Technical System for Collaborative Work

Andreas M. Kunz and Christian P. Spagno

Center of Product Development, Swiss Federal Institute of Technology Zurich, Zurich, Switzerland

Abstract
Virtual reality makes it possible to realize distributed collaborative teamwork. In this case objects can be represented three-dimensionally in different visualization installations which are connected with each other over a network [7]. Up to now the user remains mostly without consideration. For distributed collaborative teamwork the user should be visualized three-dimensionally together with the other virtual objects [14]. In the presented paper a special projection installation is described which allows simultaneous projection and acquisition of images of the users.

Keywords:
Collaborative VR, picture acquisition, switchable projection screen, active illumination, camouflaged cameras, third shutter step.

1.   Introduction

By the increasing dissemination of information technology in companies the need arises to use virtual reality in the field of product design. Virtual reality is used already to visualize complex geometries and results of complex calculations. This visualization is not only used in the automotive industry but with increasing number also in small and medium size enterprises. Thus the need arises to use this technology also in other business fields, for instance to support team-oriented processes. Work that must be carried out in a team requires that the team members get together at one place in order to work on a given task. Present information channels, for example telephone or video conferencing systems, do not suffice and their transmission quality or rate is too limited [13].

For efficient communication, not only the exchange of virtual models between visualization installations such as a CAVE® [8], [10] is necessary, but also the exchange of virtual representations of the users [3]. The simultaneous representation of a virtual object and of a person from the other unit in such a visualization installation does not create any problems [9]. On the other hand, the simultaneous picture acquisition of a user and a continuous projection prepare major difficulties.

- Almost synchronous bright and dark phases must be implemented. The bright phases are necessary for the cameras in order to guarantee a satisfying texture acquisition and position recognition of the persons in the visualization installation. However, such bright phases disturb the projection and have to be kept away from the users eye. Thus also dark phases must be included for the projection [2].

- For the complete acquisition of the user's texture he must be continuously in the field of view of several cameras. The cameras have to be placed directly in front of the user to register his gestures and expressions. However, these cameras are always in the user's field of view. In many cases the camera is mounted on a tripod or is directly integrated into the projection screen and thus is visible to the user [6]. Parts of the projection are concealed and the immersion decreases. Furthermore, it is no longer possible for the person to use the complete space of the CAVE®. If a person gets too close to the projection screen, he leaves the field of focus of the cameras and appears blurred in the remote projection installation.

- Special projectors which can perform a stereoscopic projection without flickering are quite expensive. Currently active as well as passive stereoscopic projections are used. The active stereoscopic projection technology is based on CRT-projectors and their calibration is very time consuming and therefore very expensive. On the other hand, if passive stereoscopic systems are used, the three-dimensional effect becomes dependent on

the user's head inclination. As soon as the viewer leaves the plane of polarization, the projected picture darkens rapidly and the immersion decreases.

The following table gives a comparison of the two possible projection systems.

	Passive	**Active**
Number of projectors	2	1
Projector costs	medium	high
Costs for glasses	low	high
Sensitivity against head tilting	high	low
Calibration effort	minimal	large
Brightness	high	low
Portability of the system	good	poor
Requirements for projection screen	must keep polarization	none
Front projection	possible	possible
Back projection	possible	possible

Figure 1 *Comparison of the two possible projection systems.*

The problems described above exist in almost all highly immersive systems and frequently result in poor acceptance of those systems by the industry. In the presented paper, a system solution is introduced by which the above problems can be eliminated. It allows the acquisition of the textures of persons without lowering the immersion by the recognizable existence of cameras. The basic idea consists in placing the cameras behind the projection screen and outside of the beam paths of the projectors. The screen is alternately switched between a translucent and an opaque mode. During the opaque mode the projection is visible to the user while during the translucent mode the cameras can capture the texture of the person inside the CAVE®.

