Digital Holography - Principles and Challenges of Holographic Projection Systems

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Keywords : electro-holography, holographic display, computer-generated holography, 3D projection

Abstract

In the field of 3D displays, holographic displays are the only technology allowing optimal user comfort. We have developed systems based on compact projection optics, that allow advantageous new features, like large size full-color3D scenes generated at high rate on a micro-display with state of the art resolution.

1. Introduction

Displaying 3D has come a long way and started to gain commercial significance. The most recent example is the new installation of several hundred digital 3D cinemas in the U.S. By end 2007 the number will exceed 800. Nevertheless, the overwhelming quantity of displays is sold in the desktop and TV market. Quality of products has improved significantly but competition is fierce. A revolutionary feature as 3D will provide a solid basis for sales in existing as well as new markets. A universally accepted technology will quickly take the step from a high-end professional product to a consumer commodity.

The easiest and most economical way to display 3D content is the technically already well-developed family of stereo/multi-views displays. Nevertheless, there has been no real commercial breakthrough of these technologies due to the fact that they suffer from a well-known and severe side-effect: the disparity between eye focus and convergence (Fig.1), generating eyestrain that drastically impacts the ergonomics of such systems.

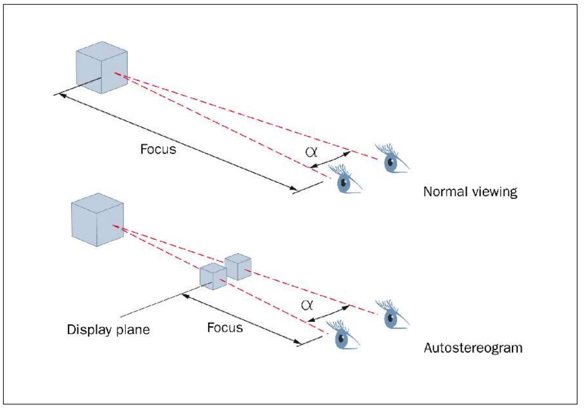

Fig. 1 Difference focus/convergence on stereodisplays, causing eyestrain

Only holographic displays are capable of overcoming this limitation, as they generate a scene (or "reconstruction") that matches with natural viewing: from the observer's point of view, light precisely comes from the position in space where the 3D scene is supposed to be (Fig.2)

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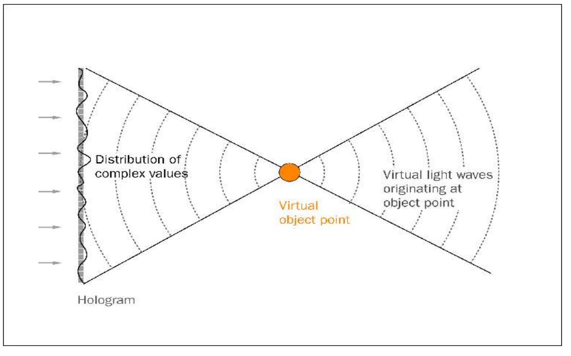

Fig. 2 General principle of a holographic display

This effect is obtained by the use of a “phase modulator” (or Spatial Light Modulator SLM), a display device that modifies the wavefront locally, so that the wavefront in the observer’s position is the same as if it were generated by a real object (for example, for generating a single point, the phase modulator changes the wavefront into a spherical wave centered on the position of the point, as a lens would do).

Although research has been conducted in the field of holographic displays for a long time, no technology has been developed that can be considered capable of creating products, until now. This is due to one of the basic laws of holographic displays, the fact that the observed (3D) reconstruction can be observed only in a limited zone of space. This so-called “space-bandwidth product (SBP) limitation” can be summarized as: for a given hologram size, the size of the angle in space from where one can observe the holographic reconstruction is proportional to the resolution of the hologram (which is the resolution of the phase modulator). This effect can rapidly result in astronomical requirements for display resolutions.

SeeReal Technologies has developed a way to overcome this limitation by focusing on reconstructing the scene as it has to be seen from the observer’s eye pupil, and not on the scene itself. Thus, we limit the required amount of information. A “Viewing Window” (VW) is generated at the position of the observer’s pupil, and from this position only the reconstruction can be observed.

The VW is basically the periodicity interval that is generated by the discrete structure of the phase modulator. The original method used by SeeReal Technologies is then to use this interval not as a location of the reconstruction (as it is made in the other holographic displays), but as the “window” through which an observer may view the reconstructed 3-D scene when looking towards the hologram.

Encoding any other information on the object that would not reach the VW would increase the phase modulator resolution, to generate information that would be wasted (Fig.3). Furthermore, this method allows a significant decrease in the required flow of data, allowing the encoding and display of real time reconstructions.

