Implementation of the VHOE-based Multiview 3D Display System by using Optimized Exposure-Time Scheduling Scheme

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Abstract

A new exposure time scheduling scheme to implement the optimized photopolymer-based VHOE is proposed and using this method, the 8-view VHOE system is experimentally developed. The CGS dependence on the exposure energy is mathematically modeled using the fourth-order polynomial function and using this model optimized exposure-time schedule for recording the given multiple gratings in the photopolymer is calculated. In addition, basing on this suggested exposure-time schedule, 8-view VHOE is finally implemented and its performance is discussed.

1. Introduction

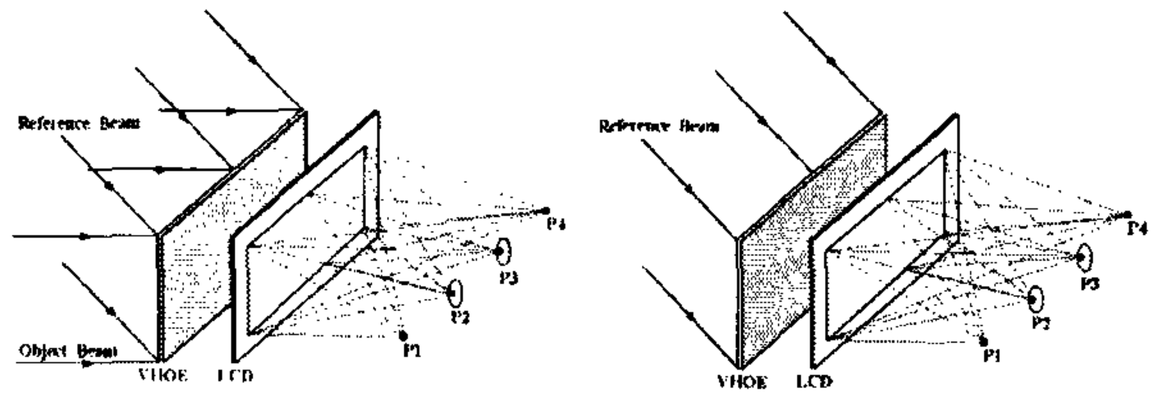
Recently, many research works are actively being done on 3D display technology due to high interest throughout the world. Future 3D display system requires full-color, full parallax 3D imaging capabilities. These advances will provide the viewer with the feeling of being present in the scene. Depending on the developments of 3D imaging & display technology, various degrees of resolution and spatial perception will be offered.

However, in most of the developed 3D display systems, they require the viewer to wear special glasses to feel the depth, which is the main shortcoming they cant gain the wide acceptance until now. Therefore, many researchers have studied the autostereoscopic 3D display system, because the autostereoscopic display system can present 3D image to the viewer without the need for any special glasses.

In this paper, a new time-sequential autostereoscopic 3D display system using a VHOE(volume holographic optical element) is proposed. In this system, the VHOE(volume holographic optical element)can be made from volume-holographic recording materials such as photopolymers and used for time-sequentially projecting multi-view images of a scene to the spatially different directions in front of the display. Since this technique is based-on the VHOE made from the photopolymer, the resolution and parallax number of the proposed VHOE-based 3D display system are mainly limited by the photopolymer's physical and optical properties. Accordingly, in this paper, for implementing a new VHOE-based time-sequential multi-view 3D display system, various optical and physical characteristics of the Dupont photopolymer-based VHOE is discussed. Especially, the exposure schedule to implement the optimized VHOE for the multi-view autostereoscopic 3D display system is mainly analyzed

