Exploring robust and blind watermarking approach of colour images in DWT-DCT-SVD domain for copyright protection

Hongcai Xu, Xiaobing Kang*, Yihan Wang and Yilan Wang

Department of Information Science,
Faculty of Printing, Packaging Engineering and Digital Media Technology,
Xi’an University of Technology,
Xi’an Shaanxi 710048, China
Email: xhc7ny8@163.com
Email: kangxb@xaut.edu.cn
Email: wangyiszq@163.com
Email: 1462147642@qq.com
*Corresponding author

Abstract: This paper presents a new robust and invisible blind watermarking approach of colour images for copyright protection in hybrid DWT-DCT-SVD domain. In the proposed method, firstly the luminance component (Y) of the cover image is decomposed up to one level of discrete wavelet transform (DWT) coefficients and the low frequency band (LL) is transformed by discrete cosine transform (DCT). Then several selected low and intermediate frequency DCT coefficients of each block are extracted to generate a feature matrix and singular value decomposition (SVD) transform is applied to the feature matrix. Finally the watermark information is embedded by modifying the singular values of the feature matrix. Experimental results demonstrate that the proposed approach outperforms some popular existing watermarking methods in robustness against median filtering, Gaussian filtering, salt and pepper noise, average filtering, Gaussian noise, histogram equalisation, and so on, especially in case of lossy JPEG compression in addition to good imperceptibility.

Keywords: robust and blind watermarking; discrete wavelet transform; DWT; singular value decomposition; SVD; discrete cosine transform; DCT; Arnold transform.


Biographical notes: Hongcai Xu is studying in the College of Printing, Packaging Engineering and Digital Media Technology as a graduate student, Xi’an University of Technology, Xi’an, China. His current research interests include computer vision, and machine learning.
Xiaobing Kang is currently working as an Associate Professor in the Department of Information Science, Xi’an University of Technology, Xi’an, China. He received his BE degree in University of Science and Technology Beijing, China, his ME and PhD degrees in Northwestern Polytechnical University, Xi’an, China, respectively. He is a member of the IEEE, the ACM and the CCF. His main research interests include signal and image processing, multimedia forensics and security, and machine learning.

Yihan Wang is studying in the College of Printing, Packaging Engineering and Digital Media Technology as a graduate student, Xi’an University of Technology. Her research interests include image processing and information security.

Yilan Wang is currently pursuing her MS in Signal and Information Processing at the Xi’an University of Technology. Her main interest directions lie in image processing, and intelligent optimisation.

1 Introduction

Digital watermarking is an information security technology which uses multimedia data as the carrier with the purpose of copyright protection and content authentication (Hafiz et al., 2015). Important properties of a watermarking scheme include its robustness, capacity, security, and imperceptibility which are essential requirements of any watermarking technique (Ramamurthy and Varadarajan, 2012). Transform domain watermarking techniques are widely used by reason of high robustness and good imperceptibility. The most common transforms are discrete wavelet transform (DWT), singular value decomposition (SVD), and discrete cosine transform (DCT) (Chen and Ur-Rehman, 2015). In the view of the robustness, digital watermarking methods can be classified into robust, semi-fragile and fragile watermarking. Watermarking techniques are divided into blind scheme and non-blind scheme according to requirements of watermark extraction or detection. Watermarking schemes can be segmented into visible and invisible watermarking in terms of the perceptibility criterion (Hai et al., 2014). This paper focuses on a robust and blind digital watermarking technology.

2 Related work

Watermark embedding can be performed in different transform domains including DWT (Singh and Singh, 2016; Bhatnagar et al., 2012; Mishra et al., 2014; Priyanka and Maheshkar, 2016), DCT (Priyanka and Maheshkar, 2016; Roy and Pal, 2017; Kalra et al., 2015; Takore et al., 2016), SVD (Shah et al., 2015; Priyanka and Maheshkar, 2016; Hu and Hsu, 2015) and others (Chen et al., 2014; Cedillo et al., 2014). Preda and Vizireanu (2015) devised an image authentication scheme which works in DCT domain. Currently, most of the existing digital watermarking algorithms still use gray images (Cai et al., 2015) as the host images, but colour images have been applied in many occasions, so digital watermarking technology based on colour image (Roldan et al., 2016; Sadreazami et al., 2015) has more research significance. Su et al. (2013) proposed a blind colour image watermarking method based on DC component. This method chooses the spatial
domain to embed watermark bits by modifying DC coefficients. It performs well in imperceptibility and has resistance to JPEG compression attack while weak behaviour on other attacks. As illustrated in Parah et al. (2016), watermark bits are embedded by calculating the difference of DCT coefficients between adjacent blocks at the same location. Priyanka and Maheshkar (2016) proposed a digital watermarking method using a combination of DWT, SVD and differential evolution (DE), in which DE is used for optimum embedding strength searching. First, the cover image is transformed by DWT and the generated sub-band LL is operated by SVD to obtain singular values. Then the watermarking image is embedded through alteration of singular values. Hu and Hsu (2015) embedded watermarking by quantising index modulation in the compounded domain (including DWT, DCT and SVD). Kalra et al. (2015) exploited the advantages of DCT, DWT, Arnold transform and chaos theory, and presented an adaptive digital image watermarking for colour images in frequency domain. Takore et al. (2016) put forward an advanced blind watermarking technology. The LL sub-band of one level DWT was decomposed to two sub-images, singular values of the second image were employed to modify the values of first image. Fu (2013) proposed a watermarking scheme by modulating relationship of DCT coefficients.

