Multi-Resolution-Display System for Virtual Reality Setups

Jürgen Grüninger[1,3], Hilko Hoffmann[1,2], Uwe Kloos[5], and Jens Krüger[1,2,3,4]

[1] Intel Visual Computing Institute, Saarbrücken, Germany
[2] German Research Centre for Artificial Intelligence, Saarbrücken, Germany
[3] Interactive Visualization and Data Analysis Group, Saarbrücken, Germany
[4] SCI Institute, University of Utah, USA
[5] Reutlingen University, Reutlingen, Germany
grueninger@intel-vci.uni-saarland.de

Abstract. Most large-area video projection systems offer only limited spacial resolution. Consequently, images of detailed scenery cannot be displayed at full fidelity. A possible but significantly more costly strategy is a tiled projection display. If this solution is not feasible then either aliasing occurs or some anti-aliasing method is used at the cost of reduced scene quality.

In this paper we describe a novel cost effective multi-resolution display system. It allows users to select any part of a stereoscopic projection and view it in significantly higher resolution than possible with the standard projection alone. To achieve this, a pair of video projectors, which can be moved by stepper motors, project a high-resolution inset into a small portion of the low-resolution image. To avoid crosstalk between the low and high resolution projections, a mask is rendered into the low resolution scene to black out the area on the screen that is covered by the inlay.

To demonstrate the effectiveness of our multi-resolution display setup it has been integrated into a number of real life scenarios: a virtual factory, an airplane cabin simulation, and a focus and context volume visualization application (see Figure 1).

Keywords: projection, virtual reality, multi-resolution.

1 Introduction

In a number of computing areas today, like simulation or graphic design, image data is provided that contains far more detail than computer screens are able to display. Even very common data such as a digital photographs made with cheap consumer cameras can exceed the resolution of most high definition displays. If those or even lower resolution images are used as detail textures in a three dimensional scene the problem becomes even more obvious as those regions normally do not cover the entire display, further reducing the effective resolution (see Figure 1 A & B). Especially in visualizations of highly detailed scientific datasets (such as the visible human [1] in Figure 1C) this is an undesired effect.

M.M. Robertson (Ed.): Ergonomics and Health Aspects, HCII 2011, LNCS 6779, pp. 180–189, 2011.

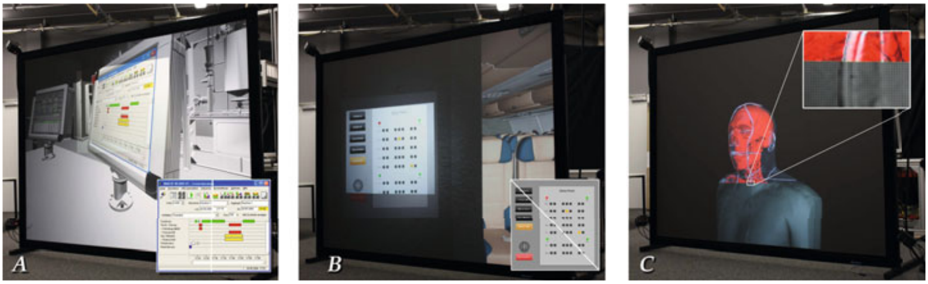

Fig. 1. The three scenarios for the multi-resolution display. Image A shows a virtual factory scene, were the inlay is placed such that the program output on the virtual screen becomes readable. The small image demonstrates the difference between the two resolutions. In image B the inlay is used to improve the usability of a virtual control panel, again the effect of the resolution increase is shown in a small image. In image C the inlay is used in a focus and context volume visualization system [5,11]. In this case the small image is a closeup photo that shows the pixel size on the projection screen at the transition between the inlay and context region.

In most cases, it is not sufficient to simply zoom into a specific region of the data until the screen provides adequate resolution to display the data, as this causes the context information to be lost. Often, however, it is possible to separate the dataset into a number of scales such that a low resolution version of the dataset exists (e.g. a down-sampled version of an image) that gives an overview over the data while finer details can be displayed when in a focus region. These types of data or documents are referred to as "multi-scale" documents [3,6].

The multi-scale problem also applies to stereoscopic virtual reality (VR) systems. Especially projection-based systems, in which large projection screens and limited projector resolutions are common, show a low level of detail. In extreme cases even the wiring on the projector LCDs are visible in the stereoscopic image which disrupts the feeling of immersion. To counter this, we have developed a multi-resolution stereo display system consisting of a pair of video projectors controlled by stepper motors. These projectors display a high-resolution inset into a small portion of the low-resolution image. To avoid crosstalk between the low and high resolution projections, we use a mask to prevent the low resolution projection from appearing in the area where the high resolution inlay appears.

