HoloVizio – True 3D Display System

Tibor Balogh[1], Péter Tamás Kovács[2], Zoltán Megyesi[3], Attila Barsi[4]

[1,2,3,4]Holografika, Budapest, Hungary

E-mail: [1]t.balogh@holografika.com, [2]p.kovacs@holografika.com, [3]z.megyesi@holografika.com, [4]a.barsi@holografika.com

Abstract: **This paper presents HoloVizio true 3D display technology, and its real life implementations, the HoloVizio display models from Holografika. Our patented technology uses a specially arranged array of optical modules and a holographic screen. Each point of the holographic screen emits light beams of different color and intensity to various directions. The light beams generated in the optical modules hit the screen points in various angles and the holographic screen makes the necessary optical transformation to compose these beams into a perfectly continuous 3D view. With proper software control, light beams leaving the pixels propagate in multiple directions, as if they were emitted from the points of 3D objects at fixed spatial locations. We describe the 10 Mpixel desktop display and the 50Mpixel large-scale system. We cover the real-time control issues at high pixel-count systems with the HoloVizio software environment, give solutions for displaying various kinds of content, including 3D scenes from existing computer applications, 3D CAD models and natural content. We also describe concrete 3D applications developed in the frame of European projects.**

Keywords: 3D display, 3DTV, holography, stereoscopic, autostereoscopic, multiview, projection

1 INTRODUCTION

Displaying 3D images is a major step towards realistic visualization. Providing perceivable 3D information can be crucial in applications of many areas including architecture design, chemical and biological research, industrial engineering, geological surveying, medical visualization and more. However, displaying 3D images is not an easy task.

A 3D image contains much more information than a corresponding 2D image. To display proper three-dimensional images 3D systems should produce sufficient number of points in a given time frame, i.e. to provide appropriate pixel/sec rate. This is the TB law (total number of beams). In case the system does not globally have the capability of supplying sufficient number of independent spots or pixels per second, the resulting 3D image will not be compromise-free. By this calculation it is possible to determine the quality of any 3D solution immediately, independently of what is promoted.

Direction selective light emission is the common feature for any 3D system comprising of a screen (this is true for the outer surface of volumetric systems even with exotic arrangements).

In case we would have a light emitting surface on which each point is capable to emit multiple light beams of various intensity and color to multiple directions in a controlled way, the problem of 3D displaying would be solved and we would have a perfect 3D display.

2 STATE OF THE ART 3D DISPLAYS

The most widespread solutions are stereoscopic displays with tracking. Stereoscopic displays [6] can emit only two distinguishable light beams from each pixel, this is the reason for the compromises: the necessity of being positioned at the sweet point, the viewer dependent view, or the necessity of tracking [7] to create motion parallax, which is still for single/few user only and imply inaccuracies and latency.

Multiview systems [5] produce 8-16 views, which is still strongly compromised causing the jumpy character, limited FOV and invalid zones. Since most of these systems, except time multiplexing solutions, use 2D panels as the base, there is a tradeoff between directions and resolution: introducing n directions decrease the resolution to the 1/n part. This is especially true for integral imaging where the vertical views eat up the available resolution. In other words integral imaging is a full version multi-view system with vertical parallax.

Volumetric systems do not follow current displaying conventions, they rather follow the looking into than the looking out philosophy. The same global number applies also to volumetric systems however the number represents the number of addressable spatial spots, while at the other systems the spatial positions are represented by the available combinations of light beams. This leads to the problem of missing occlusion. Light never covers light, bright spots in the back will never disappear and there is no way to show natural scenes with hidden edges, translucent images or wire-frames only.

Holographic systems generate holographic patterns to reconstruct the wavefront. These systems suffer fundamental limitations on realistically achievable image sizes, viewing angle and it must be noted such systems also do not have infinite resolution in the FOV. Having the same imager as the base, the overall number of spots is the same that can be produced by diffractive or refractive imaging. In practice holographic solutions show poorer performance because of the limited phase modulation capabilities of available components.