This paper presents a robust and invisible blind watermarking scheme for colour images. The main idea of the proposed algorithm is to perform DWT, DCT and SVD, then embed watermarking bits by modifying the distribution of the singular values. The results of experiments indicate that the proposed algorithm outperforms some existing methods (Preda and Vizireanu, 2015; Su et al., 2013; Takore et al., 2016; Fu, 2013) in resisting common attacks especially in case of lossy JPEG compression while better imperceptibility compared with those (Parah et al., 2016; Priyanka and Maheshkar, 2016; Hu and Hsu, 2015; Kalra et al., 2015).

The rest of this paper is organised as follows. Section 3 introduces the background materials in this work. Section 4 gives a detailed description of the proposed watermarking scheme. Section 5 shows experimental results and discussions. Section 6 draws conclusions.

3 Preliminaries

This section presents the background materials for subsequent sections in this work.

3.1 DCT

DCT is the most frequently applied linear orthogonal transformation in digital signal processing. Strong energy compaction ability is significant property of the DCT which is used widely in the field of image processing and watermarking (Moosazadeh and Ekin, 2017; Bouslimi and Coatrieux, 2016). Given that the experimental images are two dimension (2D), the definition of 2D-DCT transform is depicted in equation (1) (Singh and Singh, 2016). The size of digital image matrix \( f(x, y) \) is \( N \times N \):

\[
F(u, v) = \frac{c(u)c(v)}{2N} \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} f(x, y) \cos \left( \frac{2\pi (2x+1)}{2N} \right) \cos \left( \frac{2\pi (2y+1)}{2N} \right)
\]  
(1)
where \( x, y, u, v = 0, 1, 2, \ldots, N - 1 \). The inverse DCT transform (IDCT) is given in equation (3):

\[
f(x, y) = \frac{2}{N} \sum_{u=0}^{N-1} \sum_{v=0}^{N-1} c(u)c(v)F(u, v) \cos \frac{u\pi(2x+1)}{2N} \cos \frac{v\pi(2y+1)}{2N}
\]

where \( f(x, y) \) is the pixel value of an image and \( F(u, v) \) is the DCT frequency coefficient.

The proposed watermark algorithm embeds watermark bits into the low and intermediate frequency coefficients for improving performance in resisting multiple attacks (median filtering, Gaussian filtering, average filtering, salt and pepper noise, Gaussian noise, histogram equalisation), especially lossy JPEG compression.

### 3.2 DWT

DWT (Ansari et al., 2016a) is obtained by discretising continuous wavelet function and continuous wavelet transformation. Corresponding definition of discrete wavelet function \( \psi_{j,k}(t) \) is depicted in equation (4):

\[
\psi_{j,k}(t) = \frac{1}{\sqrt{2^j}} \psi\left(\frac{t}{2^j} - k\right)
\]

DWT of an arbitrary function \( f(t) \in L^2(R) \) can be represented as equation (5):

\[
Wf(j, k) = \int_R f(t) \frac{1}{\sqrt{2^j}} \psi\left(\frac{t}{2^j} - k\right) dt = \langle f, \psi_{j,k} \rangle
\]

In DWT-based watermarking techniques, the cover images are decomposed by 2D-DWT transform to generate four sub-bands low frequency sub-band (LL) and three high frequency sub-bands (LH, HL and HH) as shown in Figure 1. The watermarking is embedded into the LL component to improve the robustness under the premise that it does not affect the image quality. DWT has the characteristics of spatial localising and multi-resolution decomposing ability, which conforms to the human visual system (HVS), therefore it is a preferred choice in digital watermarking (Fazli and Moeini, 2016).

