Future of Photorefractive Based Holographic 3D Display

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ABSTRACT

The very first demonstration of our refreshable holographic display based on photorefractive polymer was published in Nature early 2008[1]. Based on the unique properties of a new organic photorefractive material and the holographic stereography technique, this display addressed a gap between large static holograms printed in permanent media (photopolymers) and small real time holographic systems like the MIT holovideo. Applications range from medical imaging to refreshable maps and advertisement. Here we are presenting several technical solutions for improving the performance parameters of the initial display from an optical point of view. Full color holograms can be generated thanks to angular multiplexing, the recording time can be reduced from minutes to seconds with a pulsed laser, and full parallax hologram can be recorded in a reasonable time thanks to parallel writing. We also discuss the future of such a display and the possibility of video rate.

Keywords: Holography, Photorefractive polymer, 3D display.

1. INTRODUCTION

Human vision is three-dimensional by nature. We can comprehend depth thanks to different clues like parallax and occlusion. The information content in a 3D scene is much richer than in 2D, and can be used to our advantage for situational awareness like in medical imagery, mission planning or technical training. Holography has shown the path for realistic rendering of any given scene in 3D with both parallax and depth of field. Unfortunately, and in spite of many scientific efforts, those holographic reproductions remain static. Some systems have tried to adventure to dynamic holographic displays but the amount of information is so large that applications have been strongly limited in size[2].

A lot of different solutions exist for reproducing 3D by the mean of stereoscopy. Many of them rely on eyewear which substantially limit their use. In these techniques, one image is projected to the left eye and another one to the right eye. The brain interprets this pair of image as a 3D picture. But in this case, there only exist 2 scenes, and if the viewer moves around, the parallax does not change; a lot of information is lost[3].

Recent developments from television manufacturers have lead to an evolution of integral photography where multiple scenes taken at different angles are redirected toward the viewer eyes to reproduce 3D[4]. In this system, a lens array is placed in front of a regular screen and pixels are combined together to form a particular view angle. There are many advantages with that solution for television since it is native full color, video rate, and use existing communication network. However, a compromise has to be made between the number of pixels bonded together to produce lateral resolution and the extent of those pixels that provides the lateral resolution. So far, less than 10 angles of view can be reproduced and the viewer needs to stand at a fixed distance from the display to experience the best 3D effect. The resolution is strongly degraded compare to the actual HDTV.

Integral holography is the sister technique of integral photography. Instead of using regular screen and lens array, it combines the different image perspectives into a holographic pixel, or hogel. The advantage is that a better resolution can be achieved since there is no need for a physical extend of the pixel or the lens array. The hogel can be so small that it is beyond the human eye resolution. Integral holography, sometime called holographic printing, can reproduce any given scene, real or computer generated on a very large size media as it has been proved in the past. So far this is the best technique to reproduce the most realistic 3D scenes with vivid colors and deep third dimension impression[5].

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Unfortunately, holographic recording media available for the moment are permanent. Silver halide emulsion, dichromated gelatin, photopolymer, etc., all are write once read many and the recorded image can not be refreshed.

2. PRESENT STATUS

After more than 10 years in material research in photorefractive polymer, we developed a holographic recording material that can fill the gap and make refreshable holography a reality. This material is based on a copolymer matrix (PATPD-CAAN) loaded with chromophore molecules (FDCST) that reorient in electrical field, and changing the material refractive index locally. The matrix also provides the charge generation and transport function for the photorefractive space charge field to be produced during illumination.

Devices are manufactured by melting the compound between two glass plates coated with ITO electrode. 100 µm spacers are inserted to control the film thickness. Samples as large as 12x8.5 inch have successfully been manufactured (see Figure 1).

Figure 1: A 12x8 inch photorefractive device in front of a computer screen. The device is operational and has been tested to record holograms.

That material is sensitive enough to exhibit 100% diffraction efficiency at an applied voltage of 4kV with 400mJ/cm² of energy at 532 nm. Moreover, the use of a higher electric field during the recording decreases the exposure time dramatically. Reducing the field afterward prolongs the reading time to several hours. This technique, we call the “voltage kickoff”, has been described elsewhere[6].

So far, we have demonstrated the recording of large holograms constituted of hundreds of hogels with a sub millimeter resolution (0.8mm). They can be read either with red or green light bulbs (LEDs). The recording time is 1 second per hogel with a recording intensity of 100mW/cm² (sum of both beams). As a numerical example, a 4x4 inch screen can be recorded in 2 minutes and the hologram will last for a couple of hours. Horizontal parallax only has been used to reduce the number of hogels while keeping depth perception thanks to the lateral separation of human eye. Pictures of some of those holograms at various angles are presented in Figure 2.