2. Characteristics Analysis of Photopolymer for Making an Optimal VHOE.

The basic concept of new multi-view autostereoscopic 3D display system shows in Fig. 1. To make the photopolymer-based VHOE to be applicable for a multi-view autostereoscopic 3D display system, the photopolymer must be capable of achieving some properties such as low distortion of the diffracted light beam, high diffraction efficiency and uniform intensities of the diffracted lights from the multiply recorded diffraction gratings. Fig. 1 shows the operational principle of the proposed VHOE. The VHOE device can be made by using a angularly-multiplexed holographic recording technique in which several object plane waves with different incident angles corresponding to multiple view points of a scene are recorded in the photo-refractive medium as the grating patterns by interference with another reference plane waves with different incident angles. Then, the constructed VHOE is placed in the right back of the high-speed SLM and multi-views of a scene are displayed sequentially on this high-speed SLM. And the diffracted beam from the VHOE reads the displayed image of each viewpoint on high-speed SLM and projected to the specified direction predetermined by the viewpoints. Accordingly, the multi-view images can be scanned sequentially just by changing the angle of the reference beam in VHOE. Therefore, when a viewer sees the projection screen in a particular direction, the light beam is reached at the viewer eyes only at the moment when the light beams are diffracted from the VHOE in those directions of the reference beam.



(a) Recording **(b) Reconstruction**

Fig. 1 Conceptual diagram of VHOE-based multiview display system

3. Analysis of Pre-Exposure Time

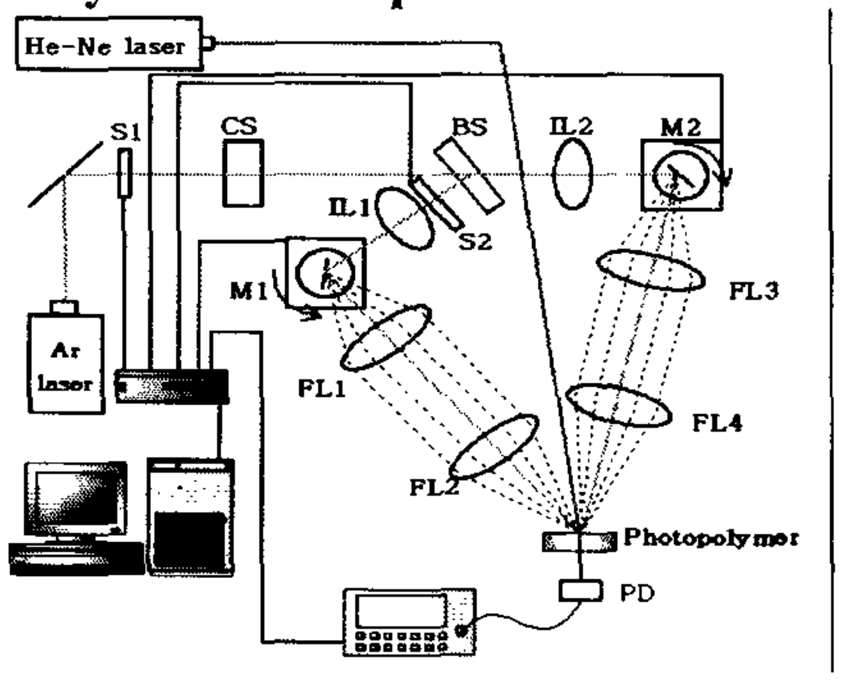


Fig. 2 Optical setup for determining the exposure time schedule for multi-view 3D display system

In this section, the pre-exposure time for exciting molecules is analyzed and the diffraction efficiency is measured as the degree between reference and object beams is changed. From this result, best experimental conditions are obtained. Fig. 2 shows the optical system for producing a pre-exposure time and deciding the optimal exposure time schedule using several physical characteristics of Dupont photopolymers. [1][2]

Initially the angle of the signal and reference beams is 52 degree, and two beams are moved 1.8 degree inside. The intensity of writing beam is 50㎼/㎠ and its wavelength is 532nm. Since the material is not sensitive to red light, the exposure and subsequent grating formation are monitored in real time by using the He-Ne laser with a wavelength of 633nm. The photopolymer is fairly insensitive at first and then exhibits a quasi-linear recording behavior until the material saturates. To obtain the best grating strength the photopolymer is pre-exposed to bring to the quasi-linear region and the recording schedule are used to equalize the holograms. Therefore the pre-exposure time is found before finding the exposure schedule for multi-view 3D display.