3 THE HOLOVIZIO DISPLAY SYSTEM

The patented HoloVizio technology uses a specially arranged array of optical modules and a holographic screen. Each point of the holographic screen emits light beams of different color and intensity to the various directions. The light beams generated in the optical modules hit the screen points in various angles and the holographic screen makes the necessary optical transformation to compose these beams into a perfectly continuous 3D view, see Fig. 1. With proper software control, light beams leaving the pixels propagate in multiple directions, as if they were emitted from the points of 3D objects at fixed spatial locations. [3] [4] The direction selective light emission is a general requirement for every 3D system and provides quantitative data on the FOV, on the angular resolution, determining field of depth of the displays, affecting the total number of light beams necessary for high-end 3D displaying.

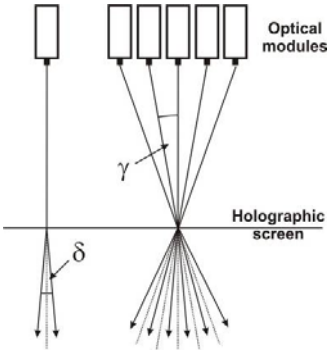

Figure 1: HoloVizio principle

The HoloVizio technology can be used to build both small-scale and large-scale display systems.

In the following we first present the hardware and software components of the 50Mpixel large-scale system, and then the small-scale systems.

4 LARGE-SCALE HOLOVIZIO SYSTEM

4.1 Hardware system

We developed a 50 Mpixel large-scale system [1] with a screen diagonal above 1,8m, see Fig. 2. The system has a slightly immersive curved configuration. The optical system consists of compact projection modules, arranged in horizontal rows. The projector modules are densely arranged in horizontal-only-parallax configuration behind the holographic screen and all of them project their specific image onto the holographic screen. The system has a high angular resolution, and approximately 50 independent light beams originate from each pixel.

Considering the 50 Mpixel overall resolution, the 2D equivalent image resolution with conventional terms would correspond to 1344x768 and such views build up a 3D view with continuous motion parallax.

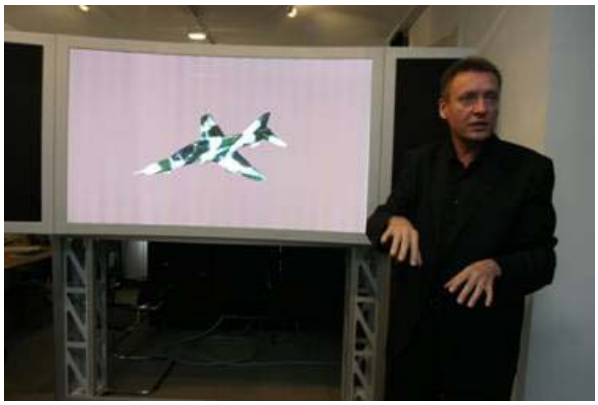

Figure 2: HoloVizio 640RC

The display could work at 25 frames/sec refresh rate in color sequential mode, though the refresh rate is different of the frame rate that depends on the user's computing hardware. The display is prepared to work in hybrid mode, that is, it can show exceptional brightness when high brightness is needed, even for outdoor illumination conditions, or it is possible to alter the illumination system working in economic mode as a LED display.

A PC-based render cluster feeds the display with 50 Mpixels in real-time and a sophisticated control system controls the projectors, PCs, the network, power supplies and monitors all system parameters. The control system architecture consists of two main subsystems. The first is the PC based render cluster of 16 PC-s with dual PCI-Express x16 and high-end nVidia graphics cards, high-speed dual Gbit ETH network components and the server.

The cluster is responsible for the rendering process and it feeds the display with 50 Mpixels in real-time. The data input is up to a dual Gigabit Ethernet or Infiniband. As of the further management functions, the second part, a sophisticated control system controls the projectors, PC-s, the network, cooling system, power supplies & UPS and monitor all system parameters.

With the HoloVizio approach we can build displays that have excellent image resolution of 1920x1080 or beyond, large FOV above 100 degrees, large Field-of-Depth, and at the same time we state the number of pixels being in the range of hundreds of millions. As a result the system architecture it is not limited in any of the general 3D display's parameters; various systems could be achieved for various applications based on the principle.

4.2 Software system

We provide several possibilities for displaying 3D data on the HoloVizio.