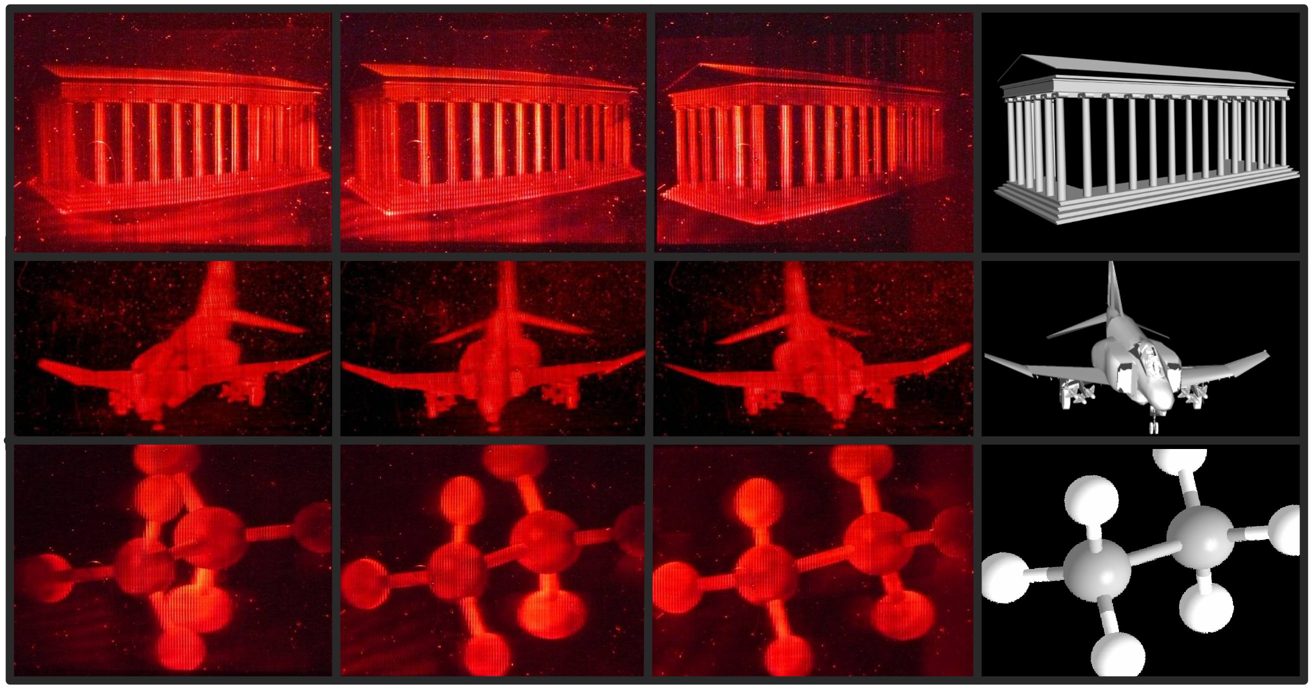

Figure 2: Camera capture of holograms according to different angles of views. The last column presents the computer model used to record the hologram.

3. NEXT PHASE

The natural evolution of the holographic 3D system will be to bring color, decrease the recording time, demonstrate full parallax and demonstrate an even larger screen. We discuss here the different approaches that can solve those issues.

3.1 Color holograms

For encoding color holograms an important distinction has to be made between transmission or reflection geometry holograms.

We are currently using the transmission geometry since the material is more efficient in this configuration. Transmission holograms in Bragg regime have a very broad superblaze curve but are angularly selective. This means that you can change the wavelength at which you read the hologram providing you are also changing the angle of incidence. Thus, the same hologram can be read in various wavelengths independently of the recording wavelength.

Color encoding in transmission geometry can be made by recording three holograms at different angles with the same laser source. Each one will diffract a different color when read at different angle. By taking into account the diffracted Bragg angle, those colors will superimpose in the viewer eye and the 3D image will be perceived as colored. In this case, a single laser is required for writing the hologram, and though a white light bulb can be use for reading, the best result is obtain with three colored sources positioned at different angles. Transmission color hologram geometry eases the recording process but puts constrains on the reading geometry.

In reflection geometry, the hologram acts as a band pass filter, and the diffracted wavelength is strongly dependent on the writing wavelength. Color is achieved by writing three different holograms with three different wavelengths. This requires different lasers (red, green, and blue) which put a lot of constraints on the recording setup. But, as a benefit, those holograms can be read with white light at a broad orientation. Usually, room light can be used.

The recording of the three holograms required for color, either in transmission or in reflection, can be done by superimposing of the hologram in the same location (multiplexing) or, like in a regular 2D screen, by aliasing the holograms side by side. In the case of the multiplexing, the dynamic nature of the holograms induces a reduction of the overall diffraction efficiency, but the resolution is better than using aliasing.