2. Contributions

The aim of the presented paper is to realize a highly immersive networked environment as illustrated in Figure 2.
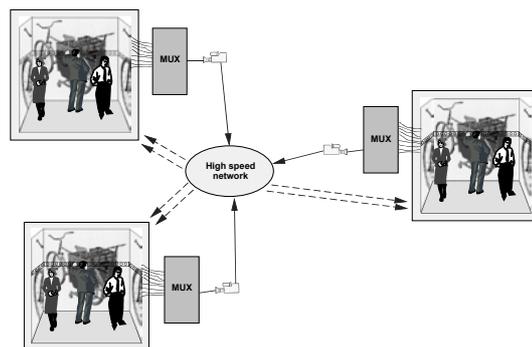

Figure 2 *Networked immersive environment.*

The technical capabilities of existing CAVE® projection theatres are to be extended by insertion of video cameras synchronized with the projection hardware. The envisioned system will allow both to record live video streams of CAVE® users and to project virtual reality scenes simultaneously (Figure 2). Connecting multiple installations via a high-speed network will eventually allow remotely located users to meet, communicate and collaborate in virtual spaces.

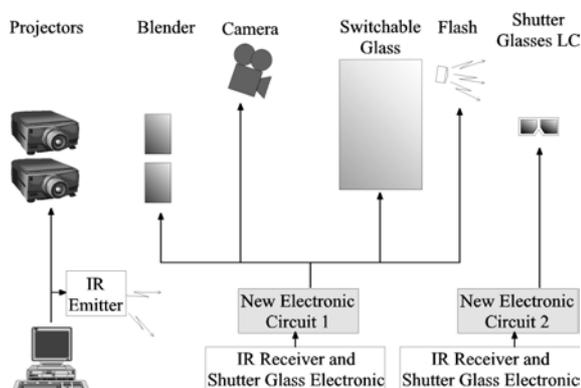An overall technical set-up for one installation was built as shown in the following illustration:

Figure 3 *Diagram of the test set-up.*

The system consists of two LCD- or DLP-projectors which are modified with external blenders. The cameras are camouflaged by electrically switchable glass. In addition, with the third step of the modified shutterglasses, the user is not disturbed by the flash illumination [1]. Additional electronic circuits produce the driving signal for the active components. Apart from the use of new materials and devices, the new principle

is based on the implementation of a third step in the overall system. In this third step, the whole picture acquisition takes place. The third step complements the 1st and the 2nd step which are necessary for the presentation of a three-dimensional picture. The following illustration shows the integration of the third step into the timing diagram. This third step is used to acquire the user's texture inside a visualization installation.
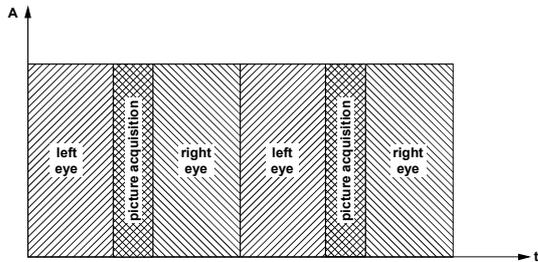

Figure 4 *Chronological integration of the third step.*

If this third step is short enough and if it is placed in every picture sequence, it will no longer be visible due to the limited chronological resolution capability of human perception. On the other hand it must be long enough in order to provide sufficient time for the picture acquisition of the cameras. The third step is based on the two steps of the shutter glasses for an active stereoscopic projection where the left and the right shutterglass is darkened alternately. As already shown in [1] and [2], a third step where both eyes are dimmed is now symmetrically inserted during the transition from the darkening of the left eye to the darkening of the right eye. This third step is shorter than those for the left and the right eye. It is held as short as possible in order to provide sufficient time for the picture recognition by the human eye (step 1 and 2). Because of the insertion of the third step, the general impression of the presented scene becomes slightly darker. However, this can be neglected compared to the brightness of the LCD- or DLP-projectors. This implies that CRT projectors can not be used anymore within this new system, although a shutter technology is used. Thus additional devices have to be available that allow the use of active shutter glasses together with LCD-projectors. The third step is not only used for the triggering of the shutter glasses, but also for other active components of the system which will be discussed later.

Some additional electronics are needed to implement the third step and to synchronize the different components. The modifications to the shutter glasses are discussed in [2]. Basically, the modification consists of an electronic circuit that extends the dark time for the left and the right eye, respectively. The two original

steps were prolonged and overlap and thus a third step is created where both glasses are darkened. Additional options of the electronic circuit allow to change the repetition frequency of the third step as well as the width of the step. No technical modifications of the triggering signal have to be carried out since these modifications would not be supported by most existing data processing systems. The synchronization still can be done with the usual infrared emitters so that a simple implementation of the third step is possible.

