Bożena Janowska, Jadwiga Szydłowska

On Recording of Colour Images in Thin Holographic Emulsions

1. Introduction

The method of colour reconstruction of holographic images was first proposed by LEIGHT and UPATNIEKS [1]. It consists in independent registration of three independent interference patterns produced by light of three different colours in the holographic emulsion. The photographic emulsion is here considered as a two-dimensional medium. In this case, each of the reference beams must fall upon the emulsion under a different angle, to enable a spatial separation of the parasitic images from the true multi-colour image in the reconstruction step. Another method of spacial separation of the parasitic images in two-dimensional emulsions was developed by MANDEL [2]. This method does not require any directional separation of reference beams and is based on the angular separation of the diffraction images. In reality, the holographic emulsion is a three-dimensional medium, and the hologram is recorded in the whole volume of the lightsensitive material. Therefore, the light diffraction on the recorded volume pattern in the reconstruction process exhibits maximum intensity if the hologram is positioned in accordance with the Bragg Law. Basing on this property of holographic recording, PENNINGTON and LIN [3] managed to reduce the intensity of the parasitic images. In the present work the recording method of the multi-colour volume images developed by Pennington and Lin has been employed by using Scienta 8E75 emulsion of 7 μm thickness.

2. Theoretical fundamentals of colour recording

Assume that P_1, P_2 and P_3 represent the complex amplitude of the light scattered by the object for three basic colours, respectively. Then the complex amplitude P of the multi-colour object light beam may be expressed as follows

$$P = \sum_{i=1}^{3} P_i. \tag{1}$$

Similarly denoting by R_1, R_2 and R_3 the complex amplitudes of the reference beams carrying three basic colours, the complex amplitude R of the multi-colour reference beam may be represented as

$$R = \sum_{j=1}^{3} R_j. \tag{2}$$

The intensity of the light incident on the emulsion is equal to

$$I = \langle (O+R)(O+R)^* \rangle = |O+R|^2. \tag{3}$$

Assume that the waves of different lengths are mutually incoherent [2]. Then the intensity I amounts to

$$I = \left| \sum_{i=1}^{3} O_i + \sum_{i=1}^{3} R_i \right|^2 \times \delta_{ij}, \tag{4}$$

where δ_{ij} denotes the Kronecker delta symbol. Hence

$$I = \sum_{i=1}^{3} (O_i^2 + R_i^2 + O_i R_i^* + O_i^* R_i). \tag{5}$$

This is an intensity distribution in the interference pattern being recorded on the holographic plate. If C_1, C_2 and C_3 denote the respective complex amplitude of the reconstructing waves of different lengths the incident wave in the hologram plane may be described by the formula

$$C = \sum_{k=1}^{3} C_k. \tag{6}$$

Let the amplitude transmittance of the developed holographic plate be proportional to the intensity I. Then the wave emerging from the hologram may be described as follows:

$$H = \sum_{k=1}^{3} T_k C_k \sum_{i=1}^{3} (O_i^2 + R_i^2 + O_i R_i^* + O_i^* R_i, \tag{7}$$

where T_1, T_2 and T_3 are the hologram transmission coefficients for three colours of the used light, respectively. The second component of the sum represents the waves producing virtual images, which result from diffracting the light beams of three wavelengths on the three holographic patterns recorded on the hologram. Thus we end up with nine images U where

$$U = \sum_{i=1}^{3} \sum_{k=1}^{3} T_k C_{ki} O R_i^*. \qquad (8)$$

In the case when $i = k$, the formula (8) corresponds to the situation, when three images are produced from the holograms made with beam wavelength identical with that of the reference beam. The images exhibit the same spatial orientation as that of the object and determine the proper multi-colour virtual image. Letting $i \neq k$ in the formula (8) we obtain six intermodulation terms, which describe the diffraction of the waves of different lengths on the patterns produced by light beams of different colours. The images produced in this way will be called parasitic images. They are angularly separated from the true image in the λ_k/λ_i ratio and are magnified as shown in [5]. When choosing three waves of possibility different lenght [2] the greatest angular separation of the parasitic images is obtained.

In the above considerations the light-sensitive material is treated as a two-dimensional medium. As the emulsion has, in reality, a finite thickness an additional attenuation of parasitic image intensity proves to be possible [3, 6].

3. Experimental

Holograms of multi-colour objects have been performed in an experimental set-up (shown in Fig. 1) by applying the method of three successive single-colour expositions recorded on one photographic emulsion. This method enables an accurate matching of the intensity ratio for each colour. A four-colour set of dices has been holographed, i.e., yellow, dark green, black, and light green ones. The holograms were recorded on Scientia 8E75 plates of Agfa-Gevaert production, the thickness of each amounting to 7 μm.

