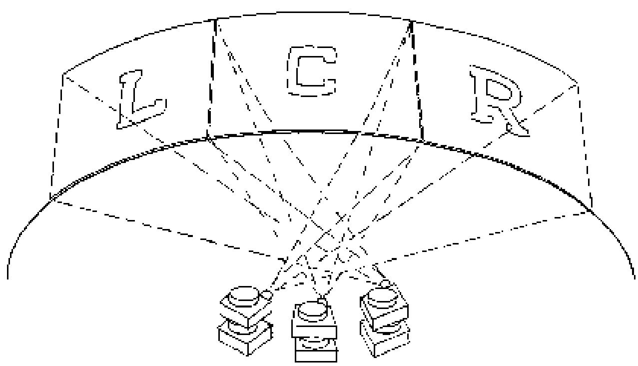

Fig. 3. Multi -Projection System

Fig. 4. Two remote participants work in different locations adapted from [13]

effecting desired actions based on the resulting mental model constructed from perceiving the AV space is improved compared against real-world experience. This study was devised in a way to study the effects of the merging of real entities into a virtual environment on the nature of a person's perceptual and cognitive performance as compared with a purely real environment. Furthermore, this study was conducted to investigate human's experience (e.g., the sense of presence) that results from the interpretation of the mental model constructed within the AV space. Usability questionnaires were developed in order to assess certain usability features of the AV space, such as extent of presence. The development of the questionnaires was based on the Wang and Dunston's previous work [16] and widely accepted theoretical models such as the model of presence [17] that can be easily generalized to the AV case. In addition, this system can be focused on validating the collaborative benefits offered by the system. The test task(s) can be collaborative design defects inspection between two remote participants shown as in Fig. 5), which are specifically designed to address issues of designer's comprehension and retention of spatial information. One can use the multi-projection systems to walk through the AV environment as shown in the right side of the Fig.4. Another one can wear the Head Mountain Display (HMD) to explore the AV environment as inserted in the left side of the Fig.4. They can work as a team to collaborate remotely.

5 Experiment

The purpose of the usability experiment is to investigate whether human's capability of comprehending the spatial information and effecting desired actions based on the resulting mental model constructed from perceiving the AV space is improved compared with completely real environments. Furthermore, the experiment was conducted to investigate human's experience (e.g., the sense of presence) that results from the interpretation of the mental model constructed within the AV space.

This experiment has been conducted, where participants worked on several usability tasks and then completed a set of questionnaires. The experiment took about one hour including time to complete the questionnaires. This experiment involves individual usage of the AV environment to reveal the potential usability issues involved in the system. The second experiment was implemented in the context of practical application where photo-based method was used as the benchmark to compare with the AV system in their effectiveness of inspecting defects remotely, in order to validate the spatial benefits provided by the 3D AV space. Each session took about one hour including time to complete the questionnaires. Six human subjects were invited to attend the experiment to perform tester task(s) in the following environments. The subjects are from various backgrounds such as architecture, IT, accounting and finance. The ages are around 25 to 29.

5.1 Experimental Procedure

An AV environment is provided to the participants. The experimental task is to explore the AV environment provided, and draw a sketch layout map of it. The participants can draw down everything that appears to be part of the environment.The participants are expected to carefully explore the computer-generated AV space and record as many details as possible (e.g., the relative size of different rooms, size of furniture, the orientation and etc). It was suggested that the participants should record any significant marker, pattern, or picture which helps them to perform the task.

The participants were also recommended to record any objects from the photo background but seems to be part of the environment space. At any point, where draft drawing is not applicable, participants can always write shorts comments to explain in detail.

In another section, a set of print photos of the real space/place are provided to the participant. These photos were taken from different positions and perspectives to cover the entire sight of the real place. A general 2D site map of this space is also provided to the participant. The task is to identify the defects from the photo, and record them in details on the site map.

After identifying all the defects, the participant should redesign the arrangement of interior space. Firstly, they should identify all the entrance/exit and the locations of emergency equipment of this space, and draw the possible walk flow. Then, participants need to rearrange the furniture to the appropriate place. During the process, the participant should also take into consideration of the nature of the functions at different areas of the space. The same task and procedure were required to be implemented using the AV system in the second session.

