Securing information by use of digital holography

Bahram Javidi
Department of Electrical and systems Engineering, University of Connecticut
Takanori Nomura
Department of Opto-Mechatronics, Wakayam Univeristy, Japan

Presenter: Nitin Rawat

Considering the threat of accessing and tempering data by an unauthorized person, a secure transmission of multimedia information like image data using cryptography technique has received attention in recent years. The encryption methods enable security of data by converting it into more complex form. Besides security, the database and communication problems are critical problems due to large data size and complexity. It has become important to reduce the size of the data by preserving the complexity.

Image Encryption using FFT with Single random matrix

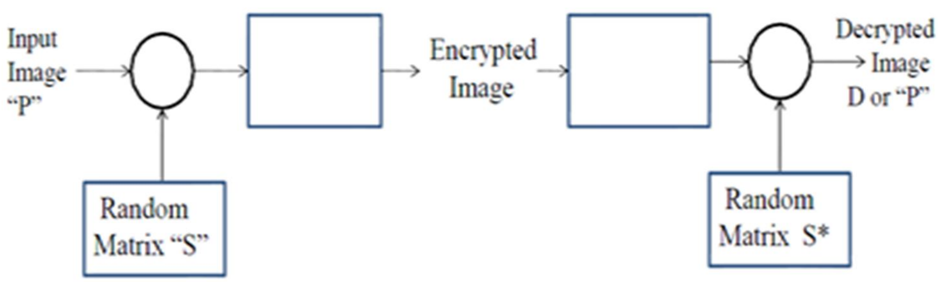


Fig. 1. FFT based Encryption and Decryption using single random phase matrix

Fig. 1 shows the Encryption approach using single random phase method. Let an image multiplied by a single random matrix $\exp[i\phi_1(x,y)]$ and further taking Fourier transform of the result to get an encrypted image.

Decryption process is reversed by taking the complex conjugate of the random phase and further its inverse Fourier transform. Here the key is formed by the combination of the transform and the random matrix.

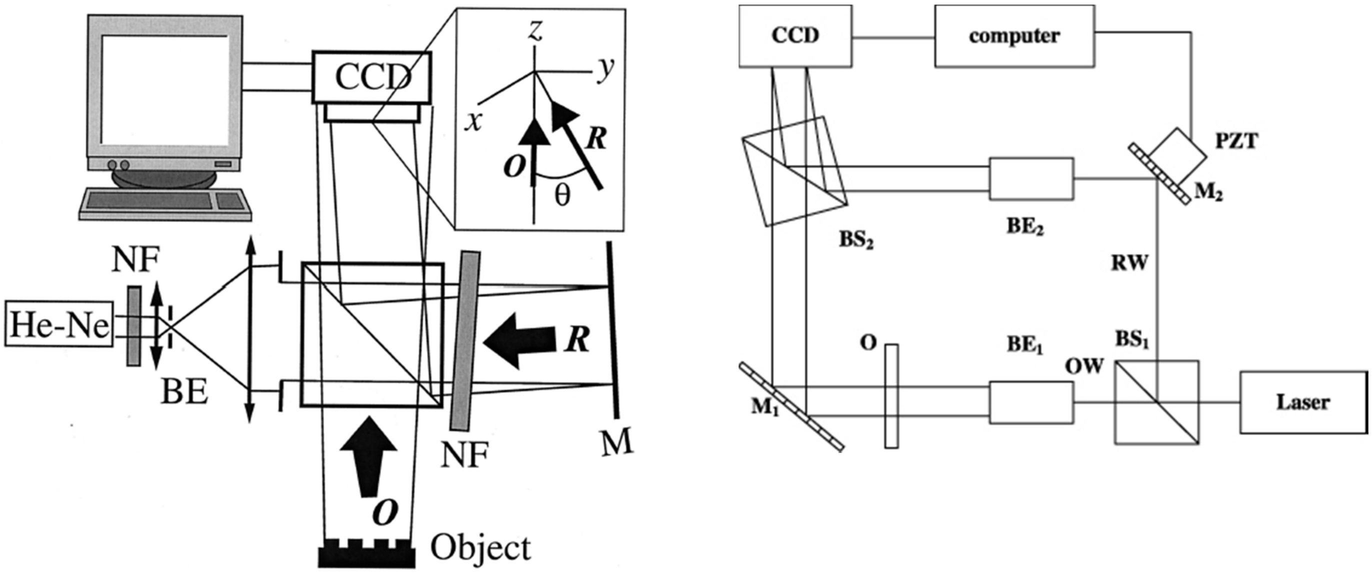


Fig. 2. Experimental setup of digital holography

Let the object wave $O(x, y)$ and reference wave $R(x, y)$ interferes. The intensity is calculated by

