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스테레오그램과 홀로그래픽 광 메모리 기술을 이용한 3차원 영상 표현 시스템

정회원 김 철 수*, 김 수 중**

Three-Dimensional Image Display System using Stereogram and Holographic Optical Memory Techniques

Cheil-Su Kim*, Soo-Jung Kim** ***Regular Members***

요 약

본 논문에서는 스테레오그램과 많은 영상들을 자동으로 저장하고 재생할 수 있는 홀로그래픽 광 메모리 기술을 이용하여 3차원 영상 표현 시스템을 구현하였다. 제안된 시스템에서 스테레오 영상들을 저장하고, 재생하기 위해서 기준빔의 입사각이 실시간으로 제어가 되어야 한다. 이를 위해 이진 위상 홀로그램과 LCD를 이용하였다. 즉 기준빔은 SA 알고리듬으로 설계된 이진 위상 홀로그램들을 푸리에 변환 함으로써 얻었고, 이진 위상 홀로그램은 스테레오 영상 재생을 위해 0.05초 간격으로 LCD에 표현했다. 그리고 입력영상들은 입력영상의 밝기에 상관없이 균일한 빔 세기를 유지하도록 편광기가 없는 LCD에 표현하였다. 입력영상과 이진 위상 홀로그램은 영상 저장시 같은 기록 시간 간격을 가지도록 응용 소프트웨어인 포토샵을 이용하여 편집하였다. 재생되는 스테레오 영상은 영상의 위상 정보를 밝기 정보로 바꾸어 주는 편광기 뒤에서 CCD 카메라로 획득함으로써 얻었다. 그리고 출력면에서 입체감을 느끼기 위해 좌우안 영상이 표현되는 모니터에 동기화된 LCD 셔터를 착용하였다. 제안된 홀로그래픽 광 메모리 기술을 이용하여 $BaTiO_3$에 네 개의 스테레오 영상을 저장하고, 재생하는 광 실험을 하였다

ABSTRACT

In this paper, we implemented a three dimensional image display system using stereogram and holographic optical memory techniques which can store many images and reconstruct them automatically.

In this system, to store and reconstruct stereo images, incident angle of reference beam must be controlled in real time, so we used BPH(binary phase hologram) and LCD(liquid crystal display) for controlling reference beam. The reference beams are acquired by Fourier transform of BPHs which designed with SA(simulated annealing)algorithm, and the BPHs are represented on the LCD with the 0.05 seconds time interval using application software for reconstructing the stereo images. And input images are represented on the LCD without polarizer/analyzer for maintaining uniform beam intensities regardless of the brightness of input images. The input images and BPHs are edited using application software(Photoshop) with having the same recording scheduled time interval in storing. The reconstructed stereo images are acquired by capturing the output images with CCD camera at the behind of the analyzer which transforms phase information into brightness information of images. In output plane, we used a LCD shutter that is synchronized to a monitor that display alternate left and right eye images for depth perception. We demonstrated optical experiment which store and reconstruct four stereo images in $BaTiO_3$ repeatedly using the proposed holographic optical memory techniques.

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* 경주대학교 컴퓨터전자공학부 (kimcs@kyongju.ac.kr), ** 경북대학교 전자전기공학부 (sjkim@palgong.knu.ac.kr)

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Ⅰ. INTRODUCTION

Human being receives most of the information through the eyes. The eyes of human being are perceived three dimensional image, but most of images which display in the conventional life are two dimensional. Recently, due to the technological advanced, three-dimensional image display systems have received significant attention.[1,2] And the demands on three-dimensional image generation and displaying are continuously increasing for the scientific visualization, animation, visual communication and many other purposes. Especially the emergence of the virtual reality systems have instigated the three dimensional research field. Generally, the research for the three dimensional image display system can be classified into two techniques.[3,4] One is holographic technique which store interference pattern between reference and object beam. It is very difficult to implement the system because the optical devices which support the system doesn't developed yet. but it can reconstruct perfect three dimensional image. The other is stereographic technique which require parallax images and eye glasses. parallax images are acquired by two cameras based on binocular disparity, and provided an observer through a special pair of glasses. Then an observer feels that a three-dimensional image has appeared. As this technique is easy and useful to implement the system, most virtual reality systems employ it.