Figure 1  Block diagram of one-level dwt frequency sub-band (see online version for colours)
3.3 Singular value decomposition

SVD (Priyanka and Maheshkar, 2016) has been widely used in the digital watermarking technology. The definition of SVD transform is shown in equation (6):

$$A = USV^T$$  \hspace{1cm} (6)

where $A$ is a positive semi-definite matrix with rank $r$, and $A \in m \times n$. $A$ is decomposed into three matrix: $U = Rm \times m$, $S = \text{diag}(\lambda_1, \lambda_2, \ldots, \lambda_r)$, $V = Rn \times n$, where $\lambda_1 \geq \lambda_2 \geq \ldots \geq \lambda_r \geq 0$, $r = \text{rank}(A) = \text{rank}(A^T A) = \text{rank}(AA^T)$. Equation (6) is viewed as the SVD form of matrix $A$. $S$ is diagonal matrix while diagonal element $\lambda_i$ for $r \geq i \geq 1$ are the singular values of the matrix $A$.

One of the important properties of SVD is that the singular values of the matrix have excellent stability. When the image suffers from a very small perturbation, its singular values change very slightly, and visual quality is not affected. In the proposed method, the watermark bits are embedded to the cover image by modifying the magnitude distribution of the singular values based on the unique advantage of SVD (Vaishnavi and Subashini, 2015; Ansari et al., 2016b).

3.4 Arnold transform

Arnold transform is applied widely in digital watermarking image scramble because of its periodicity and mathematic characteristic. The transform is a process of clipping and splicing that realign the pixel matrix of digital image (Wu et al., 2009). Watermark for copyright protection and ownership authentication must be unique and contain certain semantic information. The proposed method selects four logo images with the copyright information as the watermark images, as depicted in Figure 2.

**Figure 2** Watermark images and the scrambled versions by Arnold transform with $K = 5$

![Watermark images](image)

The Arnold scrambling transform (Wu et al., 2009) with secret key $K$ is a kind of traditional chaos mapping. A two-dimension Arnold scrambling transformation is defined as shown in equation (7):

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 1 & 2 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \mod N$$  \hspace{1cm} (7)

where $(x, y)^T$ and $(x', y')^T$ are the pixel coordinates of the original image and the scrambled image. $N$ is the height or width of the original square image processed. Encrypted watermark matrix is obtained after Arnold scrambling, as shown in Figure 2.

Anti-Arnold transform (Wu et al., 2009) is used to recover the original image from the scrambled image. The Anti-Arnold transform is given by equation (8):
\[
\begin{pmatrix}
    x' \\
y'
\end{pmatrix} = \begin{pmatrix}
    2 & -1 \\
    -1 & 1
\end{pmatrix} \begin{pmatrix}
    x \\
y
\end{pmatrix} \mod N \tag{8}
\]

4 Proposed watermarking scheme

This section elaborates a new robust and invisible blind image watermarking technique, in which a colour host image \( H \) of size \( M \times N \) is used to embed a binary watermark image \( W \) with the size \( (M/16) \times (N/16) \). The detailed procedures are discussed in the following subsections.

4.1 Watermark embedding

The watermark embedding procedure can be divided into three stages. Firstly the cover image is decomposed by DWT transform and its LL sub-band is extracted. Secondly DCT transform is applied to the LL sub-band, and then the former 16 low-medium frequency AC coefficients are extracted to create a matrix with size 4 \( \times \) 4. Thirdly the matrix is processed by SVD transform and watermarking insertion is implemented by modifying the feature vector which consists of four singular values. The block diagram of watermark embedding is shown in Figure 3.

Figure 3 Watermark embedding procedure (see online version for colours)

The specific embedding procedure is described as follows:

1. The colour host image \( H \) with the size \( M \times N \) is converted from RGB space to \( Y\bar{C}b\bar{C}r \) space, and the \( Y \) component is extracted.

2. Using Haar filter, one-level DWT is applied to \( Y \) component to generate four sub-bands, as shown in equation (9). Each one will be of size \( M/2 \times N/2 \).

\[
[LL, LH, HL, HH] = \text{DWT}(Y) \tag{9}
\]
Exploring robust and blind watermarking approach of colour images

3. After dividing the LL sub-band into non-overlapped blocks of size $8 \times 8$, DCT operation is performed on each block to achieve the coefficient matrix $D_{ij}$, subject to $i \leq M, j \leq N$, as shown in equation (10):

$$D_{ij} = \text{DCT}(LL)$$  

(10)

4. A one-dimensional feature vector $DZ_{ij}$ is obtained by zigzag scanning the coefficient matrix $D_{ij}$. Scanning pattern is shown in Figure 4.

5. A feature matrix $A_{ij}$ with size $4 \times 4$ is created by extracting the former 16 coefficients of $DZ_{ij}$ except the DC coefficient, as depicted in Figure 5.

