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Low spatial frequency characterization of holographic recording materials applied to correlation

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ABSTRACT

In this work we expose the results obtained with a wide variety of phase holographic recording materials that we have characterized in the range of low spatial frequencies (≤ 32 lines/milimeter). We have considered bleached photographic emulsion, silver halide sensitized gelatin and dichromated gelatin. This low spatial frequency characterization is necessary in order to generate optimum computer-generated holograms on these materials by means of a low cost technique. In this work, we have generated correlation filters for optical pattern recognition. The experimental results confirm that the correlation filters generated on all the phase materials exhibit a good performance.

Keywords: holograhic recording materials, computer-generated hologram, diffractive optical element, pattern recognition, optical information processing, correlation

1. INTRODUCTION

Different technologies, such as lithography, single-point diamond turning, and laser and electron-beam pattern generators, can be used to record computer-generated holograms (CGHs)[1]. With these technologies we can obtain good diffractive optical elements (DOEs) with high diffraction efficiencies. Nevertheless, these techniques are not easily available, because the equipment needed is very expensive. Furthermore, certain applications (optical correlation filters[2], interconnects[3], etc.) do not need the production of very high-resolution holograms.

In a previous work we demonstrated an inexpensive and easily available technique to obtain phase computer-generated holograms[4]. First, binary absorption masks are produced by a high-resolution graphic device[5]. In a second step, by means of a copying process we store the interference pattern of the mask on a holographic recording material. The master is placed in direct contact with the recording material, with the master and the photosensitive layer of the copy placed together. We use partially coherent light, which enables to work with more economical sources and devices, and provides stability conditions that are not as strict as those used in conventional holographic devices. With this technique the typical frequencies of the diffractive optical elements that can be registered range a maximum of 32 lines/milimeter.

2. METHODOLOGY

In general, the holographic recording materials are used in the range of high spatial frequencies (> 1000 lines/milimeter), which is the typical range in holography and in the recording of holographic optical elements (HOEs)[6]. Thus, a low spatial frequency characterization of these materials is necessary in order to be used in the copying process. We have considered a wide range of phase holographic recording materials: bleached photographic emulsion, silver halide sensitized gelatin (SHSG) and dichromated gelatin (DCG). We have considered three different bleaching processes: solvent, conventional rehalogenating and fixation-free rehalogenating. Different drying processes were also considered in the case of SHSG and DCG. The characterization of the materials at low spatial frequencies is made using diffraction gratings of different spatial frequencies. First, they are generated using the high resolution graphic device; then, they are copied onto the holographic recording material. This characterization enables to find the optimum exposure time providing the maximum diffraction efficiency in the frequency range of interest. We can also analyse if the materials which exhibit a good performance at high spatial frequencies are also good in the low range.

The ultimate goal is to produce computer-generated holograms (CGHs) on a phase material. The phase hologram is much more efficient that the original binary absorption CGH. In this work we focus on producing correlation filters for

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optical pattern recognition. We have generated phase-only filters (POF) encoded by using the Burckhardt's method[7]. We have studied the performance of the filters in terms of their impulse response and their ability to produce a correct discrimination in the optical correlator. In the impulse response we have measured the noise reduction ratio (energy per unit area in the reconstruction signal divided by the energy per unit area in its vicinity) and the diffraction efficiency (percentage of the incident light that is directed to the reconstruction signal). This analysis will enable us to determine which phase materials are suitable for generating low spatial frequency CGHs.

3. RESULTS

In Figure 1 we show the scene that we use for the recognition task in the optical correlator. The filter is adapted to recognize the lower butterfly. The two butterflies have a practically identical outer shape but the inner features are different.

We are interested in comparing the performance of the correlation filter in terms of the phase materials used in the copying step. In Table I we show the experimental results obtained. In the case of the SHSG and the DCG we show the results when using a vacuum chamber in the drying step. In the second row we show the results corresponding to the original master. In the second and third column we give the values of the parameters measured when we study the impulse response of the filters: noise reduction ratio (NRR) and diffraction efficiency (DE). In the fourth and fifth column we give the values of the parameters measured when we study the correlation plane: autocorrelation maximum (peak value in the autocorrelation signal) and discrimination capability (DC), which is defined as follows,

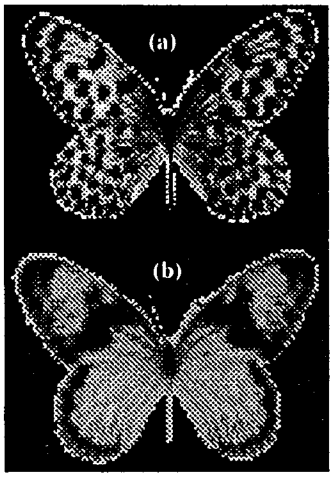

Figure 1. Scene. Butterfly (b) is the target to which the filter is matched.

$$DC = 1 - \frac{\text{maximum crosscorrelation peak}}{\text{maximum autocorrelation peak}}$$

MATERIAL	NRR	DE	Autocorrelation maximum	DC
Master	0.27	3.4 %	66	0.70
Solvent	0.21	16 %	190	0.63
Conventional	0.17	16 %	200	0.65
Fixation-free	0.11	12 %	170	0.65
SHSG (vacuum)	0.21	15 %	210	0.65
DCG (vacuum)	0.12	7 %	125	0.65

Table I. Performance of the filters in terms of the different materials.

A high value in the different parameters (NRR, DE, autocorrelation maximum, and DC) indicates a good performance of the filter.

4. CONCLUSIONS

We have found that in all the cases, the copied filters on the holographic phase materials exhibit a better performance than the original absorption filter. The diffraction efficiency doubles and in some materials is even more than 4 times higher than in the master. The discrimination capability in the optical correlation operation is totally ensured in all the cases. From these results we have found that fixation-free rehalogenated emulsion and DCG, which are low scattering materials, produce the best noise reduction ratios. The maximum diffraction efficiency values are given by the SHSG, and by the conventional and the solvent bleached emulsion. These results will be useful in order to copy not only correlation filters but also other possible CGHs, and in general, when using these materials in the low spatial frequency range.

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