Layered Multiple Displays for Immersive and Interactive Digital Contents

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Abstract. In this paper we introduce the concept of 'Layered Multiple Displays (LMD)' for visualizing immersive and interactive digital contents. The LMD platform integrates various display technologies into a unified interaction space by providing natural visualization of three-dimensional virtual spaces, especially in terms of depth perception. Each display component complements one another, providing not only natural visualizations of three dimensional spaces but also personalized point of views. We describe our implementation of a prototype LMD platform with a game application, and discuss about its usability issues, and present future research directions.

Keywords: ubiquitous computing, immersive display

1 Introduction

Recently, ubiquitous (a.k.a. pervasive) and wearable computing environments became hot topics in information and communication technology field. Under this new trend, various sensors and new user interfaces are invented and applied to contemporary computing environment, and such newly introduced user interfaces and services are driving the culture and trend of end users' computing experiences. Popularization of various personal computing devices (from desktop computers to mobile smart phones) made people to own multiple computing devices. And while having more than one computing environments, the users came to need integration (and/or synchronization) of services and information between individual devices, so that the users could have consistent experiences throughout their switches between different computing devices. Among many aspects in integrating multiple device interfaces within ubiquitous and wearable computing environments, in this research we especially focus on visual display interfaces.

Among the five modalities of human senses, visual modality is the one that has the biggest weight in our everyday life. Hence, there is no doubt on that a lot of researches have been developing various technologies for visual displays and interfaces. Nowadays, a huge range of visual displays are available in terms of its size and the number of audience supported. Those with huge sizes, such as large projection displays, are used for multitudes of audiences, while those in the midrange (e.g. PC monitors or television sets) support a small group of people. Recently, great advances in mobile devices, such as smart phones and personal digital assistants (PDA), popularized tiny displays held on the users' hands, and even head (or face) mounted displays (HMD or FMD) are ready for getting popularized.

In the near future, where computing environments become ubiquitous and wearable, we can easily suppose that users would need to use multiple visual display interfaces concurrently. Users will carry their own personal visual displays, while there would be a number of public visual displays (such as information kiosks or advertisement displays) available in the surrounding environment. And as users interact with these various displays, we do not suppose that each display will only visualize information individually, but do expect that they will interact with each other, forming an integration of information as well as its visualization. This can be thought of as each visual display interface providing a layer of visualization. And by working together and complementing each other, multiple displays can be integrated into a single information/virtual space. In this paper, we refer to this concept (or configuration) as 'Layered Multiple Displays' or 'LMD' in short.

In the rest of this paper, we first review previous works related to our research topic, and then describe the concept of Layered Multiple Displays in detail with various application scenarios. Next, as a proof of concept, we illustrate our prototype implementation of the LMD platform and its application. And finally, we conclude this paper by discussing usability issues of our new display platform design, and by presenting future research directions.

2 Related Works

Many researchers have been working on developing various visualization techniques to overcome certain disadvantages in visual display interfaces.

One of the most well known criteria for evaluating a display system is the field of view (FOV). There have been various efforts to overcome the narrow field of view of display devices. Other than simply making the display surface bigger, various immersive displays have been proposed for providing wide field of view to the user in visualizing immersive virtual environments. One of the most well known display system developed for such purpose is the CAVE [4] system. The CAVE system integrates three to six projection screens into a cube shaped room for immersive visualization. The FOV of this system scales up to omni-directional depending on the number of screens used.

Although projection-based immersive displays have good solution for providing wide field of views, they still have disadvantages with occlusion problems. Since the projection screens are at a certain distance from the user's viewpoint, other physical objects, such as user's hands or interaction devices, may occlude the visualized image. This does not matter when the virtual object visualized on the occluded image is actually farther than the physical object covering the screen. However, when a virtual object is supposed to be visualized in front of a physical object, projection-based display systems normally fails to visualize the image correctly.