4.2.1 OpenGL wrapper

Legacy interactive graphics applications are interfaced to the holographic displays through a special implementation of OpenGL, the HoloVizio OpenGL wrapper. This wrapper library intercepts all calls and related data (textures, vertex arrays, Vertex Buffer Objects (VBO), shaders, etc.) the application sends to OpenGL.

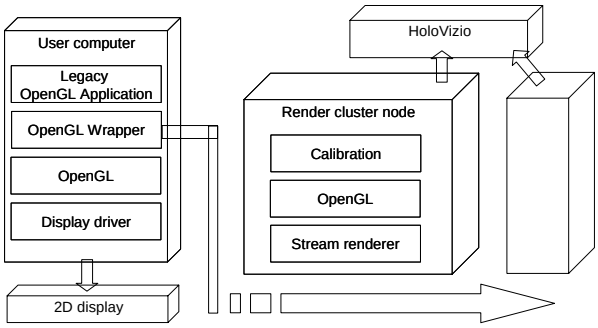

Figure 3: OpenGL wrapper operation

The rendering process is about generating the set of images to be projected from different positions according to the connected optical modules. In fact, the captured OpenGL call stream is transferred through the network and replayed on the rendering nodes in a slightly modified and reordered way. One simple example of reordering is a texture that is deleted at the end of the frame, but when replayed, must be kept till all required frames are rendered, and deleted after that.

Figure 4: Visual Molecular Dynamics [11] running on HV640RC using the OpenGL Wrapper

The OpenGL wrapper supports most of the usual features of the OpenGL 2.0 standard, including user-defined GLSL shaders in the application and VBOs.

It has been used with various industrial applications, and is compatible with applications based on the following common OpenGL-based visualization libraries: OpenInventor, Inventor, Coin3D, OpenSceneGraph, AVS/Express.

The OpenGL wrapper provides real-time operation with well-engineered applications, some of them achieve 60 Frames Per Second (FPS) update rate on the RC640 display model.

4.2.2 Model viewers

In case directly wrapping an application is not desirable, it is also possible to export models from various applications, and display them interactively with Holografika's highly HoloVizio-optimized viewers. We provide viewers for several model formats including IV, VRML, 3DS, FBX, MD5.

By exporting and possibly converting models, we are able to visualize models from 12 CAD and 7 modeling applications without any loss, and this list is far from exhaustive.

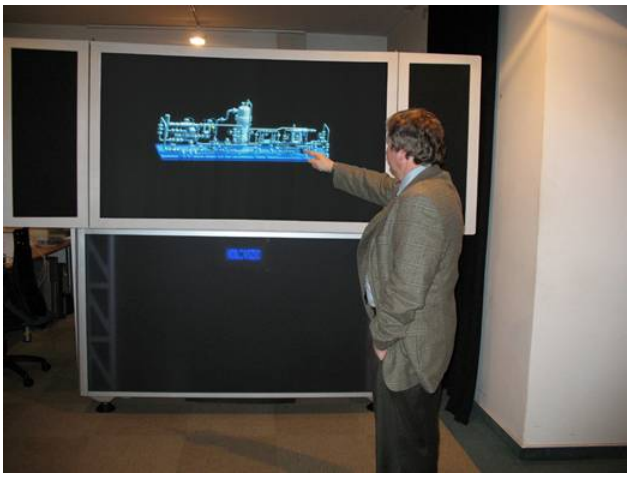

Figure 5: CAD model displayed using ModelViewer and OpenGL wrapper on the HV640RC (data courtesy of Shell)

Using Holografika's model viewers has the additional benefit of providing a possibility to use a wide range of input devices including mouse, joystick, gamepad, Wii Remote, or any kind of OpenTracker-compatible input device including 3d mouse, trackers and even a markerless hand tracking system developed in cooperation with the University of Bonn.

4.2.3 Pre-rendered content

For displaying other content (eg. pre-rendered images or animations rendered using 3DS Max), we provide a video player application. We also provide a 3DS Max plug-in that can be used to render a scene from numerous viewpoints, and software that combines these images / videos taken from different viewpoints into a video stream that can be played on the display. This is an off-line process, which takes a few seconds per frame. After that finished, the resulting video stream can be played back on the displays in real-time.

