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Encryption of a volume hologram by complementary input image and binary amplitude mask

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Abstract

A novel volume-hologram encryption system is proposed, in which the stored binary image can be restored only by the correct random binary amplitude mask. In our system the encryption is done by overlapping two holograms in the same volume of the crystal; one is the hologram of the original binary image and the other is that of the complementary image. The principle of the system is explained with schematic diagrams and then the experimental data is shown.

1. Introduction

The security of two-dimensional (2-D) data has attracted much attention because it has become increasingly easy to counterfeit identification cards, credit cards, currency notes, and so on. Currently, 2-D data such as fingerprints and logos are displayed with holograms bonded to them for security and authentication. However, these holograms can be read by intensity-sensitive detectors and then simply copied. Many authors have reported on the use of optical encryption techniques to improve the security of 2-D and 3-D data and their holograms [1–24].

Double-random phase encoding technique was proposed to convert an original 2-D amplitude image into a stationary white noise image [1–3]. In phase-encoded image encryption an original 2-D amplitude image was first encoded into a phase information and then encrypted by random phase masks [4–7]. It was shown that 2-D images could be encrypted by either phase or amplitude masks inserted in the fractional Fourier domain [8,9]. Optical exclusive-OR operation was proposed for encryption of binary and gray scale images

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[10,11]. In polarization-encoded image encryption system the polarization state at each pixel was scrambled by a random mask to change the polarization state into a random state [12]. Digital hologram recorded in charge-coupled device (CCD) was encrypted by inserting a random phase mask in the path of the reference beam [13]. Hologram encryption technique was proposed using a random phase mask in the path of the reference or the signal beam for the security of the stored hologram rather than the original image itself [14–21]. Encryption of phase-encoded Fourier-type polarization holograms in thin film was reported by phase coding the reference beam [22]. The shifting selectivities of the volume holograms encrypted by a random phase mask were studied shifting the mask laterally and longitudinally [23,24].

When different phase masks are inserted in the path of the reference beam during recording holograms in the conventional system, different 2-D images can be stored independently in the same volume of a crystal. If, however, random binary amplitude masks are used instead of the phase masks, it is not possible to store multiple holograms in the same volume because of interpage crosstalks. In this case a stored hologram can be read by any reference beam. In this paper we propose a novel volume-hologram encryption system using random binary amplitude masks. The encryption of a hologram is done by multiplexing two holograms in the same volume of a crystal; one is the hologram of the original input image and the other is that of the complementary of the input image. The operation principle is explained with schematic diagrams and experimental results are presented. Bit error rates and correlations of the restored images are measured by changing percent usage of the correct amplitude mask and by changing percentage of wrong pixels in the amplitude mask.

2. Principle of encryption

Fig. 1 schematically shows recording of a binary image, (a), and reading of its hologram, (b)–(d), with a binary amplitude mask in the conventional method. In real experiments holograms were recorded or read in the experimental setup shown in Fig. 3. In Fig. 1(a), the volume gratings represented by groups of diagonal lines are recorded by interference between the signal and the reference waves after passing through the binary image and the binary amplitude mask, respectively. In the real experiment the volume gratings may be spatially overlapped in the crystal. However, they are assumed angularly separated satisfying the Bragg selectivity with no interpixel crosstalks and therefore considered independent of each other. The spatially separated gratings in Fig. 1(a) represent the angular separation of the gratings in the real experiment. In the figure the curved solid lines represent the wavefronts of the signal and reference waves, which were focused into the crystal in the real experiment. Fig. 1(b)–(d) shows hologram reads in the conventional method where the correct amplitude mask, a plane wave, and a randomly-generated incorrect amplitude mask are used in the reference wave, respectively. It is noted in this case that the binary image is fully restored by the correct amplitude mask or by a plane wave. It is also noted that the binary image can be restored, with a reduced intensity, even by a randomly-generated amplitude mask because, statistically, half of the pixels in the incorrect mask are the same as in the correct mask.

Fig. 2 shows schematic diagram of our volume hologram encryption system. After the original binary image is recorded in the conventional method in Fig. 2(a), the complementary of the input image, or the contrast reversed input image, is recorded in the same volume of the crystal by interference with the complementary of the binary amplitude mask in Fig. 2(b). Fig. 2(c)–(d) shows read of the overlapped holograms with different amplitude masks. In Fig. 2(c) and (d), the original image or the reversed image is fully recovered when the overlapped holograms are read by the correct amplitude mask or the complementary mask. This is because two holograms are recorded such that beams from the correct amplitude mask only diffract from the first hologram and those from the reversed mask only diffract from the second hologram. In Fig. 2(e), only white-noise-like image is produced in the output when the overlapped holograms are read by a plane wave. In Fig. 2(f), white-noise-like image is also produced