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Review Article

Studying the Recent Improvements in Holograms for Three-Dimensional Display

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Displayers tend to become three-dimensional. The most advantage of holographic 3D displays is the possibility to observe 3D images without using glasses. The quality of created images by this method has surprised everyone. In this paper, the experimental steps of making a transmission hologram have been mentioned. In what follows, current advances of this science-art will be discussed. The aim of this paper is to study the recent improvements in creating three-dimensional images and videos by means of holographic techniques. In the last section we discuss the potentials of holography to be applied in future.

1. Introduction

No matter how much one is familiar with holography, a scientist or an ordinary person, he would soon engage with holography spontaneously. Increasing applications of holography will soon find their way through everyday life. Dennis Gabor found basic principles of holography while trying to improve the efficiency of transmission electron microscope in 1948 [1]. He performed his first experiments using mercury vapor lamp. After 23 years of experiments, Gabor won the Nobel Prize in 1971. Nowadays, the most beautiful 3D pictures and movies are created by means of holograms. Digital holography was invented in 1900. The improvement of computer science led to delivering the recording and reconstructing processes to the computers and hence the creation of computer generated holograms (CGHs) in which artificial holograms are made by means of numerical methods [2]. CGH-based display systems can be built nowadays. Their high cost makes them impractical for many applications. However, as various computer hardware costs decrease, CGH displays will become a viable alternative in the near future and thus pave the way for commercial real-time holographic 3D imaging [3, 4]. Nowadays, holography has many growing applications in different sciences such as biology, medicine, IT, communication, architecture, security, and packing. There are optical applications existing for holography, and some of them are still developing [5–9]. Making holographic three-dimensional displays providing realistic images without the need for special eyewear is one the most interesting application of holography. Michael Bove et al. from MIT media laboratory have described the characteristics of a true holographic television display in a simple way [10]. A good holographic three-dimensional telepresence system has been developed using large-area photorefractive polymer with very high diffraction efficiency [11]. Scientists always try to make floating and updatable 3D holographic displays [12–17]. There is a paper which investigates the ability of holographic projection on a mobile device [18]. Takaki presents a new holographic three-dimensional display using a MEMS spatial light modulator that increases both viewing zone angle and screen size [19]. Updatable holography is considered as the ultimate technique for true 3D information recording and display. However, it is very hard to preserve the required features of both nonvolatility and reversibility which conflict with each other when the reading has the same wavelength as the recording. Wu et al. demonstrate a nonvolatile and updatable holographic approach by exploiting new features of molecular transformations in a polymer recording system

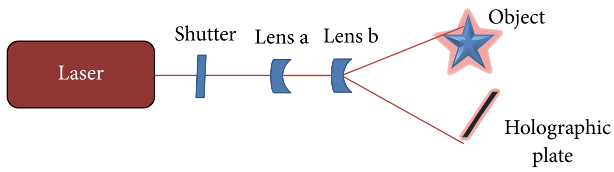

Figure 1: Off-axis single beam setup.

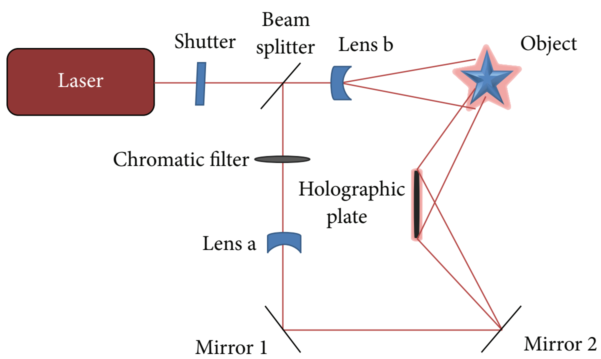

Figure 2: Split-beam setup.

[20]. The present paper has done a theoretical and experimental study on creating 3D images by means of holography. Also, a much more universal future is predicted for this technique.