This setup allows users to display a region of the projection screen in significantly higher resolution. In our proposed setup we achieve resolutions in the inlay that are close to the maximum resolution of the average human eye, at normal working distance. As our system only adds a few components to an existing stereo projection setup it can be installed as an upgrade for many existing projection-based VR systems.

2 Related Work

Projection-based systems allow the setup of wall-size stereoscopic displays without disrupting effects like display borders. Due to the projection of the image the pixel density decreases with distance as mentioned before. A straight forward solution to this issue would be the use of higher resolution projectors. Therefore, commercial projectors e.g. for digital cinemas, provide horizontal resolutions of up to 4096 pixels [8] which would offer enough resolution to drive a 2.5 meters projection screen near the maximum resolution of the human eye at a working distance of 1.5 meters (which is approximately 39-58ppi). The projectors, however, are extremely costly (currently about $50,000 per unit). Tiling of images from lower resolution projectors is another way to increase the overall resolution, but the complexity of the calibration process increases rapidly with the amount of projectors [10,4]. Another solution to achieve high resolution of large images without the calibration issues are tiled displays made up of a number of LCD screens. However the unavoidable display bezels inevitably interrupt the image. The extent to which this disturbs the stereo perception has been mostly unexplored thus far.

A completely different approach to achieve high resolution images that cover the entire field of view are head mounted displays (HMDs). Nowadays, commercial HMDs are available [9] that offer resolutions close to eye resolution (viewing angle between pixels $\approx \frac{1}{30}^{\circ}$). To even further increase the resolution of HMDs, Yoshida et al. [18] built a low cost head mounted display system that used two liquid crystal displays and fixed optics to place a high-resolution insert into a contextual view at the gaze point of the user. Using HMDs for multi-user environments, however, requires everyone to wear such a device, multiplying the costs of such a system with the number of simultaneous users.

Focusing on immersive video communication, Naemura et al. [13] proposed a multi-resolution stereoscopic system based on a setup of four cameras. For each eye, one camera recorded a wide angle view while the second camera captured a close-up of the central part. An additional compositing step combines these images. After enlarging the central high-resolution area only for the left eye, users reported that they see a "triple resolution" image, in which the high-resolution from the left eye overlapped with the already low-resolution image of the right eye created a sensation of a medium-resolution boundary.

Most closely related to our work is a setup by Baudisch et al. [3]. They describe a system which they refer to as "foveal display". It consists of a projector to display a large contextual view on a projection surface in which they placed a LCD screen with a significantly higher resolution to display the focal view. Similar setups were developed for 2D [17] and even 3D stereoscopic projections [7]. The latter system consisted of four projectors that are aligned to each other and did not include the correction of the increased inset brightness which was seen as an advantage of foveal displays.

We also base some of of our setup parameters on the recently work by Ogawa et al. [15]. They presented a study targeting the perception of multi-resolution images. They demonstrated that reducing the resolution of an image to $\frac{1}{4}$ at

20°angle and $\frac{1}{10}$ at 40°angle from the center of gaze results in images indistinguishable from the full resolution imagery.

2.1 Contribution

In this paper we present an extension to the work presented by Baudisch et al. [3]. We extend their idea in that we developed a hardware and software environment to move the high resolution inlay to any position on the projection. This extension allows for a number of novel applications. First of all the users are not restricted to moving the area of interest into the center of the projection — they can select an arbitrary region on the projection to be shown in high resolution. They can also dynamically move this high resolution area like a lens, following and exploring parts of the scene or data.

The remainder of this paper is structured as follows: In the following section we first present the conceptual design of our setup followed by a more detailed description of the components used. In Section 5 we give a detailed analysis of the performance of our system. We conclude the paper with a summary and give directions for further research.

3 Concept

To achieve the goal of a dynamic "foveal display" system we propose a setup with four identical projectors: Two equipped with wide angle lenses for the context and two with zoom lenses for the focus/inlay region. The focus projectors are mounted on a movable rig that is driven by two stepper motors (see Figure 2). This rig consist of two main parts: the basic rectangular, box-like horizontal moving-unit, and the vertical moving-unit, containing the two projectors and a counterweight to balance out their weight and minimize the stress on the stepper motor. This allows a 2D motion parallel to the projection screen resulting in no image distortion while moving the high resolution inset to different parts of the contextual image. To avoid overlapping of the contextual image and the inset image, the area covered by the inset has to be masked out. If needed, image correction has to be applied to the inset image to correct the higher brightness and color differences due to the smaller projection area of the inset projectors in comparison to the contextual image.