In this study, a pre-defined AV environment is given to the participants. The experimental task is to explore the AV environment and then sketch out its layout and also fill in the post-session questionnaires for their experience and reflections. The participants should draw down everything that appears to be part of the environment and is useful for them to mentally re-construct the given virtual environment. The participants are expected to carefully explore the computer-generated AV space and memorize as many details as possible (e.g., the relative sizes of different rooms, size and orientation of furniture, etc). It is suggested that the participants should memorize the layout of the environment based on landmarks and features while navigating. At any point where sketching is not applicable, the participants can always write short comments to explain.

6 Development of Questionnaires

Firstly, some questions regarding the participant's background need to be investigated such as if the participants feel comfortable to work on computers. There are some options from dislike, neutral, comfort and others for them to describe. Another essential question is that if they have been playing AV which helps to locate computer gamers. The result shows three participants found it's comfortable and another three participants found it's neutral. The reason to ask these questions is that if certain data in the following questionnaires seems special among the others, their background information might be an influence to see if there is a correlation between their background and particular data. There is one participant who has 5 to 10 years experience and another one who has no experience at all with playing video games. The others have less than 5 years experience.

There are 18 items (see Fig. 5) for users to complete in this pilot study. The rating for the experience for each question was categorized with none, poor/mild, moderate, good and excellent. Corresponding to this rating scale, the numeric scale was set from 1 (none) to 5 (excellent). In the first study, these eighteen questions have been designed to cover six major aspects including sense, recognition, mechanism, consistency, environment reflection and distraction. Furthermore, the sensory part is considered as the being present, object moving, orientation and environment reflection. The relationships between these aspects are shown in Fig. 5.

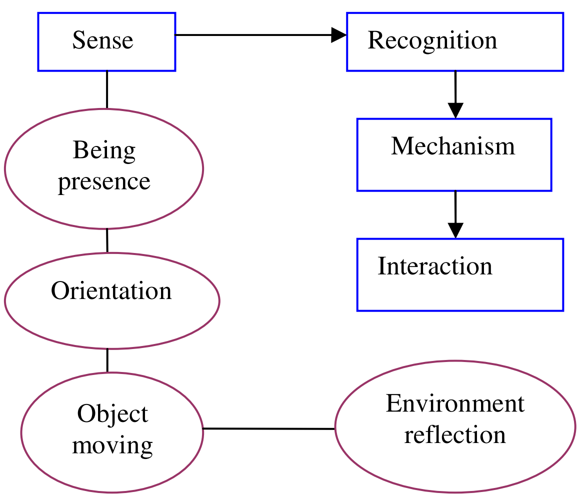

Fig. 5. Questionnaire Structure

The 18 questions have been designed to categorized from the sense, recognition, mechanism and the interaction. Furthermore, the sensory part has been considered from the being present, object moving, orientation and environment reflection. The relation between these aspects can be shown in a structure as depicted in Table 1.

Table 1. List of Questionnaires

No	Structure	Questions	Average
1	Sense	How strong was your sense of being present in the AV environment?	3.50
2	Sense	How strong was your sense of objects being present in the AV environment?	4.00
3	Sense	How strong was your sense of object moving in the AV environment?	3.00
4	Sense	How strong was the sense of movement (yourself) in the AV environment?	3.50
5	Sense	How strong was the sense of presence in the AV environment provided by the multi-projection system comparing with single desktop display?	3.33
6	Sense	How well could you maintain the sense of direction in the AV environment?	3.33
7	Sense	How strong is the realistic feeling of the AV environment?	3.50
8		How well could you actively examine virtual objects in the environment?	3.67
9	recognition	How well do you recognize the AV environment from the real environment?	4.17
10	recognition	To what extent did the environment seem realistic to you?	3.50
11	recognition	To what extent did your movements in the AV environment seem natural to you?	3.17
12	Mechanisms	To what extent did the mechanisms which controlled your movements in the environment seem natural to you?	3.00
13	Consistency	To what extent did your experience of the experiment seem consistent with your real world experience?	2.83
14	Environment reflection	To what extent did the environment's reactions to your action seem realistic?	3.17
15	Distraction	How much efforts did your spend when looking at the multi-projection screen system?	2.67
16	Environment Reflection	How responsive was the AV environment to actions that you preformed?	3.50
17	Distraction	To what extent did the control devices distract you from performing assigned tasks?	4.00
18	Distraction	To what extent did the multi- projection display distract you from performing assigned tasks?	3.00