Fig. 3 shows that the pre-exposure time of 0, 15, 20, 25, 30, 35 seconds are used to record one hologram. From Fig. 3, it is found that the maximum diffraction efficiency is occurred at the pre-exposure time of 30second, in which the diffraction efficiency is reached to over 70%. Accordingly, 30 second pre-exposure(about 1.5mJ/㎠) is applied for all experiments. To use the quasi-linear region, the saturation time is measured to be 240 seconds.

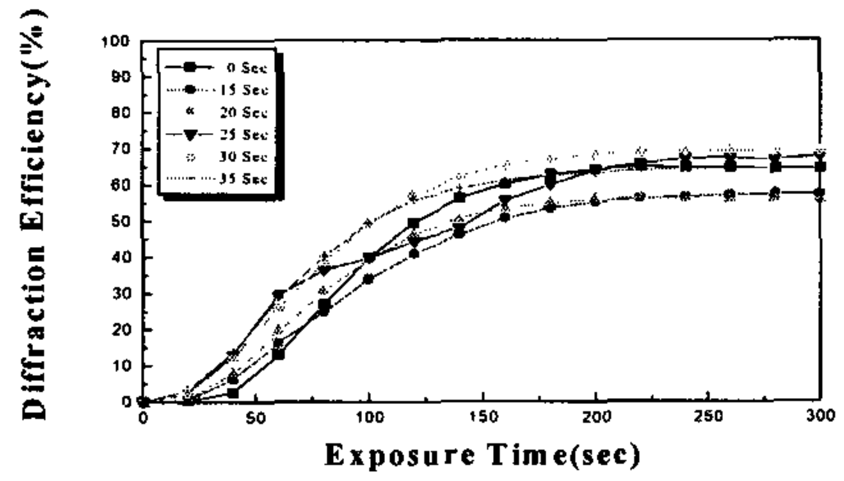
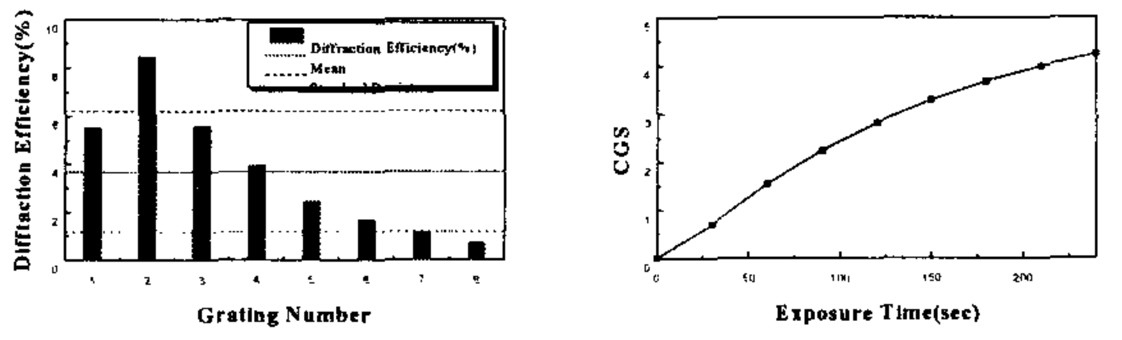


Fig. 3 Distribution of exposure time vs. diffraction efficiency

4. Mathematical Model to Analysis the Exposure Time Schedule

The recording behavior of the photopolymer can be characterized by the cumulative grating strength, which is given by a function of exposure energy. The cumulative grating strength is obtained by integrating the square root of the diffracted power. Because the cumulative grating strength is the total energy recorded in photopolymer, the cumulative grating strength should be made equal to all holograms to get the diffraction efficiency of the hologram uniform.

