Journal of the Korean Institute of Illuminating and Electrical Installation Engineers Vol. 16, No.6, pp. 1~6 November 2002 논문 16-6-1

움직이는 창과 이중 초점 렌즈를 이용한 프랙탈-공간 다중화 기법

(A Novel Fractal-Space Multiplexing using Moving Window and Double-Focusing Lens)

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요 약

움직이는 창과 이중 초점 렌즈를 이용한 프랙탈-공간 다중화 기법의 홀로그래픽 메모리 시스템을 제안하였다. 이 시스템은 기존의 움직이는 창을 이용한 홀로그래픽 메모리 시스템의, 수직 방향으로 인접한 움직이는 창의 열에 의한 누화를 제거할 수 있으며, 이를 광학적 실험을 통해 그 가능성을 입증하였다.

Abstract

We proposed a novel fractal-space multiplexing holographic memory system using moving window and double-focusing lens, which can eliminate crosstalk due to two neighboring moving window rows in the vertical direction of the conventional moving window holographic memory system, and demonstrated its feasibility through optical experiments.

Key Words : moving window, holographic memory, double-focusing lens, fractal-space multiplexing

1. Introduction

After the photorefractive effect[1] was discovered, a variety of multiplexing schemes[2] to store a large amount of data in photorefractive materials were proposed and their feasibilities were demonstrated through optical experiments. Angular[3], wavelength[4] and phase code[5,6] multiplexings are the most prominent holographic multiplexing methods that allow the storage and retrieval of independent pages of data in a common recording volume. Besides those methods, shift and spatial multiplexings using the speckle patterns of optical fibers were introduced[7]. Also, a hybrid multiplexing scheme combined with two or more multiplexing methods was proposed[8].

Among them, angular multiplexing is one of the most commonly used schemes of storing multiple holograms within a common volume. Angular multiplexing has the potential for recording a large number of high-resolution images in a compact volume and has been used widely. Mok[3] reported that 5,000 holograms were recorded and retrieved using angular multiplexing in 1993. Angular multiplexing can store a large quantity of information by using reference plane waves with different incidence angles. The incidence angles of

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the reference plane waves were changed by using a stepping motor or an acousto-optic deflector (AOD). Mechanical control of the incidence angle using a stepping motor is simple; however during data recording and retrieval, mechanical error of the stepping motor occurs, and Bragg condition is not satisfied. As a result, in the case of data retrieval, the reconstructed data contain data of another address, noises. Using AOD, the above-mentioned problem can be eliminated, but this holographic memory system is expensive and is difficult to align.

Recently, by controlling the pixels of a liquid-crystal display(LCD) electronically, we fabricated real-time moving window(MW) on an LCD, through which light passes, and suggested a new angular multiplexed holographic memory system without mechanical movement by controlling the incidence angle of reference wave electronically by the moving window[9,10].

The proposed holographic memory system can multiplex holograms by moving the window left and right, or up and down. However, the vertical angular sensitivity is less than the horizontal one. Accordingly, we can not use a part of the LCD used in our system for multiplexing holograms. This limits storage of a large number of holograms.

In this paper, a novel fractal-space multiplexing combining the conventional MW holographic memory system with a double-focusing lens(DFL) to eliminate crosstalk in the vertical direction and utilize all parts of the LCD was suggested, and its feasibility was demonstrated through optical experiments.

2. Angular multiplexing using a moving window[9,10]

The spatial light modulator such as an LCD consists of hundred of thousands pixels and electronic on or off switching of each pixel is possible. By applying voltage to the electrode of the LCD, we can switch each pixel of the LCD on or off. By switching specific pixels of the LCD on and the rest off, we can fabricate a window on the LCD, through which light passes. By controlling the window electronically, we can move it on the LCD, and call it a moving window. Figure 1 shows that a window is moving on the LCD. The size of window can be controlled electronically and varied arbitrarily.