The presence in the context of this study includes self-presence reflected by the question 1 and the object presence reflected by the question 2. Question 3 and 4 considered participants' sense of movements of themselves and the objects respectively. In particular, the question 5 asked the participant to compare the sense of presence in the context of the multi-projection system and the traditional desktop display. Moreover, the feeling for realism has influences on the recognition for human. Therefore, some aspects such as the sense of direction and the responsive performance were examined by question 8 to 11. The consistency as reflected by the question 13 was compared between the real world experience and the virtual environment. Another aspect in the questionnaire was focused on the realism of the AV environment's responses to actions from participants as measured by the question 14 and 15.

7 Results for Data Analysis and Interpretation

Question 1 to 7 in Table 1 aimed to investigate the sensory aspects in the AV environment. The average rating score for these seven questions (3.5/5.0) showed that the participants gained a better sense from the AV environment. Initially, it was noted that the average rating of the sense of being present in the AV environment was 3.5/5.0, compared with the 4.0/5.0 for the sense of objects being present in the AV environment. The question 3 and 4 focused on the sense of movements. It is necessary to discern the differences between the average rating 3.5/5.0 for the sense of participant movement and 3.0/5.0 for the sense of objects movement in the AV environment. It implied that the AV system might enable participants to control their own movements (e.g., participants could navigate the AV space through the sensor pad with 4 arrows in four directions) in a natural way.

It was also observed that the multi-projection system provided more sense of presence in the AV environment as compared with single desktop displays from the score of 3.33/5.0. However, many subjects complained about the dumbness of the sensor pad. It may be because of the navigational cue that the participants haven't really been adapted from traditional mice and keyboard combination to the sensor pad.

Both the sketches and the rating for question 6 (3.33/5.0) showed that it was helpful to use the AV system to maintain the sense of direction in the AV environment. Particularly, all the participants had no trouble to recognize the orientation through the drawing and identify most of defects in the AV environment (see an example of a sketch from one participant in Fig.6). They could accurately place the main entry, main door and classrooms in correct orientation and good order, even the location of the toilet, however, they might have problems with the exact locations of tables and chairs. It was apparent that the participant could accurately draw the location of objects in details with the interaction of the AV system. Objects such as desks, draws, windows/exits could be well recognized and memorized from the AV space. In contrast you can see the drawing based on photos from Fig. 7 that the participant hardly can locate any detailed defects except the entries and exits. Similar positive performance results were also observed from other participants' sketches. However, this is the first time the participants had been experiencing and interacting with the AV system. If more training were allowed, the performance results should have been even better.

As apparently shown in the consistent ratings from the question 7 and 10 (both were rated as 3.5/5.0), most participants found that the AV environment looked quite natural and realistic as the real world. The rating for the question 8 (3.67/5.0) suggested that the AV system can well support participants to actively examine virtual objects. The sensor pad-based navigation enabled the participants to control the distances from the objects for a closer view. The questions 9 to 11 focused on the issue of recognition. The average from these values was 3.61 which implied that

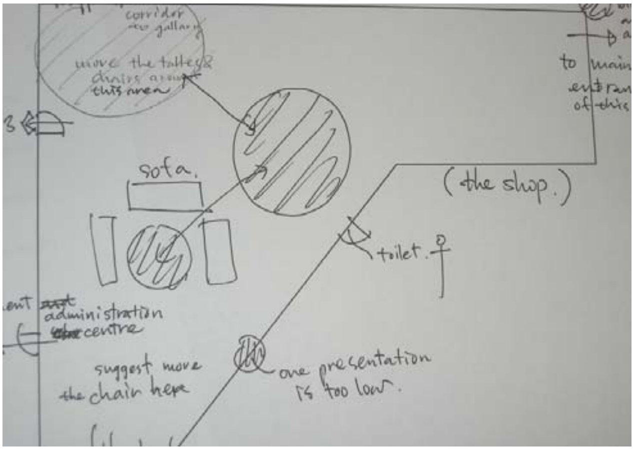

Fig. 6. An example of how students address the defects with descriptions while using the AV environment