During the third time-step, when both glasses are darkened, an active illumination is triggered, using an illumination device that is also synchronized with an infrared receiver. The illumination is preferably done with white light in order to achieve a true colored texture recognition. It is possible to use a stroboscope or white light-emitting diodes (LEDs). Figure 5 and Figure 6 show how this active illumination can be kept away from the user's eye with the help of the third step of the active shutter glasses.
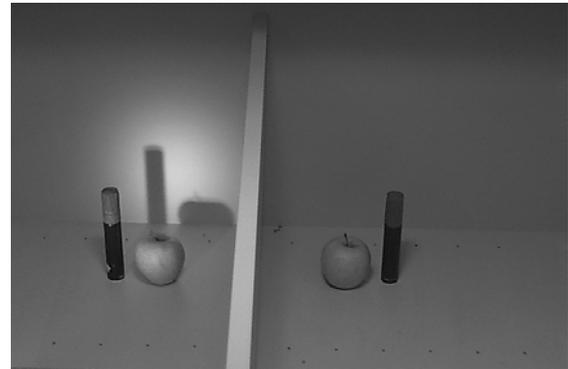

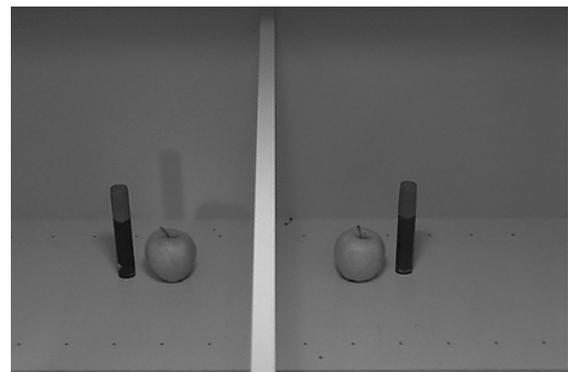**Figure 5** *Active illumination without the third step.*

Figure 6 *Active illumination with the third step.*

In Figure 5 the illumination is shown as it can be seen without the third step; in Figure 6 the user's impression is shown after activating the third step within the shutter glasses. In each case, the picture on the right side shows an object that is only illuminated by ambient light.

With sufficient brightness of the illumination it is now possible to achieve satisfactory picture acquisition. The cameras which are to record the user's face have to be placed in front of him without being in his field of view [11]. Therefore the best position would be behind the projection screen where they can not be seen by the user (Figure 7). Similar to the combination of brightness and darkness, it is necessary to have a projection screen that is translucent for the cameras but not for the user who wants to see a projection on the screen.
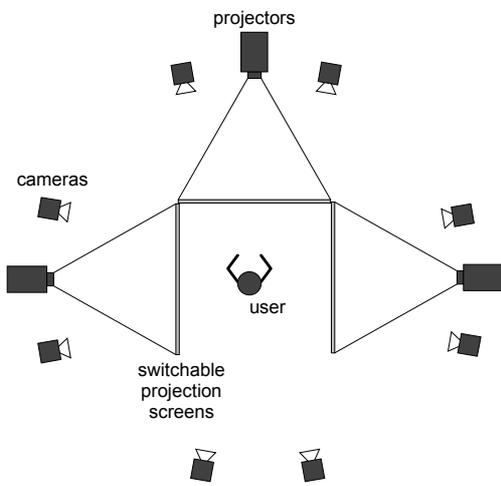

Figure 7 *Positioning of the cameras.*

This problem was solved by using electrically switchable glass, which can be switched from an opaque to a transparent state and vice versa by applying an electrical voltage. Without applying an electrical voltage the glass remains opaque and when a voltage is applied, it turns transparent.
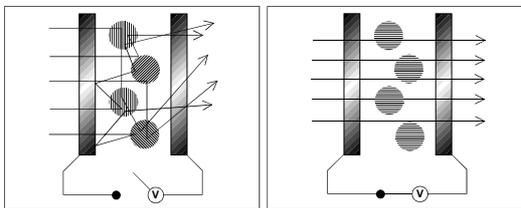

