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Abstracts

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Poster session

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Merim Nafissa Balas	Iris pattern localization method
Vahideh Farzamrad	Detection of Calcium-induced morphological changes on red blood cells by digital holographic microscopy and blinking optical tweezers
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Poster

Analysis of volume holograms using the technique of Green's tensor

C. Neipp, J. Francés, S. Gallego, S. Bleda, M. Álvarez, V. Navarro, A. Márquez, I. Pascual and A. Beléndez, Instituto Universitario de Física Aplicada a las Ciencias y las Tecnologías, Universidad de Alicante, Alicante, Spain

Abstract— The holographic storage of information is based on the interference of two waves: the reference wave and the object wave, the latter is generated by using a spatial light modulator, and in the case of applications of data storage this corresponds to a binary pattern of one and zeros. The interference pattern is recorded in a photosensitive medium (photopolymers, photographic emulsions, photorefractive, etc.), so that when illuminated by the reference wave the object wave is reproduced. In order to properly investigate the characteristics of the generated hologram it is necessary to adequately study the interaction of electromagnetic radiation with the recording medium. In this work we develop a completely vectorial formalism for solving the Helmholtz equation that allows investigation of electromagnetic dispersion in dielectric media in which the refractive index varies spatially. The method is based on the technique of Green's tensor and allows to correctly simulate the behavior of a volume hologram. This method is compared with the method of discrete dipoles and a formalism based on the first Born approximation to determine the intensity of light scattered by a volume hologram.

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Keywords—Volume hologram; Holography; Green's tensor

I. INTRODUCTION

Volume holography is an active field of research due to its great number of applications. One of the most important features a volume hologram exhibit is its Bragg selectivity. Due to this property some applications are feasible as fiber bragg gratings [1], Distributed feedback lasers [2], holographic optical elements [3], or holographic memories [4] among others.

The simplest volume hologram is a volume diffraction grating, which properties can be easily understood by using analytical expressions due to Kogelnik's Coupled Wave Theory [5]. Nonetheless, for general volume holograms analytical expressions cannot be obtained, so numerical methods must be employed to accurately simulate their properties. In this work we present a technique based on the Green's tensor technique to simulate the diffraction properties of volume holograms.

A volume hologram can be considered as a dielectric material whose dielectric permittivity varies spatially. There are many numerical techniques to simulate a dielectric non-inhomogeneous material such as the finite element method, the finite difference method, the method of lines, the method of moments, etc. In our case we have chosen a volume integral method based on the use of a Green's tensor [6]. This method

has been largely applied, for instance in the study of the scattering of particles of different size and form [7]. A modified version of the method is the so called discrete dipole method, which has successfully applied to the scattering of particles of different sizes.

II. THEORETICAL

A volumen hologram can be considered as a medium with a spatially varying dielectric permittivity, $\epsilon(\mathbf{r})$. If this medium is illuminated by an incident monochromatic field $\mathbf{E}^0(\mathbf{r})$, the total electric field is a solution of the equation:

$$\nabla \times \nabla \times \mathbf{E}(\mathbf{r}) - k_0^2 \epsilon(\mathbf{r}) \mathbf{E}(\mathbf{r}) = 0 \quad (1)$$

In this equation $\mathbf{E}(\mathbf{r})$ is the total field, that is the scattered field plus the incident field, and k_0 is the wave number of light in vacuum. Equation (1) can be rewritten as:

$$\nabla \times \nabla \times \mathbf{E}(\mathbf{r}) - k_0^2 \mathbf{E}(\mathbf{r}) = k_0^2 \Delta \epsilon(\mathbf{r}) \mathbf{E}(\mathbf{r}) \quad (2)$$

where: $\Delta \epsilon(\mathbf{r}) = \epsilon(\mathbf{r}) - 1$. So the homogeneous equation (1) is transformed into an inhomogeneous one and the Green's tensor formalism can be applied.

The Green's tensor $\mathbf{G}(\mathbf{r}, \mathbf{r}')$ is solution of the following equation:

$$\nabla \times \nabla \times \mathbf{G}(\mathbf{r}, \mathbf{r}') - k_0^2 \mathbf{G}(\mathbf{r}, \mathbf{r}') = \mathbf{1} \delta(\mathbf{r} - \mathbf{r}') \quad (3)$$

Where δ is the Dirac delta and $\mathbf{1}$ is the unit dyad in three dimensions.