2. Making a Transmission Hologram

In this section, the experiments done for making transmission holograms are demonstrated. In these experiments, two kinds of transmission setups, off-axis single beam and split-beam setup, have been used, which have been, respectively, shown in Figures 1 and 2. One can find the principle of holography in a simple way in [21]. Usually the coherent light source of lasers is used to record holograms, but it is possible to record the holograms using low-coherence light sources [22]. There is a paper that reports the reconstruction of an image which is taken by a 300-camera system with monocolor LED illumination [23]. In another interesting work, the generation of a real-time phase-only color holographic video display system using LED illumination has been reported [24].

The intensity of the reference wave must be higher than the object wave, and this is an important factor in the diffraction efficiency. For a desired result 4 : 1 relation was selected. The difference path between the reference wave and the object wave must be less than the coherence length of the applied laser, that is, about 15–30 cm in the case. The applied holographic plate is PFG-01, silver halide emulsion purchased from GEOLA [25]. This plate is fine-grained red sensitive, 600–660 nm, and is illuminated by CW lasers. Average grain size is 40 nm, resolving power more than 3000 line/mm and the emulsion thickness 7 μm. The index of refraction is 1.61 and the mass per unit surface of silver halide is 2.7 g/cm^2. These types of plates have been designed

Figure 3: The reconstructed virtual image.

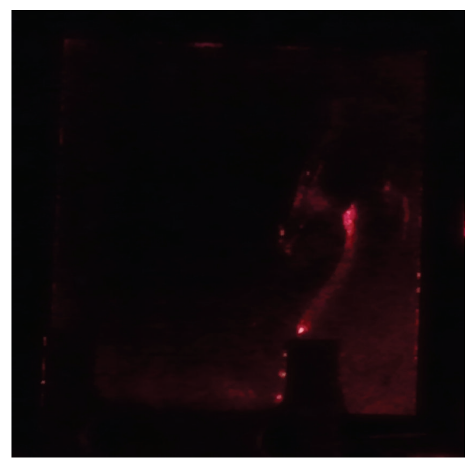

Figure 4: The reconstructed virtual image is orthoscopic.

for both transmission and reflection hologram recording. The PFG-01 light sensitivity is maximized at approximately 80 microJ/cm^2. The maximum diffraction efficiency is more than 45%. These plates are 63 × 63 mm. The applied laser is 1.5 mW He-Ne laser, and the objects used are plastic white pawns, chess game pieces. The exposure process is done in mere darkness, and the exposure time is calculated 6 seconds.

If the chosen object for recording is too large, too small, or transparent, the holographer must use special techniques to record and reconstruct it [26, 27].

After recording, the plate is removed from its set place to perform the exposure procedure done in green safe light. In order to develop the plates the JD-2 developer, the most commonly used developer and processing chemical, is used. This process includes two steps, developing and bleaching, despite the old processes which had three steps, developing, bleaching, and fixing. Before the experiment all three solutions must be provided, but the two parts of developing solution have to be combined with 1 : 1 relation just before using them. There are two real and virtual images in holographic reconstruction. Figures 3 and 4 represent

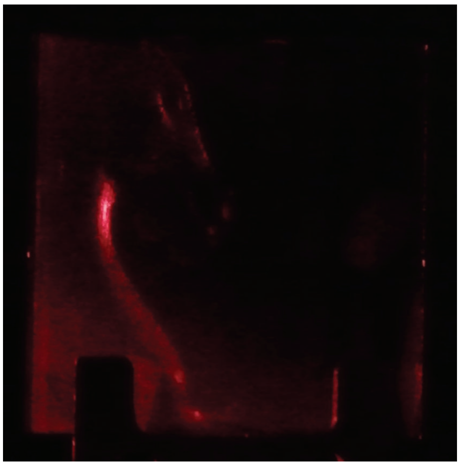

Figure 5: The reconstructed real image is pseudoscopic.

the reconstructed virtual image and Figure 5 represents the real images.