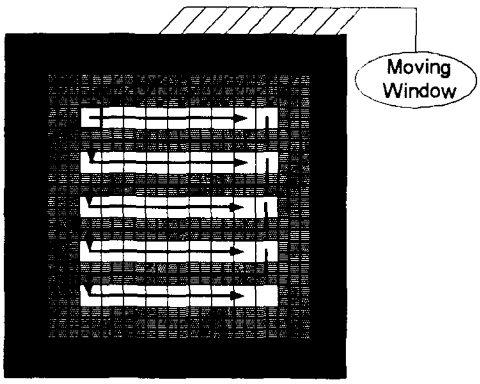

Fig. 1. Schematic diagram of MW on LCD SLM.

As shown in Fig. 1, by controlling electronically which pixels of the LCD are switched on and off, the window can be moved left and right, or up and down. Then each window makes a reference wave with a different incidence angle, and by moving the window in this manner, we can store angular-multiplexed holograms.

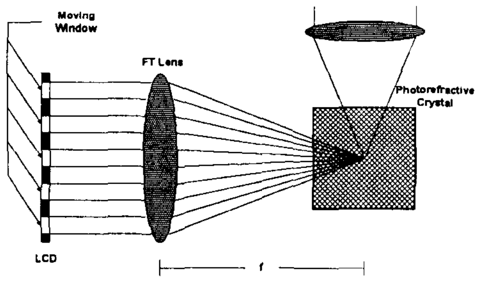

Fig. 2. Principle of angular multiplexing using MW.

Figure 2 shows that when light passing through windows of the LCD is transformed by Fourier transform (FT) and interferes with object waves in the photorefractive material, the light beam passing through each window has a different wave vector. In Fig. 2, the windows do not overlap with each other and can move left and right. If we move a windows left and right by Bragg angular selectivity and store holograms, no crosstalk will be observed in the reconstructed information.

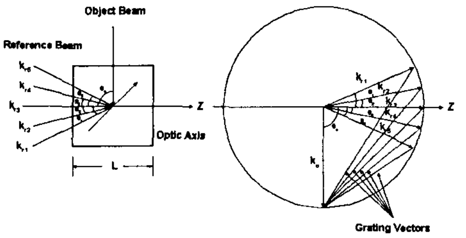

Fig. 3. Wave vector description of holographic interaction.

Figure 3 shows the reference and object wave in Fig. 2 represented as wave vectors, where θ_0, θ_1, θ_2, θ_4, and θ_5 are the incidence angle of object and reference beams measured inside the photorefractive crystal and k_o is the wave vector of object beam, and k_{r1}, k_{r2}, k_{r3}, k_{r4}, and k_{r5} are wave vectors of reference beams. As shown in Fig. 3, when we use the lights passing through the windows as reference waves, the reference waves are focused at the same location but the direction of the wave vector of each reference wave is different. Accordingly, interference of the object waves with the same wave vector and reference waves with different wave vectors makes different grating vectors. On reconstruction, we can predict that different object waves will be reconstructed with each reference wave. We can also multiplex the holograms by moving the window up and down. In this case, because of degeneracy condition the vertical angular selectivity must be more than two times the horizontal angular selectivity, and then storage capacity is limited[3,11].

Figure 4 shows the concept of the angular selectivity represented as wave vectors in the horizontal and vertical directions, where k_s and k_r are the object and reference wave vectors, respectively, K_r' is the incident reference wave vector(possibly detuned from original position), and k_g, k_{g1}, and k_{g2} are the grating vectors by interference of the object and reference waves.

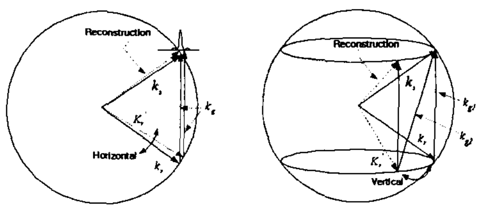

Fig. 4. Wave vector space description of angular selectivity on angular multiplexing (a) Horizontal axis (b) Vertical axis.