Occlusion problems are relatively easier to deal with when using head mounted displays. With opaque head mounted displays, occlusion problems never occur since users are not able to see anything from the real world. Besides, for augmented and mixed reality environments [8], where users see virtual objects registered to the real world space, see-through displays are used. In this case, virtual image is always visualized on top of the real world view even when physical objects are in front. Such incorrect occlusions can be solved by drawing only the certain regions of virtual scene those are in front of physical objects [3][9], and these regions can be decided by depth information of the real world scene [3][5].

Although when the depth information of the real world is available, it is still hard to visualize correct occlusions with optical see-through displays, which provides more natural view of the real world in comparison to video see-through method. Optical see-through displays use half-mirrors to combine the virtual and the real world scenes. The problem is that the transparencies of these mirrors are usually fixed, and hence the users are always able to see certain amount of lights from the real world, preventing full occlusion of the real world view even when it is necessary.

As we can see above, although visual display technology has been advanced a lot through decades, there is no perfect display available yet and each display has its own merits and disadvantages. Under this notion, lately, there were a couple of attempts to use different types of display technologies together and take advantages from each.

Bimber et al. [1] combined hologram image with projection displays to take advantage of high resolution three-dimensional visualization from the hologram and interactivity from projection displays visualizing computer graphics. Winterbottom [11] addressed possibilities of testing newly designed head mounted displays within a fighter plane simulator which uses projection displays for visualizing the virtual environment. Although his purpose was usability test rather than using both displays for visualizing three-dimensional space, he showed the possibilities of using multiple displays in a layered fashion.

3 Layered Multiple Displays

3.1 Concept

Layered Multiple Displays (LMD) is a set of visual display interfaces registered and synchronized with each other to form and visualize an integrated interaction space to the users (see Fig. 1). We propose LMD as a visual display platform for providing immersive and interactive experiences to the users by visualizing virtual contents in more natural and dynamic fashion. LMDs are especially good for visualizing dynamic three-dimensional (3D) virtual spaces in terms of supporting concurrent visualization of both near body and far environmental virtual spaces.

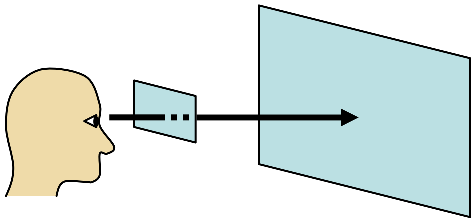

Fig. 1. Layered Multiple Displays: users see virtual information space through multiple visual display interfaces

As mentioned formerly, there are no ultimate display technologies available yet, and each display device has its own advantages and disadvantages. With LMD, each visual display interfaces are complemented by one another, using multiple heterogeneous visual displays forming physical/virtual layers of visualization.

Images visualized on a large projection displays easily get occluded by the users' body or other physical user interfaces used together. On the other hand, head mounted displays can visualize virtual images right in front of users' eyes, preventing occlusions by other physical objects. By using these two displays in a LMD configuration, occlusion problems can be resolved by visualizing the virtual objects in between the user's eyes and user's hands on the HMD and other objects on the projection display behind.

Another advantage of using LMD is extending field of views of each single displays. Large projection displays provide wide field of view, while the FOVs of HMDs are relatively narrow. By using it behind the HMD, a large projection display can provide broader peripheral views to the user. On the other hand, although fixed displays (e.g., projection displays) usually have broader geometrical FOV in comparison to HMDs, they still have physical limits in their physical viewing direction. However, HMDs can provide virtually omni-directional view when head tracking is available. Therefore, when a virtual object visualized on the fixed display gets out of the border, it can still be visualized with LMD configurations by transferring the virtual object onto the HMD.

