상보 이미지와 이진 진폭 키를 이용한 체적 홀로그램 암호화 시스템에서 SNR 측정

SNR Measurement in Volume-Hologram Encryption System by Complementary image and Binary amplitude key

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In recent years, there have been extensive studies on encryption and security of 2-D images since Javidi and co-workers proposed double-random phase encoding[1]. We proposed previously an idea to encrypt a volume hologram of a binary image by complementary image and binary amplitude key[2]. Also reported were an error analysis and SNR(*signal-to-noise ratio) measurement in double-random phase encoding system*[3-5].

In this work we present the results of SNR and BER(bit-error-rate) measurements in our volume-hologram encryption system. In our system a binary image is first recorded as a volume hologram by interference of a random binary amplitude key of 40 × 60 cells as shown in Fig. 1. Next, a hologram of the complementary image by interference of the complementary key is recorded over the first hologram. It was shown experimentally that the proposed encryption system is robust to blind decryptions by white and incorrect keys whereas the original image(or complementary image) can be restored only when the medium is exposed by the correct key(or complementary key). It was also noted in the experiment that stored hologram of the original image can be read by white or incorrect keys as well as the correct key when only a single binary key is used as a mask. Figure 2 shows the experimental results.

When $O(m, n)$ and $R(m, n)$ represent an original image and restored images captured by CCD camera, the SNR is given by

$$SNR = \frac{\sum_{m=1}^{N_x}\sum_{n=1}^{N_y}|O(m,n)|^2}{\sum_{m=1}^{N_x}\sum_{n=1}^{N_y}|O(m,n)-R(m,n)|^2} \tag{1}$$

where N_x, N_y represent the pixel numbers and the BER in our system is calculated by

$$BER = \frac{1}{\sqrt{2\pi}}\int_Q^{\infty} exp(-x^2/2)\,dx \tag{2}$$

where it is assumed that the bit error probability obey the Gaussian distributions with means of E_1, E_0 and variances of σ_1^2, σ_0^2, respectively, and Q factor is defined as $Q = (E_1 - E_0)/(\sigma_1 + \sigma_0)$. Here $E_1(E_0)$ and $\sigma_1^2(\sigma_0^2)$ correspond to the mean and variance of bit *one*(*zero*) of a binary image, respectively.

The SNRs(root-mean-square errors) were measured to be 14.1(33.5), 19.7(44.7), 0.6(164.0), and 1.1(123.3), respectively, for the images restored by the correct, reversed, white, and incorrect keys as shown in Fig. 2. From Eq. (2), these corresponded to the BERs of 2.7×10^{-2}, 4.3×10^{-2}, 3.3×10^{-1}, 3.4×10^{-1}, respectively, when the mean-square error was supposed to be equal to the variances of bit *one* or *zero*. In conclusion, it was shown in the experiment that the SNR of images decrypted in our system was larger than that in double-random phase encoding system[5].

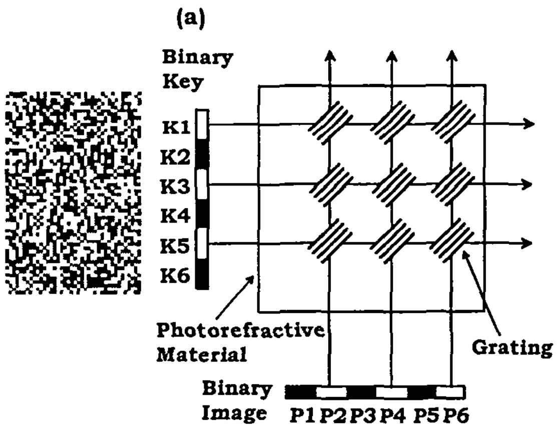

Fig.1. Schematic diagrams of our volume-hologram encryption system. First, hologram of an original image is recorded by interference of a binary key, shown by solid lines in (a) and next, hologram of a reversed(complementary) image is recorded over first hologram by interference of reversed(complementary) key, shown by dotted lines in (b). Note that this is only a conceptual picture of the independence of gratings formed by different pixels and in practical the signal and reference beams are well-separated plane waves in the material to satisfy the Bragg selectivity.

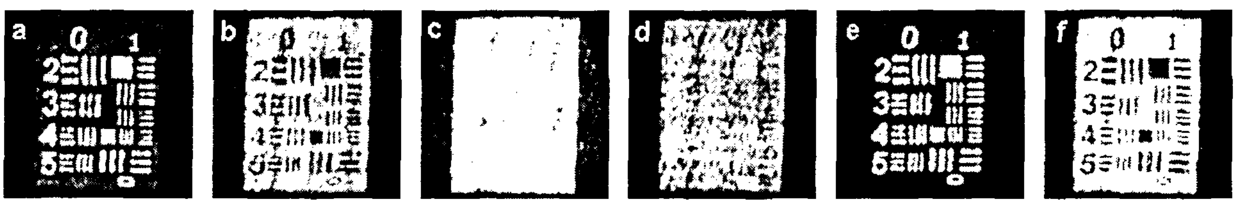

Fig. 2. Experimental results. (a) The original image was restored by the correct key, (b) The complementary(reversed) image restored by the complementary(reversed) key, and white-noise-like images produced by (c) white key or (d) incorrect keys. (e) and (f) are the original image and the reversed image captured by CCD camera for measuring the SNR.

References

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