$$I(x,y) = |O(x,y) + R(x,y)|^2$$
$$= \left(O(x,y) + R(x,y)\right)\left(O(x,y) + R(x,y)\right)^*$$
$$= \boxed{R(x,y)R^*(x,y) + O(x,y)O^*(x,y)} + O(x,y)R^*(x,y) + R(x,y)O^*(x,y) \quad \ldots.. (1)$$

Zero order term

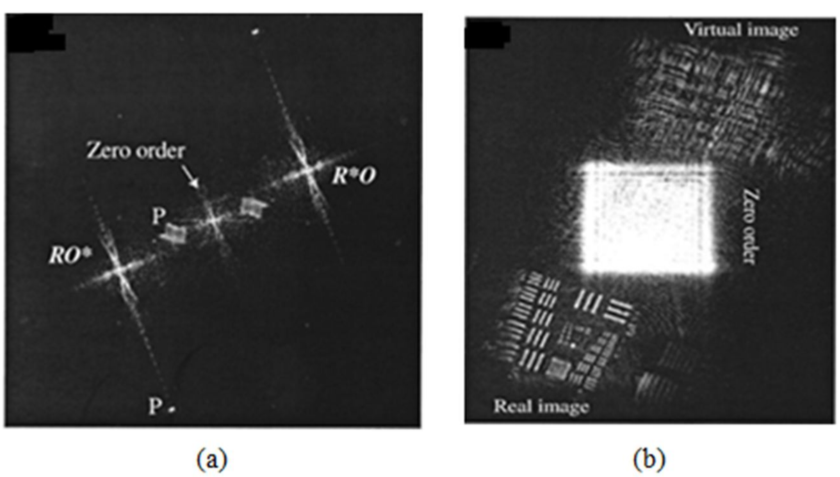


Fig. 3. Elimination of zero-order term of diffraction. () Two-dimensional Fourier spectrum of the original hologram, (b) amplitude-contrast image obtained by numerical reconstruction of the original hologram.

Let $f(x,y)$, $\alpha(x,y)$, and $H(\xi,\eta)$ denote the image to be encrypted, the input random phase mask, and the Fourier random phase mask, respectively.

$f(x,y)$ Image

$\alpha(x,y)$ RPM

$H(\xi,\eta)$ FRPM

The input random phase mask $\alpha(x,y)$, is bonded with the image $f(x,y)$. The resultant product of the two images is Fourier transformed and is multiplied by the Fourier phase mask $H(\xi,\eta)$.

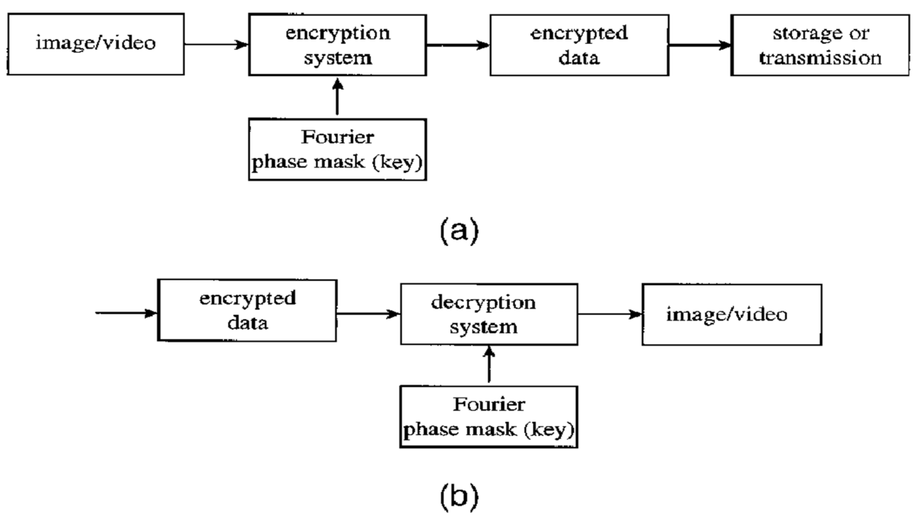


Fig. 4. Secure image/video-data-storage/transmission system that uses a combination of double-random phase encryption and a digital holographic technique: (a) transmitter-encoder, (b) receiver-decoder.

