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A SPECKLE METHOD OF GRAY LEVEL PSEUDOCOLORING

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A simple method of pseudocoloring gray level images is proposed. It is based on Young's fringes modulated speckle encoding of images. Reconstruction from a photographic register is obtained using two light beams with different wavelengths at the same time. Pseudocoloring is produced by the superposition of a (diffracted) direct image in one color and a (directly transmitted) contrast reversed image in another color.

1. Introduction

Pseudocoloring of density-modulated black and white images is a technique for transforming a monochrome image in a colored one, where different colors are assigned to the several gray levels present in the B and W image. The importance of the pseudocolor operation is based on human eye better ability to distinguish different colors than gray levels.

Historically, the use of pseudocolor encoding filters in imaging was first introduced by Rheinberg [1] in 1896, who reported the applications of color filtering in microscopy. In the last few years, several methods of pseudocoloring have been developed. In general, these methods can be classified into three classes: computer techniques [2] where the images are initially digitized, methods which involve the use of halftone screens [3–5], and methods that use holographic or spatial filtering techniques [6–10]. Due to image sampling the first two classes of pseudocoloring methods will produce color-coded images with a loss of spatial resolution. With regard to the third class methods, Yu et al. [6,7] proposed an approach using a one-step rainbow-holographic encoding technique where the encoded hologram images can be reproduced employing white-light illumination. More recently, Santamaría et al. [8] developed a new method for pseudocoloring an image without loss of resolution and without intermediate steps, where one conventional image and a contrast reversed image of the same object are added, each one with a different color. Although this technique has several advantages over the previous ones, a coherent source is still needed in addition to an incoherent one. After that, Chao et al. [9] proposed an alternative approach using a white-light source, but it is still necessary to perform a spatial filtering operation.

In a recent communication, Guel Sandoval et al. [10] presented a new method of pseudocoloring through an image-hologram where the reconstruction step is performed with two partially-coherent sources and no spatial filtering operation is needed.

In this paper we describe a simple method of gray level pseudocolor encoding through Young's fringes modulated speckle. As in the case of the image-hologram technique, an image of the original transparency is obtained by diffraction in one color, and a contrast reversed one by direct propagation in another color. The reconstructing sources may be two partially coherent white-light lamps with appropriate color filters and no spatial filtering operation is required.

2. Description of the method

As in the case of pseudocoloring through contrast reversal filtering [8], the method we propose is based on the addition of a positive monochrome image and a negative one of a gray level black and white transparency, each image formed with a different color. In

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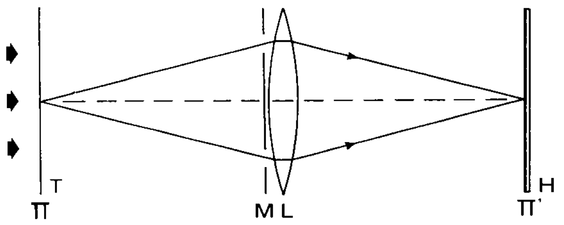

Fig. 1. Schematic diagram of the experimental set-up used to register Young's fringes modulated speckle encoding of the image.

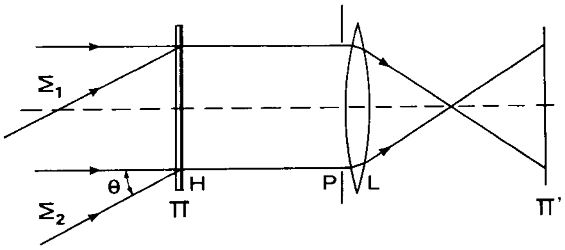

Fig. 2. Schematic diagram of the experimental set-up used to obtain the pseudocolored image.

our case, both the positive and the negative images are encoded together in the same photographic plate, registering an image of the object in a coherent optical system where the lens pupil consists of two identical apertures. In this way, the intensity distribution on the image consists in Young's fringes modulated speckle [11]. The scheme of the optical system used to encode the transparency is shown in fig. 1. The intensity distribution $I(\xi, \eta)$ registered by a high resolution photographic plate H in the output plane (ξ, η) of the system can be expressed as:

$$I(\xi, \eta) = C|h(\xi, \eta) * T(\xi, \eta)|^2, \qquad (1)$$

where C is a real constant, $T(\xi, \eta)$ the amplitude transmittance of the object transparency T, $*$ denotes a convolution product, and $h(\xi, \eta)$ the "point-spread function" of the system which in this case will be:

$$h(\xi, \eta) = [J_1(a\pi\sqrt{\xi^2 + \eta^2}/\lambda D)/\sqrt{\xi^2 + \eta^2}]$$
$$\times \cos(\pi d \xi/\lambda D), \qquad (2)$$

a being the diameter of the apertures in the mask M, d the separation between them, D the image distance, and λ the wavelength of the coherent radiation. The Bessel's function J_1 determines the average size of the speckle grains in the image, while the cosine function takes into account the Young's fringes. So, the intensity distribution will consist of speckle grains that form an image of T, modulated themselves by Young's fringes.