The diffraction efficiency and cumulative grating strength of the angular multiplexed (8) holograms recorded with a uniform exposure schedule is shown in Fig. 4. Each hologram is exposed for 30 seconds, which is derived from division of 240 seconds by 8.



(a) **(b)**

Fig. 4 Diffraction efficiency and cumulative grating strength of the angularly multiplexed (8) holograms with 30 seconds exposure per hologram (a) Diffraction efficiency (b) cumulative grating strength

Here, a mathematical model of the exposure schedule for making the diffraction efficiency of the multiply recorded holograms equal is derived. The polynomial function is used to mathematically model the cumulative grating strength dependence on the exposure energy.

$$A = a_0 + a_1 t + a_2 t^2 + \cdots + a_n t^n \tag{1}$$

Where A and t is the cumulative grating strength and exposure time, respectively. And some parameters of a_0 through a_n can be obtained from the procedure of fitting curve using the original data as shown in Fig. 4(b). As the higher-degree polynomials are used, the deviations of the point from the curve will reduce. And when the degree of the polynomial, n , equals $N-1$, there is an exactly match and we have an interpolating polynomial, but it's to be more complex. To determine the degree of polynomial, next coefficients are used.

$$e_i = A_{ei} - A_i \tag{2}$$

$$S = \sum_{i=1}^{N} e_i^2 = \sum_{i=1}^{N} (A_{ei} - a_0 - a_1 t - a_2 t^2 - \cdots - a_n t^n)^2 \tag{3}$$

Where e_i is the deviation of the point from the curve, A_{ei} is represent an experimental value, and let A_i be a value from the equation. S is the lease-square error and N is the number of grating. One increases the degree of approximating polynomial as long as there is a statistically significant decrease in the variance, Π^2 , which is computed by Eq. (4).

$$\Pi^2 = \frac{S}{N-n-1} = \frac{\sum_{i=1}^{N} e_i^2}{N-n-1} \tag{4}$$

The degree of the polynomial made to fit the data is varied from 3 to 6, we obtained the result shown in Table. 1. The numerator of Eq. (4), the sum of the deviations squared of the points from the curve, should continually decreases as the degree of the polynomial is raised. It is the denominator of Eq. (4) that makes σ^2 increases as going the optimum degree. From Table. 1 the criterion of Eq. (4) chooses the optimum degree as 4.

Table. 1 The least-square error and variance of each degree of polynomial

Degree of Polynomial	Least-Squares Error	Variance
3	0.009834	0.002459
4	0.002824	0.000947
5	0.002496	0.001248
6	0.001645	0.001645

Therefore, fourth-order polynomials are selected to model the experimental data as shown in Eq. (5).

$$A = a_0 + a_1 t + a_2 t^2 + a_3 t^3 + a_4 t^4 \tag{5}$$

And some parameters of a_0 through a_4 can be obtained from the procedure of fitting curve using the original data as shown in Fig. 4(b). In case eight gratings are recorded in the photopolymer, the saturated cumulative grating strength is equally divided into eight parts, and then the exposure schedule can be calculated by using Eq. (6). [3]

$$\frac{nA_{sat}}{8} = a_0 + a_1 t_n + a_2 t_n^{\ 2} + a_3 t_n^{\ 3} + a_4 t_n^{\ 4} \tag{6}$$

Here, an optimized distribution of diffraction efficiency is analyzed in our experiment. To analysis the experimental data, the means and standard deviations of the diffracted beam could use. The mean and standard deviation of the diffracted beam become:

