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Volume holographic optical correlator based on fractal-space/shift multiplexing

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Abstract

In this paper, we demonstrate theoretically and experimentally a new multiplexing method for volume holographic optical correlator using fractal-space/shift multiplexing. We multiplex the hologram recording by repetition of fractal-space multiplexing with partial area-overlap. This method makes a way for high recognition rate and full use of the dynamic range for volume holographic optical correlator.

Keywords: Fractal-space multiplexing; Shift multiplexing; Volume holographic optical correlator; Exposure time

1. Introduction

Volume holographic storage based on the photorefractive crystal is in more and more important position for its high redundancy, very high data-transfer rates, fast access time, the possibility of fully parallel readout, and high capacity [1]. Once information is stored in a volume holographic medium, same as information reconstruction, it can serve as volume holographic optical correlator [2], implemented by correlation of input pattern against all the stored patterns simultaneously. If the pattern on the SLM is similar to one of the stored holograms, the corresponding reference beam is reconstructed and the strength of it is proportional to the similarity between the input pattern and the stored pattern [3].

To volume holographic optical correlator, more correlation peaks are limited by the output space of CCD. In order to get high recognition speed, as many as correlation peaks are needed to be received by the output plane of CCD at the same time. So fractal-space multiplexing [4,5] is adopted. In fact, the number of reference beams that the output space of CCD could receive is not enough for full use of the dynamic range of the volume holographic medium. In this paper, a novel volume holographic optical correlator is reported which utilizes shift multiplexing [6] as well as fractal-space multiplexing. In the following sections, the operation of the correlator is discussed and preliminary experimental demonstration is presented.

2. Fractal-space/shift multiplexing

Conventional angular multiplexing utilizes the object space in two dimensions and the reference space in one dimension within the plane containing reference beam and object beam (called in-plane). When out-of-plane (orthogonal to in-plane) multiplexing of reference beam is used also, which is called fractal-space multiplexing, the reference space becomes two dimensional and CCD could get more correlation peaks by its output plane at

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one time which is beneficial for high recognition speed of the volume holographic optical correlator. To realize nondegeneration hologram storage and minimize inter-row cross-talk, the deflection angle of reference beam in out-of-plane is required to be larger than the divergence angle of signal beam.

In the in-plane, $\Delta\theta$ required to reach the first mull in Bragg condition for angular multiplexing from outside of the recording materials can be measured by

$$\Delta\theta = \sin^{-1}\left(n \sin\left(\frac{\lambda \cos(\sin^{-1}(\sin\theta_s/n))}{nL \sin(\sin^{-1}(\sin\theta_s/n) + \sin^{-1}(\sin\theta_r/n))} + \sin^{-1}\left(\frac{\sin\theta_r}{n}\right)\right)\right) - \theta_r, \tag{1}$$

where n is the index refraction of the recording material, λ is the wavelength of the laser, L is the thickness of the recording material, and $\theta_s(\theta_r)$ is the angle between the signal (reference) ray and the surface normal of the recording material.

As shown in Fig. 1, to fully make use of the dynamic range, once the fractal-space multiplexing has been done at one spot, the material is shifted a little distance, which is less than the size of the spot, to implement fractal-space multiplexing the same as the former again. According to the study of Bernal et al. [7], an aperture with a width $D_N = \lambda f/\Gamma$, where Γ is pixel spacing of SLM and f is the focal length of the Fourier transforming lens, is placed at Fourier plane as a low-pass filter to get high area density and little pattern distortion. So the signal pattern could be treated as composing of many spherical beams with their convergent points within the aperture in Fourier plane. To Fig. 1, point 1 and point 2 are adjacent marginal points of the apertures before and after shifting and the relative distance of them is denoted as δ. For every ray from point 1, the deflection angle to the intersecting ray from point 2 is denoted as

$$\Delta\theta^{\Pi} = \frac{\delta \cos\theta_s}{h}, \tag{2}$$

where h is the range between Fourier plane of the signal beam and recording material surface. Because many rays from point 1 intersect with rays from point 2, a lot $\Delta\theta_s^{\Pi}$ can been got and each one is needed to be larger than all $\Delta\theta_s$ decided by the ray from point 1 and all parallel reference beams used in the fractal-space multiplexing. Thus, the maximum of δ_s, denoted as δ_{max}, is obtained and the shifting distance needed for avoiding cross-talk can be expressed as $\delta' = D_N + \delta_{max}$.

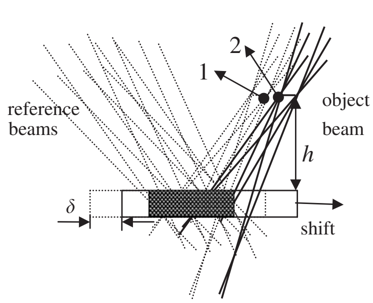

Fig. 1. Fractal-space/shift multiplexing.

On the other direction, orthogonal to the in-plane, the shifting multiplexing is not employed to avoid degeneration.