The images are seen in the same red color of the He-Ne laser. The virtual image is orthoscopic and is reconstructed in the back of the plate and the real image is pseudoscopic and is reconstructed in front of the plate. In order to reconstruct the real image, the hologram has to be illuminated with the conjugated reference wave. To do so the hologram must be turned by 180°.

Zhong et al., using a spherical reference wave, succeeded in reconstructing a diffractive object at short distance having a good resolution [28]. They made an in-line phase shifting digital hologram. They found that in this condition the distance between the object and CCD and the distance between the point source of the reference wave center and CCD have to be measured carefully to achieve a high quality reconstructed image. In addition, other methods have been reported to improve the resolution of the reconstructed holographic images [29].

Reconstructed holograms deliver colored but mostly monochromatic images. To record a hologram in which both the 3D shape and the color of the object are accurately reproduced, at least three laser wavelengths are needed. There is an old paper about wavelength selection problem for true-color holography [30].

3. Advances in Creating Three-Dimensional Images and Videos Using Holographic Techniques

In recent years, 5000 lines/mm for a holographic plate seems to be a normal amount. Previously, holographic plates were sensitive to a very limited spectral range of wavelengths; hence, they were classified into red-sensitive and green-sensitive holographic plates and films. Nowadays, the holographic plates which are sensitive to the whole visible range of lights are easily manufactured, for example, TCC-2 (photothermoplastic) and PFG-03C (silver halide). PFG-03C is designed for the production of full-color reflection holograms with CW laser radiation, and for pulsed color hologram recording a special version of PFG-03C called GEO was developed. Though these full-colored plates expire sooner, they produce high-quality images. Recently, some other new panchromatic ultra-fine-grain silver halide materials are available from various manufacturers such as Sphera-s in Russia, Colour Holographics in UK, and Ultimate in France. There is one paper presenting a comprehensive comparison between these materials [31]. Most successful recording materials that have been used in holographic displays include photographic emulsions and photopolymers. Photopolymers have proved to be useful for different holographic applications. However, most photopolymers have certain undesirable features, such as the toxicity of some of their components or their low environmental compatibility. For this reason, the Holography and Optical Processing Group at the University of Alicante has developed a new dry photopolymer with low toxicity and high thickness called Biophotopol [32]. When the thickness of holographic recording materials increases, it is necessary to study their behavior using real 3D models rather than 2D models. For example, Gallego et al. have studied the 3D behavior of photopolymers as a holographic recording material [33]. The optimization of photopolymer materials for holographic data storage has been reviewed [34]. Also, there is a comprehensive review which describes the current state-of-the-art of photorefractive polymers for holography [35]. Holographic recording materials are usually characterized by recording holographic gratings [36]. The main advantage of this method is the characterization and optimization of materials. For instance, it is possible to measure the signal-to-noise ratio using this method. A good comparison of large-area, erasable holographic materials, such as Bacteriorhodopsin, Azo-dye, Electrothermoplastic, Amorphous Chalcogenide, Photorefractive polymers, and Liquid crystal systems by Peyghambarian's group can be found here [37]. To be used for updateable 3D displays, these materials must satisfy certain requirements, such as high diffraction efficiency and sensitivity, reversible recording, high spatial resolution, large area, long storage time, and fast recording. The process