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New holographic scheme for multiplex image storage in photorefractive crystals

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Abstract

The new holographic scheme with a photorefractive crystal, which is based on the interference of two identical object beams, are studied for the purpose of multiplex image storage. It is shown, that every image recorded by the proposed method possesses a property of associative readout. The proposed scheme can be applied in optical implementation of associative network, all-optical associative memory, template matching, optical interconnection.

1. Introduction

The ability of the associative response in coherent optical information processing is of great practical importance. In such systems this allows one to extend a set of possible operations as well as to increase their stability and to improve the accuracy of performances. The possibility of the associative response is very useful for high density optical memory systems when many different holograms are superimposed in a volume medium.

In the present paper we consider a new approach to the problem of formation of an optical signal in a holographic scheme. It is based on the correlation method for stabilization of space-angle characteristics of a coherent beam [1]. Contrary to the usual holographic methods [2, 3 and others], in which the associative signal response is created in two steps, the proposed way allows to attain the formation of such signal automatically in one-step.

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2. The theoretical description

Method of direct associative response of a holographic scheme [4] is used in the present research. The method is based on the fact, that a hologram may be reconstructed by any fragment of an input optical image with forming a copy of the entire image. This can be reached by maintaining two features of the holographic scheme. The first one consists of providing equal responses from different fragments of the optical signal in the scheme (the deterministic response). The second one includes the combination of the deterministic response with a possibility to form the required signal. Such properties are inherent for the holographic scheme, in which both signal and reference beams are indistinguishable by their shapes. In that case the well-known scheme with the deterministic response [1] will reconstruct whole image been identical to the input one.

Such idea can be realized in the known Fourier holographic scheme [5]. Generally the scheme may be considered as a telescopic system consisted of two objectives with coincided focal planes. Amplitude-phase transparencies, which form signal and reference beams, are placed at the front focal *plane (x_1y_1) of the first objective. In our case two identical transparencies are used for producing the* field of the signal under study. The hologram is recorded due to interference of angular spectra both signal and reference beams at the mid-position common focal plane (x_2y_2) at the time t_1. Retrieval of the image is at the back focal plane (x_3y_3) of the second objective, which makes the operation of the reverse Fourier transformation. It happens at the time t_2.

According to the presented scheme a hologram records intensity of interference pattern formed by two fields with identical angular spectra $\omega(x_2,y_2,t)$ of an input signal field $A(x_1,y_1,t)$, i.e.:

$$|\omega(x_2,y_2,t_1)|^2 = |a'(x_2,y_2,t_1) + a''(x_2,y_2,t_1)|^2 = |a'|^2 + |a''|^2 + a'a''^* + a'^*a'' \qquad (1)$$

where $a' = \hat{F}\{A'\}$, $a' = \hat{F}\{A''\}$, $\hat{F}$ is the Fourier transformation operator.

The last component in equation (1) determines the transmission of the hologram $T(x_2,y_2)$ in the direction of the first diffraction order:

$$T(x_2, y_2) \propto a'^{*}(x_2, y_2, t_1) \cdot a''(x_2, y_2, t_1) \tag{2}$$

The copy of the reconstructed optical signal taking into consideration the convolution theorem is described by the following equation:

$$\begin{aligned} A''(x_3, y_3, t_2) = \hat{F}^{-1}\left\{a'(x_2, y_2, t_2) \cdot a'^{*}(x_2, y_2, t_1) \cdot a''(x_2, y_2, t_1)\right\} = \\ \left[A'(x_3, y_3, t_2) * A'^{*}(x_3, y_3, t_1)\right] \otimes A''(x_3, y_3, t_1) \approx \delta(0,0) \otimes A''(x_3, y_3, t_1) \end{aligned} \tag{3}$$

where the designations $\hat{F}^{-1}$, *, $*$, $\otimes$ are the operators of reverse Fourier transformation, complex conjugation, correlation and convolution correspondingly. The expression in the square brackets describes a spatial autocorrelation function for field of whole investigated signal, and its central maximum is approximated closely by the δ-function at the conditions that stationary field distributions are coincided at the moments t_1 and t_2 $A(x_1, y_1, t_1) \equiv A(x_1, y_1, t_2)$ [5].

We consider in which extent the relation (3) is fulfilled at the condition of the system associative response, i.e. the investigated signal consists of several fragments and only one of them is used for hologram reconstruction.