After processing, the amplitude transmittance $t(\xi, \eta)$ of H, in the linear region of the $(t - E)$ curve, will be:

$$t(\xi, \eta) = t_0 - \beta|h(\xi, \eta) * T(\xi, \eta)|^2, \qquad (3)$$

where t_0 and β are constants depending on the developing process.

To observe the pseudocolored image, the developed plate H is placed in the optical system shown in fig. 2. Two plane waves, originated in two diaphragmated white-light lamps with adequate color filters, illuminate the processed plate. One of them propagates along the optical axis and gives rise to the contrast reversed image. The other wave forms a certain angle θ with the optical axis such that one of the waves diffracted by Young's fringes also propagates along the optical axis and forms the direct contrast image. In this way, the intensity distribution of the output plane (x, y) of the achromatic lens L, will be:

$$I(x, y) = I_{\lambda_1}(x, y) + I_{\lambda_2}(x, y),$$

I_{λ_1} being the intensity of the photographic plate image given by the Σ_1-wave, and I_{λ_3} the intensity corresponding to the Σ_2-wave.

Taking into account (3), the amplitude U_1 of the transmitted wave, in the (ξ, η) plane is:

$$U_1(\xi, \eta; \lambda_1) = K_1[t_0 - \beta|h(\xi, \eta) * T(\xi, \eta)|^2],$$

where K_1 is a constant. Due to the special form of the "point-spread function" (given by (2)), the amplitude distribution U_1 will contain a zero order component propagating along the optical axis and two ±1 diffracted orders propagating at certain angles $+\psi, -\psi$ from the optical axis. If the value of ψ is great enough, so that the lens aperture $P(u, v)$ collects only the zero order component, Σ_1 gives rise to an intensity distribution in the image plane π':

$$I_{\lambda_1}(x, y) = |\mathcal{F}\{P(u, v)$$
$$\times \mathcal{F}\{t_0 - \beta|h(\xi, \eta) * T(\xi, \eta)|^2\}\}|^2,$$

which represents a contrast reversed image of T, with a color given by λ_1. On the other hand, Σ_2 gives rise to an intensity in the same plane π':

$$I_{\lambda_2}(x,y) = |\mathcal{F}\{P(u,v)\,\mathcal{F}\{|h(\xi,\eta) * T(\xi,\eta)|^2\}\}|^2. \quad (4)$$

In this case $P(u, v)$ cancels the central order and one of the diffracted orders of the term $\mathcal{F}\{|h(\xi,\eta) * T(\xi,\eta)|^2\}$. So, (4) represents a direct contrast image of T with a color given by λ_2. Then, in the output plane (x, y) of the lens L where both images superpose, we obtain a pseudocolored image of the original transparency.

3. Experimental results

It must be pointed out that the encoding of the image speckle pattern of the transparency by Young's fringes produces not only a narrowing of the space-central band but a shifting of the spectrum to higher frequencies equal to $d/\lambda D$. Then, it means that the appropriate value of θ that produces two waves propagating in the same direction (a direct transmitted one and a diffracted one) will be:

$$\text{sen}\,\theta = \lambda_2 d/\lambda D.$$

Some experiments have been performed on X-ray pictures and gray-level variation patterns. To perform the encoding operation a partially-coherent white-light source or a laser source may be used. In the first case a color filter is needed. The diameter a of the apertures was 10 mm, the distance d between them was 70 mm and λ was 633 nm. In this way, the average size of the speckle grains was 10 μm and the interfringe of Young's fringes was 2 μm. This loss of resolution may be reduced varying the various parameters a, d and D.

For obtaining the pseudocolored images, two diaphragmated white-light lamps were used. In order to select λ_1 and λ_2, an interferometric green filter and a spectroscopic red filter were used. In this way, the pseudocolored images showed a broad range of pseudocolors as well as a continue variation in hue corresponding to continue gray level variations in the original transparencies.

4. Conclusions

A new method of pseudocolor encoding of gray level information is proposed. As in the case of pseudocoloring through an image hologram, it is based on the addition of a direct image obtained by diffraction and a contrast reversed one obtained by direct propagation of light. In our approach, laser is not essential for the encoding step. Due to the geometry used, the only spatial filtering operation involved corresponds to the natural diaphragme of the eye or achromatic lens. Besides, the register is not affected by quadratic phase factors as in the case of holographic methods, and no contrast variation of the transmitted image is present as may occur in image-holograms due to the existence of the reference wave.

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