Figure 8 *The modes of operation of the electrically switchable glass [4].*

Between two panes of glass with evaporated metal electrodes a LC film is integrated that can be changed between transparent and opaque. These films are able to change their states within a few milliseconds [5]. Since the projection screen is synchronized with the active shutter glasses and the active illumination, it can be switched with correct timing from transparent to opaque and vice versa. The switching frequency of the electrically switchable glass is high enough to follow the needed picture repetition frequency of at least 30 Hz. Even higher frequencies are possible.

When selecting a projection material, it has to be taken into account that the diffusion properties have to be very small. The diffusion properties describe the expansion of the light beam by the scattering qualities of the projection material. If the diffusion properties are too poor, the projected picture becomes blurred and therefore the material can not be used for a projection screen anymore. In order to evaluate the material, a test pattern of a black cross on a white background was projected on the screen. A standard material for back projection was used as a reference. The following illustration shows the qualitative results:
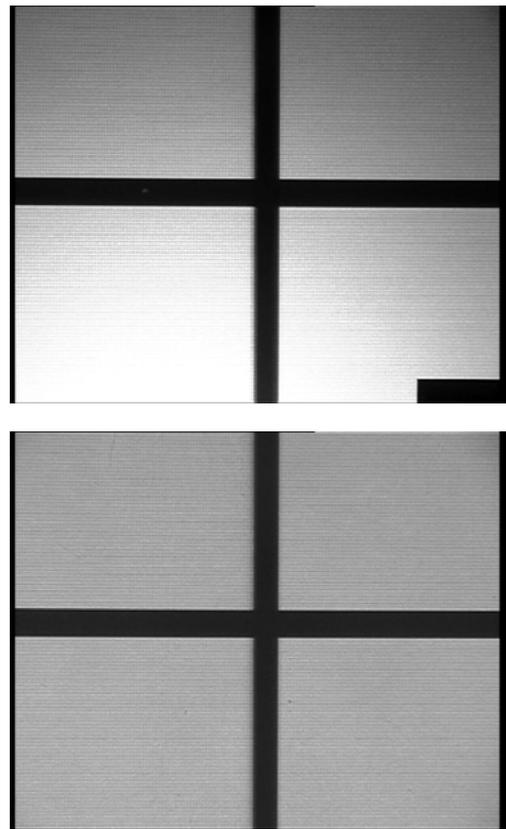

Figure 9 *Illustration of the diffusion behavior.*

In Figure 9 the electrically switchable glass is shown in the upper image, while in the lower image a material is shown that is especially optimized for back projection. It can be seen that in both cases the diffusion behavior is very similar. The electrically switchable glass is nearly equivalent to the material especially designed for back projection.

Since the user does not always perpendicularly look at the screen but frequently under a certain angle, it is important that the projected images do not change their color or darken. This is especially important in a cube-shaped visualization installation, where the user is surrounded by the projection screens. Therefore images of the electrically switchable glass were compared under several viewing angles.
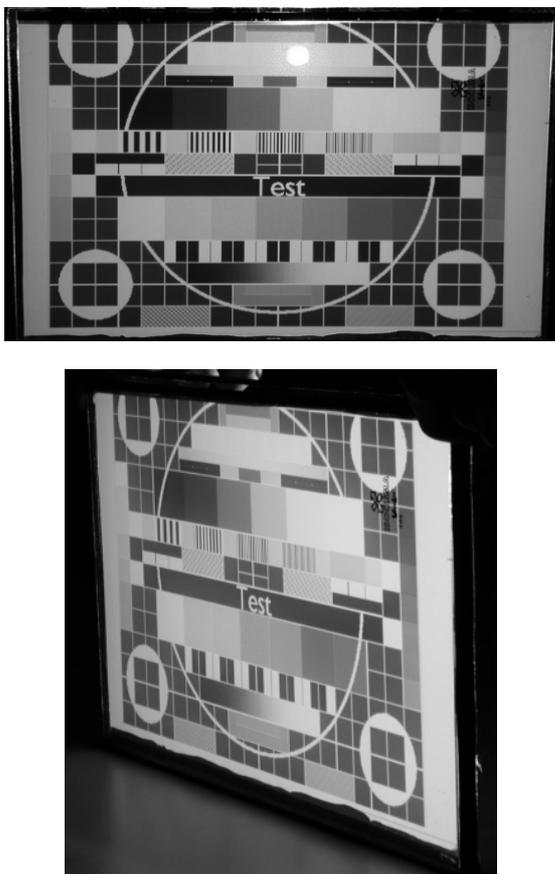
Figure 10 *Angle of emission; 0°, 60° against perpendicular.*