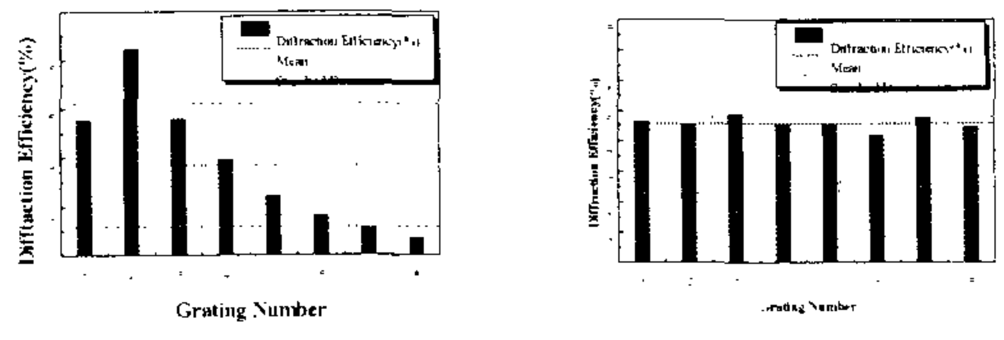
$$m = \frac{1}{M} \sum_{i=1}^{n} E_i' \tag{7}$$

$$\sigma^2 = \frac{1}{M} \sum_{i=1}^{n} (E_i' - m)^2 \tag{8}$$

$$\sigma = \sqrt{\frac{1}{M} \sum_{i=1}^{n} (E_i' - m)^2} \tag{9}$$

Where m is the mean of diffraction efficiency, M is the number of gratings, E_i' is the diffraction efficiency, σ is the standard deviation of the diffraction efficiency. But in case two means are equal then, the standard deviation could express the distribution properties, whereas for the opposite case, the standard deviation could not express the distribution properties. The variation coefficient (ν) is used to express the distribution properties of data. Therefore, the variation coefficient considering the mean and standard deviation is used to express the distribution properties of data, which is defined as Eq. (10)

$$\nu = (\frac{\sigma}{m}) \times 100\% \tag{10}$$



(a) (b)

Fig. 5 Diffraction efficiency dependence on equal exposure time & exposure time schedule (a) Equal exposure (b) 3rd iteration

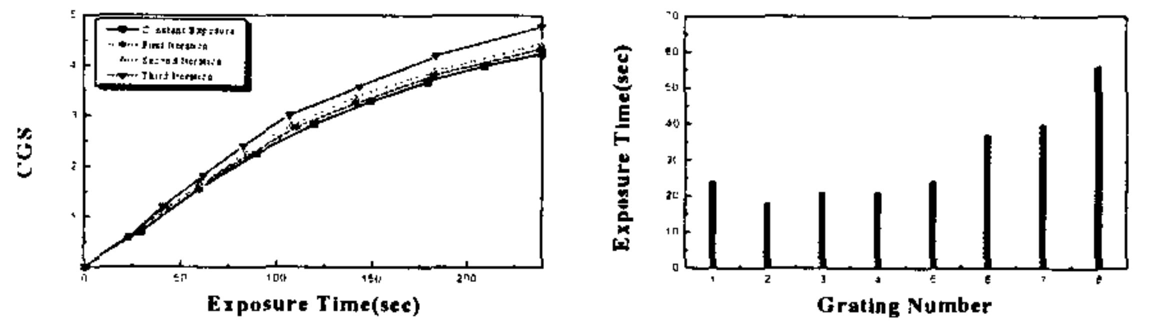
This procedure repeated until the exposure time schedule is reached to the best condition and results are shown in Fig. 5 (b). In Fig. 5 solid line represented the mean of diffraction efficiency, and dotted line represented the standard deviation.

Table. 2 Mean, standard deviation, coefficient variation of diffraction efficiency per iteration

	Constant exposure	First iteration	Second iteration	Third iteration
Mean (m)	3.686%	3.402%	3.520%	4.573%
Standard deviation(σ)	2.524%	0.576%	0.399%	0.193%
Coefficient of variation (v)	68.47%	16.95%	11.34%	4.21%

Table 2 shows the mean, standard and coefficient variation of the diffraction efficiency. The coefficient of variation of the constant exposure is given by 68.47%. This means that the diffraction efficiency is distributed over a 68.47% over the mean. Iterating the experiment, the coefficient of variation is decreased to 16.95%, 11.34% and 4.21%. The decrease of the coefficient of variation means that the diffraction efficiency of each grating is uniformly distributed. The above procedure can be repeated until the desired uniformity of the diffraction efficiency can be reached.

