Optics Communications 359 (2016) 234–239

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

Multiple-image encryption using spectral cropping and spatial multiplexing

Pingke Deng [a,b], Ming Diao [a], Mingguang Shan [a,*], Zhi Zhong [a], Yabin Zhang [a]

[a] College of Information and Communication Engineering, Harbin Engineering University, Harbin, Heilongjiang 150001, PR China
[b] Academy of Opto-Electronics Chinese Academy of Science, Beijing 100094, PR China

ARTICLE INFO

Article history:
Received 23 July 2015
Received in revised form
14 September 2015
Accepted 16 September 2015
Available online 3 October 2015

Keywords:
Multiple-image encryption
Discrete multiple-parameter fractional Fourier transform
Spectral cropping
Space multiplexing

ABSTRACT

A multiple-image encryption scheme is proposed using spectral cropping and space multiplexing based on discrete multiple-parameter fractional Fourier transform (DMPFRFT). Spectrum of each original image is firstly cropped by a low-pass filter, and the image is then recovered with the same size of the filter. The recovered images are spatially shifted and multiplexed into a complex signal with the same size of original image. The complex signal is multiplied by a pixel scrambling operation and random phase mask, and then encrypted into one image by DMPFRFT. The multiplexing images can be retrieved with correct keys, and the original images can be then obtained by enlarging the demultiplexing images. Numerical simulations have been done to demonstrate the validity and the security of the proposed method.

1. Introduction

With the increased exchange of images in the contemporary communication society, the security of image transmission has become important in every walk of life. Various optical image encryption techniques [1–8] have been proposed to achieve the security for their fast inherent computing and parallelism, and multiple degrees of freedom. Especially recently, multiple-image encryption (MIE) has caught increasing attention due to its high efficiency, which can encrypt many images into one image. Much work has been done MIE. For example, Situ and Zhang [9,10] proposed MIE by using wavelength multiplexing or position multiplexing methods. But the qualities of the decrypted images are not perfect due to the cross-talk noises between images. Liu et al. [11] proposed double image encryption using iterative computation to improve quality of decrypted images, which can also extend to encrypt multiple images [12–14]. But the computational complexity and the time consumption increase obviously as the number of images increases. Mosso et al. [15] proposed MIE using theta modulation and double random phase encoding (DRPE), and Shan [16] then proposed MIE using modified theta modulation and discrete multiple-parameter fractional Fourier transform (DMPFRFT). Alfalou et al. [17,18] proposed MIE using a specific spectral multiplexing and DRPE, which can reduce the information to be stored and/or transmitted. But it required a complex segmentation criterion to minimize the cross-talk. Liu et al. [19] proposed MIE by selecting lower frequency parts of the original images and shifting the frequency. But the encrypted information increases with number of images, which then increases the burden of storage and transmission. Deepan et al. [20] proposed MIE using space multiplexing, compressive sensing (CS) and DRPE. However, for most of CS-based compression encryption methods, the whole matrix requires to be transmitted regardless of whether the matrix is a key, which also increases the burden of storage and transmission. In this paper, a method using spectral cropping, space multiplexing and DMPFRFT is proposed to realize MIE. Numerical simulations show that the proposed scheme provides an efficient way for MIE.

The remaining sections of this paper are organized as follows: Section 2 introduces the principle of the proposed MIE method, Section 3 presents the numerical simulation results to demonstrate the performance of the method, and Section 4 states the conclusions.

2. Principle of MIE

2.1. Spectral cropping

As we all know, most of the spectral information of general images concentrates on the part of lower frequencies. Therefore,

* Corresponding author.
E-mail address: smgsir@gmail.com (M. Shan).