4 Setup

Our multi-resolution display setup consists of four *projectiondesign F20 sx+ projectors* [16], each with a resolution of 1400x1050 pixels. Two of these projectors are fixed and serve as context projectors for the entire wall (see C in Figure 3) . Two others are mounted on a moving rig made of aluminum profiles (see F in Figure 3). Two Nanotec Plug&Drive PD6-I89 stepper motors [14] drive the rig vertically and horizontally (see M_x and M_y in Figure 3).

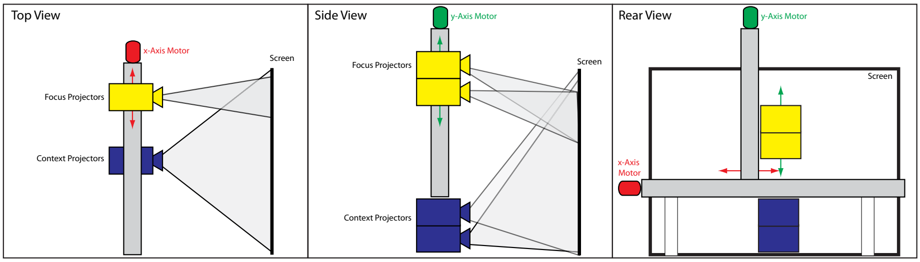

Fig. 2. Conceptual overview of our proposed multi-resolution display system

The four projectors are connected to two commodity PCs, each equipped with an Intel Q6600 2.4GHz quad-core CPU with 4GB DDR2 RAM and two NVidia GeForce GTX285 graphics cards. The motors are also connected to one of these PCs via a serial RS485 interface [2]. To issue motor commands we developed a custom driver that sends commands directly to the serial interface. This driver runs as a server on the PC to allow for multiple connections from different machines to control the inlay.

To render the VR environment both computers are using the VR-software "Lightning" [12]. To synchronize them we use Lightning's built in cluster protocol. To ensure that the context projectors do not render any low-resolution imagery into the inlay region covered by the focus projectors we render a black rectangle of the size of the inlay on top of the context projection. The images for the focus region are generated from the same model but with different camera parameters, which are adjusted when the focus region is moved. To allow for a brightness compensation and edge blending we also render a semi-transparent full screen rectangle over the entire focus region. Tcl scripts running inside the Lighting software are used to control these additional objects and adjust the camera settings.

Normally, our VR system is controlled by various input devices (e.g. mouse, joystick, IR markers) that are directly connected to one of the computers that runs Lightning. Via the aforementioned Tcl scripts we could add interaction techniques for the inlay directly into Lightning and control the focus and context overlay rectangles and the focus camera parameters. Unfortunately, it is not possible to access the RS485 interface and thus the stepper motors from within the application. Consequently, we either need to change the source code of Lighting and add this functionality or develop an external solution. In order to have a general and re-usable setup we decided not to modify Lighting but to handle the user input from an application that sends control signals via the network and multiplexes VR commands to Lighting and motor commands to the RS485.

With this solution we can attach any given input device to the control computer which then forwards these commands. With the input devices available in our lab we performed an informal internal user study that favored our