3.2 Pulsed recording

To increase the recording speed, one should deliver the light intensity needed for efficient holograms in the minimum amount of time. Toward this goal, we plan to replace the continuous wave laser used for recording with a nanosecond pulsed laser.

We have already demonstrated that a pulsed laser can be used to write a diffraction gratings in photorefractive polymers[7]. However in that case, the persistency time was very small (ms), a characteristics that was sought at that time.

For the actual application, we want diffraction efficiency over one percent and a long persistency time. Though several hours, like with the CW setup, will not be necessary with a faster recording time, several minutes are still expected. Preliminary results obtained with four wave mixing measurement on small samples are encouraging. A 100Hz laser with 200mJ/pulse has been used to record uniform diffraction grating. A HeNe diffracted beam was clearly visible for several minutes and no optical damage has been reported after several recording erasing cycles. With such a pulsed laser, we calculated the recording time will be improved by a factor of 100.

Yet another advantage of using a nanosecond pulsed laser is the desensitization of the setup to the ambient noise. CW holography is plagued with the requirement for fringe stability during the recording. This means the use of damped optical table, enclosure, and sometimes a fringe tracking system. Nanosecond pulses are short enough that mechanical vibration, thermal fluctuation, or air turbulence are too slow to significantly move the fringes during the recording. This is true for single pulse recording. If multiple pulses are necessary, the stability must be assured from pulse to pulse.

3.3 Full parallax

The 3D display system we have developed has horizontal parallax only (HPO). This is a good enough approximation considering the human vision comprehends mostly depth due to the horizontal separation of both eyes. However, for better reproduction of 3D and for horizontally mounted displays, full parallax is required. The problem that comes with full parallax is that the number of hogels required to write the hologram increases by a square factor compare to HPO, and so does the recording time.

As an numerical example, for a 4x4 inches display recorded in 2 minutes and containing roughly 100 hogels in HPO, 10,000 hogels are necessary for full parallax, and the recording time will be 200 minutes. By the time the last hogels is recorded, the first part of the hologram has already disappeared.

Though the pulsed setup discussed earlier will help to reduce the recording time to 2 minutes for the 4x4 size hologram, larger displays like the one presented in Figure 1 will require yet another speed improvement.

A solution consists to multiplex the recording head. In HPO, the hogel has the shape of a slit with about 1cm² of surface. In full parallax the hogel is squared (or round) with a surface of 1mm² (or less, depending of the resolution). So, the energy can be re-distributed to several subapertures to record several hogels at a time. Though, several technical challenges have to be overcome to use this multiplexing technique, a factor 10 at least can be gained in the recording speed.

3.4 Larger screen

We have demonstrated a 12x8 inches active device. 12x12 inches should be feasible with the actual technique of pressing the melted material between ITO coated glass plates. However, to go for even larger screens of m² size or more, some sort of tiling will be necessary. There are several reasons for this. First the force needed to spread the polymer during the film formation increases with the surface since the pressure must be constant. At large sizes, the glass plates will brake. Second, the thickness homogeneity of the film becomes more and more problematic due to the contraction of the polymer when the pressure is released, bowing the glass. Assembling several devices side by side while minimizing the border defects appears to be a viable approach.

Patterning the electrode is also considered. A tremendous improvement of the device stability, in terms of dielectric breakdown, has been made the last couple of years. We are now manufacturing a large film that can hold 9kV for months. However, when dielectric breakdown happens, the whole area of the film becomes inoperative since the shortcut is conductive and prevents applying further voltage. By patterning the electrode we could isolate the defective area and still display a large hologram on the rest of the device.

4. THE FUTURE OF HOLOGRAPHIC DISPLAY

Thanks to the above mentioned improvements, it is possible to have a full color, full parallax, refreshable holographic 3D display a meter square in size in the near future. This kind of display can be used for specific applications like medical imaging, command and control terrain maps, architectural and art displays, and advertisement. Such a display, correctly packaged, could be only $1m^3$ in size with the screen as one of the sides of the cube. The pulsed writing beam will not leave the enclosure thanks to reflective coating on the sample itself or absorption filter in front of it.

At this stage, we are limited by the laser technology and/or the material sensitivity. Theoretically, it would be possible to write faster to achieve video rate with a kilohertz laser. Photorefractive material has already proved to be that fast[7]. But the pulse power of such a laser (diode pumped YAG) is to low to achieve descent diffraction efficiency. Since it is doubtful that a multi-kilowatt pulsed laser will be soon developed, we are currently looking to improve the sensitivity of the material so only a few mJ/cm^2 of power, instead of hundreds, is needed to write the hologram. Possible ways are sensitization via functionalized nanoparticles.

Increasing the sensitivity of the photorefractive material by, at least, an order of magnitude is the key element that will unlock the door of a *video rate holographic 3D display* for everyday applications.

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