So, we have:

$$A'(x_1, y_1, t_1) = \sum_{i=1}^{N} A'_i(x_1, y_1, t_1), \qquad a'(x_2, y_2, t_1) = \sum_{i=1}^{N} a'_i(x_2, y_2, t_1) \tag{4}$$

In that case the equation (3) takes the following form:

$$A''(x_3,y_3,t_2)=\hat{F}^{-1}\left\{\left[\sum^{N} a'_i(t_2)\cdot\sum^{N} a'^{*}_j(t_1)\right]\cdot\sum^{N} a''_k(t_1)\right\}=$$

$$\hat{F}^{-1}\left\{\begin{vmatrix} a'_1(t_2)a'^{*}_1(t_1) & a'_1(t_2)a'^{*}_2(t_1) & \dots\dots & a'_1(t_2)a'^{*}_N(t_1) \\ a'_2(t_2)a'^{*}_1(t_1) & a'_2(t_2)a'^{*}_2(t_1) & \dots\dots & a'_2(t_2)a'^{*}_N(t_1) \\ \dots & \dots & \dots & \dots \\ a'_N(t_2)a'^{*}_1(t_1) & a'_N(t_2)a'^{*}_2(t_1) & \dots\dots & a'_N(t_2)a'^{*}_N(t_1) \end{vmatrix}_N \cdot a''(t_1)\right\}=$$

$$\left(\begin{vmatrix} A'_1 * A'^{*}_1 & A'_1 * A'^{*}_2 & \dots\dots & A'_1 * A'^{*}_N \\ A'_2 * A'^{*}_1 & A'_2 * A'^{*}_2 & \dots\dots & A'_2 * A'^{*}_N \\ \dots & \dots & \dots & \dots \\ A'_N * A'^{*}_1 & A'_N * A'^{*}_2 & \dots\dots & A'_N * A'^{*}_N \end{vmatrix}\right) \otimes A''(t_2) \tag{5}$$

In the equation (5) the factors, which are responsible for the formation of the copy of the whole optical image (i.e. for the associative response), are grouped together as the square matrix of the order of N. Among them the diagonal elements only have been of our main interest. They are responsible for coherent superposition of N plane waves along the direction of the optical axis of the first diffraction order. They form a synthesized plane wave, which determines whole reconstructed image. This image is observed in the background of a diffusion field caused by cross-talk elements of the matrix. To have analogy with estimations of an autocorrelation function of a diffuser [6], one can obtain the result, that for the case of whole image at the input plane relative parts of energy concentrated in the signal and in the background are equal.

If one illuminates the hologram only a fragment (or several fragments) of an input image, then the output image will be defined by a rectangular matrix of the order of N×(N-M), where M determines fragments which are shut. In that case relative contributions of matrix factors with coincident indexes decreases but the background component part increases. The contrast of the output image therewith goes down. For example, if one shuts one-half of the input image, the energy of the output image is decreased by a factor of four. In the limiting case, when a small point fragment is used for hologram readout, the output image is described by a spatial autocorrelation function of the investigated image in accordance with equation (5). In this case the equation is coincided formally with the one for the case of holographic decreasing of radiation divergence for compound coherent beams [7].

4. Experimental set-up and results

To investigate the described principle of the direct associative response in the holographic correlation scheme the telescopic system consisted of two connected objectives O_1 and O_2 was built up (Fig.1). This scheme was used for multiplex recording of Fourier holograms in a volume photorefractive crystal (PRC). The input optical signal (or its fragment) was formed with the help of amplitude-phase transparency Tr at the front focal plane of the first objective O_1. The diffuser D was set before the transparency to ensure uniform distribution of speckle-field at the hologram plane within a circle of the diameter about 3 mm. Holograms were recorded in the crystal $LiNbO_3$:Fe of the size of 2×14×17 mm^3, which was fastened on an adjusted rotated table and positioned at the middle focal plane of the telescopic scheme. A light split system consisted of a half-transparent mirror Sp and a turned mirror M was placed before the hologram. This system provided superimposing two identical beams P_1 and P_2 with the intensity ratio 2:1 as well as their interfering at the hologram plane at the angle about 20^0. Detection of the investigated signal and/or its holographic response was at the back focal plane of the objective O_2 with the help of a photodetector C (a photocamera or a TV-camera).

In this scheme holograms from different transparences were recorded consecutively by turning the photorefractive crystal around its vertical axis. The holograms were reconstructed by the field of the corresponding transparency, which may be either open or shut partially.