Since with this approach 3DS Max is used for rendering the source images, creation of ultra high quality 3d images is possible, optionally using 3rd party rendering and ray-tracing engines like Mental ray, VRay or Brazil. The built-in rendering cluster of the large-scale HoloVizio systems can also be used as a Backburner rendering cluster, thus 3DS Max rendering work can be offloaded to 16-18 rendering nodes. Using clustered rendering is integrated into the 3DS Max plug-in.

Figure 6: Pre-rendered car model on HV640RC (model courtesy of PSA)

This option compensates for the increased rendering workload associated with rendering a 3D image compared to rendering a 2D image. Using this solution, creating and playing a full-length ray-traced 3D movie in real 3D became possible.

4.2.4 Calibration

Both real-time and off-line image generation methods are fed with the optical module geometry (position, frustum) and physical specifications. The latter are used for real-time calibration to correct geometrical nonlinearities and differences in the optical modules, to adjust color and intensity response and match the screen diffusion capabilities. This comes from pre-recorded data sets obtained through a fully automated, iterative display calibration process.

4.2.5 Compatibility

All HoloVizio software are designed to be multi-platform and can be run on Windows XP (32-bit and 64-bit), and various 64-bit Linuxes including but not limited to Suse Linux, Fedora Core, Redhat Linux, and Gentoo Linux.

5 SMALL-SCALE HOLOVIZIO SYSTEMS

5.1 Hardware system

As of monitor style 3D displays currently we produce two models, a 32", 10 Mpixel, 16:9 aspect and a 26" 7,4 Mpixel 4:3 aspect model [2]. These models are in the dimensions of normal TV sets. The 10 Mpixels and 7,4 Mpixels provided by 128 and 96 LCD microdisplay panels respectively. The modules contain the fast LCD panels and dedicated plastic aspheric optics. The optical modules are densely arranged in horizontal-only-parallax configuration behind the holographic screen and all of them project their specific image onto the holographic screen. The imaging optics of the modules have a wide angle, which results in a 50 degrees FOV and the angular resolution of the displays is 0.8 degrees. This means that ~60 independent light beams originate from each pixel in this FOV. The 10Mpixel display with conventional terms this would correspond to 60 views, each of 512x320.

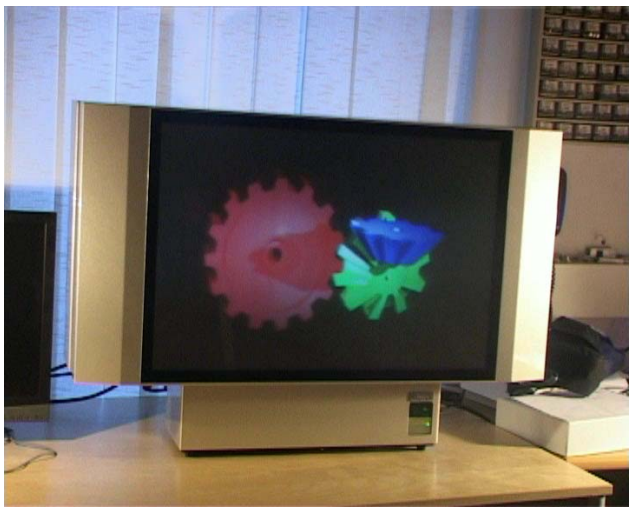

Figure 7: HoloVizio 128WLD

It fits quite well certain applications like medical, where the CT, MR DICOM datasets are of 512x512 resolution. If we multiply the numbers, this is what 10 million pixels can back-up in 50 degrees FOV and a FOD in the range of the screen size volume. In subjective tests however viewers estimate better (approx. a normal TV) resolution, because the brain integrate the details from the eyes and spontaneous movements. As a consequence of the technology the displays can show 2D without the need of switch through, thus providing a smooth compatibility and coexistence with conventional 2D TV systems. The displays work at a high 50 frames/sec refresh rate in color sequential mode. The refresh rate is different from the frame rate that depends on the user's computing hardware.

