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Simultaneous image compression, fusion and encryption algorithm based on compressive sensing and chaos

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ABSTRACT

In this paper, a novel approach based on compressive sensing and chaos is proposed for simultaneously compressing, fusing and encrypting multi-modal images. The sparsely represented source images are firstly measured with the key-controlled pseudo-random measurement matrix constructed using logistic map, which reduces the data to be processed and realizes the initial encryption. Then the obtained measurements are fused by the proposed adaptive weighted fusion rule. The fused measurement is further encrypted into the ciphertext through an iterative procedure including improved random pixel exchanging technique and fractional Fourier transform. The fused image can be reconstructed by decrypting the ciphertext and using a recovery algorithm. The proposed algorithm not only reduces data volume but also simplifies keys, which improves the efficiency of transmitting data and distributing keys. Numerical results demonstrate the feasibility and security of the proposed scheme.

1. Introduction

With the rapid development of communication and information processing technologies, image compression, fusion and encryption have been three hot topics in the image processing field. Image compression is used to eliminate redundancies of image data, which is essential in reducing the storage space and bandwidth requirements [1]. Image fusion can integrate multi-source images into a single visual perception enhanced image to better describe the scene [2]. Image encryption technique is used to secure the image from information leaking during the storage and transmission processes [3,4].

In general, these aforementioned image processing techniques are independently applied to accomplish a specific purpose. Recently, due to the intrinsic compression feature of compressive sensing (CS) theory [5–7], several image fusion methods [8–12] and image encryption methods [13–17] based on CS were proposed to realize compressive image fusion or compressive image encryption schemes. Wan et al. [18] presented a CS based image fusion framework and investigated the construction performance under different sampling patterns. Yang et al. [19] used adaptive local energy metrics to fuse measurements. In Liu's scheme [20], the sparse representation coefficients were firstly fused and then measured, which achieves a better fusion result. In the research of compressive image encryption, a number of CS based image encryption algorithms aiming at reducing data volume and improving security have been proposed. Zhou et al. [21] proposed an image encryption algorithm using logistic map to generate the measurement matrix, which is beneficial to keys distribution and storage. Lu et al. [22] proposed an image encryption method by CS and classical double random phase encoding algorithm, which can significantly reduce data volume. Subsequently, the Arnold transform is introduced into the proposed compressive encryption scheme to enhance the security [23]. To resist data expansion and security risks of linear transforms, an image encryption scheme by combining CS and nonlinear fractional Mellin transform [24] was proposed [25]. By utilizing CS and chaotic map, a joint image encryption and watermarking algorithm was proposed [26].

Although combining two image processing techniques at the same time has a wide application prospect, the three techniques need to be implemented in some certain circumstances. For example, in telemedicine, the multi-modal medical images not only need to be fused to integrate complementary information but also require to be encrypted to protect the privacy of patients. In military surveillance, infrared and visible images are need to be fused to enhance visual perception and then encrypted for secure transmission. In these mentioned applications, it is also necessary to reduce the amount of transferred data. Therefore, it is of great practical importance to accomplish image compression, fusion and encryption simultaneously.

In this paper, a simultaneous image compression, fusion and encryption approach based on CS and chaos is presented to ensure the efficiency and security of image transmission. Firstly, the multi-modal source images are sparsely represented with discrete