Certain of obtained results are shown in the photos in Fig.2. It shows two images recorded in one place of the crystal. The first is the slide of the size of 7×7 mm^2 with the image of a dog. The second is a tested mira with the squares 1.2×1.2 mm^2. The photos of input images are in the Fig. 2A. The photos in Fig. 2B are corresponding output images, which actually are the associative responses obtained in the present holographic system. You can see that output images do not depend practically on diaphragming of input optical signal.

5. Conclusion

In the paper the possibility to employ the correlation holographic system with direct associative response is considered. The effective work of such system for hologram multiplex recording in volume photorefractive media is shown.

6. References

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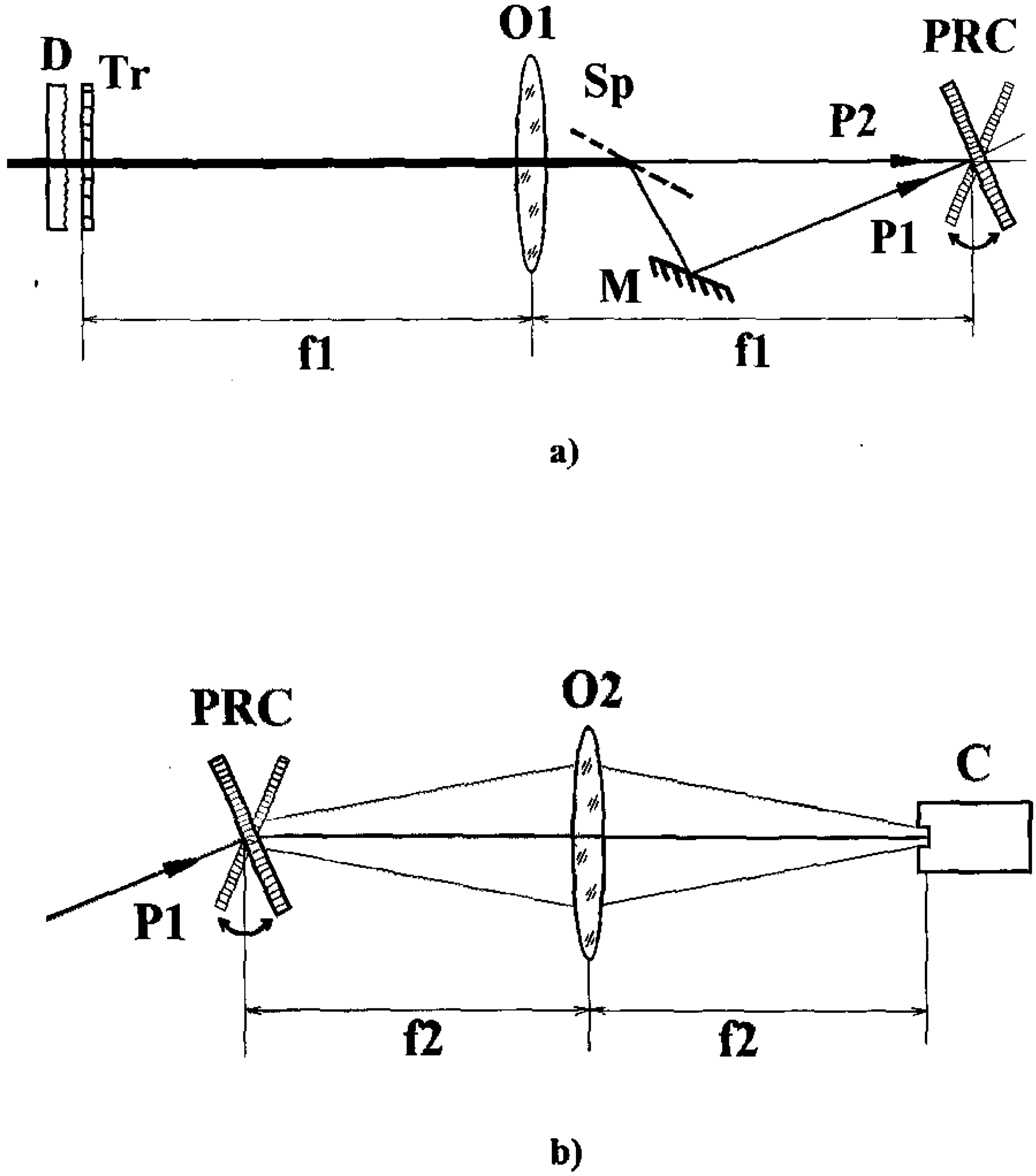

Figure 1. The holographic schemes (a) for recording of the hologram and (b) for image reconstruction.