Fig. 6(a) shows the resulting cumulative grating strength as a function of exposure time for each scheduled recording. The saturation grating strength for the iterated scheduled recording is higher than the constant time recording and previous scheduled recording. This is because the scheduled recording uses the dynamic ranges of the recording material more efficiently though better-managed exposures.



(a) (b)

Fig. 6 (a) Variation of the cumulative grating strength per iteration, (b) Optimized exposure-time schedule for 8-view VHOE

Fig. 6(b) shows the optimized exposure time schedule for 8-view VHOE. Using this exposure time schedule the photopolymer-based 8-view VHOE, which has been proposed as an optical directional modulator, is manufactured. As the reference beam as implemented time sequentially, the beams can be time sequentially and spatially diffracted each viewpoint. Fig. 7 shows the 8 reconstructed images from the multiplexed hologram that is recorded with the proposed exposure-time schedule. Centered point(represented by P) is the check point to distinguish the space.

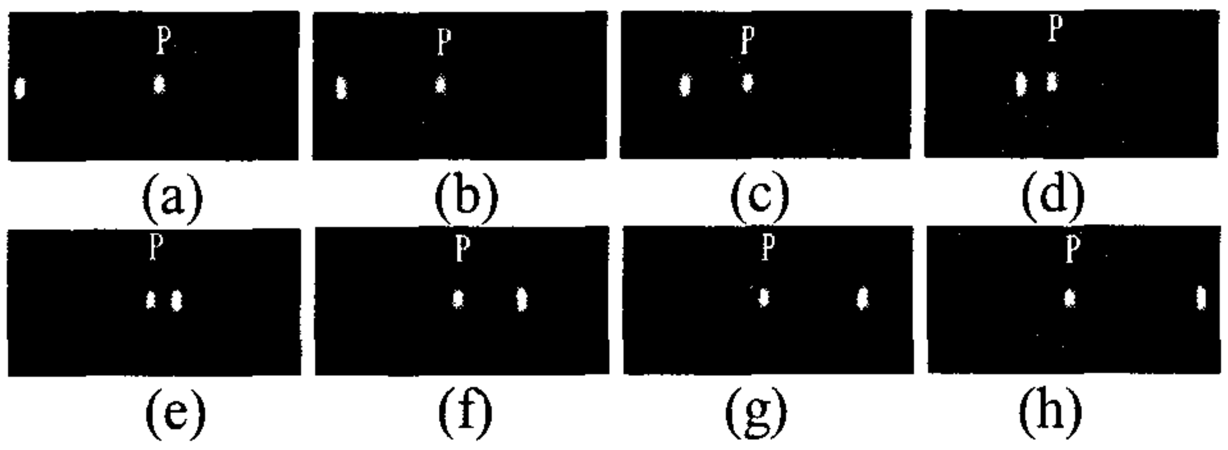


Fig. 7 Diffracted 8-view beams

5. Conclusion

In this paper, the exposure-time schedule of the photopolymer for implementing the optimized VHOE(volume holographic optical element), which has been proposed as an optical directional modulator, is analyzed. The recording property of the photopolymer is characterized by the function of the cumulative grating strength, which is a function of exposure energy. The cumulative grating strength dependence on the exposure energy is mathematically modeled by using the fourth-order polynomial function. Using this model, the exposure schedule of the photopolymer for recording the given multiple gratings has been calculated. The coefficient of variation is used to analyze the distribution of diffraction efficiency of the diffracted beams. This procedure is repeated until the exposure-time schedule is reached to the best condition that means the coefficient of variation distributed in 5%. From some experimental results, a possible of implementing the optimized VHOE device by using the proposed exposure-time schedule is suggested.

6. Acknowledgements

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7. References

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