Commutative watermarking and encryption for media data
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Abstract. A commutative watermarking and encryption scheme is proposed for media data protection. In the scheme, the partial encryption algorithm is adopted to encrypt the significant part of media data, while some other part is watermarked. The commutative property brings conveniences to practical applications in secure media transmission or distribution. © 2006 Society of Photo-Optical Instrumentation Engineers.

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1 Introduction
Several means have been proposed to protect media data, among which, media encryption and digital watermarking have been attracting more and more researchers. Media encryption encodes media data into an unintelligible form, which protects media data’s confidentiality. Digital watermarking embeds identification information into media data imperceptibly, which protects media data’s ownership. Because they realize different functionalities, the two means are often applied independently. To remain secure, they can be used together. For example, media data are first watermarked, and then encrypted. However, in this case, the encrypted media data should be decrypted before the watermark can be extracted or another watermark can be embedded.

It is secure to commute watermarking and encryption, although it is still difficult to find a practical solution. As a commutative watermarking and encryption process, the following condition is satisfied:

\[ M = E_m(C, W, K_w) = E_m(E_m(P, K_e), W, K_w) \]
\[ = E_m(E_m(P, W, K_e), K_w) \]

(1)

where, \( P, C, M, P', W, K_r, \) and \( K_w \) denote the original media, cipher media, watermarked cipher media, watermarked media, watermark, encryption key and decryption key, respectively; and \( E_m(), D_r(), E_m(), \) and \( E_r() \) denote the encryption function, decryption function, watermark embedding function, and watermark extraction function, respectively. The proposed commutative scheme is defined as follows.

1. The partial encryption/decryption process is

\[ C = E_n(P, K_e) = E_n(X, Y, K_r) = Z|Y \]
\[ P = D_r(C, K_e) = D_r(Z,Y,K_r) = X|Y. \]

(2)

2. The selective watermark embedding/extraction process is

\[ P' = E_m(P, W, K_w) = E_m(X, Y, W, K_w) = X'|Y' \]
\[ W = E_r(P', K_w) = E_r(X, Y', K_w). \]

(3)

3. The commutative encryption and watermarking process is

\[ M = E_m[E_m(X, Y, K_r), W, K_w] = E_m(Z, Y, W, K_w) = Z|Y' \]
\[ = E_m[E_m(X, Y, W, K_w), K_r] = E_m[E_m(X, Y', K_r)] = Z|Y'. \]

(4)

4. The watermark extraction process is

![Diagram](https://www.spiedigitallibrary.org/journals/Optical-Engineering/figs/fig1.png)

**Fig. 1** Commutative encryption and watermarking based on partial encryption.
Based on wavelet transformation, we propose the commutative scheme shown in Fig. 2. Here, the $M \times N$ image is transformed by a four-level wavelet.

1. The subbands in the lowest level (LL3, LH3, HL3, and HH3), composed of $(M/8) \times (N/8)$ coefficients, are encrypted completely. The algorithms proposed in Refs. 4 and 5 can be used.

2. The subbands in the high level (LH1, HL1, HH1, LH0, HL0, and HH0), composed of $3 \times (M/4) \times (N/4) + (M/2) \times (N/2)$ coefficients, are encrypted with sign encryption, which keeps the coefficient amplitudes unchanged.

3. The subbands in the middle level (LH2, HL2, and HH2), composed of $3 \times (M/8) \times (N/8)$ coefficients, are both encrypted and watermarked. The encryption algorithm is sign encryption, and the watermarking algorithm can be spread spectrum method, the quantization index modulation (QIM) method, the methods proposed in Refs. 12 and 13, etc.

In our scheme, the selection of the wavelet coefficients in middle frequency depends on the requirements of security and robustness. Without considering sign encryption, the more the coefficients in the low-frequency band are encrypted, the more confused is the encrypted image. Figure 3 shows the relation between the encrypted frequency band and the quality of the encrypted image. The coefficients are encrypted with the Advanced Encryption Standard (AES) as proposed in Ref. 4. Similarly, the more watermarked coefficients are in the low-frequency bands, the more robust the watermark is to signal processing operations (compression, noise, filtering, etc.). Figure 4 gives the relation between the watermarked frequency band and the robustness to JPEG2000 compression. The QIM method
is used as the watermark algorithm. To obtain a trade-off between the security and robustness, the coefficients in the highest level frequency bands (LL4, HL4, LH4, and HH4) should be encrypted, and the coefficients in the second highest level frequency bands (HL3, LH3, and HH3) can be watermarked.

This method can be combined with JPEG2000; that is, the image can be compressed and encrypted/watermarked simultaneously. The watermark is embedded immediately after quantization, coefficient encryption, and sign encryption can be applied following the entropy encoding process. As an example, “Airplane” (colorful, 256×256) is encrypted partially, then watermarked with QIM, finally decrypted and extracted. The results in Fig. 5 show that the scheme is commutative.

4 Conclusions and Future Work

We proposed a commutative encryption and watermarking scheme that is based on partial encryption. Based on the scheme, a commutative image encryption and watermarking algorithm in wavelet codec was presented, and the trade-off between security and robustness was analyzed. The encryption/watermarking algorithm can be combined with JPEG2000 codec, which is time-efficient compared with JPEG2000 codec. In future work, the commutative scheme’s security and robustness and its extension to other codecs will be further studied.

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References