It can be seen from the above figures that the difference in color and brightness of the projected picture can be neglected and thus the material is suitable for the use as a projection screen. Even under a large angle of 60° against perpendicular there is no visible change in brightness or color.

The cameras are placed on the backside of the screen and thus are not in the user's field of view. The cameras can acquire images through the electrically switchable glass in the moment when the interior of the CAVE® is illuminated and both eyes of the user are darkened.

Figure 11 shows the difference between transparent mode and opaque mode in the realized visualization room. It can be seen that the transparency of the electrically switchable glass is good enough to have a clear view of the user from outside the installation. In the picture only the middle glass pane was triggered in order to have a clear comparison between both states.
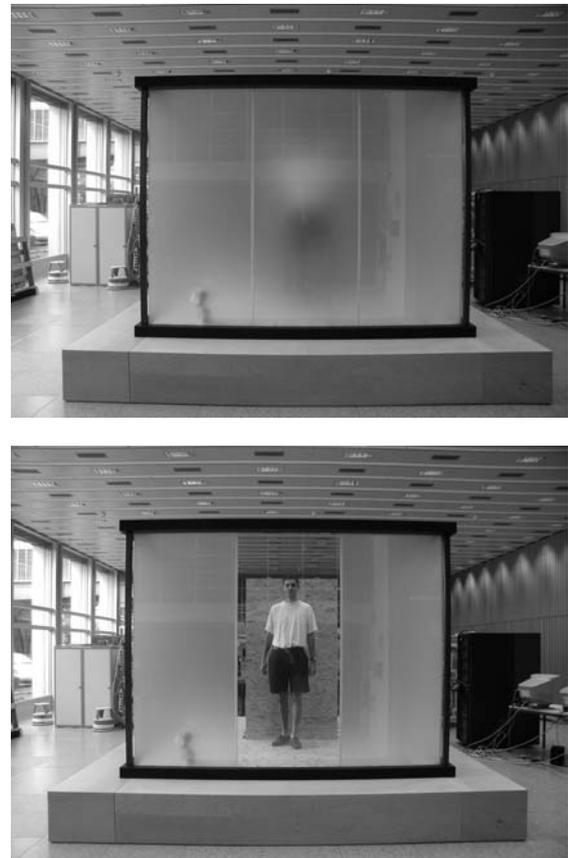
Figure 11 *Difference between both states of the electrically switch able glass.*

In order to avoid reflections of the projection on the backside of the screen (and to prevent irritations of the cameras), the projectors are provided with additional shutters that block the projection exactly in the moment when the electrically switchable glass is translucent and the eyeglasses are darkened. These shutters can be realized with electrically switchable glass or with especially designed LC shutters. In the first case, the projection is not dimmed completely but slightly illuminates the surrounding room during the picture acquisition. In the second case, the projector is dimmed completely and the illumination of the CAVE® is achieved only by the active illumination.

All active components of the overall system - eyeglasses, flash, projection screens, shutters and cameras - are synchronized via an infrared link. The triggering of the components does not have to be synchronous with the image refresh rate of the computer, which is responsible for the image generation. As it was represented in [2] an array of white LEDs can be used to realize the active illumination. These have the advantage of low costs and a long life time. Moreover, the LEDs emit a white ambient light. On the other hand, a stroboscope is not suitable for the generation of an active illumination since it is very expensive and has a short life time. Furthermore, gas-discharge lamps are very noisy and the steep electrical excitation and discharge flanks of the stroboscope cause electric interference which can jam the synchronization of the entire visualization installation.