The displays have 4 DVI inputs to support the required bandwidth. A high-speed image-processing unit decodes the input DVI streams. The DVI channels work at 1280x1024 at 60/75Hz and are thus capable of transmitting up to 280 MB/sec per channel. Due to the flexible system architecture it is possible to use the displays with 1,2,3 or 4 DVI channels. The user can use a PC with standard 3D graphics cards and depending on the number of DVI outputs used, the displays will work at different frame rates. By one or two DVI channel 8 or 16 frames/sec can be reached respectively. An uncompressed 3D image for the 10Mpixel display is 30MB, thus 3 DVI channels are sufficient for the 25 frame/sec real-time operation. A typical configuration is the dual display mode, using 3 DVI channels for the HoloVizio and 1 for a 2D display.

5.2 Software system

We have an OpenGL wrapper for driving the small-scale displays too. In this case, there is no need to use a rendering cluster, the display is driven by a single PC, the same that runs the user’s application. One or two video cards (including the one that renders the application and the desktop itself) are used to render several pictures from different points of view to an off-screen surface, which are then transferred to the display device through DVI connector(s). The same image-enhancing techniques described at the large-scale system are performed on this platform too.

Figure 8: Medical data on the HoloVizio 128WLD

In order to run very complex OpenGL applications with high speed on the small display, an alternative approach is under development that will allow the user to use a small rendering cluster (consisting of 2-4 computers) to drive the HoloVizio, and offloading rendering work from the user's computer.

6 NATURAL CONTENT

To display natural content on a 3D display, it is not enough to show an image recorded by a single conventional camera. Additional sources are needed to provide 3D information. For large FOV displays like the HoloVizio systems, several cameras are needed to capture natural scenes, and they must be placed so that to provide information from a large FOV. Depending on the number of cameras, different algorithms exist to extract 3D information from the camera images. If the number of cameras is high (70-100), the light rays necessary for composing 3D scenes can be calculated using interpolation methods also used for Light Field Rendering [8]. If the number of cameras is lower (7-11), depth information must be calculated and intermediate views must be rendered [9, 10]. This, however is a computation costly process and must be performed off line. Figure 4 illustrates natural content visualized on the Large Scale HoloVizio System.

Figure 9: Natural 3D content on the HV640RC (model courtesy of Aenima CGS)

7 APPLICATIONS AND FUTURE WORK

Holografika is involved in several R&D projects in the frame of the EU FP6, FP7 and national programs, targeting next generation 3D displays and novel 3D applications. Among these we are developing displays above 125Mpixels based on the very latest microdisplay and LED technology. The FP6 project OSIRIS aims to create novel display systems including a high resolution LED based compact display that is capable of real time processing and playing of live captured natural content. In the same project the HoloVizio technology is applied in an even larger scale, to create a 3D Cinema application.

Figure 10: Car model on HV640RC (model courtesy of PSA)

The FP7 3DPHONE project aims to develop technologies and core applications enabling a new level of mobile 3D experience, by developing an all-3D imaging mobile phone. The aim of the project is to realise all fundamental functions of the phone i.e. media display, user interface (UI), and personal information management (PIM) applications in 3D but usable without any stereo glasses.

The 50Mpixel system was developed for automotive application, and was tested by a major European car manufacturer in selected use scenarios in the car design process, where each viewer see the 3D view simultaneously with correct positions enabling collaborative work without glasses or other supplementary devices freeing up the viewer's hands and significantly enhancing collaborative interactive medical work while investigating 3D images originating from CT, MR, PET, 3D Ultrasound or other suitable medical applications.

The wider scope is to develop a networked holographic audio-visual platform to support multi-user real-time collaborative 3D interaction between geographically distributed teams. In the frame of the project together with European partners we develop additional system components, such as a camera based gesture recognition system to intuitively interact with the 3D objects in the displayed scene.

Using the OpenGL wrapper technology, we have successfully visualized scenes from numerous existing software packages, including CAD, medical and oil-industry related software in real time. Further systems are under development for air-traffic control, architectural and terrain visualization, virtual theatre and telepresence applications.

