

Some peculiarities of the associative holographic image formation and quality: the comparative analysis

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The peculiarities of associative holographic image formation at the initial image saving stage in different registration media have been studied. It is shown that the recovered associative holographic image quality can be theoretically predicted and is defined by the recovering beam area. The experiment and simulation results on the associative holographic image quality with the different reconstruction beam area are shown.

Исследованы особенности формирования ассоциативного голографического изображения в процессе начальной записи информации в различных регистрирующих средах. Показано, что качество восстановленного ассоциативного изображения может быть теоретически предсказано и определяется площадью восстанавливающего пучка. Представлены результаты экспериментальных исследований и моделирования качества ассоциативного голографического изображения при различных значениях площади восстанавливающего пучка.

The formation of associative holographic images is an actual problem of coherent optics, image processing and optoelectronics due to the increasing need of optical information coding/decoding, image correction, and image transmission through a distorting medium. To solve these applied problems, non-phase detecting methods were proposed to be used in some cases. In such methods, information and energy losses are high, so it is impossible to detect a low intensity signal.

The correlation holography [1] and adaptive optics methods seem to be among the most successful and promising solution methods for those problems. The associative image formed by means of those methods is, however, not always ideal. For example, in case of phantom image forming, its information structure does not essentially differ from the original, but the image intensity over the field is inhomogeneous [2]. And vice versa, when the recovered associative image is homogeneous to the maximum extent, its information structure does not completely meet the initial one [2]. Therefore, the studies on formation and quality of the associative holographic images are actual and necessary both from physical and applied point of view. The aim of this research is to determine the relationship between the recovered associative image quality, the distortions produced at the reconstruction stage, and the limiting distortion at which the image is still identifiable.

The holographic scheme that provides the recovered signal closest to ideal response is Fourier holography scheme with equal reference and signal beams [3]. In general, this scheme is a telescopic system with two objectives that have a common focal plane. In the front focal plane (x_1,y_1) of the first objective, an amplitude-phase transparent is placed which defines the structure of the optical signal being investigated. The hologram formation process occurs in the common focal plane (x_2,y_2) at the time point t_2. Then, in the back focal plane (x_3,y_3) of the second objective, which provides the inverse Fourier transformation of the optical signal at time point t_3, the recovered signal is recorded.

According to [3], the recovered image $A(x_3,y_3,t_2)$ will be defined by the "square" matrix $N{\cdot}N$:

$$A(x_3,y_3,t_2) = \qquad (1)$$

$$= \hat{F}^{-1}\left\{\left[\sum_{i,j=1}^{N} a_{ij}(t_2)\cdot\left(\sum_{k,l=1}^{N} a_{kl}(t_1)\right)^*\right]\cdot\sum_{o=1}^{N}\sum_{p=1}^{M} a_{op}(t_1)\right\} =$$

$$= \left(\begin{vmatrix} A_1 & E_{21} & K & E_{N1} \\ E_{12} & A_2 & K & E_{N2} \\ \Lambda & \Lambda & \Lambda & \Lambda \\ E_{1N} & E_{2N} & K & A_N \end{vmatrix}\right) \times A''(t_2).$$

The "diagonal" elements

$A_1 = A'^{*}_{11}(A'_{11})^* + E_{11}$,

$A_2 = A'^{*}_{22}(A'_{22})^* + E_{22}$,

$A_N = A'^{*}_{NN}(A'NN)^* + E_{NN}$ define the useful signal while non-diagonal ones produce the background illumination.

If the hologram is recovered with a part of the beam, then the recovered signal will be defined as a "rectangular" matrix $N{\cdot}(N - M)$, where M is the number of missing elements in the recovering signal. In this case, the number of "diagonal" elements decreases, thus, the contribution of the non-diagonal elements will additionally increase the background component, which makes the image quality worse. It is seen that in both cases, the recovered image will be a result of background and useful constants overlapping.

