Classification-based Image Watermarking Using Rank Order in the Wavelet Domain

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Abstract

In this paper, we propose a novel digital watermarking technique called Classification-based Image Watermarking using Rank Order in the Wavelet domain (CIWROW) for gray-level images. Due to WT (Wavelet Transform) having the characteristics of using both spatial and frequency resolutions, it can be effectively used to approximate target functions. Several relationships among the subbands in wavelet domain are explored and then employed to designate a classification algorithm using rand order for all wavelet blocks of an image. During watermark embedding, the target blocks to be watermarked are embedded by different methods according to which class the blocks belong to. The CIWROW technique retrieves watermarks without the original images. Finally, experimental results are included in this paper to illustrate that the performance of the CIWROW technique is acceptable. Furthermore, the CIWROW technique is rather robust to be immune against basic image-processing attacks.

Keywords: Watermarking, Data Hiding, Wavelets, Classification, Image Authorization.

1. Introduction

Due to the rapid development of the Internet, various formats of digital products (image, audio, video) have been widely distributed through the Internet. Therefore, it speeds up digital-product interchange. However, digital products could be illegally duplicated and readily distributed through the Internet. The problems of copyright protection and content authentication for digital products become very crucial. To solve these problems, digital products (plaintexts) can be directly encrypted to be ciphertexts using cryptography algorithms, such as DES (Data Encryption Standard) or RSA [3, 7]. Even though the cryptography schemes can be used to solve the problems of illegal duplicate of digital products, but the ciphertexts cannot be directly employed unless the ciphertexts have to be decrypted to be plaintexts in advance. The process for decrypting the ciphertexts requires extra time computations.

Recently, digital watermarking is effectively employed to protect copyrights of digital products [1,2,4,5,8]. Digital watermarking hides owner information (digital signatures) in the contents of original digital products. Subsequently, the hidden information can be retrieved and then be applied to authenticate the ownership of the digital products. In contrast to the cryptography algorithms, watermarked digital products can be directly utilized without decryptions. To achieve the goal of copyright protection of digital images, the image watermarking techniques have to satisfy the imperceptibility to human eyes and robustness against common attacks, such as image manipulations [1,4,5,8]. Several image watermarking methods have been developed in frequency domain, especially in wavelet domain. In recent years, the wavelet transform is applied in a wide range of image processing applications, for examples, watermarking verification and the upcoming image compression standard JPEG-2000 [1]. Recently, many image watermarking methods developed in wavelet domain have obtained prominent results [1,4,5,8].

In [4], Xie obtained a value via applying a nonlinear transformation (a rank-order operator, such as the median operator) to coefficients in a subband. The target coefficient in the subband was then replaced with the value while embedding a watermark bit. The method of Barni employed a weighting function to fit the behavior of the Human Visual System (HVS) while embedding watermarks [5]. Therefore, the method of Barni possessed quite imperceptible capability. The perceptual invisibility is a main factor while developing the method of Barni. However, another factor, robustness, was not been considered significantly. Consequently, the method of Barni cannot perform well robust capability. In [8], the algorithm of Wang was proposed to achieve both perceptual invisibility and robustness. The algorithm of Wang inserted watermarks into the middle-frequency range to reach both imperceptibility and robustness. Paqueta *et.* proposed a quantization-based method in the wavelet domain for image authentication [1]. The method of Paqueta also considered the characteristics of HVS while embedding watermarks. The method of Paqueta embedded watermarks by modifying 64 coefficients in separate subbands.

Previous methods have failed in finding robust features in individual subbands at the same level, without considering the relationships among subbands at the same level. Hence it inspired us to propose the CIWROW technique, which looks for the features among details subbands at the same level. The CIWROW technique also uses a nonlinear transformation (median operator) to get the feature of each detail subband. The distances between these features are then employed to classify the wavelet blocks into three categories. The distinct watermark-embedding algorithm is designed for each category. Observing the experimental results, the CIWROW technique achieves both perceptual invisibility and robustness.

The rest of this paper is organized as follows. Section 2 presents the CIWROW technique. First, Section 2 introduces the representation of a gray-level image and watermarks, and then reviews the wavelet decomposition. Next, watermark embedding and watermark extraction are presented in Section 2. Subsequently, Section 3 shows experimental results. Finally, Section 4 gives discussions and conclusions.