In this paper, we implemented a three dimensional image display system using stereogram and holographic optical memory techniques. Using holographic optical memory techniques, many stereo images store in the single crystal such as 45° cut $BaTiO_3$ and reconstruct them very fast. An observer use an LCD shutter that is synchronized to a monitor that displays alternate left and right eyed reconstructed image for depth perception. In the holographic optical memory techniques, it is necessary to determine three factors, memory device to be used,[5] multiplexing methods,[6-8] and recording techniques.[9,10] we used an angular multiplexing for the storing many images in 45° cut $BaTiO_3$ with scheduled recording technique. $BaTiO_3$ has large electro-optic coefficients, so widely used at low level laser power. For the angular multiplexing, reference beams are controlled using LCD and BPH designed with SA algorithm.[11] The stereo images and BPHs are edited using application software(Adobe Photoshop ver. 6.0) with having the same recording scheduled time interval in storing, and represented on the LCD for the real time processing. For the reconstructing of the stereo image with uniform intensity, the phase information of an stereo image is inputted in the recording material by representing on a LCD without a polarizer/analyzer. We demonstrated optical experiment which store and reconstruct four stereo images in 45° cut $BaTiO_3$ repeatedly using holographic optical memory techniques.

Ⅱ. THREE DIMENSIONAL DISPLAY SYSTEM USING HOLOGRAPHIC OPTICAL MEMORY SYSTEM

1. volume hologram

The simplest way to produce a volume hologram is to employ two beam interference inside a nonlinear medium.[12] Consider the interaction of two beams in the medium during the storing and reconstructing of a hologram. The electric field of two beams can be written as

$$\begin{aligned} E_O &= A_O \exp[j(\omega t - \boldsymbol{k_O}\cdot\boldsymbol{r})] \\ E_R &= A_R \exp[j(\omega t - \boldsymbol{k_R}\cdot\boldsymbol{r})] \end{aligned} \qquad (1)$$

where A_O, A_R are complex amplitudes of the object and reference fields, ω is the angular frequency, and $\boldsymbol{k_O}$, $\boldsymbol{k_R}$ are the wave vectors. The interference intensity of the two beams inside the medium can be written as

$$\begin{aligned} I = & |A_O|^2 + |A_R|^2 \\ & + A_O^* A_R \exp[-j\boldsymbol{K}\cdot\boldsymbol{r}] \\ & + A_O A_R^* \exp[j\boldsymbol{K}\cdot\boldsymbol{r}] \end{aligned} \qquad (2)$$

where

$$\boldsymbol{K} = \boldsymbol{k}_R - \boldsymbol{k}_O \tag{3}$$

and $|\boldsymbol{K}| = 2\pi/\Lambda$, where Λ is the period of the fringe pattern. According to Kukhtarev's model, such an interference intensity pattern will generate and redistribute photocarriers, creating a space-charge field in the medium. This field induces a volume index grating due to Pockels effect. In general, index grating has a spatial phase shift relative to the interference intensity pattern. The index of refraction, including the fundamental component of the intensity- induced gratings, can be written

$$n = n_0 + [\ \frac{n_1}{2}\exp(j\varphi)\frac{A_O A_R^*}{I_0} \times \\ \exp(-j\boldsymbol{K}\cdot\boldsymbol{r}) + c.c.] \tag{4}$$

where

$$I_0 = I_O + I_R = |A_O|^2 + |A_R|^2 \tag{5}$$

n_0 is the index of refraction when light is absent, φ is real, and n_1 is a real and positive number. For the sake of simplicity, we have assumed a scalar grating. The phase φ indicates the degree to which the index grating is shifted spatially relative to the interference intensity pattern. In $BaTiO_3$, which is operated by diffusion only, the magnitude of φ is $\pi/2$ with its sign depending on the direction of the c-axis. $\boldsymbol{K}$ is the grating wave vector given by Eq. (3). The parameter n_1 depends on the grating spacing and direction, and on the material properties of the crystal, e.g., the electro-optic coefficient. This index of refraction contains the product of the amplitudes A_O and A_R. This grating is a hologram formed by an "object" beam A_O and a "reference" beam A_R. The diffraction component of the transmission function of such a hologram is given approximately by

$$t \sim \Delta n \sim A_O^* A_R \exp[-j\boldsymbol{K}\cdot\boldsymbol{r}] \\ + A_O A_R^* \exp[j\boldsymbol{K}\cdot\boldsymbol{r}] \tag{6}$$