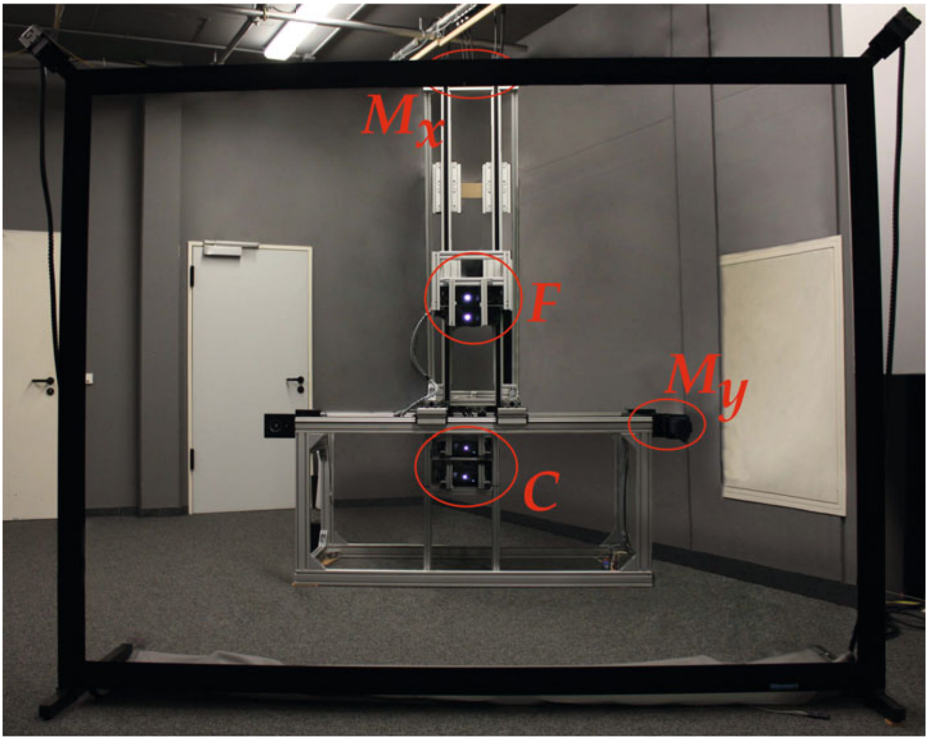

Fig. 3. Photograph of the actual setup of our multi-resolution display. The stepper motors (M_x and M_y allow horizontal and vertical movement of the projectors (C: context region projectors, F: focus region projectors).

multi-touch input table (see Figure 4) as the most intuitive means of control for the inlay position. In addition the custom-developed multitouch framework software also allowed a quick integration of further functionality which made the multitouch the first choice of implementing a “proof of concept” interaction for the multi-resolution display system. To control the high resolution inset, a map-like graphical user interface (GUI) was added to the multitouch software, acting as a metaphor for the projection screen. A red rectangle shows the current inset position which can be modified by using drag & drop gestures. Additional sliders and checkboxes at the side of the GUI allow the manipulation of transparency and color values of the overlay used for inset image corrections (see Figure 4). The introduction of linear functions and “borders” to map the position of the red rectangle on the multitouch to a position on the projection screen allows the usage of the software for different sizes of multi-resolution display systems. This also allows fine scale movement of UI or other elements.

Once assembled, setup of the whole system is very simple. It is only necessary to align the projection screen plane parallel to the moving-units, adjust the projectors to the desired screen sizes, and calibrate the stepper motor control