The in-plane angular variation as shown in Fig. 4(a) is determined by Bragg angular selectivity. The number of multiplexing holograms can be increased if the reference wave can be multiplexed orthogonal to the diagram plane as well, as shown in Fig. 4(b). Generally, such out-of-plane multiplexing violates the degeneracy condition well known in volume holography, and crosstalk become excessive. However, if the propagation vectors of the reference and object waves conform certain geometries, known as fractal geometries, out-of-plane multiplexing is possible[3]. Fractal-space multiplexing utilizes the unused geometric capacity by fitting more cells into the reference space. By conforming to this configuration, the grating vectors of the stored holograms will be nondegenerate, and interrow crosstalk will be minimized. Fractal-space multiplexing is good method for eliminating crosstalk due to neighboring reference rows, but the unused reference space occurs. In next section, we propose the method that can utilize the full reference space using moving window (MW) and double-focusing lens(DFL) to increase storage capacity of holographic memory system. It is desirable that reference waves from neighboring window rows in the vertical direction in the angular multiplexing using MW must reconstruct different crosstalk-free information, but in this case only when we move the windows at their width apart up and down or more than two times the horizontal angular selectivity, the crosstalk in reconstructed data will not occur. Accordingly, to eliminate crosstalk due to two neighboring MW rows in the vertical direction, the distance between two neighboring moving windows must be more than the vertical angular selectivity.

3. Fractal-space multiplexing using moving window and double-focusing lens

In this paper, we proposed a novel fractal-space multiplexing method combined with angular and shift multiplexings to overcome crosstalk due to two neighboring moving window rows in the vertical direction of the conventional MW holographic memory system. The proposed method could eliminate crosstalk in the vertical direction by combining DFL, which has periodical curvature of radius R1 and R2 with focal lengths F1 and F2, respectively, as shown in Fig. 5, with moving window on the LCD.

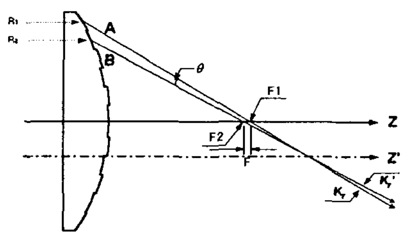

Fig. 5. Geometric structure of double-focusing lens.

Light beams from A and B parts of double-focusing lens are focused at F1 and F2 locations, respectively, to occur different reference wave vectors K_r and K_r'. By such shift multiplexing effect, we can eliminate crosstalk due to two neighboring MW rows in the vertical direction on the reconstruction.

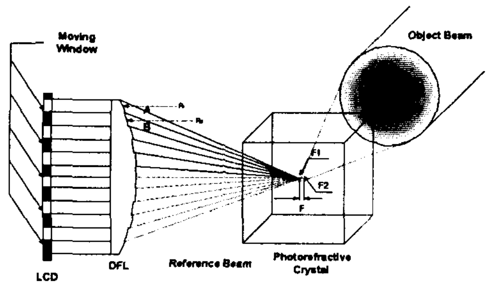

Fig. 6. Geometric structure of fractal-space multiplexing using MW and DFL.

Figure 6 shows geometric structure of the proposed multiplexing using MW and DFL. As shown in Fig. 6, the reference waves coming from moving windows on the LCD pass through A and B parts of DFL to generate different reference wave vectors by shift effect. Therefore, it is possible to utilize the full reference space using MW and DFL.

4. Experimental Results

Figure 7 shows the holographic memory system proposed in this paper.

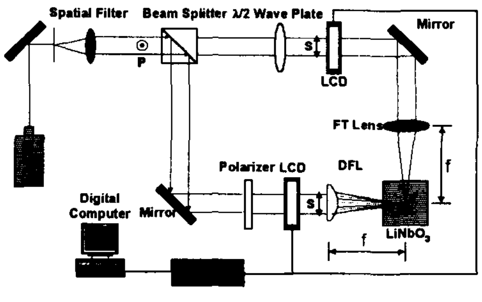

Fig. 7. Experimental setup for fractal-space multiplexing using MW and DFL.

In this figure, light coming from spatial filter is divided into reference and object waves by the beam splitter. Polarization of the laser is vertical. The reference wave changes into light with horizontal polarization after passing through the LCD. The object wave after passing through the $\lambda/2$ wave plate changes into light with horizontal polarization. Reference wave passing through each window has a different wave vector. In this experiment, we stored and retrieved 16 Roman alphabets from A to P.