The light-emitting diodes are attached to the upper and lower edge of the projection screen and guarantee a ambient illumination of the CAVE® due to their spatial distribution. Since these diodes do not have any infrared part in their spectrum, they do not disturb the infrared link for the synchronization. The cameras are placed around outside the CAVE®, so that it is guaranteed that the user can move freely in the projection room and nevertheless remains in the field of view of several cameras. In total, 16 cameras are used.

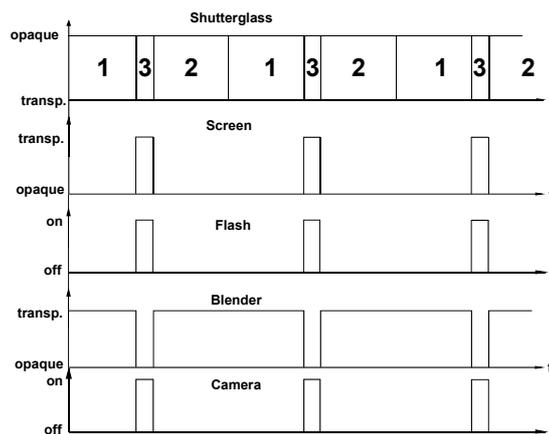The timing diagram of the individual components is illustrated in the following figure:

Figure 12 *Timing diagram for the synchronous switching of the individual components.*

While the picture is projected for the right or left eye (steps 1 and 2), no voltage is applied to the electrically switchable glass and thus it is opaque. The shutters (blenders) in front of the projectors are switched transparent and no active illumination appears. As soon as both eyeglass are darkened, the screen is switched transparent, the shutters in front of the projectors become dark and the flash illumination is triggered. The picture acquisition with the cameras is done simultaneously. Preliminary tests showed that the point of switching from the darkening of the left glass to the darkening of the right glass is suitable to activate this triggering sequence. A more frequent darkening of both eyes is not useful, because on the one hand the limited image processing time of the cameras has to be considered and on the other hand the picture presented to the user becomes too dark. A frequency lower than the image refresh rate is disturbing for the user, since it is lower than the resolution frequency of the human eye.

Basically, the above described system can be realized with a CRT projector as well as with two LCD- or DLP projectors per projection screen [5]. Two LCD projectors can be used in combination with external shutters. Each of the two projectors projects an image for the left and the right eye respectively. The shutters in front of the projectors are alternately opened and closed. They are synchronized with the shutter glasses. By doing so, they generate an active stereo projection [5]. Furthermore, they block both projectors during the third step for the picture acquisition in order to prevent the active camera from being disturbed by the projected image. The LCD-projectors emit polarized light which does not have to match the direction of polarization of the active shutter glasses. As shown in Figure 8, the opacity of the electrically switchable glass is realized by

multiple reflection of the light within the LC-foil. This also causes a complete depolarization of the projected light. Therefore, active shutter glasses can be used in this kind of installation. Thus the stereoscopic projection is not dependent on the head inclination and free exploratory movements of the users are possible. If DLP projectors are used, no polarized light appears. However, it must be ensured that these projectors do not use a color wheel to dismantle the white light. The periodic darkening of the projector by a shutter in combination with a color wheel would result in a color corruption of the projected picture.

The usage of LCD- or DLP-projectors results in smaller acquisition costs and in a reduced calibration time for the projectors. Thus a faster set-up of the overall system becomes possible. Thanks to the higher brightness of the projectors, it will be possible to use the projection system in rooms that are not completely darkened.

3. Conclusions

A new system was introduced that allows simultaneous stereoscopic projection and picture acquisition. The immersion of the user is not disturbed by the short-term illumination of the projection room. Through the selection of an electrically switchable projection screen, it is possible to camouflage the cameras for the picture acquisition so that they are no longer in the user's field of view. In addition, the depolarizing properties of this material allow the use of LCD-projectors together with active shutter glasses. The following illustration shows the realized construction of the overall system (the third screen is not mounted in this figure):

Figure 13 *Realized construction.*

The construction and the test of the above represented installation showed the effectiveness of the entire system. However, the use of the electrically switchable glass, which must have a certain thickness for safety reasons, requires special caution during the construction. The weight of these panes combined with a high sensitiveness to punctual burden requires a precise preparation of the integrating frame. In order to guarantee sufficient stiffness, a construction of fiber reinforced plastic was chosen.