of Bacteriorhodopsin materials is based on conformational change and their efficiency is very low. Another low efficiency material is Azo-dye whose process is based on molecular orientation. Li et al. have fabricated a holographic display system using an azo-dye-doped liquid crystal [38]. Liquid crystal systems work drawing on liquid crystal orientation. The efficiency of such systems is very low. The efficiency of Electrothermoplastic materials is better than that of mentioned materials and their process is based on photoconduction and melting but their resolution is worse than them. Another erasable holographic material is Amorphous Chalcogenide which works with electronic structure changes. This material has a good efficiency near 80% but needs a high exposure that limits its performance. Photorefractive polymers stand out as attractive candidates for updateable holographic displays. Their efficiency is over 90% and they can be made in large-area formats. Tsutsumi et al. have fabricated an updatable three-dimensional holographic stereogram display device using an organic monolithic compound which has the capability of recording and displaying new images within a few seconds and fixing at ten seconds and viewing for a longer time without applying any electric field. [39, 40]. Ishii et al. have developed a real-time, dynamic holographic material using a fast photochromic molecule that exhibits rapid colouration upon irradiation with UV light and successive fast thermal bleaching within tens of milliseconds at room temperature [41]. Using some of photorefractive crystals has enabled scientists to use the recording media to record a new holographic image again, after recording and reconstructing the previous image. Lynn et al. have investigated the recent advances in photorefractive holographic imaging [42]. Poly(4-(diphenylamino)benzylacrylate)-based and poly(N-vinylcarbazole)-based photorefractive composites have shown a good ability for dynamic holographic displays [43, 44]. Huang et al. have carried out a research on a novel wideband dry sensitive photopolymer which is appropriate for multiwavelength recording in digital holography [45]. This photopolymer has been made from rose bengal and methylene blue. Their analyses show that the scattering play an important role in the process of holographic recording and the scattering phenomenon may reduce the maximum diffraction efficiency in such holograms. An attempt for optimization of diffraction efficiency can be found here [46]. In a research the performance of polyvinyl alcohol/acrylamide photopolymer PVA/AA photopolymers for holographic recording has been improved [47]. The improved photopolymer has presented low scattering and diffraction efficiencies as high as 85%. Recently, a new and even more remarkable panchromatic photopolymer is available from Bayer Material Science (BMS) [48]. This material has many advantages such as long life time, stability, environmentally robust (no shrinkage), and less postprocessing (thermal or wet) [31]. Another photopolymer receiving ever greater attention in the literature is phenanthrenequinone (PQ) doped poly(methyl methacrylate) (PMMA) photopolymer material. This material has many applications in various research areas such as holographic data storage, hybrid optoelectronics, solar concentrators, self-trapping of light, and diffractive optical elements [49]. Atsushi Shishido has prepared optically transparent films with a thickness of >200 μm [50]. These rewritable holograms are based on azobenzene-containing liquid-crystalline polymers. In this research, it has been reported that when two writing beams are made to overlap in the film, a periodic change in refractive index is induced and an incident probe beam is diffracted at about 100% diffraction efficiency. This type of recorded holograms can be erased by thermal treatment or photoirradiation with a single writing beam. One can find another good paper reporting development of an updatable holographic three-dimensional display in [51]. Zhu et al. have made a high-quality single-layer panchromatic dichromated gelatin material for color holography [52].