Three beams of different colours, i.e. the red one of $\lambda = 0.647$ μm, the yellow one of $\lambda = 0.568$ μm and the blue one of $\lambda = 0.488$ μm, were produced by krypton and argon lasers, respectively. The selected set of colours assures the greatest angular separation of the parasitic images, the disadvantage of this choise being in a lower coverage of the colour diagram than it is the case for the classical red-green-yellow system. In order to attenuate the parasitic images the Bragg condition has been exploited by applying the maximally large angle between the reference and the object beams, which was restricted only by the resolution of the holographic plate. In our experiment this angle amounted to 120°.

The reconstruction of the recorded images was performed in the set-up shown in Fig. 2. The hologram was simultaneously illuminated

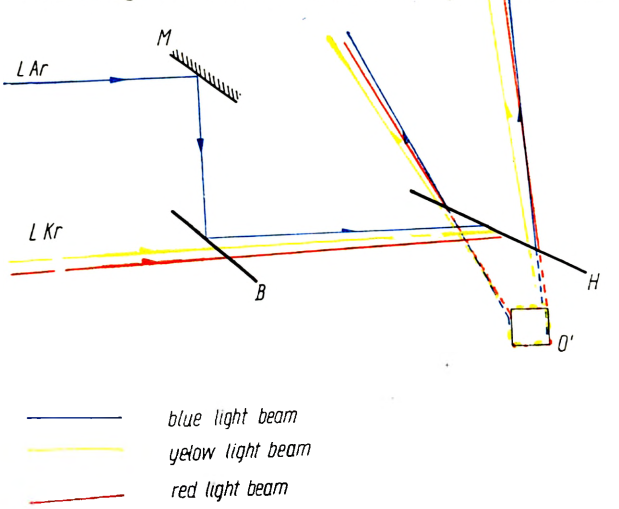

Fig. 2. Schematic representation of a system for multi-colour image reconstruction

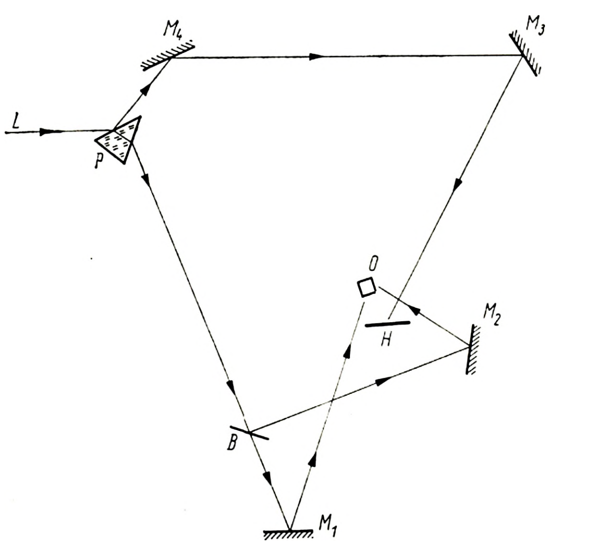

Fig. 1. Schematic representation of a holographic system for multi-colour image registration

by three beams: red, yellow and blue. The red and yellow beams were produced by a Krypton laser while the blue one was obtained from the argon laser. The multi-colour virtual image was photographed with a Polaroid camera, the Polaroid Land Roll Film 48 being used.

4. Results and discussion

The multi-colour image reconstructed from the hologram is presented in Fig. 3. On its

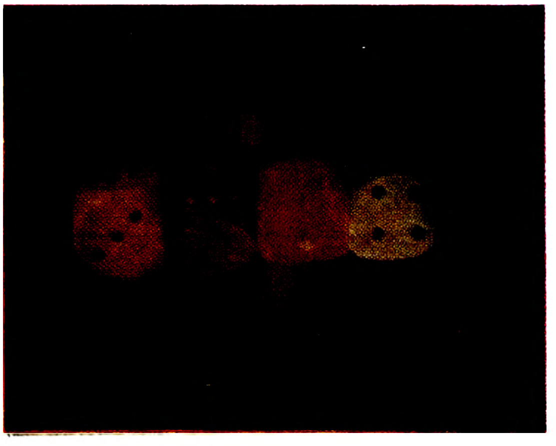

Fig. 3. A multi-colour image reconstructed from a hologram

both sides the residual parasitic images are visible. Their elimination is not complete because of the emulsion thickness [5], which being too small restricts the application of the Bragg condition. Nevertheless the observation of the proper multi-colour is not disturbed. Since that the parasitic images are spatially separated.

In the multi-colour image the colours of the successive dices are recovered correctly, if taken into account that the object illumination was realized by three laser beams, each of them having an extremely small spectral width and all of them covering only a part of the full colour triangle. This causes a change in the resulting colours when compared with those produced by white light illumination.

It should be emphasized that the diffraction efficiency of the multi-colour image is lower than that of an image reconstructed from a single-colour hologram. This is caused by the overlap of three single-colour holographic patterns and additional diffraction of light in the direction of parasitic images.

Colour holography allows to record the images of the objects not only three-dimensionally but also in a full colour palette. An application of thicker holographic emulsions will results in a complete disappearance of the parasitic images.

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