Besides FOV problems, another issue in visualization is to provide correct stereoscopic images in terms of depth focus. Most of the stereo displays (including head mounted displays, stereo monitors and projection displays) provoke depth sensation by visualizing two separate images to each left and right eyes, rendered with certain disparity according to the depth value of the visualized object. Human eyes tilt inward to make a certain convergence to the depth of location in interest according the disparity of the image displayed. However, the accommodation (or focus) is still fixed to the actual display surface (or virtual image plane for HMDs) and this may cause confusions or even cyber sickness to the user. Developing visual displays with adjustable depth of focus is challenging. However until they become available, using proper combinations of displays with different depth of focus in LMD configuration would be helpful to address this problem. Each virtual object could be visualized on an appropriate display layer according to its distance from the user's viewpoint and the depth of focus of the display.

Visualizing stereoscopic images correctly requires knowing the positions of the user's viewpoint. When multiple participants try to see stereoscopic images on fixed displays, other users except the user being head tracked see incorrect stereoscopic images and this causes misunderstanding of 3D geometries. With LMD, those objects that are needed to be visualized correctly in 3D space could be visualized on personal displays (e.g. HMDs), while other objects (such as background environments) are shown on public displays (e.g. large projection displays).

Besides combing different display technologies for better quality of visualization, certain merits such as providing privacy control can also be found by using LMD configuration. LMD configuration can provide separate visualization of public and private (or personal) information using multiple displays. Private information that are needed to be hidden from other participants can be visualized on the user's personal displays, such as HMD or hand held displays, while public information can be visualized on the public display.

Recent researches on multi-participant games show the importance of providing privacy on visual interfaces. Szalavari [10] presented a multi-participant augmented reality game, where the users played a Chinese game 'Mah-Jongg'. In this game, each player held a private virtual display to hide his game blocks from the other players. Recently, Kitamura [6] proposed to use a table display with a display mask for providing public and private display regions. Users were able to see their private information at a certain viewpoint where they can see their private display region through the display mask. These works show managing privacy becomes more important in collaborative computing environments.

In summary, the merits of LMD configuration could be thought in three aspects: providing context consistent integrated visualization space, improving (or complementing) visualization qualities of each displays, and providing privacy controlled visualization in multi-participant applications.

3.2 Visual Display Interface Spectrum

Various visual display interfaces used in LMD environment can be categorized into a number of types according to its relative distance from the user's viewpoint (or eyes). Similar to the category made by Bimber et al. [2], here we categorize visual display devices into five types: retinal, head attached, near-body (or hand-held), spatial and environmental displays. Fig. 2 illustrates the relative distance from the user's viewpoint to each type of visual displays.

Retinal displays (http://www.hitl.washington.edu/research/ivrd/) are the most nearest ones to the user's viewpoint. Actually its display surface is the retina itself so that no other displays can visualize images closer than these. Head attached displays are those attached near to users' eyes. Head mounted displays or helmet mounted displays fall into this category of visual displays. Next comes the near-body (or hand-held) displays those are within the near-body space. By the near-body space, we refer to a spatial volume that extends to the distance of hand reach. Hence, near-body displays are usually held or worn by the user. By spatial displays, we refer to those within a distance where human visual sensory can percept depth information according to stereoscopic view. Spatial displays are usually fixed at a certain location in the environment. Finally, the environmental displays are those far beyond from the user's viewpoint.