The level of their mutual contribution can be estimated using the image quality evaluation procedure comparing the relative brightness of the recovered image elements. Thus, in case of one-bit image, the average relative brightness of the white fragment (the transparent gauzy part) is compared with the average brightness of the dark fragments (corresponding to 100 % absorption of the appropriate transparent part). Hence, the model for objective determination of the image quality is created. In the common case, the formula that characterizes the image quality can be written as

$$Q = \frac{\sum_{k=1}^{W}\left[\dfrac{\dfrac{\sum_{i,j=1}^{S_W}(I_W)_{ij}}{S_W} - \dfrac{\sum_{i,j=1}^{S_D}(I_D)_{ij}}{S_D}}{\dfrac{\sum_{i,j=1}^{S_W}(I_W)_{ij}}{S_W} + \dfrac{\sum_{i,j=1}^{S_D}(I_D)_{ij}}{S_D}}\right]}{W}, \qquad (2)$$

Q is the quality of the image (the identification level); I_W, the relative brightness of the white fragment; I_D, that of the dark fragment; S_W, the white fragment area; S_D, the area of dark fragments surrounding a white fragment; and W, the number of white fragments. The summation over i and j corresponds to the summation over all the pixels of the image. It is to note that the calculation error can be minimized by averaging I_W and I_D values over the all pixels, because the dot value in the detector raster is substantially smaller than the real physical one.

Comparing (1) and (2), it is easy to show that the identification level of the associative holographic image will be defined by the number $(N - M)$ of "diagonal" elements in the matrix (1), i.e. by the area of the recovering beam. Thus, the identification level of the recovered associative holographic image will depend linearly upon the recovering beam area.

To study the associative holographic image formation depending of the recovering beam visible area and to evaluate the image quality, an appropriate optical scheme for the hologram saving and recovering was assembled (Fig. 1).

At the hologram storing stage, the laser radiation expanded by the telescopic system passes through the amplitude-phase transparent Tr and hits the beam splitting system SP. Then the two beams pass the Fourier-transformation objective O_1 at the intensity ratio 2:1 and angle 12° and interfere in the medium H. The beam splitter system consists of beam splitter cube Sp_1 and rotary prism Sp_2. Two media with different recording mechanisms were used to store holograms: a photorefractive $LiNbO_3(Fe^+)$ crystal and thermoplastic film of poly-N-epoxypropylcarbazole (PEPC).

At the hologram recovering stage, one of the beams is intercepted. The recovering

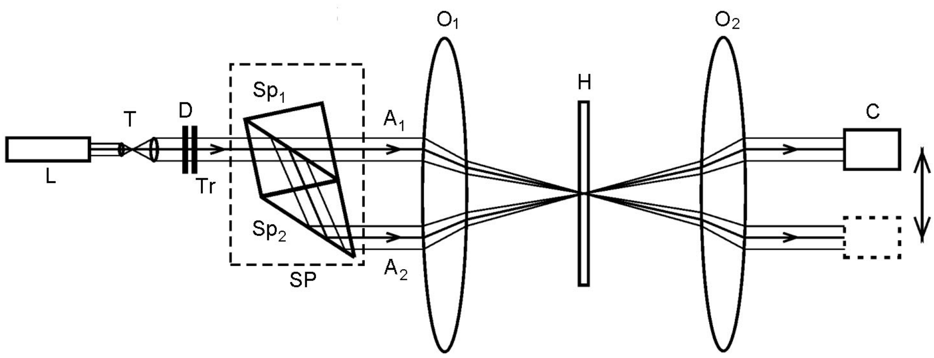

Fig. 1. The optical scheme of the saving and recover hologram.