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0030-4018/

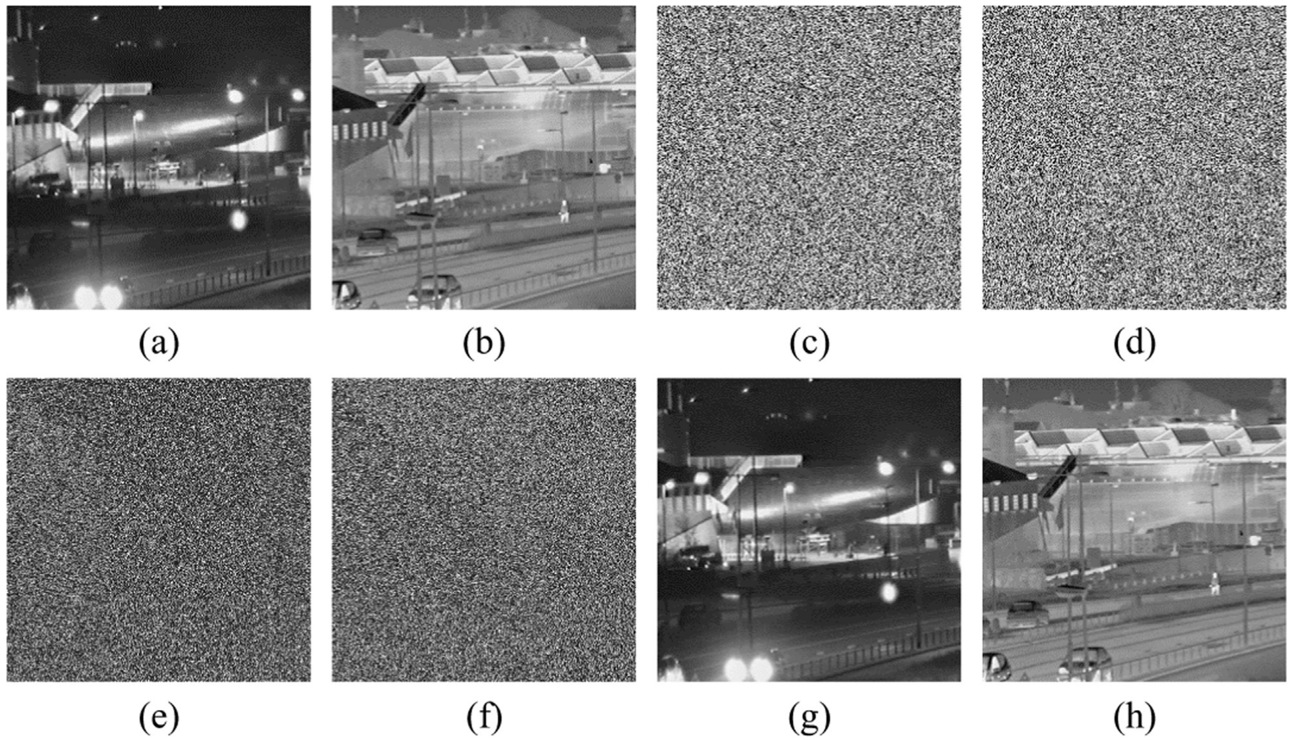

Fig. 1. The pixel scrambling results using the improved pixel exchanging technique.

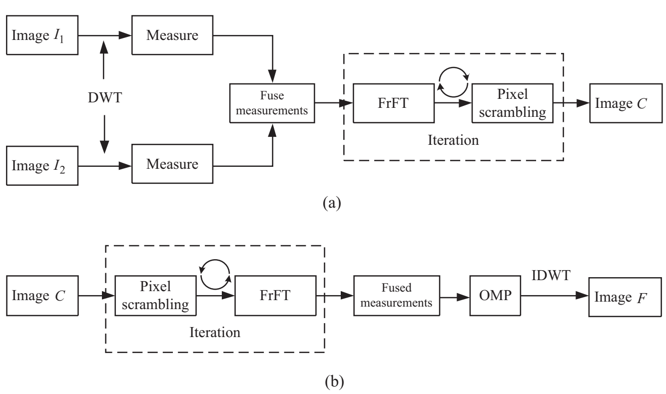

Fig. 2. The flowchart of the proposed scheme.

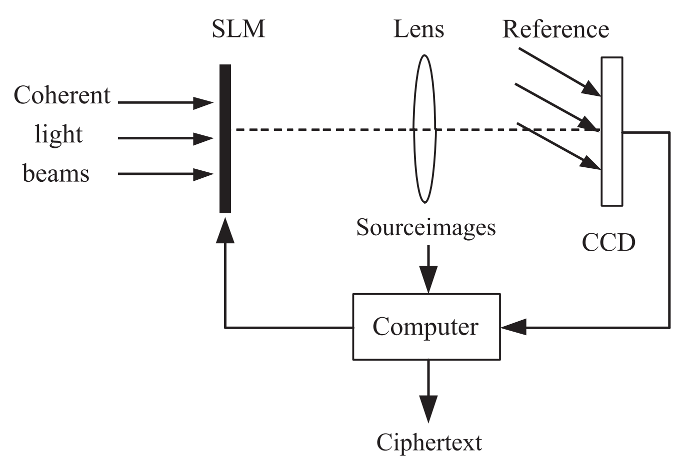

Fig. 3. The designed optoelectronic hybrid setup of the proposed scheme.

wavelet transform (DWT) and then the coefficients are measured with a key-controlled measurement matrix constructed by logistic map. The obtained measurements are fused by the proposed adaptive weighted fusion rule. The final ciphertext can be obtained by encoding the fused measurement with iterative pixel scrambling and fractional Fourier transform (FrFT) operations. At the received terminal, the fused image can be reconstructed by decrypting the ciphertext and using a recovery algorithm. The proposed algorithm has the merits of data volume reduction, keys simplification, high security and high transmission efficiency, which are verified by numerical simulation results.

2. Basic theory

In this section, some fundamental principles including CS theory, logistic map and FrFT are briefly introduced.

2.1. Compressive sensing

CS theory demonstrates that sparse signals can be perfectly reconstructed from random measurements, the samples of which are far fewer than the traditional Nyquist sampling theorem required. Therefore, the CS-based image processing techniques possess intrinsic compression feature, which is promising in significantly reducing computational costs.

For a one-dimensional compressible signal $x \in R^N$, it can be sparsely represented with an orthogonal transform matrix Ψ as

$$x = \Psi\xi, \tag{1}$$

where ξ denotes the transform coefficients. If there are only K non-zero components in ξ, then ξ is said to be K−sparse.

The process of sensing is to get the linear measurement y with an incoherent measurement matrix $\Phi \in R^{M\times N}(M << N)$, i.e.

$$y = \Phi x = \Phi\Psi\xi. \tag{2}$$

Then the approximation of ξ can be retrieved by solving a non-convex optimization problem as follows: