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A Novel Technique of Optical Image Encryption Using Fresnel Transform

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Abstract— Cryptography is a technique where the data is converted into some other gibberish form and then it is transmitted. None other than the intended recipient can unscramble the information from the encrypted data. In this communication we present a novel technique of image encryption in optical domain. Fresnel transform is used to realize the optical encryption technique. The results are simulated and explained.

Keywords— Optical encryption, optical signal processing, cryptography, Fresnel transform, spatial light modulator

I. INTRODUCTION

Cryptography is the art and science of scrambling information so that it appears as random and meaningless to a side observer or attacker. However, the same distorted information can be reproduced correctly by the intended user. In today's communication systems, cryptography has emerged as an important issue because the information is easily vulnerable to attack, stolen and can be forged. Therefore, encryption of the information is indispensable. Many researchers have proposed novel techniques to achieve this [1-3]. The development of encryption and decryption techniques in optical domain may create more efficient system because optical encryption is faster compared to digital (electronic) encryption and computing speed is expected to be determined by the speed of light. The optical encryption can be stored in the form of phase and/or amplitude and it has a large scope of development. However, optical techniques require high precision instruments to encrypt and decrypt.

In the last few decades, a number of optical encryption methods have been proposed. Among them, the most widely used and highly successful optical encryption scheme was proposed by Refregier and Javidi [4]. The encoded image was generated by applying random-phase encoding technique in both the input and the Fourier planes. The statistical properties of this process were then analyzed. It was evident from the result that the encoding transforms the input signal into stationary white noise and that the retrieval process is robust. Unnikrishnan *et. al.* [5] suggested an optical architecture that aids in encoding a primary image to stationary white noise with the help of two statistically independent random phase codes. The encoding technique was accomplished in the fractional Fourier domain. Monaghan *et. al.*[6] proposed an optical encryption technique using linear canonical transform. Fast algorithms were used to compute linear canonical transforms which may be utilized to simulate paraxial optical systems. They used spatial light modulators and high-resolution cameras to perform optical signal-processing operations. They discussed the design and analysis of experimental set-up used in the capture, encryption/decryption and display of 2-D (image) data.

In this communication, we intend to present a novel image encryption/decryption technique where the entire process may be implemented in the optical domain. We use Fresnel transform for this purpose. The concept of Fresnel transform is believed to stem from Fresnel diffraction integral. Therefore, propagation of optical wave from one point to another point in space may be represented by Fresnel transform. The information carried by the optical wave may be encrypted by multiplying it by a suitable complex mask at the transmitting end and at the receiving end we can use the complex conjugate of the said complex mask to retrieve the information. Here, the proposed method is simulated to realize the cryptography process. However, an optical set-up may be arranged to implement the cryptography technique in optical domain.

II. PROPOSED METHOD

An optical set-up to implement our proposed cryptography technique is shown in Fig. 1. We consider an object at the transmitting end. The object may be self-illuminated or illuminated by a source of light. The optical wave emitting from the object propagates through air. This part of wave propagation can be represented by Fresnel transform. Now the light falls on a spatial light modulator on which a complex mask can be generated. The corresponding wave is encrypted after passing through the spatial light modulator. At the receiving end another spatial light modulator is used to generate the complex conjugate of the previous mask. When the light wave passes through it, the image data is decrypted and we get image data back after considering an appropriate inverse Fresnel transform. This part can again be represented by optical wave propagation. Here, it may be mentioned that some spatial light modulators work in amplitude-mostly mode which means they provide a discrete set of amplitude values with little or no variation in phase, or they work in phase-mostly mode. But most of the spatial light modulators perform in a coupled mode and there is a degree of coupling between the amplitude and phase. One of the techniques to obtain full complex modulation is to use a cascade of two spatial light modulators- one in the amplitude-mostly mode and the other in the phase-mostly mode. We neglect the optical wave propagation between transmitter and receiver for an initial study.