One can find nice pictures of computer generated holograms which have been made for 3D display in an article by Hiroshi Yoshikawa et al. [53]. They have studied different types of computer generated holograms for 3D displays including real-time holographic video displays. In another paper Bjelkhagen et al. studied color holography to produce highly realistic three-dimensional images [54]. A demonstration of a large-size real-time full-color three-dimensional display can be found here [55].

Scientists have been always trying to use an appropriate setup and a good CCD or CMOS camera, with a suitable pixel pitch, to make high resolution digital holograms [56, 57]. Pixel count is an important factor in quality of holographic displays, and there have been always attempts to increase it [58]. In an experimental research which has used a high resolution CMOS sensor, full-color compact lensless holographic display has been evaluated [59]. The advantage of this method is using a small and simple lensless optical setup. In the mentioned paper the image finesse, color fidelity, contrast ratio, and influence of speckles have been evaluated and compared with other techniques of holographic color image encoding. The speckle noise has always been an undesirable phenomenon in holograms. Kang has proposed a simple and effective method to reduce speckle noise in digital holography [60]. Other related studies have been reported in [3, 61, 62].

Zheng et al. proposed a method for high quality optoelectronic 3D holographic display using Fourier transform [63]. Fourier transform holography can well assure the precise superposition of the reconstructed images. Zhao et al. have used lensless Fourier transform holography technique [64]. They have recorded three monochromatic digital holograms with various wavelengths (namely, red, green, and blue) for a color object using a monochrome CCD, and then they concluded that the reconstructed monochromatic images should not only be identical in size but also be superposed precisely in order to get an accurate digital color holographic image of a color object.

Shimobaba et al. have a numerical study on color holographic projection and have tried to avoid the superimposing of unwanted images on a wanted image [65]. Scientists have always looked forward to fast generation of digital 3D video holograms [66]. For real-time holographic video display, it is important to generate holographic fringes as fast as possible. It is also important to display the true-color image with a simple display system. A practical investigation on image holograms for fast calculation and the display optics for full-color holograms has been done [67]. In the mentioned work the true-color hologram has been displayed on a holographic video display system that uses part of the original optics and liquid crystal on silicon (LCoS) panels of the conventional video projector to separate and combine color components. Also the development of a wide viewing-zone-angle full-color electronic holography reconstruction system using very high resolution liquid crystal display panels has been reported [68].

Nowadays, most curators produce holographic 3D images from their valuables. It is possible to copy these holographic plates without having access to the main object. In a project named "bringing the artifacts back to the people," holograms of twelve different artifacts were recorded using the single-beam Denisyuk color reflection method. In this project white laser light was produced from three combined cw RGB lasers: a red krypton-ion laser, a green frequency-doubled Nd-YAG laser, and an argon-ion laser and panchromatic ultra-fine-grain silver halide materials were used for the holographic recording. It is interesting to know that one of the recorded artifacts included a 14,000-year-old decorated horse jaw bone from the ice age, which is kept at British Museum in London [69]. In many parts of the world, exhibitions are held for the public to see the beautiful holographic images. These images are mostly reflective, because as already stated reflective holograms are easily reconstructed by means of the white light of small projectors, and it is not necessary to use laser beam which is likely to damage human eyes.

4. Future of Holography

Lance Winslow has written a comprehensive book beautifully predicting the future of holographic projection technologies [70]. Reading this book is recommended to all interested people. These predictions include the application of this technology in cellphones, television sets, computer games, billboards, simulation, and education. Some other sections of this book discuss the potential of this technology in different fields; for instance, this technology can greatly help traffic police to show the traffic signs. It can also help people to have a virtual trip. In another section of this book, which is far beyond our imagination, the author predicts that holographic images will be used as clothing and even makeup in the future. Although, nowadays, holographic 3D movies and pictures are produced in a way that surprises the observer, it is predicted that the quality of this science-art will be improved to an extent that it will be impossible to distinguish holographic images from real objects. An effort has been done to achieve three-dimensional television by electroholography [71]. A simple method of performing color electroholography has been proposed. In this method three colored light-emitting diodes (red, green, and blue) as reference lights were placed at the apexes of a small right-angled triangle. The well-known scientists, Yeh and Gu, reviewed the current status of stereoscopic 3D displays and discussed using flat panels for the display of both phase and intensity of video image information, leading to the ultimate display of 3D holographic video images [72].

5. Conclusions

We studied the recent improvements in creating three-dimensional images and videos by means of holographic techniques. Holography has so many various applications in different sciences. Due to the improvement of light sources, optical elements, holographic plates, and the other holographic recording media, the quality of holographic images has been significantly improved. A report on creating and reconstructing of transmission red-sensitive holograms has been provided. In what follows, this paper discusses the holographic projection technologies of the future. Scientist predicts a very bright future for this technology, and it is predicted that this science-art will find its way from exhibitions and laboratories to the everyday life. The advantage is the real three-dimensional display without the use of any other viewing aids. Although, nowadays, holographic 3D movies and pictures are produced in a way that the observer is surprised, it is predicted that the quality of this science-art will be improved to an extent that it will be impossible to distinguish holographic images from real objects.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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