3. Determination of exposure-time sequence

To pure fractal-space multiplexing, if the writing- and erasure-time constants, τ_W and τ_E, and the index modulation at saturation, Δn_{max}, are known, the refractive-index modulation of the Nth hologram can be obtained from [8]

$$\Delta n_N = \Delta n_{sat}\left[1 - \exp\left(-\frac{t_N}{\tau_w}\right)\right] \exp\left(-\frac{T_N}{\tau_E}\right), \tag{3}$$

where t_N is the exposure time and T_N is the total erasure time of the Nth hologram. But to fractal-space/shift multiplexing, the calculation of T_N is particular. It is supposed the erasure of a hologram by the later hologram belonging to a different fractal-space multiplexing is proportional to the area-overlapping fraction of two holograms at the middle surface of the recording material. If shifting multiplexing was done by N times and each including M angular multiplexing, the index modulation of the mth hologram belonging to the nth shifting multiplexing, which is denoted by (n, m), can been expressed as

$$\Delta n_{n,m} = \Delta n_{sat}\left[1 - \exp\left(-\frac{t_{n,m}}{\tau_W}\right)\right] \exp\left(-\frac{T_{n,m}}{\tau_E}\right), \tag{4}$$

where the erasure time $T_{n,m}$ is given by

$$T_{n,m} = \sum_{i=n+1}^{N} \sum_{j=1}^{m} W_{n,i} t_{i,j} + \sum_{j=m+1}^{M} t_{n,j},$$

where $W_{n,i}$ is the area-overlapping fraction of the nth and the ith shifting multiplexing. Thus, if the exposure time of the last hologram is determined, all the exposure times can be calculated.

4. Experiment and results

The experiments are performed with setup shown in Fig. 2 by the exposure schedule discussed above with 0.8s exposure time of the last hologram. The writing- and erasure-time constants are 58 and 870 s, respectively. Plane-wave reference beam is adopted and the medium used for recording is an iron-doped (0.01%) lithium niobate crystal placed 4 mm behind the Fourier plane with a thickness of 5 mm. The angles of object ream and reference beam to the normal of the recording material are both about 30° outside of the recording

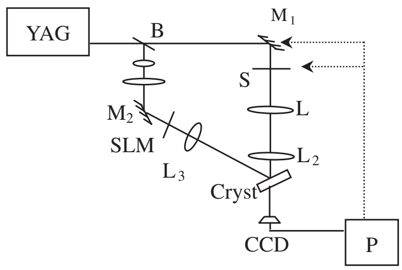

Fig. 2. Sketch map of volume holographic optical correlation system.

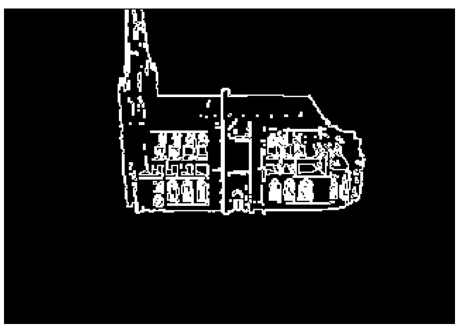

Fig. 3. Pattern for storage in the experiment.

materials. Note that, with a focal length of 50 mm, a pixel spacing of 22 μm, and a 514.5 nm wavelength, D_N corresponds to 1.29 mm comparing with 3.8 mm of reference beam spot size to cover the full spot of object beam in the material.

To the experiment, the pattern for storage is a series of buildings after first-order Laplacian edging operation such as that shown in Fig. 3.

In fact, we find that the shifting distance is not needed to be equal to $(D_N + \delta_{\max})$ exactly. This is because to ordinary pattern, the energy distributes in low-frequency field, corresponding to center part of the aperture of width D_N, mainly. When the shifting distance is to some value, although which is less than $(D_N + \delta_{\max})$, the overlapping part has very low diffraction energy and the former fractal-space multiplexing would have little influence on the later. On another aspect, the distribution of phase in Fourier plane is varied to one same pattern and different to two different patterns. In the experiment, fractal-space/shift multiplexing was realized by shifting 0.8 mm for 10 times. Fig. 4 shows the correlation peaks' output space including 70×12 correlation peaks of the fifth fractal-space multiplexing and the result shows that anyone of the 840 patterns may be recognized accurately.

5. Conclusion

In this paper, we have presented a volume holographic optical correlator based on fractal-space/shift multiplexing for the first time. The exposure schedule for this multiplexing method is also studied and has been experimented. The theoretical and experimental investigations have shown that this method is promising for the achievement of both high recognition rate and full use of the dynamic range for volume holographic optical correlator.

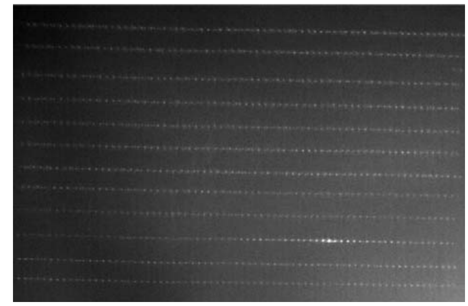

Fig. 4. Output space of CCD for the fifth fractal-space multiplexing.

Acknowledgments

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