2. The CIWROW Technique

2.1 Image Denotation

A gray-level image, X, with size $L \times K$ can be defined by $X = [x_\rho]_{L\times K}$, where $x_\rho \in \{0, 1, \ldots, 255\}$. That is, x_ρ represents the pixel value located at position $\rho = (i, j)$ over X, where $i \in \{0, 1, \ldots, L\text{-}1\}$ and $j \in \{0, 1, \ldots, K\text{-}1\}$. Fig. 1 shows that is segmented into $\left\lfloor \frac{L}{8} \right\rfloor \times \left\lfloor \frac{K}{8} \right\rfloor$ nonoverlapped blocks with size 8 × 8. For example, b_{21} stands for a block that the center pixel in the block is located at position (2, 1) on X. Let $b_{21}(r, c)$ denote the gray level of a pixel at the position (r, c) in the block b_{21}. As a result, these nonoverlapped blocks in X can be denoted by

$$\Phi = \left\{ b_{ij} \mid i=1,\cdots,\left\lfloor \frac{L}{8} \right\rfloor, j=1,\cdots,\left\lfloor \frac{K}{8} \right\rfloor \right\}, \qquad (1)$$

where each b_{ij} is of size 8 × 8.

Let a 2D binary image represent a watermark, W, in the experiment of the paper. The image can be represented by a binary sequence in a row-major fashion. The watermark is denoted by

$$W = \left(w_1, w_2, \cdots, w_k, \cdots, w_m\right), \qquad (2)$$

where m represents the size of W and $w_k \in \{-1, 1\}$.

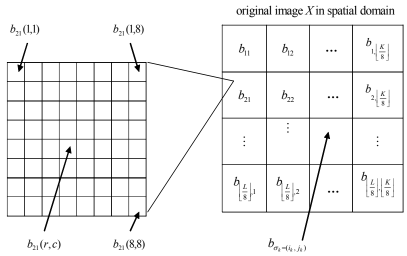

Fig.1 The segmented image in spatial domain.

2.2 Wavelet Transformation

Fig. 2 illustrates that each nonoverlapped block b_{ij} in Φ for an image X is decomposed through Discrete Wavelet Transform (DWT). Let B_{ij} represent the corresponding wavelet block consisting of eight coefficients. Moreover, $B_{ij}(r, c)$ stands for the coefficient at the position (r, c) on the block B_{ij}. Fig. 3(a) shows b_{ij} is transformed through DWT in two levels. Each wavelet block B_{ij} at each level consists of four bands (components): low-low band (LL1), low-high band (LH1), high-low band (HL1), and high-high band (HH1). LL1 band can be further divided into four subbands: low-low subband (LL2), low-high subband (LH2), high-low subband (HL2), and high-high subband (HH2). Generally, HL2, LH2, HH2, HL1 and LH1 are called middle-frequency components (subbands).

For convenience to describe the computations to wavelet blocks, let b_{ρ_k} be transformed by DWT to obtain the corresponding wavelet block B_{ρ_k}. Further let $B_{\rho_k}^{l,\theta}$ be a subband at resolution level l = 1, 2 and with orientation $\theta \in$ {1, 2, 3, 4} = {LL, HL, LH, HH}. The coefficient $B_{\rho_k}^{l,\theta}(r, c)$ is at position (r, c) in the subband $B_{\rho_k}^{l,\theta}$. In this paper, features are obtained by calculating the wavelet coefficients belonging to the three detail bands at level 2. When the block B_{ρ_k} is selected to be embedded, the CIWROW technique modifies the wavelet coefficients being in the three detail bands $B_{\rho_k}^{2,\theta}$ for θ = 2, 3, and 4. Fig. 3(b) exhibits an example for the three detail bands.

2.3 Watermark Embedding

Fig. 4 illustrates the structure of watermark-embedding algorithm in the CIWROW technique. First, two seeds s_1 and s_2 are given and then presented in the pseudo-random number generator (PRNG) component for generating a sequence of random positions,

$$\Gamma = \{\rho_1, \rho_2, \ldots, \rho_k \ldots, \rho_m\}, \quad (3)$$

where $\rho_k = (i_k, j_k)$. In the CIWROW technique, a set, Ψ, comprises m blocks which are randomly selected from Φ by using the PRNG scheme [6]. The set Ψ can be defined by

$$\{b_{\rho_k=(i_k,j_k)} \mid \rho_k \in \Gamma\}, \quad (4)$$

where $k = 1, 2, \ldots, m$. That is, $|\Psi| = m$. Note that each b_{ρ_k} is of size 8 × 8. In the block diagram, B'_{σ_k} denotes a wavelet block corresponding to the spatial block b_{ρ_k}.