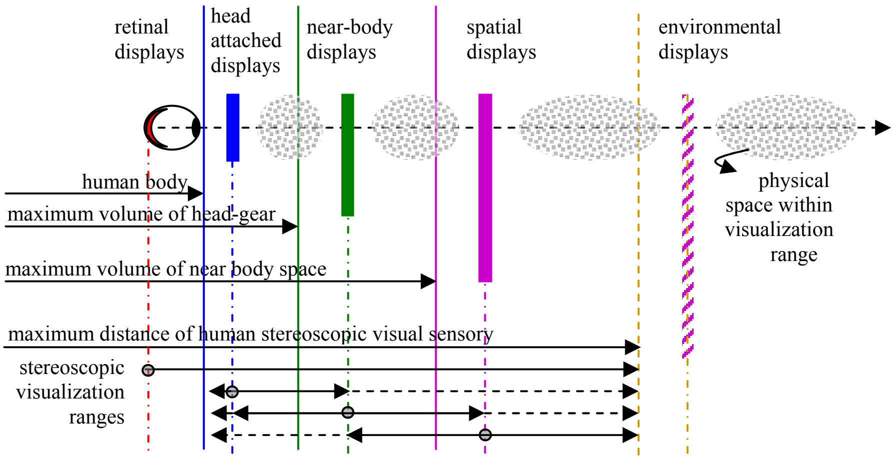

Fig. 2. Visual display interface spectrum for Layered Multiple Displays

Display devices in LMD platform can provide either monoscopic or stereoscopic visualizations. With monoscopic visualizations, images are formed on the display surface of the device, hence the visualization range in depth is fixed to the distance between the user's viewpoint and the image plane of the display interface. In the case of providing stereoscopic view, the visualization range in depth becomes a volume covered with max disparity in stereoscopic image. The lower part of Fig. 3 illustrates such ranges for each display types. The ranges are subject to change according to the size of the screen, so that each type of displays has main visualization range marked with solid lines, while they can be extended out to dashed lines with bigger screens.

Although see-through displays are not that common in current visual display markets, display interfaces in LMD configuration are expected to be visually semi-transparent (i.e. optical see-through displays), so that the users could see another display through it. On the other hand, video see-through displays could be another alternative for allowing users to see the scene behind the display interface.

3.3 Use Case Scenario

Here we describe a use case scenario of Layered Multiple Displays according to the illustration shown in Fig. 3. In the figure, the three participants are referred as u1, u2 and u3, four visual display interfaces are referred as d1, d2, d3 and d4, and r1 and r2 are real objects within the environment.

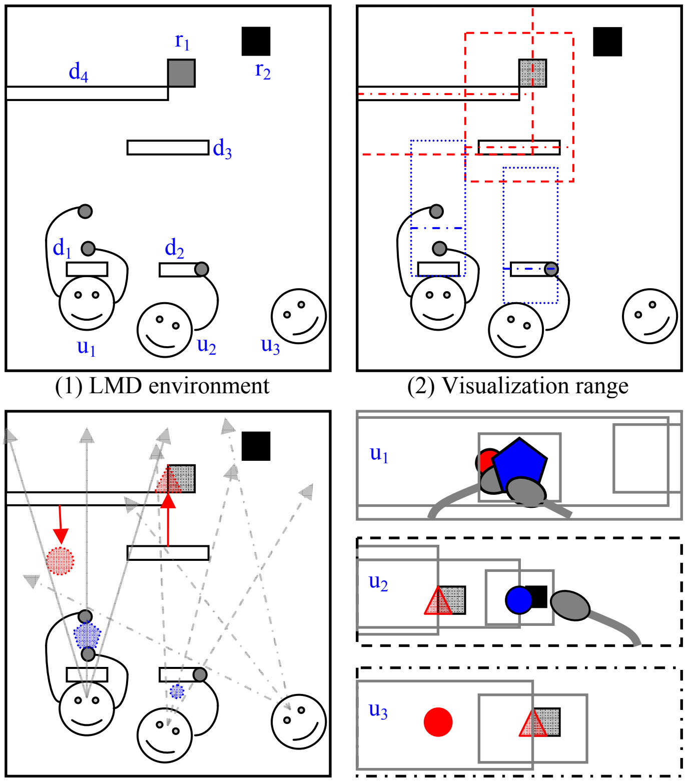

Fig. 3. Use case scenario of Layered Multiple Displays (u1-u3: participants, d1-d4: visual display interfaces, r1-r2: real objects)

The first user (u1) is wearing a head mounted display (d1), while the second user (u2) is holding a hand-held display (d2). The third participant doesn't have his/her own personal device, but still can see the images visualized on the spatial displays (d3 and d4). Fig. 3-(2) shows the visualization range in depth where each display is capable to visualize stereoscopic images (the lines in the middle of the visualization range are the image plane of the display device). Finally, Fig. 3-(3) shows the view frustum and combined view for each user. Note that the first user gets images with correct occlusion by visualizing a pentagon on the HMD (d1) and a circle on the environmental display (d4). Also, the narrow field of view of the first user with the HMD (d1) is extended by the environmental display (d4). The second user (u2) gets correct visualization of the triangle on the spatial display (d3), although the triangle was originally displayed on another spatial display (d4) and crosses its border.

