

# Multichannel image storage with application to color multiplexing

M. Araiza E.<sup>a</sup>, S. Guel S.<sup>b</sup>, C. Sifuentes G.<sup>a</sup>,  
I. de la Rosa V.<sup>a</sup>, and G. Miramontes de L.<sup>a</sup>

<sup>a</sup> *Laboratorio de Procesamiento Digital de Señales (PDS),  
Unidad Académica de Ingeniería Eléctrica, Universidad Autónoma de Zacatecas (UAZ),  
Zac.- 98000, Tel: +(492) 9239407, ext. 1518,*

<sup>b</sup> *Instituto de Investigación en Comunicación Óptica (IICO),  
Universidad Autónoma de San Luis Potosí (UASLP),  
San Luis Potosí, S.L.P.- 78000, Tel: +(444) 8250183,  
e-mail: araizama@uaz.edu.mx*

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This paper presents an improvement in the method for storing information using detour type multichannel holograms. This makes it possible to increase the number of image-processing operations at the retrieval stage. One of the main contributions of this work is in showing that this type of hologram is sensitive to color processing. As far as we know, this is the first effort made toward implementing color in binary holograms as shown in the experimental results.

*Keywords:* Multichannel holograms; image processing; spatial frequency; spatial period; sensitivity, spatial color filter.

En este trabajo se presenta una mejora al método de almacenamiento de hologramas multicanales. Esto permite incrementar el número de operaciones de imágenes procesadas en la etapa de recuperación. Pero principalmente se muestra que este tipo de hologramas presenta sensibilidad al procesado en color, siendo estos los primeros esfuerzos en implementar color en los hologramas binarios, hasta donde sabemos.

*Descriptores:* Hologramas multicanales; procesamiento de imágenes; frecuencia espacial; periodo espacial; sensibilidad; filtros de color.

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## 1. Introduction

In recent years, a class of techniques has been developed for the storage of data sets in computer generated holograms (CGH) [1-5]. One of them is the multichannel method, described in this work, with detour type CGH which encodes up to 12 multiplexed images [6]; this is different from some other methods that belong to this class, which can codify two or four multiplexed images [1-3] for different applications.

The multichannel technique is a reliable storage method, which has the necessary features in CGH [3-5]. Moreover, using color displays in the reconstruction stage of a CGH [7] produces a pleasant visual sensation [8-10] and the multiplexed number of images can be increased.

In Sec. 2, the proposed technique is shown. In Sec. 3, some experimental results are presented and at the retrieval stage, a color reconstruction can be obtained. Finally, in Sec. 4, some conclusions, merits and limitations of the proposed approach are noted.

## 2. The codification technique

Succinctly speaking, the multichannel technique may be described as follows: the fundamental cell is divided into  $Q$  subcells (see Fig. 1a). The  $q$ th subcell encodes a function of the form  $U_q = A_{q,mn} \exp[i\varphi_{q,mn}]$ , which is

the discrete Fourier Transform (DFT) of the complex one,  $u_q(x, y) = |u_q(x, y)| \exp[i\phi_q(x, y)]$ , by using an array of  $N \times N$  cells as shown in Fig. 1b, of size  $(\delta\nu \times \delta\nu)/Q$ . Each subcell contains a rectangle which is determined by free parameters, width  $W_{q,mn}$  and lateral position  $P_{q,mn}$ , which can be selected to be proportional to the amplitude  $A_{q,mn}$  and phase  $\varphi_{q,mn}$  of  $U_q$ , and defined from  $-N/2$  to  $N/2$ . Often the object used in the codification is a digitized image. Note that each subcell reduces the vertical transmittance amplitude by the factor  $(\epsilon/Q)$ , avoiding an overlapping effect between subcells, as was explained in Ref. 3. The method can codify up to four images.

The transmittance amplitude is encoded by the following relationship [4]:

$$W_{q,mn} = \frac{\sin^{-1}(A_{q,mn})}{\pi}, \quad (1)$$

$$P_{q,mn} = \frac{\phi_{q,mn}}{2\pi}. \quad (2)$$

The improvement proposed to optimize the multichannel technique can be described as follows: like the binary amplitude transmittance  $H$  at the hologram plane  $(\nu_x, \nu_y)$  (Fig. 2), it can be described as the sum of *rect* functions. For simplicity, the binary amplitude transmittance of the  $q$ th subcell is:

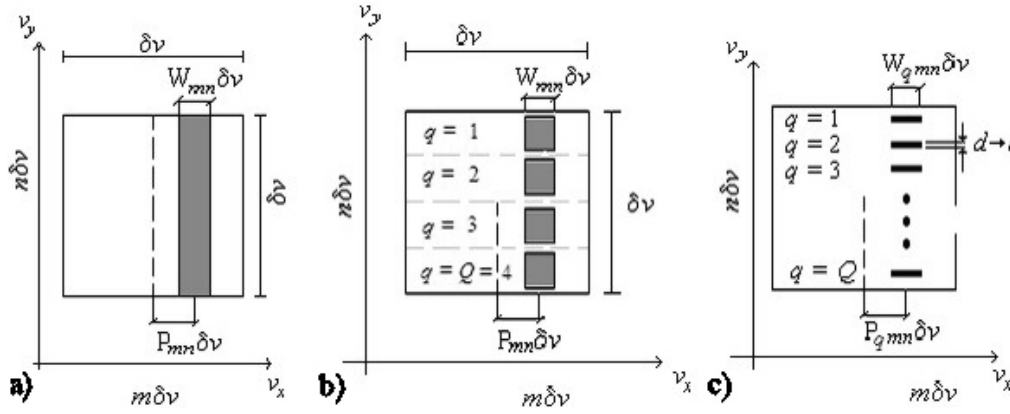


FIGURE 1. Structure of a  $(n, m)$  cell. (a) Basic cell for detour CGH. (b) Division of cell into subcells, for multichannel CGH, where  $d\nu/Q$ , (c)  $Q$  subcells division with vertical limited transmittance amplitude.

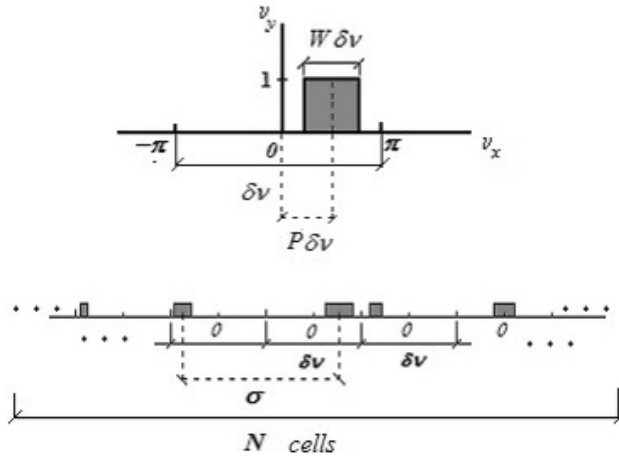


FIGURE 2. Schematic diagram of the amplitude transmittance of one cell and a row.

$$H_q(\nu_x, \nu_y) = \sum_{m,n} \text{rect} \left[ \frac{\nu_x - (n + P_{q,mn})\delta\nu}{W_{q,mn}\delta\nu} \right] \times \left[ \frac{\nu_y - (m + s_q)\delta\nu}{d\delta\nu} \right], \quad (3)$$

where  $s_q$  gives the shift between each subcell. To increase the number of subdivisions, the height of each rectangle should be decreased, which means that  $d$  should be fulfilled:  $d < \delta\nu/Q$  and  $d \rightarrow \epsilon$ , since  $\epsilon \ll$  (the smallest values), that is, the amplitude transmittance decreases and prevents contact between vertical subcells [3,7] (see Fig. 1c).

At the image plane  $(x', y')$ , the Inverse Fourier Transform (IFT) of  $H_q(\nu_x, \nu_y)$  appears as the following complex function:

$$h_q(x', y') = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} H_q(\nu_x, \nu_y) \times \exp[2\pi i(x'\nu_x + y'\nu_y)] d\nu_x d\nu_y = \sum_{m,n} W_{q,mn} \text{sinc}(x'W_{q,mn}\delta\nu) \times \exp[2\pi i x'(n + P_{q,mn})\delta\nu], \quad (4)$$

$$h_q(x', y') = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} H_q(\nu_x, \nu_y) \times \exp[2\pi i(x'\nu_x + y'\nu_y)] d\nu_x d\nu_y = \delta\nu^2 \sum_{m,n} W_{q,mn} \text{sinc}\left(\frac{x'\delta\nu}{\lambda f} W_{q,mn}\right) \times \exp\left[i\frac{2\pi x'\delta\nu}{\lambda f}(n + P_{q,mn})\right], \quad (5)$$

where  $h_q(x', y')$  represents again the  $q$ th image  $u_q(x', y')$ , which appears in the first diffraction order. Once each  $W_{q,mn}$  and  $P_{q,mn}$  have been calculated, the  $N \times N$  cells are plotted in a two dimensional array. The resulting discrete pattern is photographically reduced, and this is called a Multichannel Digital Hologram (MDH). When the MDH is set in an optical system, (Fig. 3), two conjugate images resembling  $u(x, y)$  appear at the output plane.

The generated fringe pattern, have a spatial period  $\sigma$ , with a spatial frequency of  $1/\sigma$ , as is shown in Fig. 2.

### 3. Results

As was demonstrated in Ref. 3, the technique works as a multiplexing system, where it would be able to codify four objects. In this work, twelve objects were codified into a

generated hologram of  $180 \times 180$  cells. After graphing, they were photographically reduced to small squares with an area  $0.75 \text{ cm}^2$ , approximately. When the hologram was fixed in the optical system shown in Fig. 3, each of the codified images in the hologram was retrieved. This result can be useful in performing several operations, as was shown in Ref. 3.

Figure 4 shows twelve objects (images), each with one letter of the word "Multichannel". Each letter is sketched into a specific coordinate that does not have an overlap [6]. When the hologram with the codified objects is lightened, the synthesized images of all letters are recovered simultaneously, in their original position, as can be seen in Fig. 5.