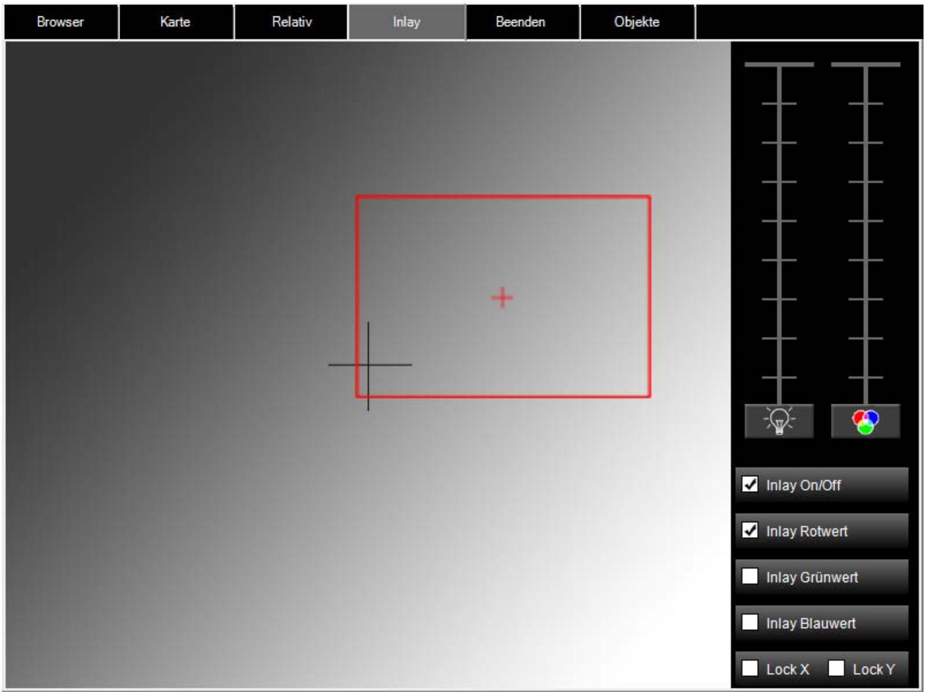

Fig. 4. The multitouch interface that controls the VR scene and the inlay

with the maximum steps possible (the number of steps needed to move the inset from the lower left corner to the upper right corner of the projection screen). The latter can be determined by using the Nanotec NANOPRO software. Using the administrative stepper motor control GUI, the sizes for the projection screen and the desired speeds for the motors have to be set. This initial setup of the whole system can be done in about 30-60 minutes. Later re-calibration, which may be necessary due to changes in the materials used to setup the rig, requires only about 5 minutes.

5 Results

The described moving-unit construction delivered satisfying results concerning resolution, speed and precision when applied to an already existing projector-based stereoscopic VR system. No formal user tests were conducted yet with this system so we give only measured timings of the setup itself.

Since identical projectors were used for the low-resolution context screen and for the high-resolution inset part, the increase of resolution is proportional to the decrease in size of the projected image. So decreasing the image size from 2.44 meters of the context area projection screen to an inset size of 1 meter yields a resolution increase by the factor 2.44. Given a working distance of 1.5 meters from the projection surface, the resulting 35.56ppi for the inset image is very close to the maximum resolution that the human eye can discern. Even by getting close (<30cm) to the projection screen, it is still hard to see the individual pixels in the inset, which is possible in the context part of the image even at working distance. The higher brightness and contrast of the inset with a switched off overlay also seems to add to the depth perception in stereoscopic scenes inside the inset. This "highlight" effect could also be used to guide the user's eye to a specific part of the image.

To measure the speeds the system can achieve, several movements with varying travel distance were conducted. The average time needed to adjust the inlay to a new position was 4 seconds with the minimum ramp-speed that could be achieved with the used stepper motors. Adjusting the ramp-speed and maximum moving speed of the stepper motors, this average time can be further reduced to about 2.5 seconds on our system. It is worth noting, that increasing these values also means an increase of forces affecting the projectors and consequently may reduce the projector lifetime. We found, however, that using values of about $0.07\frac{m}{s^2}$ for the acceleration-ramp and $0.2875\frac{m}{s}$ as maximum speed did not affect the performance of our projectors even after a several months of usage. To determine the precision of our proposed system, we moved the inlay by 3000 steps and measured how many pixels in the contextual image were covered. This test resulted in a covered distance of 601 pixels, which gives a sub-pixel precision of about 0.2 pixels per step.

6 Future Work

The proposed multi-resolution display system offers a cost effective way to increase the maximum resolution of a projection-based stereoscopic VR system. Being able to choose the size of the high resolution inset also offers the possibility to increase the resolution increase even further at the expense of projection area. Using a server-based application to steer the stepper motors, a multitude of interaction methods and software can be used.

Since the high resolution inset of the described multi-resolution display system is movable, there are a number of different use-cases for this system. So far we considered the three scenarios detailed in Figure 1. First, reading high resolution data in a virtual smart factory environment. Second, interacting with realistic control elements in a virtual scene. Third, using the inlay in a focus and context volume visualization system. For these scenarios we received very positive initial user feedback but we would like to verify and quantify the effectiveness of our system in a formal user study. In particular we are interested in a comparative study to both a standard low-resolution only projection as well as a high resolution projection with a very high resolution projector.

Finally, we will investigate novel interaction metaphors. Due to the server-based concept of controlling the inset, it is easy to use other novel devices, such as an Apple iPhone or iPad, to control the inlay.

Acknowledgements

The work presented in this paper has been co-financed by the Intel Visual Computing Institute and the Cluster of Excellence "Multimodal Computing and Interaction" at the Saarland University. The content is under sole responsibility of the authors.