4 Prototype Implementation

As a proof of concept, we implemented a prototype Layered Multiple Displays platform and its game application that provides immersive and interactive experience for multiple participants. We used three visual display interfaces (one monitor and two head mounted displays) for our prototype LMD platform.

The scenario of our prototype LMD game was motivated by a famous movie 'Ghostbusters' (Ivan Reitman, 1984). Within the game, two participants collaborate to find out and capture the ghosts hiding inside a maze (see Fig. 4). One of the participants plays the role of a driver (the left person in Fig. 4) who drives a vehicle with which they navigate through the maze. The other participant plays the role of a hunter (the right person in Fig. 4) who captures the ghosts by shooting them with a proton gun or hitting with a proton saber. Both participants can see the outside view (the maze and the ghosts outside) through the window (which is actually a display monitor) of the vehicle.

Fig. 4. The VR Ghostbusters: a prototype game using Layered Multiple Displays. Two participants are collaborating as a driver and a hunter to capture the ghosts hiding inside a maze. Public information (such as 3D visualization of the maze) are visualized on the monitor in front, while personal information (such as the dashboard for the driver and weapons for the hunter) are shown on the head mounted displays

While watching outside of the vehicle through the monitor, each participant also wears a head mounted display, on which their personal information are visualized. For the driver, the dashboard and the map are shown on his head mounted display; while the hunter can see his weapon on his HMD (Fig. 5 shows personal views of each participant). Notice that the head mounted displays are optical see-through ones so that the users can see the outside world (including the monitor and the other participant as well) along with the graphics visualized on the HMD.

Fig. 5. Personal views of each participant: the left picture is the driver's view with a dashboard visualized on the lower right corner, the middle and the right pictures are the view of the hunter using different weapons, a proton gun and a proton saber (the pictures shown are synthesized with a photograph and a screen capture due to difficulties of taking photographs directly through head mounted displays)

Though the hunter usually shoots a proton gun through the window to capture the ghosts outside, ghosts can also break into the vehicle through the window, popping out from the monitor and hovering in the real world, as shown in Fig. 6. In this case, the ghost is only visible to the hunter, who is considered to be wearing special goggles for ghost vision (which is actually the HMD). The hunter needs to change his weapon into a proton saber and try to hit the ghost with it (see the right picture of Fig. 5).

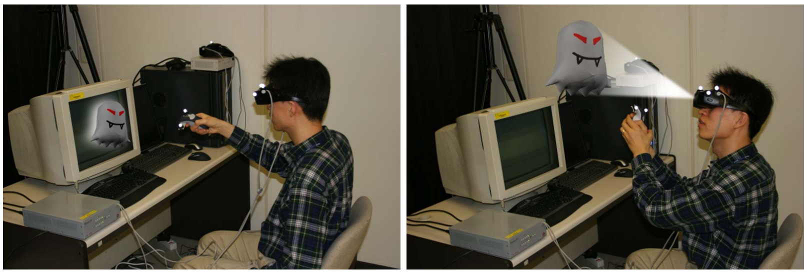

Fig. 6. A virtual object transfers from one display to another: a virtual ghost which was originally visualized on the monitor (left) popped out into the real world, visualized on the head mounted display (right)

The system was built on a PC platform running Microsoft Windows operating system. Three personal computers were linked through a gigabit Ethernet for communication and synchronization between them. As a virtual reality visualization software toolkit, we used OpenSG (http://www.opensg.org) library which provides functions for manipulating and synchronizing scene graphs over a clustered PCs.