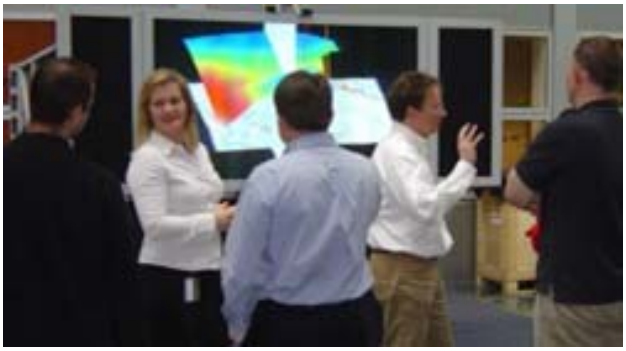

Figure 11: Collaborative work on the HV640RC

8 CONCLUSIONS

We explained that 3D systems must use more pixels or higher speed components than current 2D displays and that the direction selective light emission is a common requirement for 3D displays. Based on this we characterized known 3D solution categories pointing the limitations. We described the HoloVizio 128WLD and 96ND desktop displays and the 50Mpixel large-scale HoloVizio 640RC system that are on the market and are used in various applications.

3D displays cannot be considered anymore as just toys or novelties. The 3D data is widely used and there is an obvious need for 3D displays. The major obstacle of being accepted up to now is the fact that most of them were simply not good enough for real applications. On the long term, particularly in the 3D television only such a system will survive that does not make any inconvenience, side effects to the viewers and provide the same freedom as 2D systems. The technology is here and the 3D is evidently the next step in the displaying. While the transition from black&white to color TV represents a factor of 3x increase in the information content, HDTV represent a factor of 4-5, true 3D displaying requires orders of magnitudes, 10^2 to 10^4 boost in the display capabilities and thus it will be the most significant move, almost a paradigm shift, in the display and television technologies and the related environment for the coming years.

Acknowledgements

This work has been supported by EU IST-FP6 Integrated Project OSIRIS (IST-33799 IP) and the EU IST-FP7 Project 3DPHONE (IST- 213349 STREP).

References

[1] T. Balogh, T. Forgacs, T. Agocs, E. Bouvier, F. Bettio, E. Gobbetti and G. Zanetti: *A Large Scale Interactive Holographic Display*. IEEE VR2006 Conference, March 25-29, Alexandria, Virginia, USA

[2] T. Balogh, T. Forgacs, T. Agocs, O. Balet, E. Bouvier, F. Bettio, E. Gobbetti and G. Zanetti: *A Scalable Hardware and Software System for the Holographic Disp of Interactive Graphic Applications*. EuroGraphics 2005, Dublin, Aug. 2005

[3] T. Balogh: *Method and apparatus for displaying three-dimensional images*, U.S. Patent 6,201,565, EP 0900501, Feb 04, 1997

[4] T. Balogh: *Method and apparatus for displaying 3d images*, U.S. Patent Appl. 20030156077, EP 1 285304, May 19, 2000

[5] Cees van Berkel, David W Parker and Anthony R. Franklin: *Multiview 3D-LCD*. In Stereoscopic Displays and Virtual Reality Systems III (1996), Vol. 2653 of SPIE proceedings, pp.32

[6] D. Ezra, G. J. Woodgate, B. A. Omar, N. S. Holliman, J. Harrold and L. S. Shapiro: *New autostereoscopic display system*. In Stereoscopic Displays and Virtual Reality Systems II (1995), Vol. 2409 of SPIE proceedings, pp.31-40

[7] G. J. Woodgate, D. Ezra, J. Harrold, Nicolas S. Holliman, G. R. Jones, R. R. Moseley: *Autostereoscopic 3D display systems with observer tracking*. In Image Communication – Special Issue on 3D Video Technology (EURASIP - 1998), pp.131

[8] M. Levoy, and P. Hanrahan, *Light Field Rendering*, Proc. ACM SIGGRAPH, pp. 31-42, August 1996.

[9] C.L. Zitnick, S.B. Kang, M. Uyttendaele, S. Winder, and R. Szeliski, *High-quality video view interpolation using a layered representation.* In ACM SIGGRAPH and ACM Trans. on Graphics, Los Angeles, CA, Aug. 2004, pp. 600-608.

[10] A.W. Fitzgibbon, Y. Wexler, A. Zisserman: *Image-based rendering using image-based priors*, Proc. International Conference on Computer Vision, October 2003.

[11] *Visual Molecular Dynamics*, Theoretical and Computational Biophysics Group, University of Illinois at Urbana-Champaign