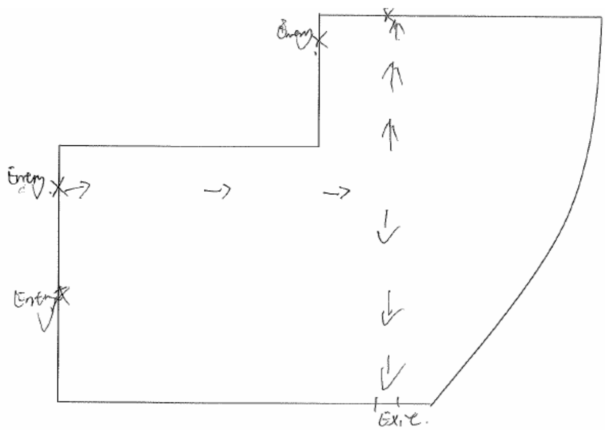

Fig. 7. An example of how students address the defects with descriptions while using the photo-based method

participants could have a natural perspective on the virtual objects inside the AV environment. The average rating 4.17 among the highest rank 5.0 for the question 9 strongly indicated the high level of realism rendered in the AV environment.

Regarding the consistency of the experience in the AV environment with the real world experience, the rating (2.83/5.0) from the question 13 indicated that the 3D modeling of the AV environment needs to be improved. For example when participants navigated the space, sometimes they might hit the wall. Unfortunately, the current AV system was not able to model the realistic wall and participants' responses. Such interactive behaviors should be modeled to improve the realism and the complexity of the AV environment.

The question 17 and 18 considered the distraction issue from the performance. For this question, it has been explained to the users that 1 represents the worst case. And 5 is the least distraction. In this case, distractions partially came from the forced engagements of participants' feet in the sensor pad for navigation and the physical and psychological adaptation to the vection created by the multi-projection system. The phenomenon of vection in human perceptual systems studies is basically defined as visually induced perception of self motion. Question 17 rated the distraction level from the use of sensor pad as 4.0/5.0. In contrast, question 18 rated the distraction from multi-projection display as 3.0/5.0.

As mentioned from the previous section, participants' background information was taken into account together with the data from questionnaires. Special attention was paid to those who had no previous experience in virtual environments. Rating results did not help to infer any correlation between participants' background and their perceptions on the system for this study.

8 Limitation and Future Work

Early experiments [10] with virtual reality technology have suggested that while the degree of presence experienced may increase with the degree of immersion, other factors also make a profound contribution. These include whether users can see their own virtual body images [11] or the use of physical walking as a means of moving through a virtual environment [11]. The same distinction can be seen in shared-space technologies. Although the system presented in [12] is a highly transporting interface through a combination of large-screen displays and background substitution with real scene, the users in the experimentation remained aware that they were standing in their own physical space. The system presented in this paper can be used for both individual and two pair participants for collaborative design activities. The possible collaboration can be considered such as the way mentioned in the section 4.1 as shown in Fig. 5. However, the system might not be appropriate for more than two participants, because navigation through the virtual environment cannot be easily tracked. Furthermore, with more participants, it is difficult to maintain forms of spatial referencing, such as gazing direction whereby participants cannot infer who is present to whom at any moment in time from the virtual representation.

The rendering time for the models in the real scene takes time to process, so sometimes the system might not give instant feedback from the instant movement of participants. Therefore, this system can be improved for further experimentation in the near future. A larger scale of experimentation could reveal more usability issues.

9 Conclusion

This paper presents a usability evaluation of the Augmented Virtuality (AV)-based system for design. This AV system allows participants to experience the real remote environment without the need to physically stepping out of the work stations. The usability study with invited subjects was conducted and the results showed that the AV system is generally helpful and supportive for designers to achieve better sense of involvement in the remote scene and it could solve some problems with low cost such as landscape design. Designers do not need to visit different places and collect all the information from past to now, the AV system could save them high cost to investigate how to evaluate and solve the problem for the overall urban design and planning in certain circumstances.