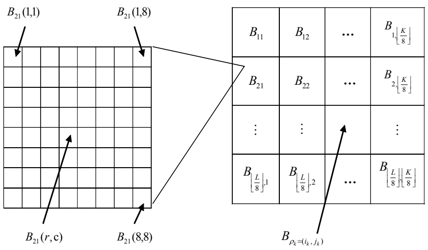

Fig. 2 The segmented image in wavelet domain.

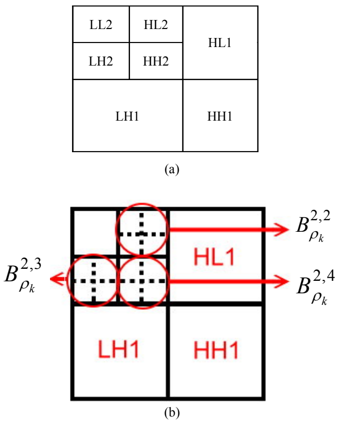

Fig. 3 Components are constituted of a 8 x 8 wavelet image block with level 2.

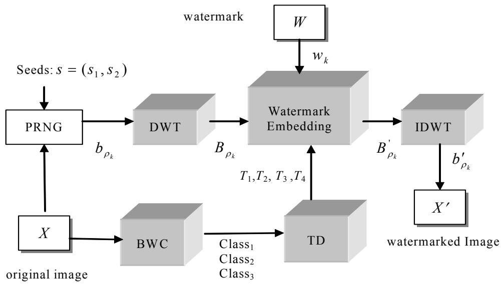

Fig. 4 The structure of watermark-embedding algorithm in the CIWROW technique.

Next, a classification algorithm is designated to determine the ranges of strengths for a modification to a target block to be embedded. In the CIWROW technique, a nonlinear transformation called the median operator is applied to the three detail subbands at level 2 while computing the features for these three subbands. Specifically, the feature for each subband is the median value among the coefficients in the subband. The relationships for the distances between these three features can be divided into three cases as shown in Fig. 5. Here the three symbols LH2, HL2, and HH2 in Fig. 5 represent three medians of coefficients in LH2, HL2, and HH2, respectively.

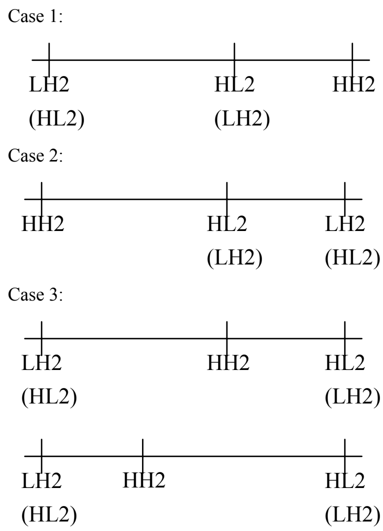

Fig. 5 The relationships for the distances between these three features can be classified into three cases.

The classification algorithm, which is named the BWC algorithm, is devised to classify a wavelet block belonging to which class according to the distances between the features of blocks in wavelet domain. The BWC algorithm is described as follows.

Step 1. Input an image X.
Step 2. Set $\text{Class}_c = \phi$, for $c = 1, 2, 3$.
Step 3. For each b_{ρ_k} where $\rho_k = (i_k, j_k) \in \{4,$

5, …, L-4} × {4, 5, …, K-4}.

Step 4. Compute $B^{2,\theta}_{\rho_k}$ = DWT(b_{ρ_k}) where θ = {1, 2, 3, 4} = {LL, HL, LH, HH}.

Step 5. Calculate three medians among HL2, LH2, and HH2, respectively, by using $med^{2,\theta}_{\rho_k} = \text{median}\{B^{2,\theta}_{\rho_k}(r,c) \mid 1 \le r, c \le 2\}$, θ= 2, 3, 4.