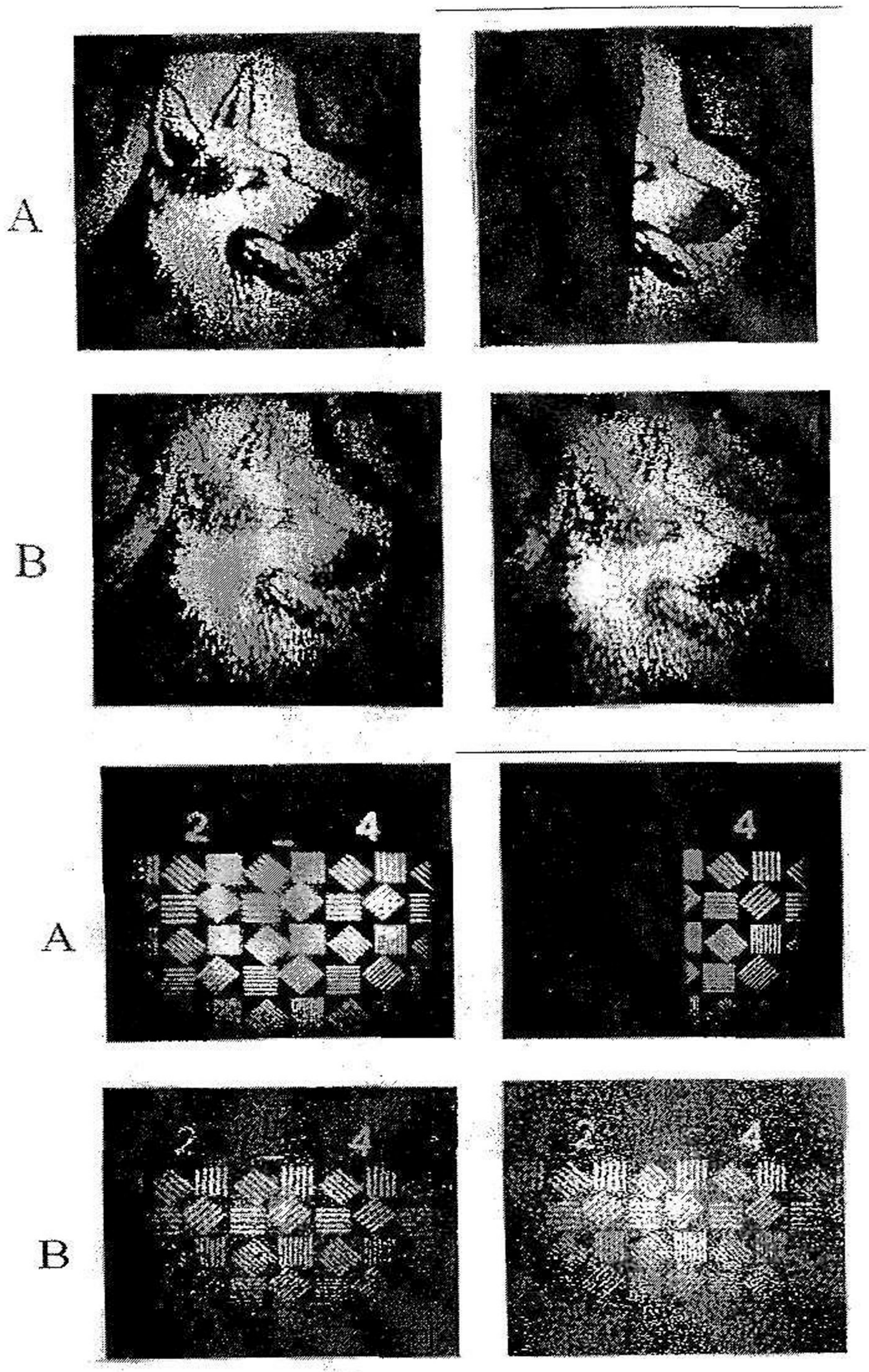

Figure 2. Photos of associative reconstruction of two images. A is the image at the readout transparency, B is the retrieval output images.