A second Fourier transform produces the encrypted data. The encrypted data as a Fourier hologram, using an interference with the reference wave $R(\xi,\eta)$ is recorded. The hologram $I_E(\xi,\eta)$ can be written as

$$I_E(\xi,\eta) = \left|\left[F(\xi,\eta)\otimes A(\xi,\eta)\right]H(\xi,\eta)\right|^2 + \left|R(\xi,\eta)\right|^2 \quad \text{Zero order term}$$

$$+\left\{\left[F(\xi,\eta)\otimes A(\xi,\eta)\right]H(\xi,\eta)\right\}R(\xi,\eta)^* \quad \text{Real Image}$$

$$+\left\{\left[F(\xi,\eta)\otimes A(\xi,\eta)\right]H(\xi,\eta)\right\}^* R(\xi,\eta) \quad \text{Virtual Image} \qquad \text{..... (2)}$$

where $F(\xi,\eta)$ and $A(\xi,\eta)$ denote Fourier transforms of $f(x,y)$ and $\alpha(x,y)$, respectively, and

$\otimes$ denotes a convolution operation.

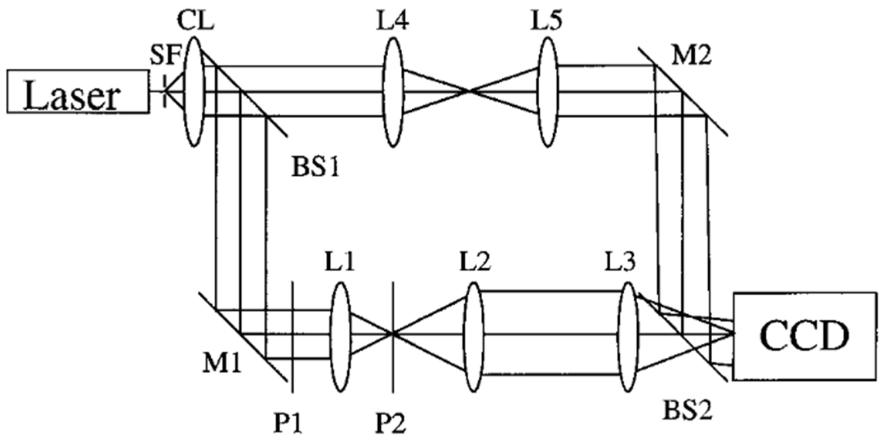


Fig. 5. Optical experiment setup: SF, spatial filter; CL, collimating lens; M, mirrors; L's, lenses; BS's, beam splitters; P1, input plane; P2, Fourier plane.

The first and second terms on the right-hand side of Eq. (2) by obtaining the power spectrum of the encrypted data and reference beam, we can get the following holographic data, $I_{E'}(\xi,\eta)$:

$$I_{E'}(\xi,\eta) = \{[F(\xi,\eta)\otimes A(\xi,\eta)]H(\xi,\eta)\}R(\xi,\eta)^{*} \quad \text{Real Image}$$

$$+\{[F(\xi,\eta)\otimes A(\xi,\eta)]H(\xi,\eta)^{*}\}R(\xi,\eta) \quad \text{Virtual Image} \qquad \text{..... (3)}$$

Similarly, we can also obtain the holographic data of the Fourier phase mask, $I_{M'}(\xi,\eta)$ given by

$$I_{M'}(\xi,\eta) = H(\xi,\eta)R(\xi,\eta)^{*} + H(\xi,\eta)^{*}R(\xi,\eta) \qquad \text{..... (4)}$$