Step 6. If ($med^{2,4}_{\rho_k} > \max\{ med^{2,2}_{\rho_k}, med^{2,3}_{\rho_k}\}$)

then Class$_1$ = Class$_1$ ∪ { $B^{2,\theta}_{\rho_k}$ }.

else

If ($med^{2,4}_{\rho_k} < \min\{ med^{2,2}_{\rho_k}, med^{2,3}_{\rho_k}\}$)

then Class$_2$ = Class$_2$ ∪ { $B^{2,\theta}_{\rho_k}$ }.

else Class$_3$ = Class$_3$ ∪ { $B^{2,\theta}_{\rho_k}$ }.

Step 7. Output three classes, Class$_c$ for c = 1, 2, and 3.

Here the paper proposes an algorithm called the TD algorithm which determines four thresholds, T_1, T_2, T_3, and T_4, before watermark embedding and extraction. Specifically, these four thresholds are used in the CIWROW technique while altering a target block for embedding a watermark bit. Note that these four thresholds should be secured against pirates for protecting image copyrights. In addition, these four thresholds are also provided during watermark extraction. Consequently, the CIWROW technique extracts watermarks without original images. The TD algorithm is presented in the following.

Step 1. Input Class$_c$ for c = 1, 2, 3.

Step 2. For c = 1 to 3.

Step 3. For each block $B^{2,\theta}_{\rho_k^c}$ ∈ Class$_c$.

Step 3.1. Compute $d2_{\rho_k^c}$ and $d3_{\rho_k^c}$ where

$$d2_{\rho_k^c} = abs(med^{2,2}_{\rho_k^c} - med^{2,4}_{\rho_k^c})$$

$$d3_{\rho_k^c} = abs(med^{2,3}_{\rho_k^c} - med^{2,4}_{\rho_k^c})\cdot$$

Step 3.2. Calculate $dS_{\rho_k^c}$ and $dL_{\rho_k^c}$ where

$$dS_{\rho_k^c} = \min\{d2_{\rho_k^c}, d3_{\rho_k^c}\}$$

$$dL_{\rho_k^c} = \max\{d2_{\rho_k^c}, d3_{\rho_k^c}\}\cdot$$

Step 3.3. End For-loop.

Step 2.1. End For-loop.

Step 4. Compute $dS^{c}_{\min}, dS^{c}_{\max}, dL^{c}_{\min}, dL^{c}_{\max}$ using

$$dS^{c}_{\min} = \min_{\forall B^{2,\theta}_{\rho_k^c} \in \text{Class}_c} \{dS_{\rho_k^c}\}$$

$$dS^{c}_{\max} = \max_{\forall B^{2,\theta}_{\rho_k^c} \in \text{Class}_c} \{dS_{\rho_k^c}\}$$

$$dL^{c}_{\min} = \max_{\forall B^{2,\theta}_{\rho_k^c} \in \text{Class}_c} \{dL_{\rho_k^c}\}$$

$$dL^{c}_{\max} = \max_{\forall B^{2,\theta}_{\rho_k^c} \in \text{Class}_c} \{dL_{\rho_k^c}\}$$

Step 5. Calculate T_1, T_2, T_3, and T_4 by using

$$T_1 = \text{median}\left\{\left\{dS_{\rho_k^1} \mid \forall B^{2,\theta}_{\rho_k^1} \in \text{Class}_c\right\} \cup \left\{dL_{\rho_k^1} \mid \forall B^{2,\theta}_{\rho_k^1} \in \text{Class}_1\right\}\right\}$$

$$T_2 = \text{median}\left\{\left\{dS_{\rho_k^2} \mid \forall B^{2,\theta}_{\rho_k^2} \in \text{Class}_2\right\} \cup \left\{dL_{\rho_k^2} \mid \forall B^{2,\theta}_{\rho_k^2} \in \text{Class}_2\right\}\right\}$$

$$T_3 = \text{median}\left\{\left\{dS_{\rho_k^3} \mid \forall B^{2,\theta}_{\rho_k^3} \in \text{Class}_3\right\}\right\}$$

$$T_4 = \text{median}\left\{\left\{dL_{\rho_k^3} \mid \forall B^{2,\theta}_{\rho_k^3} \in \text{Class}_3\right\}\right\}\cdot$$

Step 6. Output T_1, T_2, T_3, and T_4.