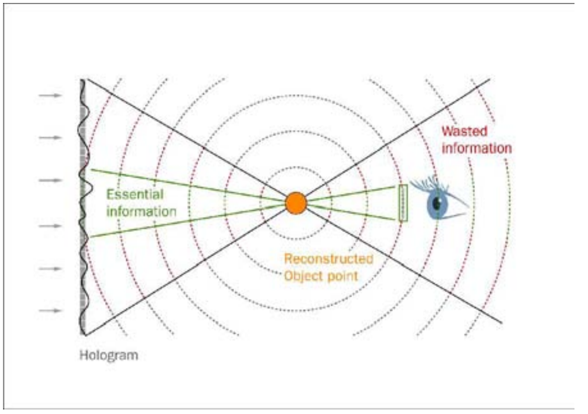

Fig.3 The amount of required information is limited to the light that passes through the pupil

A camera-based tracking system informs in real time the holographic display of the observer’s position, and the optical system adapts to this information. A pair of VWs is generated, one for each observer’s eye, with adapted content[1]. This pair of views is a pair of holographic reconstructions, perfectly substituting a natural 3D scene and therefore avoiding eyestrain of stereoscopic viewing.

This principle has already been proven with a laboratory prototype based on large-sized (20 inch diagonal) LCD as spatial light modulator [2] (SLM) for direct-view applications. The development included solutions for tracking-range improvement, and full-color reconstruction. The “direct-view” principle inherently limits the size of the display to the size of the SLM itself. While scalability of SLM will continue to take place, SeeReal extended their development scope to potentially be able working at any display scale.

2. Experimental

Consequently we adapt the direct view principle to the complementing projection market. For displaying a holographic pattern we use a high-resolution (HDTV) micro display as SLM. The modulated wavefront is processed through an optical system, in which the SLM is basically projected on a (reflective) screen. The optical properties of this screen (e.g. a spherical mirror) finally generate the VW, from which the reconstruction is observed[3] (Fig.4).

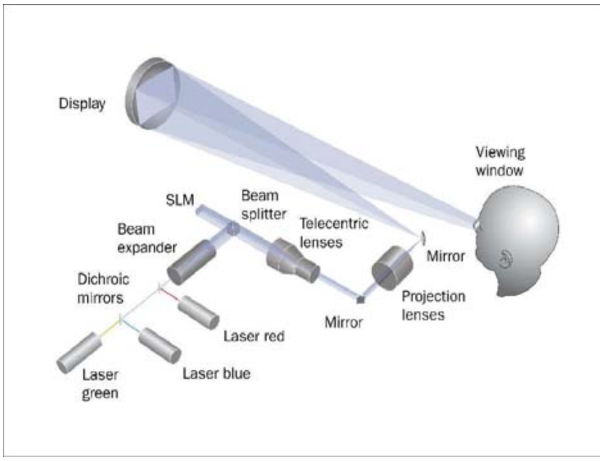

Fig.4 Projection holography setup

This method offers several new options compared to direct view: first, the optical processing includes a filtering of the parasite diffraction orders (due to the discrete structure of the SLM). This eliminates the risk of generating the typical parasite VW that can appear at an unwanted position (especially the observer's second eye). This solution allows multi-user features. Using micro SLMs (e.g. LCoS) of high resolution (HDTV) allows sufficiently sized VWs. There is a possibility to multiplex in a compact way several wavelengths as well as multiple VWs. The high refresh rate of LCoS micro displays enables full-color reconstruction with the use of a single SLM (time-modulating at 180Hz). Finally, as the lightpath is offering a comfortable degree of freedom, which allows well-sized tracking domains, the ergonomics of the display will benefit.

3. Results and discussion

The first relevant step was the realization of a prototype based on the projection of two separate 0.6 inch HDTV-LCoS on a 6 inch mirror. With this monochromatic system, we validated the projection concept, and real-time calculation and displaying of computer generated holograms.

We validated the concept by displaying a series of 5 circles : 3 20mm-diameter reconstructed 500 mm in front of the screen, 2 20mm-diameter reconstructed 500mm behind the screen.

Using a 75mm camera lens, we managed to focus on the various distances, to get a sharp image of either population of circles (Fig.5).

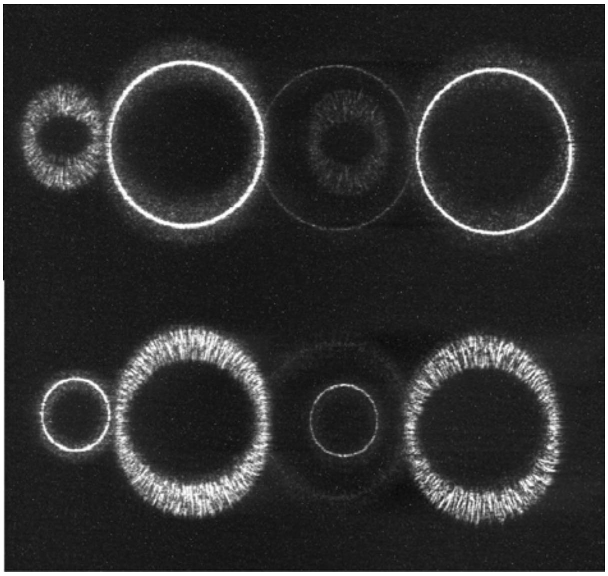

Fig.5 Focused on the +500mm circles (up) and on the –500mm circles (down)