Real Image Virtual Image

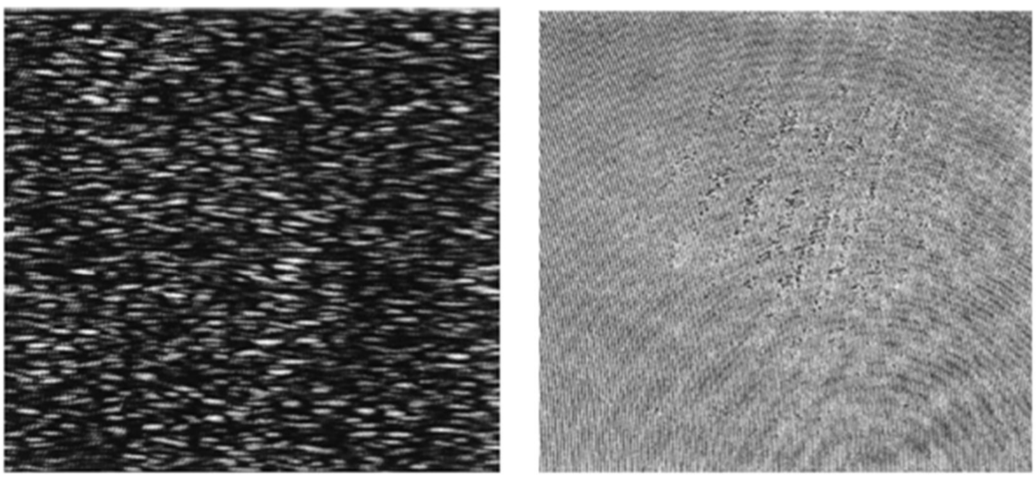
When the reference beam is a slightly inclined planar, we can extract the first term on the right-hand side of Eq. (3) and the second term on the right-hand side of Eq. (4) by Fourier transforming the holographic data to obtain the encrypted data and the Fourier phase mask, respectively. By multiplying the extracted encrypted data and the Fourier phase mask followed by inverse Fourier transformation, we can obtain the decrypted data $d(x,y)$ as:

$$d(x,y) = \mathrm{FT}^{-1}\left[\left(\{F(\xi,\eta)\otimes A(\xi,\eta)H(\xi,\eta)\}R(\xi,\eta)^{*}\right)\right]$$

$$\times \left[H(\xi,\eta)^{*} R(\xi,\eta) \right]$$
$$= \mathrm{FT}^{-1}\left[F(\xi,\eta) \otimes A(\xi,\eta) \right]$$
$$= f(x,y)\alpha(x,y) \qquad \text{..... (5)}$$

where $\mathrm{FT}^{-1}[]$ denotes the inverse Fourier transform operation and $|H(\xi,\eta)|^2$ is equal a constant because the phase masks only phase value. The intensity of Eq. (5) produces the original image because $f(x,y)$ is a positive real-valued function and $\alpha(x,y)$ is phase only.

The experimental system is shown in Fig. 5 consists of Mach-Zehnder interferometer.



(a) (b)

Fig. 6. Digital holograms of (a) the encrypted data and (b) the Fourier phase mask.

The lower arm of the interferometer is the optical path of the image encryption. The upper arm is the reference wave. The input image to be encrypted is bonded with the input phase mask at plane P1. This product is Fourier transformed by lens L1 and is multiplied by the Fourier phase mask at plane P2 and imaged onto the CCD camera by the 4-f optical system of lenses L2 and L3.

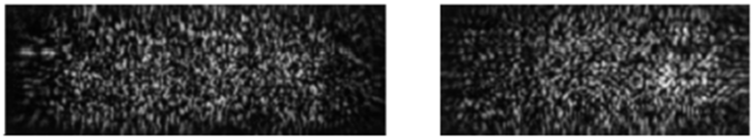


Fig. 7. Images that have been digitally reconstructed by inverse Fourier transformation of the digital hologram of the encrypted data.

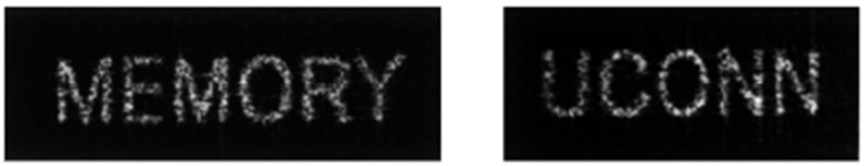


Fig. 8. Images that have been digitally reconstructed with the digital hologram of both the encrypted data and the Fourier phase mask.

Digital holograms of the encrypted data and the Fourier phase mask are shown in Fig. 6. The digitally reconstructed encrypted images are shown in Fig. 7. These images were obtained by inverse Fourier transforming of the digital hologram of the encrypted data. The original images cannot be recognized. The digitally reconstructed images that have been decrypted with the hologram of the Fourier phase mask are shown in Fig. 8

Conclusion

This paper has presented an image security method that uses digital holography. The method allows the encrypted data to be stored, transmitted, and decrypted digitally.