In Fig. 7, we used a Nd-YAG laser (Model DPSS532, COHERENT) with wavelength and output power of 532.8 nm frequency doubled and 100[mW], respectively. The total pixel number of the LCD (Model P13VM215, Epson) used is 307,200 (480 ×640) pixels and the size of each pixel is 42[μm]× 42[μm]. The photorefractive material is a Fe-$LiNbO_3$ crystal and its size is 1 cm cube. We designed an aspheric DFL, which has two focal lengths 95[mm] and 96.06[mm], to eliminate crosstalk in the vertical direction of the conventional MW holographic memory system by shift effect. The DFL was manufactured by an outside order. The moving window consists of 80×80 pixels. Figure 8 shows the moving window address of reference beam and input images. The focal length difference of double-focusing lens for shift multiplexing is 60[μm].

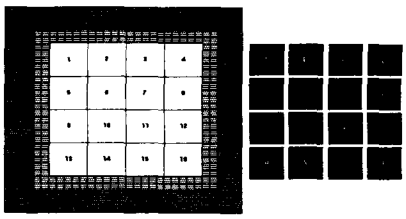

Fig. 8. Addresses of MW and corresponding object images.

Input images used in this experiments are 16 letters of the Roman alphabet as shown in Fig. 8. Figure 9 shows crosstalk effect in the reconstructed image from the conventional MW holographic memory system. These are reconstructed images using 5th, 8th, 13th, and 16th windows after storing images using 1st and 5th , 4th and 8th, 9th and 13th, 12th and 16th windows in Fig, 8, in which case a DFL was not used and the vertical angular selectivity was not two times more than the horizontal angular selectivity.

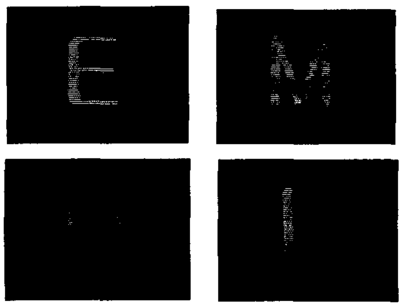

Fig. 9. Crosstalk effect in the reconstructed images without using DFL.

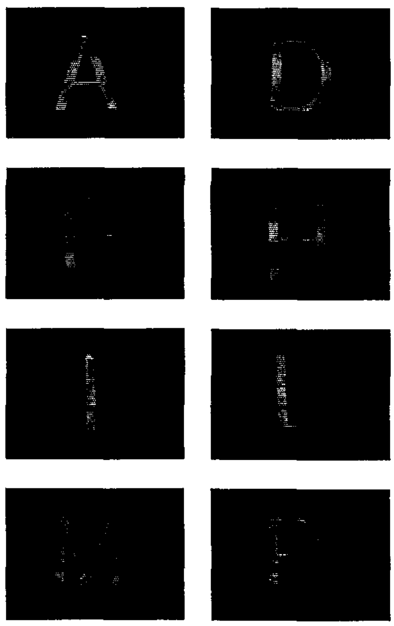

Fig. 10. Crosstalk-free reconstructed images by using DFL.

Above-mentioned problem can be solved by using a DFL. Figure 10 shows crosstalk-free reconstructed images by using DFL in the conventional MW holographic memory system.

In the figure, we can see that the reconstructed images by neighboring window rows dont contain crosstalk. Therefore, we see that by adding DFL designed to eliminate crosstalk due to neighboring window rows to the conventional MW holographic memory system, it is possible to utilize all parts of the LCD and implement more novel fractal-space multiplexing.

5. Conclusions

We proposed a novel fractal-space multiplexing system using MW and DFL, which can eliminate crosstalk due to two neighboring moving windows in the vertical direction of the conventional MW holographic memory system. In the experiment, we used the MW of 80×80 pixels and generated 16 address beams. Also, the focal length difference of a DFL designed to eliminate crosstalk due to neighboring window rows is 60[㎛]. To demonstrate the feasibility of the proposed system, we recorded the input images by placing a DFL in neighboring window rows in the vertical direction, and crosstalk was not observed in the reonstruction images.

Therefore, it is possible to record and retrieve the information using full reference space in the horizontal and vertical directions in the proposed holographic memory system. If the proposed method is combined with other multiplexings, storage capacity can be increased.

The proposed method has a drawback of low efficiency because only one window on LCD is used in the recording process. In the future, the problem will be solved.

본 연구는 한국전력공사의 지원에 의하여 기초전력공학공동연구소 주관으로 수행되었음.

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