Our next step was building a full-color projection system: we projected two HDTV LCoS on a 8 inch screen, this time performing a time-multiplexing of three wavelengths (RGB). Development of highly efficient encoding algorithms and of dedicated encoding hardware for real-time calculation of video holograms, combined with fast modulation of the SLM allowed us to observe the first full-color real-time calculated reconstruction (Fig.6 and 7).

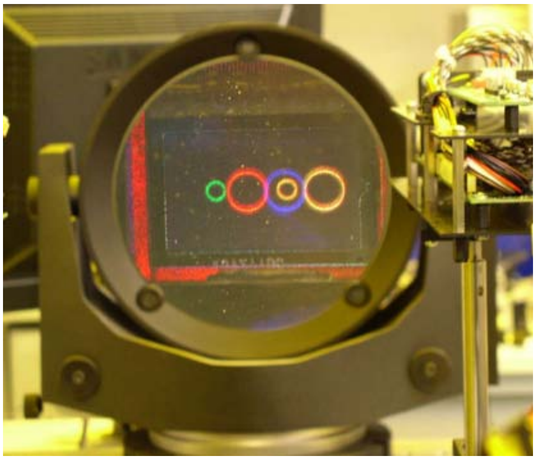

Fig.6 Full-color holographic reconstruction

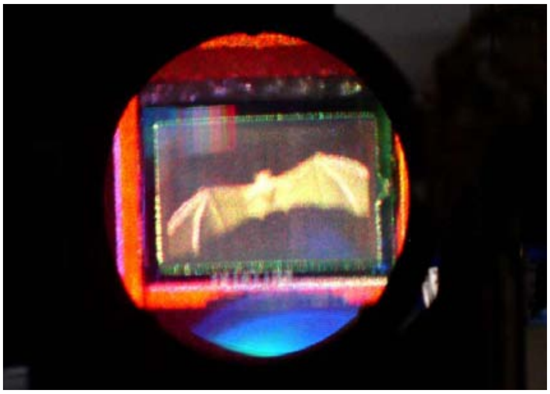

Fig.7 Full-color holographic reconstruction

Parallel to this development, we worked on key ergonomic issues by implementing an optically-tracked system. We developed a 20 inch monochromatic system, in which a hologram is projected through an optical system using only one HDTV SLM to generate the two tracked VWs. A 20 inch holographic reconstruction was visible at a distance of only 1 meter from the display (Fig.8). Demonstration of a tracking range of over 6 inch served as another verification of several base principles. One of the key tasks was the development of an optical design suppressing negative aberration effects.

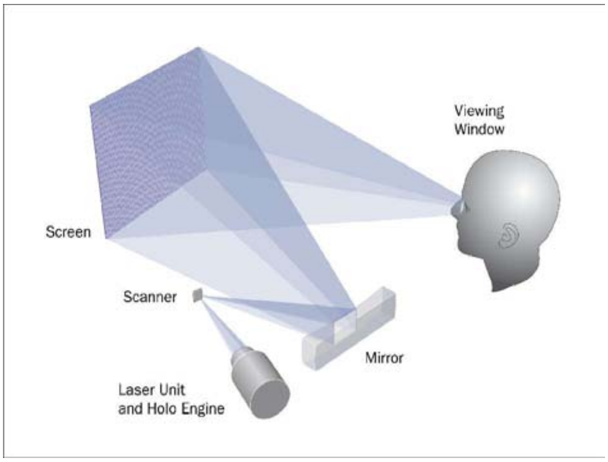

Fig.8 Artist view of the principle for a holographic projection 20 inches with tracking screen

Ongoing development is focusing on merging features as full-color real-time hologram generation with tracking, or integrating diffractive optical elements (DOE) to replace optical refractive elements (e.g. the screen). This will allow further possibilities in size of the concept.

4. Summary

The described development steps allowed us to prove our VW concept: the possibility to generate spatially-extended holographic 3D scenes with a realistic amount of pixels. Our projection systems bring a convincing evidence of the possible use of micro-displays to generate large holographic displays, even with full-color and real-time features. Finally, our 20 inch tracked system shows the possibility to develop multi-user holographic displays, with a resolution of the phase modulator being close to the state of the art.

This work was supported by all members of the SeeReal Technologies development teams. The 8-inch color prototype described in this paper was successfully exposed on the SID 2007, Long Beach, CA.

5. References

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