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Implementation of Fourier holograms using high-performance DMD SLM

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Abstract

Task of correlation pattern recognition is important in various science and technology areas, for example in optical image detection and classification. For this, binary Fourier holograms were synthesized and images were numerically and optically reconstructed using digital micromirror (DMD) spatial light modulator (SLM) Texas Instruments Discovery 4100. Obtained results have very high quality and promising to be used in optical digital correlator.

Keywords: Correlation filter; Fourier hologram; DMD

1. Introduction

In the task of correlation pattern recognition, the main advantage is the high recognition performance achieved through optics [1-4]. In modern optical correlators, it is most preferable to use spatial light modulators with the highest possible speed to output correlation filters.

Digital micromirror devices (DMD) are currently the fastest spatial light modulators [5-6]. DMD provide binary amplitude modulation of light with spatial resolution in megapixels and frequency of tens of kilohertz. Such high

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characteristics of DMD determine the high potential of their application in dynamic holographic systems, such as systems for the formation of given light distributions for various purposes and optical image correlators [1-4, 7-17].

The correlation filters used for recognition in invariant correlators are not usually real, but complex [1, 3]. To derive them in optical systems, a Fourier hologram can be synthesized. This paper presents the results of experiments on the implementation of computer-synthesized Fourier holograms using DMD. The experiments were carried out for holograms of contour and grayscale images, as well as for holograms forming distributions corresponding to invariant correlation filters [1-4, 18-28]. We used the modulator Texas Instruments Discovery 4100, based on the DLP9500BFLN chip, which provides a resolution of 1920 × 1080 pixels and maximum frame rate of 20 kHz and higher.

The synthesis of Fourier holograms is described in section 2. The description of the experimental setup and the experimental results are presented in section 3. The main results of the work are presented in conclusion.

2. Synthesis of holograms

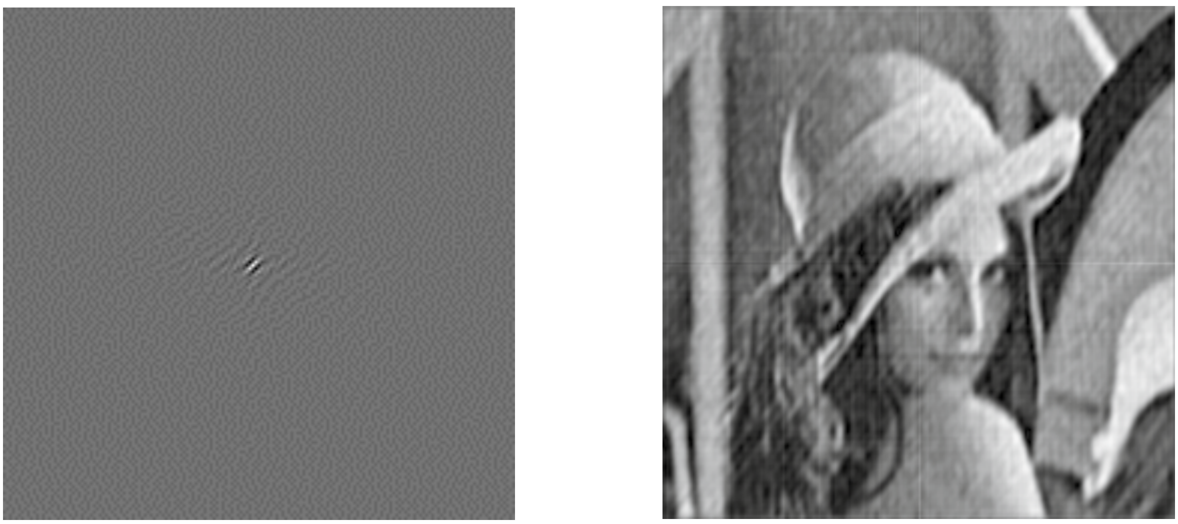
The implementation of computer-synthesized holograms using DMD involves two stages. First, it is necessary to synthesize an amplitude Fourier hologram with a large modulation depth, and then binarize it.

For a given distribution of intensity (image case) or amplitude and phase (correlation filter case) H, the Fourier hologram can be synthesized by the formula:

$$H_{holo}(x,y) = \mathrm{Re}[H'(x,y)] - \min(\mathrm{Re}[H'(x,y)]), \tag{1}$$

where H' is the matrix obtained by placing the matrix H on an empty field, 4 times larger in size, in the region shifted from the center by a quarter of the size of the final matrix H'. The obtained hologram can be reconstructed both numerically (modulus of the inverse Fourier transform) and optically (according to the standard Fourier hologram reconstruction scheme). Figure 1 shows the results of the synthesis and computer reconstruction of the Fourier hologram for the “Lena” image.

Figure 1 (b) demonstrates that the quality of reconstruction is poor. There are various methods for improving the quality of Fourier hologram reconstruction: SLM calibration [29-31], transforming to the kinoform [32-33], and etc. One such method is multiplication, applicable to any objects [33]. A multiplicated hologram is a set of identical smaller holograms located symmetrically on the same image. This approach allows getting better quality of image reconstructed from holograms. For amplitude objects, adding to each pixel random (0 or π) phase can be effective.



(a) Central part of hologram (b) Reconstructed image

Fig. 1. The results of the synthesis and computer reconstruction of the Fourier hologram for the image "Lena".

Also, since the obtained holograms represent halftone amplitude objects, they must be converted into binary form. For this, various binarization methods can be used [34]. We have investigated various methods of binarization of holograms, and experiments have shown that holograms binarized by the Bradley method [35] are best reconstructed on average.

3. Experimental results

Figure 2 shows an experimental setup for reconstructing images from Fourier holograms. A flat laser beam obtained using a collimator consisting of a micro lens L1, a micro aperture, and lens L2 illuminates the surface of the DMD. The modulated beam, reflected from DMD, is directed to the L3 lens, as a result of which a reconstructed image can be observed in its rear focal plane.

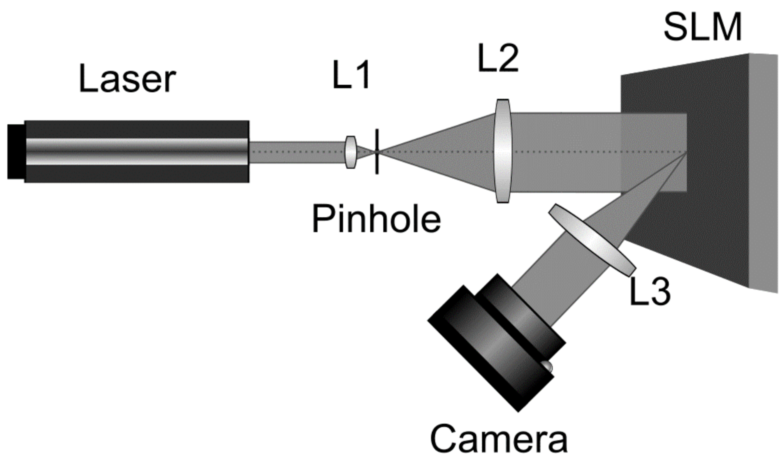
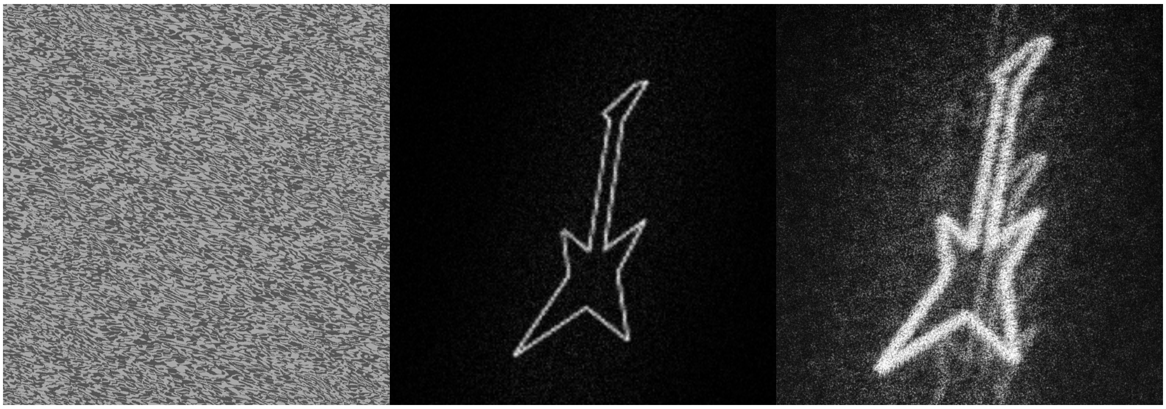