For the active illumination, stroboscopes are not suitable white light-emitting diodes were used instead. The positioning of the cameras outside the visualization room is very useful, since the complete working space of the projection installation is available for the user without leaving the focusing field of the cameras.

4. Future work

Future work will examine how the complete installation can be modified and simplified in such a way that it can be realized with reasonable costs. In addition, it will be redesigned for portable use. In particular, materials which can be used instead of the glass panes without forfeiting the use of LCD projectors will be investigated. A feasible alternative could be the use of switchable Perspex instead of glass, which would noticeable reduce the weight of the screen.

References

1. Kunz, A.; Spagno, C.: "Modified Shutter Glasses for Projection and Picture Acquisition in Virtual Environments"; IEEE Virtual Reality 2001 Conference; March 13.-17. 2001; Yokohama, Japan; ISBN 0-7695-0948-7

2. Kunz, A.; Spagno, C.: "Novel Shutter Glass Control for Simultaneous Projection and Picture Acquisition" (PPT); Immersive Projection Technology and Virtual Environments 2001, pp. 257-266; May, 16-18 2001; Stuttgart (Germany); ISBN 3-211-83671-3; Springer-Verlag Wien/New York

3. Gross, M.; Kunz, A.; Meier, M.; Staadt, O.: "The Blue-C: Integrating Real Humans into a Networked Immersive Invironment"; CVE Conference 2000;

4. Saint-Gobain; Bauen mit Glas 1998/99; Technisches Handbuch

5. Kunz, A., Spagno, C.; "Konzeption und Aufbau eines neuen Stereo-Projektionssystems durch den Einsatz geshutterter LCD-Projektoren"; ETH internal research report; May 2001

6. Tetsuro Ogi, Toshio Yamada, Ken Tamagawa, Makoto Kano, Michitaka Hirose; "Immersive Telecommunication Using Stereo Video Avatar"; IEEE Virtual Reality 2001 Conference; March 13.-17. 2001; Yokohama, Japan; ISBN 0-7695-0948-7

7. V.D. Lehner and T.A. DeFanti. „Distributed virtual reality: supporting remote collaboration in vehicle design." Computer Graphics & Applications, 17(2): 13-17, 1997.

8. C. Cruz-Neira, D.J. Sandin, and T.A. DeFanti, „Surround-screen projection-based virtual reality: The design and implementation of the cave." Proceedings of SIGGRAPH 93, pages 135-142, August 1993.

9. R. Raskar, G. Welch, M. Cutts, A. Lake; L. Stesin, and H. Fuchs. „The office of the future: A unified approach to image-based modelling and spatially immersive displays." Proceedings of SIGGRAPH 98, pages 179-188, July 1998.

10. C. Cruz-Neira, D. J. Sandin, T. A. DeFanti, R. V. Kenyon, and J. C. Hart. „The cave: Audio visual experience automatic virtual environment." Communications of the ACM, 35(6): 65–72, June 1992.

11. H. Fuchs, G. Bishop, K. Arthur, L. McMillan, R. Bajcsy, S. Lee, H. Farid, and T. Kanade. „Virtual space teleconferencing using a sea of cameras." Technical Report TR94-033, The University of North Carolina at Chapel Hill, Department of Computer Science, 1994.

12. W. Elspass, L. VanGool, M. H. Gross, A. Kunz, M. Meier, G. Schmitt, O. Staadt, P. Stucki „The BlueCave"; ETHZ-internal research proposal; Swiss Federal Institute of Technology (ETH) Zurich, Switzerland and University of Zurich, Switzerland, 1999

13. J. W. Davis and A. F. Bobick. „Sideshow: A silhouette-based interactive dualscreen environment." Technical Report 457, MIT Media Lab, 1998

14. T. Disz, M. Papka, M. Pellegrino, and R. Stevens. „Sharing visualization experiences among remote virtual environments." In Proceedings of the International Workshop on High Performance Computing for Computer Graphics and Visualization, July 1995