As each object was recorded in a different subcell, consequently the image of each subcell can be independently handled, thus recovering each one without affecting the rest of the images.

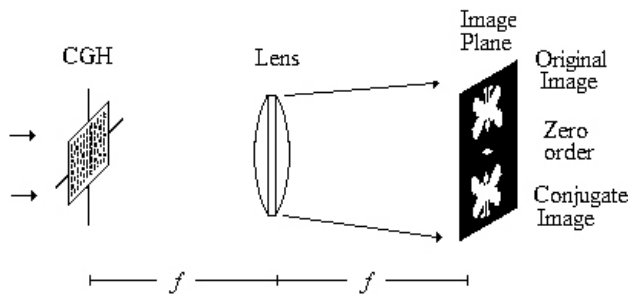


FIGURE 3. Schematic diagram for reconstructing MDH.



FIGURE 4. Objects to be encoded with the 12 subcells. One object per subcell.



FIGURE 5. Reconstructed image for 12 independent objects.



FIGURE 6. Objects with an spatial period of  $250 \times 250$  pixels.

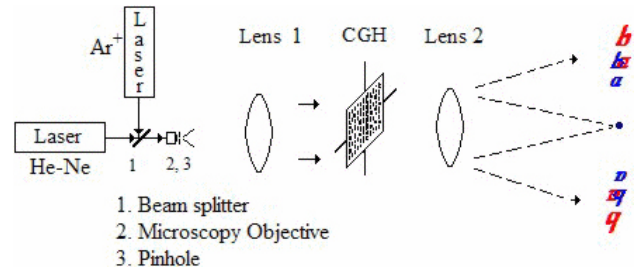


FIGURE 7. Sketch of the experimental optical setup to reconstruct color images.

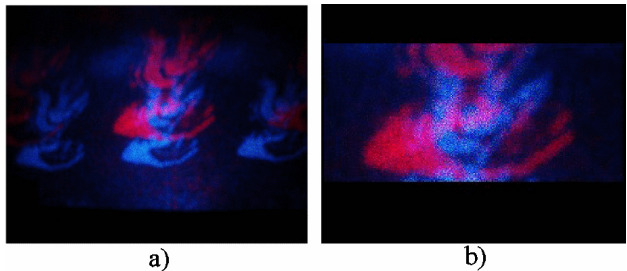


FIGURE 8. Image reconstructed: (a) and (b) without filter.

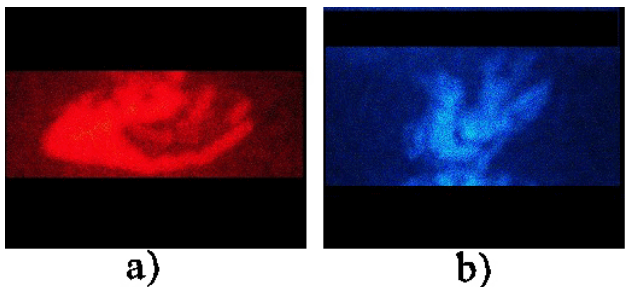


FIGURE 9. Image reconstructed: using (a) blue filter and (b) red filter.

Another interesting preliminary result is when we have monochrome objects (Fig. 6) codified into a hologram and they are graphed with a different carrier frequency. Figure 7 shows the system setup used in the reconstruction. It consists of a (He Ne) laser with an ( $\text{Ar}^+$ ) laser superposed whose wavelengths are 632 and 514 nm, respectively. Both lasers impinge on a beam splitter and together are opened wide by a microscope objective and pinhole. Then, with the help of a collimator lens and a focusing lens, the image codified in a CGH is recovered in a reconstructed plane.

For this case of only two images, some efforts have been made at color display, at the retrieval stage, to increase the number of multiplexing possibilities, which also enhances the visual sensation (see Figs. 8a). This is achieved by illuminating the hologram simultaneously with two wavelengths, giving place to overlapping of the images in different colors (Fig. 8b). Using color filters and properly selecting the overlapping sections of the reconstruction plane, it is possible to select any desired image according to its corresponding color (see Fig. 9).

#### 4. Conclusions

The first contribution of the present work is the fact that with the monochromatic object one can reconstruct color images when it is illuminated by different wavelengths. The color images are displayed simultaneously, giving a pleasant visual sensation. The color reconstructed overlapping images can give some advantage in performing spatial operations, as is done in Ref. 3. The preliminary experimental results in obtaining color reconstruction show other options for performing processing operations: reconstructed color images which can be separated by color filters.

The disadvantage of this method is that it is used only in the overlapping zone. Besides, the wavelength is not codified and it cannot make a color distinction as made by the methods in Refs. 9 and 10, respectively.

Moreover, it has been proven in this work that the experimental equipment imposes limits on the quantity of images that can be stored. It might be possible to surpass the number of codified pictures; this would depend on the technical support available. In this case, up to 12 divisions were obtained to store one object per subcell.

Several experiments have been suggested and their preparation is now in progress, such as that using higher order derivatives that was shown in Ref. 3.

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