References

1. Ackerman, M.: The visible human project. Proceedings of the IEEE 86(3), 504–511 (1998), http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=662875
2. Association, T.I.: Electrical characteristics of generators and receivers for use in balanced digital multipoint systems (ansi/tia/eia-485-a-98) (2003), http://www.tiaonline.org/standards/catalog/search.cfm?standards_criteria=TIA-485-A
3. Baudisch, P., Good, N., Bellotti, V., Schraedley, P.: Keeping things in context. In: Proc. CHI 2002, pp. 259–266 (April 2002), http://portal.acm.org/citation.cfm?id=503423
4. Bresnahan, G., Gasser, R., Abaravichyus, A., Brisson, E., Walterman, M.: Building a large scale, high-resolution, tiled, rear projected, passive stereo display system based on commodity components. In: SPIE Proc. of Stereoscopic Displays and Virtual Reality Systems X (2003), http://spie.org/x648.html?product_id=474149
5. Fogal, T., Krüger, J.: Tuvok - an architecture for large scale volume rendering. In: Proceedings of the 15th Vision, Modeling and Visualization Workshop 2010 (2010), http://www.ivda.uni-saarland.de/fileadmin/publications/2010/VMV2010a.pdf
6. Furnas, G.W., Bederson, B.B.: Space-scale diagrams: understanding multiscale interfaces. In: CHI 1995: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, pp. 234–241. ACM Press/Addison-Wesley Publishing Co., New York, NY, USA (1995), http://www.sigchi.org/chi95/proceedings/papers/gwf_bdy.htm
7. Godin, G., Lalonde, J.F., Borgeat, L.: Projector-based dual-resolution stereoscopic display. In: Proceedings of the IEEE Virtual Reality 2004, p. 223. IEEE Computer Society, Washington, DC, USA (2004), http://www.ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=1310080
8. Digital Cinema Initiatives: Dci system requirements and specifications for digital cinema - dci specification, version 1.2. Website (2008), http://www.dcimovies.com/specification/index.html
9. Inition: Comparison table for binocular head mounted displays. Website (2011), http://www.inition.co.uk/inition/compare.php?SubCatID=16
10. Kresse, W., Reiners, D., Knöpfle, C.: Color consistency for digital multi-projector stereo display systems: the heyewall and the digital cave. In: Proceedings of the Workshop on Virtual Environments, EGVE 2003, pp. 271–279. ACM, New York (2003), http://doi.acm.org/10.1145/769953.769985, http://doi.acm.org/10.1145/769953.769985
11. Krüger, J., Schneider, J., Westermann, R.: ClearView: An interactive context preserving hotspot visualization technique. IEEE Transactions on Visualization and Computer Graphics (Proceedings Visualization Information Visualization 2006) 12(5) (September-October 2006), http://wwwcg.in.tum.de/Research/data/Publications/vis06_clear.pdf

12. Landauer, J., Blach, R., Bues, M., Rsch, A., Simon, A.: Toward next generation virtual reality systems. In: International Conference on Multimedia Computing and Systems, p. 581 (1997), http://doi.ieeecomputersociety.org/10.1109/MMCS.1997.609772
13. Naemura, T., Sugita, K., Takano, T., Harashima, H.: Multi-resolution stereoscopic immersive communication using a set of four cameras. In: Proceedings of Stereoscopic Displays and Applications XI of the International Society for Optical Engineering: Stereoscopic Displays and Virtual Reality Systems VII, vol. 3957, pp. 271–282 (2000), graphics.stanford.edu/~naemura/publication/2000/MultiStereo-SPIE.pdf
14. NANOTEC: Pd6-i89 product webpage (2010), http://de.nanotec.com/page_product_archive__schrittmotor_pd6i_closedloop__de.html
15. Ogawa, M., Shidoji, K., Matsuki, Y.: Assessment of stereoscopic multi-resolution images for a virtual reality system. The International Journal of Virtual Reality 9(2), 31–37 (2010), http://portal.acm.org/citation.cfm?id=1079808
16. Projectiondesign: F20 sx+ product webpage. Website (2010), http://www.projectiondesign.com/Default.asp?CatID=1522
17. Staadt, O.G., Ahlborn, B.A., Kreylos, O., Hamann, B.: A foveal inset for large display environments. In: VRCIA 2006: Proceedings of the 2006 ACM International Conference on Virtual Reality Continuum and its Applications, pp. 281–288. ACM, New York (2006), http://doi.acm.org/10.1145/1128923.1128971
18. Yoshida, A., Rolland, J.P., Reif, J.H.: Design and applications of a high-resolution insert head-mounted-display. In: Proceedings of the Virtual Reality Annual International Symposium (VRAIS 1995), p. 84. IEEE Computer Society, Washington, DC, USA (1995), http://portal.acm.org/citation.cfm?id=527216.836018, http://portal.acm.org/citation.cfm?id=527216.836018