For unbounded media the Green's tensor is obtained by:

$$\mathbf{G}(\mathbf{r}, \mathbf{r}') = \left(\mathbf{1} + \frac{\nabla \nabla}{k^2} \right) g(\mathbf{r}, \mathbf{r}') \quad (4)$$

Being:

$$g(\mathbf{r}, \mathbf{r}') = \frac{\exp(ikR)}{4\pi R} \quad (5)$$

Where $R = |\mathbf{R}| = |\mathbf{r} - \mathbf{r}'|$

The solution of (4) is:

$$\mathbf{G}(\mathbf{r}, \mathbf{r}') = \left(\mathbf{1} + \frac{ikR-1}{k^2 R^2} \mathbf{1} + \frac{3-3ikR-k^2 R^2}{k^2 R^4} \mathbf{R}\mathbf{R} \right) \frac{\exp(ikR)}{4\pi R} \quad (6)$$

Knowing the values of $\mathbf{G}(\mathbf{r}, \mathbf{r}')$ the electric field at any point can be calculated by using the following integral, where the volume V extends to all the volume of the hologram:

$$\mathbf{E}(\mathbf{r}) = \mathbf{E}^0(\mathbf{r}) + \int_V d\mathbf{r}' \mathbf{G}(\mathbf{r}, \mathbf{r}') k_0^2 \Delta \varepsilon(\mathbf{r}') \mathbf{E}(\mathbf{r}') \quad (7)$$

By analyzing (6) one can notice that Green's function diverges for values of $\mathbf{r} = \mathbf{r}'$. In order to consider this situation the integral (7) must be evaluated as follows:

$$\mathbf{E}(\mathbf{r}) = \mathbf{E}^0(\mathbf{r}) + \lim_{\delta V \rightarrow 0} \int_{V-\delta V} d\mathbf{r}' \mathbf{G}(\mathbf{r}, \mathbf{r}') k_0^2 \Delta \varepsilon(\mathbf{r}') \mathbf{E}(\mathbf{r}') - \mathbf{L} \cdot \Delta \varepsilon \mathbf{E}(\mathbf{r}) \quad (8)$$

Where δV is a sufficient small volumen centered at point $\mathbf{r}$ and $\mathbf{L}$ is the source dyadic which depends on the geometry of the exclusion volumen δV . In order to solve (8) numerically a grid of N meshes is chosen and the discretised form of (8) is:

$$\mathbf{E}_i = \mathbf{E}_i^0 + \sum_{j=1, j \neq i}^N \mathbf{G}_{ij} k_0^2 \Delta \varepsilon_j \mathbf{E}_j V_j + \mathbf{M}_i V_i k_0^2 \Delta \varepsilon_i - \mathbf{L}_i \Delta \varepsilon_i \mathbf{E}_i, \quad i=1, \dots, N \quad (9)$$

where:

$$\mathbf{M}_i = \lim_{\delta V \rightarrow 0} \int_{V_i - \delta V} d\mathbf{r}' \mathbf{G}(\mathbf{r}_i, \mathbf{r}') \quad (10)$$

III. RESULTS

Simulations have been made for a volume hologram which dielectric permittivity varies spatially as:

$$\Sigma \varepsilon(\mathbf{r}) = 1.54 + 0.25 \cos(Kx) \quad (9)$$

Where $K = 2\pi \mu\text{m}^{-1}$

Fig. 1. Diffraction pattern of a cubical hologram of volume $729 \mu\text{m}^3$.

Fig. 2. Normalized intensity as a function of x for four different thickness.

The hologram had dimensions $9 \mu\text{m} \times 9 \mu\text{m} \times d$, where d is the thickness. The hologram was illuminated perpendicularly by a TE polarized beam with wavelength $\lambda = 633 \text{ nm}$. In figure 1 the diffraction pattern on a screen placed at a distance of 1 mm from a hologram of $d = 9 \mu\text{m}$ is shown, whereas in figure 2 the normalized intensity as a function of x is shown for four different thickness.

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