Subsequently, the watermark embedding algorithm used in the CIWROW technique is described as follows. Note that IDWT denotes the inverse of DWT.

Step 1. Input an image X and a watermark W.

Step 2. Given two seeds (s_1, s_2) to generate Γ.

Step 3. According to Γ, to find Ψ which includes the target blocks to be embedded.

Step 4. For k = 1 to m

Step 4.1. Compute B_{ρ_k} = DWT(b_{ρ_k}) where ρ_k ∈ Γ.

Step 4.2. Calculate $B^{2,\theta}_{\rho_k}$ for θ = {2, 3, 4} = {HL, LH, HH}.

Step 4.3. If (B_{ρ_k} ∈ Class$_1$)

If (w_k = 1 and $(dS_{\rho_k^1} < T_1 \text{ or } dL_{\rho_k^1} < T_1)$)

then (modify the coefficients in $B^{2,4}_{\rho_k}$ until $dS_{\rho_k^1}, dL_{\rho_k^1} > T_1$); Goto Step 4.6.

else if (w_k = -1 and $(dS_{\rho_k^1} > T_1 \text{ or } dL_{\rho_k^1} > T_1)$)

then (modify the coefficients in $B^{2,4}_{\rho_k}$ until $dS_{\rho_k^1}, dL_{\rho_k^1} < T_1$); Goto Step 4.6.

Step 4.4. If (B_{ρ_k} ∈ Class$_2$)

If (w_k = 1 and $(dS_{\rho_k^2} < T_2 \text{ or } dL_{\rho_k^2} < T_2)$)

then (modify the coefficients in $B^{2,4}_{\rho_k}$ until $dS_{\sigma_k^2}, dL_{\sigma_k^2} > T_2$); Goto Step 4.6.

elseif(w_k = -1 and $(dS_{\rho_k^2} > T_2 \text{ or } dL_{\rho_k^2} > T_2)$)

then (modify the coefficients in $B^{2,4}_{\rho_k}$ until $dS_{\rho_k^2}, dL_{\rho_k^2} < T_2$); Goto Step 4.6.

Step 4.5. If (B_{ρ_k} ∈ Class$_3$)

If (w_k = 1 and $(dS_{\rho_k^3} < T_3 \text{ or } dL_{\rho_k^4} < T_4)$)

then (modify the coefficients in $B^{2,2}_{\rho_k}$ or $B^{2,3}_{\rho_k}$ until $dS_{\rho_k^3} < T_3$ and $dL_{\rho_k^3} < T_4$).

elseif (w_k = -1 and ($dS_{\rho_k^3} > T_3$ or $dL_{\rho_k^4} > T_4$))

then (modify the coefficients in $B^{2,2}_{\rho_k}$ or $B^{2,3}_{\rho_k}$ until $dS_{\rho_k^3} > T_3$ and $dL_{\rho_k^3} > T_4$).

Step 4.6. Compute b'_{ρ_k} = IDWT(B'_{ρ_k}) where B'_{ρ_k} represents the watermarked block in the wavelet domain.

Step 4.7. End for-loop

Step 5. Output the watermarked image X'.

2.4 Watermark Extraction

Fig. 6 displays the block diagram of watermark extraction utilized in the CIWROW technique. The watermark extraction algorithm estimates the watermark without original images, and is described as follows.

Step 1. Input a watermarked image X', two seeds (s_1, s_2), and four thresholds T_1, T_2, T_3, and T_4.

Step 2. Use two seeds (s_1, s_2) to generate the set Γ.

Step 3. Find the watermarked blocks b'_{ρ_k} according to Γ.

Step 4. For k = 1 to m

Step 4.1. Compute B'_{ρ_k} = DWT(b'_{ρ_k}) where $\rho_k \in \Gamma$.

Step 4.2. Calculate $B'^{2,\theta}_{\rho_k}$ for θ = {2, 3, 4} = {HL, LH, HH}.

Step 4.3. If ($B'_{\rho_k} \in$ Class$_1$)

If ($dS_{\rho_k^1} < T_1$ and $dL_{\rho_k^1} < T_1$)

then $\hat{w}_k = -1$ else $\hat{w}_k = 1$.