Eq. (6) assumes that the modulation is weak, therefore the higher order terms can be neglected. For reconstruction, the hologram is illuminated by the reference beam $A_R\exp[-j\boldsymbol{k}_R\cdot\boldsymbol{r}]$. The diffracted beam can be written

$$\eta A_O \exp(j\psi_O) A_R^* A_R \exp[-j\boldsymbol{k}_O\cdot\boldsymbol{r}] \tag{7}$$

where η is the diffraction efficiency. Notice that the phase term of A_R cancels out and the diffracted beam is a reconstruction of the object beam $A_O\exp[-j\boldsymbol{k}_O\cdot\boldsymbol{r}]$

2. Phase modulated input method

In optical signal processing, a LCD is widely used as an input device or a phase modulator. A gray image is represented by a combination polarizer with the orientation of a molecular director in the LCD. Therefore, the amounts of beam power transmitted through a LCD, are different according to the type of image. In a multiplexing volume hologram, two recording techniques(scheduled recording and incremented recording methods) are used for uniform diffraction efficiency. These techniques has the assumption that the beam powers for all input images for storage is the same before applying on the determination of the recording time. In practice, however, the beam power transmitted through a LCD is different according to the brightness of the input image. Consequently, these two recording techniques have serious problem in the determination of a recording time.

In this paper, we have represented an input image for storage on a LCD without a polarizer/analyzer. The brightness information of the input image was transformed into phase information. So, we achieved a uniform beam power regardless of the type of input image(bright, dark, large image) and applied the scheduled recording method.

The LCD to be used in experiment was an P13SM015 model which is 1.3-inch 480,000 dots B/W panel module by Epson Co.. The modulation characteristic of the LCD was investigated using a

Mach-Zehnder inter- ferometer as shown Fig. 1.

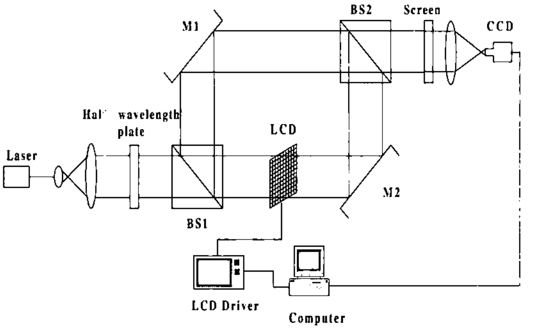
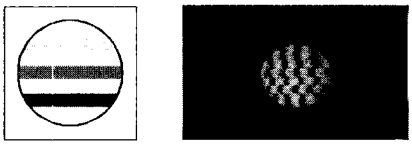
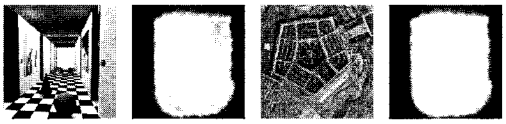


Fig. 1 Mach-zehnder interferometer for phase modulator experiment of the LCD.



(a) (b)

Fig. 2 Input patterns applied to the LCD and interferograms through a Mach-zehnder interfero meter.



(a) (b) (c) (d)

Fig. 3 Phase modulated input images (a) original corridor-left image, (b) phase modulated image of Fig. 3(a), (c) original pentagon-left image, and (d) phase modulated image of Fig. 3(c)

Fig. 2(a) is the input patterns on the LCD, which was inserted on one of the arms of the interferometer. The color of the bar was darker, so a higher voltage was applied to the LCD. The video levels for the bars in Fig. 2(a) were "192", "128", and "0" in order. Fig. 2(b) show the interference patterns for the input patterns in a Mach-Zehnder interferometer. The fringe shift varies according to the video level of the bars, With a 180° phase shift presented for the "0" level. But the fringe shift is not linear to the video level. Fig. 3 show phase modulated input images. The proposed input method generate a uniform beam power regardless of the brightness of gray level image.