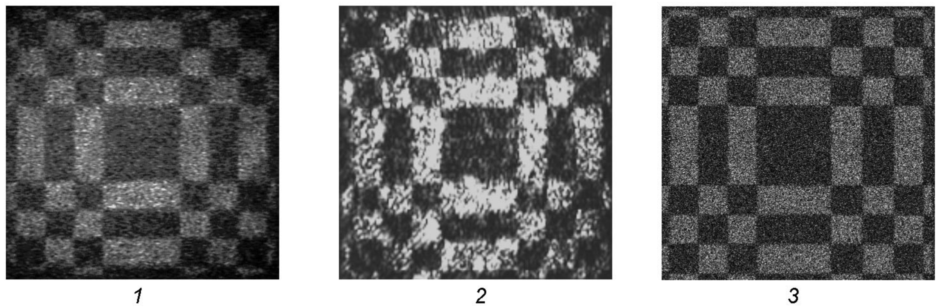

Fig. 2. Some associative images of holograms.

beam, diffracted on the hologram, after the inverse Fourier transformation produces the recovered associative holographic image which is registered on the CCD matrix of a TV camera installed in the second objective O_2 back focal plane.

While the experimental measurements were taken, the computer simulations of storing and recovering processes for the tested images were made in the MatLab. Both the recovered images and the simulated images were stored as BMP files. Then the files were imported to the MathCAD where they were analyzed by the algorithm based on the formula (2). According to the data obtained, the dependences of the Identification level Q on the recovering beam visible area S were plotted. Fig. 2 shows some associatively formed images. In Fig. 3, the plot of the identification level dependence on the recovering beam open area is shown.

It is seen that even in case when the hologram is recovered with the full recovering beam, the identification level does not attain 100 %. This is due to the correlative mechanism of the image formation, i.e. with the "non-diagonal" elements in (1), or, in other words, to the background illumination of the recording signal. Optical inhomogeneities of the recording media and optical equipment are among the experimental factors that can decrease the image quality. When considering the simulated images, it is necessary to take into account that Fourier transformation calculation algorithm is simplified.

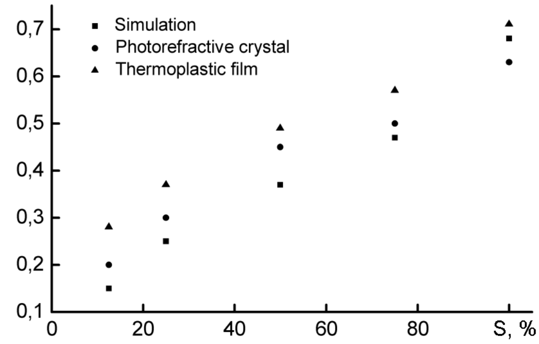

Fig. 3. The dependence of the identification level against to the scanned beam open square.

The small dynamic range of the TV camera CCD matrix is the reason of the lower identification level values for the simulated images. That is, the system cannot reproduce the whole gray level range of the recovered image due to its high resolution.

This means that at the stages of detection and analyze of the recovered image, the true color rendition is distorted by black or white brightness values pasteurization (reduction of the gray level hue number) of some pixels towards the brightness decrease or increase, respectively.

It is seen in Fig. 3 that for the thermoplastic film, the relative identification level values are higher than for the photorefractive crystal. It is also note that the thermoplastic film is more sensitive.

So, the associative holographic image forming principles have been considered. The quantitative characteristics of the recovered associative image quality for the two types of record mediums have been obtained. It has been shown that the dependence of the recovered associative image quality on the recovering beam area is linear, being in agreement with the theoretical premises. The simulation gives the results that confirm the experimental data. It has been shown that for the thermoplastic film, the relative characteristics of the recovered image quality are higher than for photorefractive crystal. Also it is necessary to note higher sensitivity, usability and recording rate of the thermoplastic film. The photorefractive crystal is less critical to the spatial shifts and can work without additional devices, which is its advantage. It is reasonable to study further the recovered associative image formation in the dependence on the overlap degree of the signal and reference beams, which is a premise to develop a general theory of holographic image formation.

References

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Порівняльний аналіз деяких особливостей формування та якості голографічного асоціативного зображення

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Досліджено особливості формування асоціативного голографічного зображення у ході початкового запису інформації в різних реєструючих середовищах. Показано, що якість відновленого асоціативного голографічного зображення може бути теоретично передбачена й визначається площею відновлювального пучка. Наведено результати експериментальних досліджень та моделювання якості асоціативного голографічного зображення за різних значень площі відновлювального пучка.