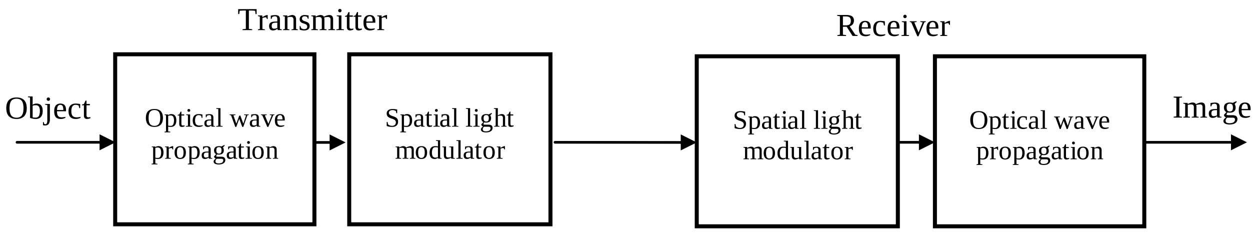


Fig. 1 Optical set-up to implement cryptography process using Fresnel transform

In order to simulate the above-mentioned optical system we begin our study considering a gray-scale image. This may be considered as an object for an optical system. The Fresnel transform of the image is then taken. This part resembles propagation of the optical wave. The transformed image is then encrypted by using a random phase mask which is supposed to be generated on a spatial light modulator in the transmitter part of the optical system. At the receiving end the image is multiplied by complex conjugate of the phase mask which can again be achieved by using another spatial light modulator. The original image is retrieved by taking inverse Fresnel transform of the processed image. We use Matlab to simulate the result. The entire process is represented by a flow chart shown in Fig. 2.

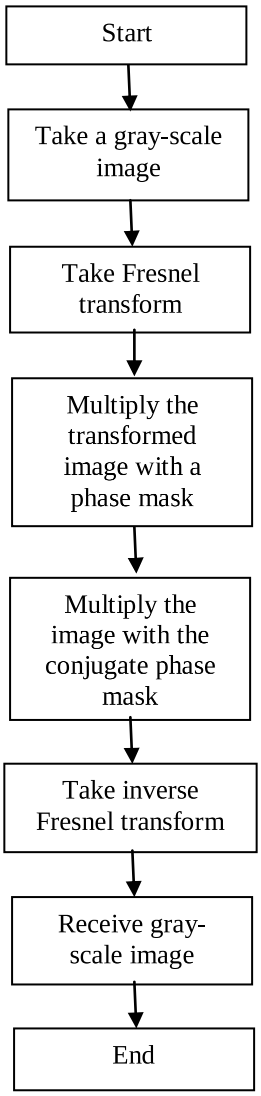
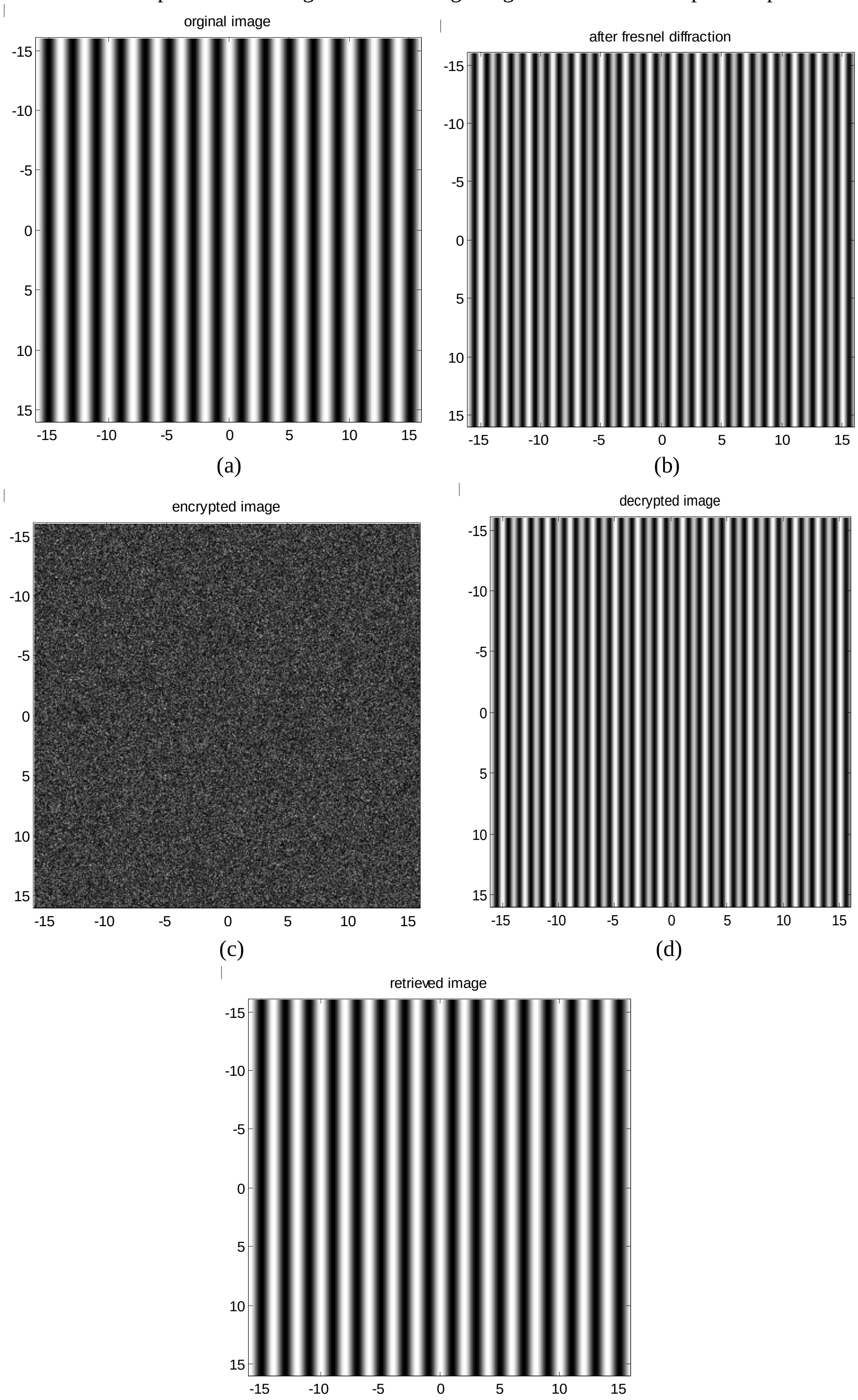