Step 4.4. If ($B'_{\rho_k} \in$ Class$_2$)

If ($dS_{\rho_k^2} < T_2$ and $dL_{\rho_k^2} < T_2$)

then $\hat{w}_k = -1$ else $\hat{w}_k = 1$.

Step 4.5. If ($B'_{\rho_k} \in$ Class$_3$)

If ($dS_{\rho_k^3} < T_3$ and $dL_{\rho_k^4} < T_4$)

then $\hat{w}_k = -1$ else $\hat{w}_k = 1$.

Step 4.6. End for-loop.

Step 5. Output the estimated watermark $\hat{W}$.

Similarly, the estimated watermark can be denoted by $\hat{W} = (\hat{w}_1, \hat{w}_2, \cdots, \hat{w}_k, \cdots, \hat{w}_m)$ where $\hat{w}_k \in \{-1, 1\}$.

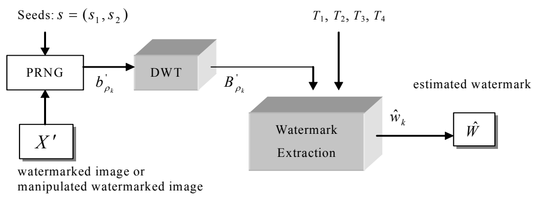

Fig. 6 The block diagram of watermark extraction algorithm in the CIWROW technique.

3. Experimental Results

In this experiment, a 64 × 64 binary image shown in Fig. 7(a) is adopted to be the signature of copyright owner.The length of a watermark is 64 × 64, i.e., m = 64 × 64 The index PSNR (Peak Signal to Noise Ratio) is employed to measure the imperceptible quality of watermarked images, and is defined by

$$\text{PSNR} = 10\log\left(\frac{255^2}{\text{MSE}}\right), \quad (5)$$

where

$$\text{MSE} = \frac{1}{L \times K} \sum_{i=1}^{L} \sum_{j=1}^{K} \left(x_{ij} - x'_{ij}\right)^2 . \quad (6)$$

Furthermore, BCR (Bit Correction Rate) is an index for evaluating the quality of estimated watermarks, and is specified by

$$\text{BCR}(W, \hat{W}) = 1 - \frac{\sum_{k=1}^{m} |w_k - \hat{w}_k|}{2m} . \quad (7)$$

Note the $\text{BCR}(W, \hat{W}) \in [0, 1]$ and the BCR value indicates the similarity between W and $\hat{W}$.

Fig. 7(b) and (c) show the original Lena image with size 512 × 512 and its watermarked version, respectively. The PSNR and BCR for the attack-free case are 41.25 and 1.0, respectively. Meanwhile, Fig. 7(b) is very similar to (c) by visual perception. Therefore, imperceptible capability of the CIWROW technique is acceptable. After presenting the original Lena image to the TD algorithm, these four thresholds are T_1 = 1, T_2 = 1.0625, T_3 = 0.375, and T_4 = 1.4375.

Besides the examination to the attack-free case, the robustness of the CIWROW technique is also assessed by common image-processing operations including brighten, cropping, painting, noising, histogram equalization, and JPEG2000 compression. Fig. 8 exhibits the results of a robustness examination for the CIWROW technique while using Lena image. Here these four thresholds are the same as those used in the attack-free case. Observing the results, we claim that the CIWROW technique possesses effective robustness to be immune against image-processing attacks under consideration.

4. Conclusions

This paper has proposed a novel watermarking technique, which is called the CIWROW technique, mainly based on the wavelet transform and a classification approach. Here we have successfully integrated wavelets theory and classification strategy to develop the CIWROW technique. Moreover, the features of classes are analyzed according to the relationships between the three detail bands at level 2 for all wavelet blocks. Experimental results are included in this paper to illustrate that the CIWROW technique is imperceptible and also robust to be immune against common image-processing attacks. Consequently, the CIWROW technique can be applied to the Digital Right Management (DRM) systems for the copyright protection of gray-level images.

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Fig. 7 (a) A stamp binary image. (b) The Original Lena image. (c) The estimated watermark is extracted from (d). (d) Watermarked Lena image is obtained by hiding (a) into (b).

Fig. 8 The results of a robustness examination for the CIWROW technique using Lena image. Six common image-processing manipulations are simulated for the robustness examination.