Each PC was equipped with multi-channel 3D graphics accelerator interfaces in order to provide rendered images of the virtual environment for three display devices: a monitor and two head mounted displays. All of these three displays provided their own stereoscopic views.

The CRT monitor (showing 1024x768 resolutions at 85Hz) was equipped with a stereo LCD shutter screen 21SX from NuVision (http://www.nuvision3d.com) which provided frame sequential stereo images through circular-polarizing filters. A pair of polarizing filters was attached in front of the optical see-through HMD so that the user could also see the stereoscopic images displayed on the monitor while wearing it [12]. (We make a note that we used a monitor due to our limited resource. This could be definitely replaced with other stereo display equipments with larger field of view and higher resolutions, such as projection based display systems.)

The head mounted displays from DEOCOM (http://www.deocom.com) provided their own stereoscopic views from multiple channel video input. The HMD supported 1280x1024 resolutions and 45 degrees of diagonal field of view.

Each user was provided with a hand held prop appropriate to his/her role. The driver was provided with a game pad to drive the vehicle, and the hunter was provided with a prop with buttons (actually a wireless mouse) for gun triggering and changing weapons (see Fig. 7). For tracking users' viewpoints and props, we used a motion capture system from Motion Analysis with three Hawk Digital cameras running at 100 frames per second, with sub-millimeter positional accuracy.

Fig. 7. The head mounted display and props used in the prototype system: upper left is an optical see-through HMD equipped with stereo circular-polarizing filters in its front, lower is a prop with buttons held by the hunter, and on the right is a game pad used by the driver. A set of infrared reflective markers were attached to the devices needed for tracking.

Image registration between multiple visual displays is the key problem for making LMD work. To achieve this, first, each display should share the same global coordinate frame in the 3D virtual and physical space. Although we used a single tracking system for all displays, in ubiquitous computing environments, there might be various sensor networks, and the coordinate frame of each tracking sensors might need to be registered. This can be easily achieved by multiplying transformation matrices of each sensor's reference frame to the tracking data.

As the 3D spatial coordinates of each display are aligned, next we need to calibrate the virtual cameras of each display. The virtual cameras of each display in LMD change their intrinsic parameters (i.e. projection matrix) as the user or the display moves, and therefore must be updated every frame. Assuming that the display image planes are planar and rectangular, we represent the virtual camera with an off-axis projection matrix, decided by the user's eye position and the size and pose of the image plane. For many display devices, image planes are identical to the physical display surface, and it is easy to measure their features physically. However, there are also some visual display interfaces, such as HMD, that have virtual image planes different from the physical display element. For this case we referred to the device specifications.

Although after we carefully measured and calibrated the system, still there were some registration errors with few centimeters. However, the registration errors were small enough for our application, showing not much disturbance to the users for playing the game. However, we surely need and are looking forward to improve the registration methods to achieve enough accuracy for general cases, including their use in industrial fields, such as virtual manufacturing and virtual work training. Calibration methods used for optical see-through displays in AR systems might be useful for this purpose.

5 Discussion and Future Work

To investigate usability issues in LMD configuration, we are planning for a formal user study. At the moment, we only had chances for informal user tests. After a short use by a couple of test users, we received positive responses of using Layered Multiple Displays in terms of its exciting experience. The users especially liked to see virtual ghosts popping out from the screen, breaking into the real world and hovering around the user. The transition of the virtual object from one display interface to another was good enough to convince users as if the virtual object pops out from the monitor into the real world.

Smoother transition of information and visualization are subjects for improvement. In our current implementation, due to the limitations of the visualization software and communication delays, we use a same copy of scene graphs over different rendering PCs and only switch on and off the virtual ghost nodes to change the display interface on which they are visualized. In order to support general cases of its use in ubiquitous computing environment (as mentioned in section 3), we need to manage and transfer information (such as 3D geometries) between visual interfaces (or computing entities) on demand. This would include managing participants joining in and leaving out from the display platform, and also other security issues in transferring personal information into the shared space.