Fig. 2 Flow chart to represent cryptography process using Fresnel transform

III. RESULTS AND DISCUSSIONS

We consider a sinusoidal grating as our original image. This image has to be reproduced after entire cryptography process. The outputs obtained at different stages are shown in Fig. 3. The sinusoidal image is shown in Fig. 3(a). The Fresnel transform of the sinusoidal grating is also a sinusoidal grating. However, the spatial frequency of the transformed grating may vary depending on whether we are considering converging or diverging spherical wave. The situation is shown in Fig. 3(b). We have then generated a random phase mask which may be produced by a spatial light modulator in an optical set-up. The output of the Fresnel transform is multiplied with the random phase mask. The image is thus encrypted [Fig. 3(c)]. In the receiving section, the encrypted image is multiplied by the conjugate phase mask [Fig. 3(d)]. The inverse Fresnel transform produces the original sinusoidal grating back. The final output is depicted in Fig. 3(e).



(e)

Fig. 3 Outputs at different stages of the cryptography process: (a) image of a sinusoidal grating, (b) Fresnel transform of the sinusoidal grating, (c) output obtained after multiplying the transformed image with a random phase mask, (d) output obtained after multiplying the image in (c) by the conjugate phase mask, (e) final result after taking inverse Fresnel transform.

IV. CONCLUSIONS

The entire optical cryptography process using Fresnel transform and its simulated results have been shown in the previous sections. We have used Matlab for obtaining the results. It is evident from the results that the cryptography in optical domain is achievable using precision optical instruments. Design of optical set-up for optical encryption/decryption process may be considered for further research.

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