http://dx.doi.org/10.1016/j.optcom.2015.09.056
0030-4018/

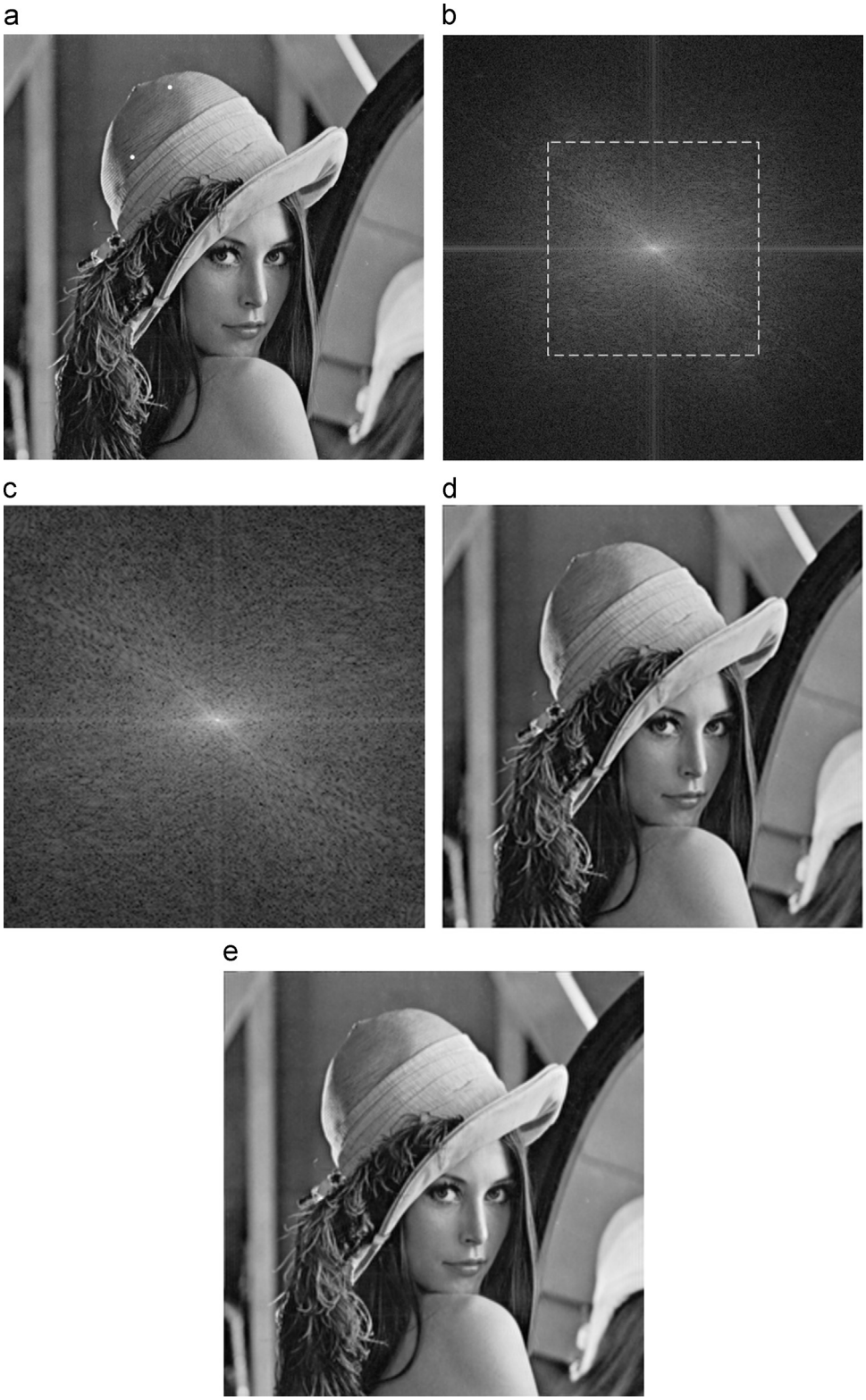

Fig. 1. (a) Original image (512 × 512), (b) Fourier spectrum (512 × 512, in logarithm scale), (c) cropped Fourier spectrum (256 × 256, in logarithm scale) (d) retrieval image using IFFT (256 × 256) (e) enlarged image (512 × 512).

the central parts of spectra can be used to retrieve the original images [19]. But in the conventional retrieval process, zero padding is used to insert the central parts of spectra to the center of an empty matrix containing the same pixels as that of the original image. Redundant data are then introduced to the retrieval process, and especially to the following encrypted process [16,19]. In fact, there is no need to use zero padding, and it is enough to continue working with only the central parts of spectra. The operation can significantly reduce the amount of image data, but still maintain the quality of the retrieval image to a certain degree. The