Fig. 2. Experimental setup for Fourier hologram reconstruction.

Figure 3 shows the results of the synthesis of multiplied holograms of contour images binarized by the Bradley method, as well as the results of numerical and optical reconstruction of the synthesized holograms. Figure 4 shows the results of the synthesis of Bradley binarized halftone image holograms with the addition of a random phase, as well as the results of numerical and optical reconstruction of the synthesized holograms. The correlation filter, in the general case, is a complex object; therefore, when synthesizing the corresponding Fourier hologram, it is not possible to add a random phase [1, 36]. Figure 5 shows an example of a synthesized and binarized Fourier hologram of the correlation filter, as well as the results of numerical and optical reconstruction of images from this hologram.

4. Conclusion

In this paper, methods for synthesizing binarized Fourier holograms of images are described and the results of numerical and optical reconstruction of images from synthesized holograms are presented. As can be seen from the results of the experiments, the images are reconstructed in acceptable quality, comparable to the quality of numerically reconstructed images. This allows us to apply these methods upon implementation of an optical digital correlator.

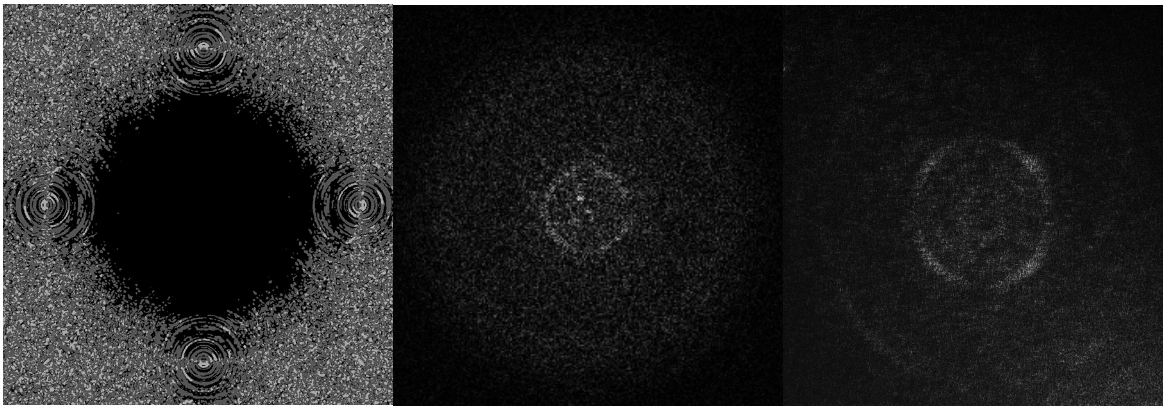


(a) Binarized hologram (b) Computer reconstructed image (c) Optically reconstructed image

Fig. 3. Synthesis, binarization and reconstruction of a hologram for a contour image.

(a) Binarized hologram (b) Computer reconstructed image (c) Optically reconstructed image

Fig. 4. Synthesis, binarization and reconstruction of a hologram for a halftone image.



(a) Binarized hologram (b) Computer reconstructed image (c) Optically reconstructed image

Fig. 5. Synthesis, binarization and reconstruction of a hologram for a correlation filter.

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