3. Angular multiplexing method using BPH and LCD

In angular multiplexing, the SA algorithm and a LCD are used to produce a reference beam in real time for image storing and reconstructing. The SA algorithm is an iterative algorithm for solving complex optimization problems. It is very effective in avoiding local minima, but requires many iterations and is very time consuming. In this paper, we used it to design the BPH for optimally generating a reference beam. The reference beam function $h(x,y)$ is obtained by the Fourier transforming of a phase hologram function $H(u,v)$. If each function consists of $N \times N$ pixels, then the discrete representation of the two functions can be described

$$h_{mn} = \frac{1}{N^2} \sum_{k=-N/2}^{N/2-1} \sum_{l=-N/2}^{N/2-1} H_{kl} \times \exp\left(j2\pi\left(\frac{km}{N} + \frac{ln}{N}\right)\right) \tag{8}$$

where H_{kl} is the (k,l)th sampled value of $H(u,v)$, and h_{mn} is the (m,n)th sampled value of $h(x,y)$. The cost function for the reference beam generation is also defined

$$E = \left(\frac{\eta}{AB} - P_{AB} \right)^2 \tag{9}$$

where η is target efficiency, and its ideal value is '1'. A and B are the positions of the reference beam in space domain. P_{AB} is the power at (A,B) positions. The algorithm can be described as follows. An initial set of values for the H_{kl}'s is randomly chosen 1 or -1, we then calculate the cost function E^{old}, and determine the initial temperature T_{init}, cooling rate D_t, and iteration number from the old cost function. One pixel of H_{kl} is changed from 1 to -1 or from -1 to 1, and the new cost function then recalculated. If the changes have resulted in a decreasing cost function, the changes are unconditionally accepted. Otherwise the changes are accepted with a probability described by

$$P(\Delta E) = \exp(-\Delta E \;/\; T_n), \quad T_n = (D_t)^n \, T_{init} \tag{10}$$

where P is the probability of acceptance, ΔE is the change in cost function, and T_n is a parameter representing the temperature of the nth annealing process. The process is repeated, and the pixels to be changed are chosen in order. After every pixel in the hologram has been selected, a single iteration is completed. The above-mentioned process is repeated for a number of iterations. Fig. 4 shows the schematic diagram of the experimental system for an optical reference beam generation in real time. A $\lambda/2$ plate is used for aligning the polarization of the light on the LCD with the molecular direction on the front surface of the device in parallel. A spatial filter(SF) is used for blocking dc spot and high order harmonics due to a transparent electrode between pixels.

Fig. 5 show the BPHs designed using SA algorithm and the reference beams which are generated by the optical Fourier transforming of the BPHs using Fig. 4.

Fig. 5(a) and (c) show that we can control the reference beam by changing the BPH on the LCD. If we synchronize the recording times of the input stereo images and BPHs using application software, many images can be stored in the photorefractive material automatically.

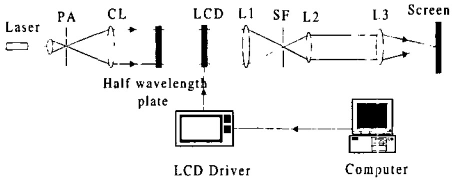
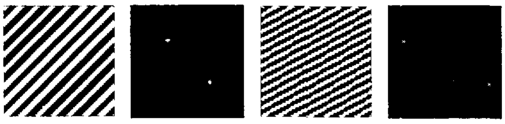


Fig. 4 Schematic diagram of the experimental system for optical reference beam generation.



(a) (b) (c) (d)

Fig. 5 BPHs and reference beams, (a) BPH for the reference beam1, (b) generated reference beam1, (c) BPH for the reference beam3, and (d) generated reference beam3.

Ⅲ. OPTICAL EXPERIMENT RESULTS AND DISCUSSIONS

We have demonstrated optical experiments which implement the proposed three dimensional damage display system using holographic optical memory technique. The experimental configuration is shown in Fig. 6. The extraordinary polarized beam from the He-Ne laser was split into two beams by a B/S(beam splitter). One beam, called the object beam, illuminates the stereo image on the LCD2, the other illuminates the BPH on the LCD1 in order to generate the reference beam for stereo image storage and reconstruction. The power of the object beam transmitted to the LCD2 was always constant regardless of the type of input image because the brightness information of the image was transformed into phase information. The structure of the reference beam generation is similar to Fig. 4. A mask was used to eliminate the reference beam which apperared in the lower plane due to the BPH. The external angle between the two beams incident upon the crystal was 15° . Thus was increased about 1° for the storing of the next image using LCD and BPH. The power of the reference and object beams were 440㎼, 215㎼, respectively. To determine the recording time of each image to be stored, the recording and erasure time constants measured through the experiment were 22sec, 30sec, respectively. And a scheduled recording technique was used to determine the recording time of each image. We edited the input stereo images and BPHs using application software Adobe Photoshop, and made animations. These two animations consist of four frames, and are synchronized for storing experiment. Using these two animation images, four stereo images are stored five times repeatedly in 45° cut $BaTiO_3$.