As we visualized virtual objects on head mounted displays, we found out that rendering dark colored objects on a optical see-through HMD is difficult (since dark colors appear transparent). To overcome this problem, adding another layer of gray level LCD into the optical see-through HMD for shutting off the outside light sources could be useful, as shown in Kiyokawa's work [7]. Besides, we are also considering using video see-through displays with stereo filters in front of video cameras instead of optical see-through ones in this aspect.

6 Conclusion

We presented the concept of Layered Multiple Displays that integrates multiple visual display interfaces into one integrated interaction space for visualizing immersive and interactive virtual contents. Visual display interfaces used in LMD configuration complement one another in the aspect of occlusion problem, widening FOV, and varying depth of focus. In addition to providing better quality of visualization, LMD can also provide privacy in multi-participant environments. The prototype implementation of LMD platform and its application showed potentialities of Layered Multiple Displays. With confidence in further researches to solve the problems discussed formerly, we expect Layered Multiple Displays will take an important role as one of the representative visual display platforms in future computing environments where computers become ubiquitous and wearable.

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References

1. Bimber, O., Zeidler, T., Grundhoefer, A., Wetzstein, G., Moehring, M., Knoedel, S., Hahne, U. : Interacting with augmented holograms. SPIE Proceedings of International Conference on Practical Holography XIX, (2005) 41-54
2. Bimber, O. Raskar, R.: Spatial Augmented Reality: Merging Real and Virtual Worlds. A K Peters, Ltd. (2005)
3. Breen, D., Whitaker, R., Rose, E., Tuceryan, M. : Interactive Occlusion and Automatic Object Placement for Augmented Reality. Computer Graphics Forum Vol.15 No.3, (1996) 11-22
4. Cruz-Neira, C., Sadin, D. J., Defanti, T. A. : Surround-screen projection-based virtual reality: the design and implementation of the CAVE. Proceedings of SIGGRAPH '93, (1993) 135-142
5. Hayashi, K., Kato, H., Nishida, S. : Occlusion Detection of Real Objects using Contour Based Stereo Matching. Proceedings of 15th International Conference on Artificial Reality and Telexistence (ICAT2005), (2005) 180-186
6. Kitamura, Y., Osawa, W., Yamaguchi, T., Takemura, H., Kishino, F. : A Display Table for Strategic Collaboration Preserving Private and Public Information. LNCS 3711: ICEC2005, (2005) 167-179
7. Kiyokawa, K., Billinghurst, M., Campbell, B., Woods, E. : An occlusion capable optical see-through head mount display for supporting co-located collaboration. Proceedings of The Second IEEE and ACM International Symposium on Mixed and Augmented Reality, (2003) 133-141
8. Milgram, P., F. Kishino : A Taxonomy of Mixed Reality Visual Displays. IEICE Trans. on Information and Systems (Special Issue on Networked Reality) E77-D(12), (1994) 1321-1329
9. Mulder, J. D. : Realistic Occlusion Effects in Mirror-Based Co-Located Augmented Reality Systems. IEEE Proceedings of International Conference on Virtual Reality, (2005) 203-208
10. Szalavari, Z., Eckstein, E., Gervautz, M. : Collaborative Gaming in Augmented Reality. Proceedings of VRST, (1998) 195-204
11. Winterbottom, M. D., Patterson, R., Pierce, B. J., Covas, C., Winner, J. : The influence of depth of focus on visibility of monocular headmounted display symbology in simulation and training applications. Proceedings of SPIE Helmet- and Head-Mounted Displays X: Technologies and Applications, Vol. 5800, (2005) 65-73
12. Yang, U., Jo, D., Son, W., Kim, H. : Visual Interface for Presenting Multiple Mixed Stereo Image. US Patents, applied no. 11/223066. (2005)