References

1. Milgram, P., Kishino, F.: Augmented Reality: A Class of Displays on the Reality-virtuality Continuum. In: SPIE Proc. Telemanipulator and Telepresence Technologies, vol. 2351 (1994)
2. Milgram, P., Kishino, F.: A Taxonomy of Mixed Reality Visual Displays. IEICE Transactions on Information Systems, Special Issue on Networked Reality E77-D(12) (December 1994)
3. Luber, J., Mackevics, A.: Multiple coordinate manipulator (mkm). A computer-assisted microscope. In: Lemke, H., Inamura, K., Jaffe, C.C. (eds.) Proc. Computed Assisted Radiology (CAR 1995), Berlin, Germany, pp. 1121–1125 (1995)
4. Edwards, P., King, A., Maurer, C.J., de Cunha, D., Hawkes, D., Hill, D., Gaston, R., Fenlon, M., Jusczyzck, A., Strong, A., Chandler, C., Gleeson, M.: Design and evaluation of a system for microscope-assisted guided interventions (MAGI). IEEE Trans. Med. Imag. 19(11), 1082–1093 (2000)
5. Jannin, P., Fleig, O., Seigneuret, E., Grova, C., Morandi, X., Scarabin, J.-M.: A data fusion environment for multimodal and multi-informational neuronavigation. Comput. Aided Surg. 5(1), 1–10 (2000)
6. Jannin, P., Morandi, X., Fleig, O., Le Rumeur, E., Toulouse, P., Gibaud, B., Scarabin, J.-M.: Integration of sulcal and functional information for multimodal neuronavigation. J. Neurosurg. 96(4), 713–723 (2002)
7. Benford, S., Bowers, J., Fahlen, L.E., Mariani, J., Rodden, T.: Supporting co-operative work in virtual environments. Comput. J. 37(8) (1994)
8. Benford, S.D., Brown, C.C., Reyard, G.T., Greenhalgh, C.M.: Shared spaces: Transportation, artificiality and spatiality. In: Proceedings of the ACM Conference on Computer-Supported Cooperative Work (CSCW 1996), Boston, MA, November16-20, pp. 77–86. ACM, New York (1996)
9. Benford, S.D., Greenhalgh, C.M., Snowdon, D.N., Bullock, A.N.: Staging a public poetry performance in a collaborative virtual environment. In: Proceedings of the 5th European Conference on Computer-Supported Cooperative Work (ECSCW 1997), Lancaster, UK. Kluwer B.V., Deventer (1997b)
10. Sherdian, T.B.: Musings on telepresence and virtual presence. Presence: Teleoper. Virtual Environ 1(1), 120–126 (Winter 1994); Slater, M., Usoh, M., Steed, A.: Depth of presence in virtual environments. Presence: Teleoper. Virtual Environ. 3(2), 130–144 (Spring 1992)
11. Slater, M., Usoh, M., Steed, A.: Depth of presence in virtual environments. Presence: Teleoper. Virtual Environ. 3(2), 130–144 (Winter 1995); Slater, M., Usoh, M., Steed, A.: Taking steps: The influence of a walking technique on presence in virtual reality. ACM Trans. Comput. Hum. Interact. 2(3), 201–219 (Spring 1994)
12. Ichika, Y., Okada, K., Jeong, G., Tanaka, S., Matushita, Y.: MAJIC videoconferencing system: Experiments, evaluation and improvement. In: Proceedings of the European Conference on Computer-Supported Cooperative Work (ECSCW 1995), Stockholm, Sweden. Kluwer B.V., Deventer (1995)

13. Wang, X., Chen, R.: An Empirical Study on Augmented Virtuality Space for Tele-Inspection of Built Environments. Journal of Tsinghua Science and Technology (Engineering Index) 13(S1), 286–291 (2008)
14. Wang, X., Gong, Y.: Augmented Virtuality-based Architectural Design and Collaboration Space. In: Proceedings of the 13th International Conference on Virtual Systems and Multimedia (VSMM 2007), Brisbane, Australia, September 23-26 (2007)
15. Schubert, T., Friedmann, F., Regenbrecht, H.: The Experience of Presence: Factor Analytic Insights. Presence: Teleoperators and Virtual Environments 10(3), 266–281 (2001)
16. Wang, X., Dunston, P.S.: System Evaluation of a Mixed Reality-based Collaborative Prototype for Mechanical Design Review Collaboration. In: 2005 ASCE International Conference on Computing in Civil Engineering, Cancun, Mexico, July 12-15, 9 pages on CD (2005)
17. Milgram, P., Colquhoun, H.: A Taxonomy of Real and Virtual World Display Integration. In: Ohta, Y., Tamura, H. (eds.) Mixed Reality: Merging Real and Virtual Worlds, pp. 5–30. Ohmsha Ltd. and Springer-Verlag (1999)