For the reconstruction, we edited the BPHs with 0.05 seconds time interval, and represented on the LCD1. The reconstructed output image are displayed on the computer2 monitor repeatedly. We used a LCD shutter to feel a three-dimensional image from the reconstructed stereo images. At this time, The operation time of the LCD shutter is also synchronized to a monitor that display alternate left and right eye images for depth perception.

Fig. 7 show the original input stereo images to be used in the experiments. They are inputted on the medium with uniform power using the phase modulated input method. Fig. 8 show the corresponding reconstructed images. The images were captured with a PULNiX TM545-I CCD camera after passing the polarizer and attenuated by the neutral density filter(NDF). The phase variation of pixel in LCD to be used is not linear to the input video signal levels, and the number of pixel in LCD and CCD camera is not the same. These are the reasons that the reconstructed images are not clear than the input image.

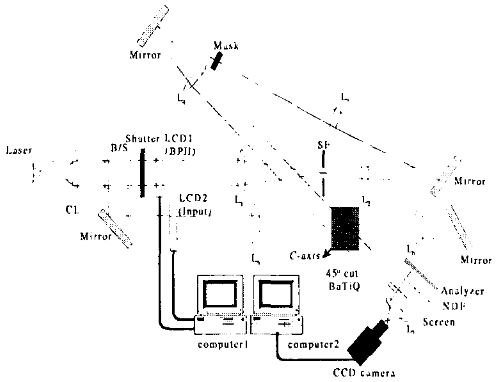


Fig. 6 The configuration of the proposed three dimensional display system.


(a) (b) (c) (d)

Fig. 7 Original input images. (a) corridor-left image, (b) corridor-right image, (c) pentagon-left image, and (d) pentagon-right image


(a) (b) (c) (d)

Fig. 8 Reconstructed images. (a) corridor-left image, (b) corridor-right image, (c) pentagon-left image, and (d) pentagon-right image

Ⅳ. CONCLUSIONS

We implemented a three dimensional image display system using stereo images and holographic optical memory technique. For storing many stereo image in nonlinear material and reconstructing them automatically, we used a 45° cut $BaTiO_3$ as memory device, angular multiplexing technique which use LCD and BPH, and phase modulated input method for the uniform input intensity. In the angular multiplexing, the incident angle of the reference beam was generated by Fourier transforming the BPH which was designed using the SA algorithm. The BPHs used for the generation of reference beam were computed, edited with animation, stored in the memory, and represented on the LCD automatically for the storing and reconstructing process. In the experiments, the LCD was operated as a phase modulator, and controlled by a computer. The input stereo images and BPHs are edited as animations using application software, and the the recording times of two animations are synchronized for the automatic storing. The BPHs for the reference beam generation edited as animation again for the automatic reconstructing. We feels that a three-dimensional image has appeared by wearing a LCD shutter and seeing the reconstructed stereo images. We confirmed the possibility of the implementation of the three dimensional image display system through the experimental storing and reconstructing of the four stereo images automatically.

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김 철 수(Cheil-Su Kim) 정회원

1989년 2월 : 경북대학교 전자공학과 졸업
1991년 2월 : 경북대학교 전자공학과 석사
1997년 2월 : 경북대학교 전자공학과 박사

1994년 3월~1995년 2월 : 경북대학교 전자공학과 조교
1995년 3월~1998년 2월 : 김천대학 전자통신과 전임강사
1998년 3월~현재 : 경주대학교 컴퓨터전자공학부 조교수
<주관심 분야> 광신호처리, 홀로그라픽 광 메모리 기술, 3차원 영상 표현, 광암호화, 워터마킹 등

김 수 중(Soo-Jung Kim) 정회원

1962년 : 인하공과대학교 전기공학과 졸업
1966년 : 인하공과대학교 전기공학과 석사
1979년 : 인하대학교 전자공학과 박사

1976년~1977년 : 미국 SUNY at Buffalo 교환교수
1980년~1981년 : 미국 UT at Austin 연구교수
1989년~1991년 : 경북대학교 전자계산소 소장 및 대학 전자계산소장 협의회 부회장
1992년~1994년 : 경북대학교 공과대학 부속 전자기술연구소 소장
1998년~1999년 : 대한전자공학회 회장
1970년~현 재 : 경북대학교 전자전기공학부 교수
<주관심 분야> 광신호처리, 광메모리, 광정보암호화, 광 컴퓨팅 등