6. The SVD operation is applied to the feature matrix $A_{ij}$ according to equation (11). Diagonal matrix $S_{ij}$ is used to construct the feature vector $FV_{ij} = (\lambda_1, \lambda_2, \lambda_3, \lambda_4)$:

$$[U_{ij} \quad S_{ij} \quad V_{ij}] = \text{SVD}(A_{ij})$$  

(11)

7. The watermark matrix $W$ is scrambled by the Arnold transform to obtain encrypted watermark matrix $W_e$ according to equation (7):

8. The watermark bit is embedded by modifying the second singular value $\lambda_2$ according to equation (12), then the modified $FV'_{ij}$ and $S'_{ij}$ are obtained in turn. $\alpha$ in equation (12) is embedding strength of the proposed watermark scheme:

$$\lambda'_2 = \begin{cases} \alpha \lambda_2 + (1-\alpha)\lambda_2 & \text{if } W_e = 1 \\ (1-\alpha)\lambda_2 + \alpha \lambda_3 & \text{if } W_e = 0 \end{cases}$$  

(12)

9. A inverse SVD is performed on $U_{ij}, S'_{ij}, V'_{ij}$ to generate modified matrix $A'_{ij}$ according to equation (13). All values in matrix $A'_{ij}$ are mapped back to their respective original positions and then we can get altered $DZ'_{ij}$ and $D'_{ij}$ successively:

$$A'_{ij} = U_{ij}S'_{ij}V'_{ij}$$  

(13)

10. A inverse DCT transform is implemented on $D'_{ij}$, as shown in equation (14):

$$LL' = \text{IDCT}(D'_{ij})$$  

(14)

where IDCT() represents the inverse DCT function.

11. A inverse DWT transform using haar filter is fulfilled on the $LL'$ sub-band, and obtain $Y'$ component with other three sub-bands HL LH and HH, as shown in equation (15):

$$Y' = \text{IDWT}(LL', LH, HL, HH)$$  

(15)

where IDWT() represents the inverse DWT function.

12. Finally, the watermarked image $I'$ is reconstructed by $Y'$, $C_b$ and $C_r$. 

4.2 Watermark extraction

This paper mainly studies the blind watermarking scheme, therefore the original host image and the watermark image are not needed during the watermark extraction process. The extraction block diagram of watermark image is shown in Figure 6. A detailed watermark extraction procedure is presented as follows:

1. The watermarked image $H'$ is converted from RGB space to $YCbCr$ space.
2. One-level DWT is applied to the $Y$ component to obtain the four sub-bands.
3. After dividing the LL sub-band into the non-overlapping sub-blocks with size $8 \times 8$, DCT transform is performed on each block, and get the coefficient matrix $DW_{ij}$. 

---

**Figure 4** Zigzag scanning pattern (see online version for colours)

**Figure 5** The way to generate a feature matrix (see online version for colours)
4 A matrix $AW_{ij}$ is produced by extracting the former 16 AC coefficients of the matrix $DW_{ij}$ according to zigzag scanning pattern, as depicted in Figures 4 and 5.

5 Performing SVD operation on the matrix $AW_{ij}$, three components $U_{ij}$, $S_{ij}$, $V_{ij}^T$ are obtained in terms of equation (16):

$$\begin{bmatrix} U_{ij} & S_{ij} & V_{ij}^T \end{bmatrix} = \text{SVD}(AW_{ij})$$

6 Extraction of the watermark bit is performed by analysing the size relationship between the three singular values $\{\lambda_1, \lambda_2, \lambda_3\}$ in diagonal matrix $S_{ij}$ according to equation (17):

$$W'_{ij} = \begin{cases} 1, & \text{if } \frac{\lambda_2 + \lambda_3}{2} \\ 0, & \text{if } \frac{\lambda_2 + \lambda_3}{2} \end{cases}$$

7 Anti-Arnold transform with secret key $K$ is applied to the extracted watermark information using equation (8), and the binary watermark image is obtained.

Figure 6 Watermark extraction procedure (see online version for colours)

5 Experiment results and discussions

The proposed watermark scheme was implemented in MATLAB 2014b. To evaluate the performance of the proposed watermark method, we selected seven colour images as cover images, shown in Figure 7. The paper uses the logo images with copyright information as the watermark images, as depicted in Figure 2. Dimensions of the cover images and the watermark images are $512 \times 512$ and $32 \times 32$ respectively.

The essential performance metrics of available watermarking methods include robustness, imperceptibility and security. The proposed watermark scheme is evaluated by various experiments in terms of imperceptibility and robustness against various attacks. PSNR evaluates the invisibility of digital watermark method. The definition of PSNR is shown as equation (18) (Pandey et al., 2014):
where $H, H'$ are the host image and the watermarked image respectively, $m$ and $n$ are the maximum size of the image. The imperceptibility is better as the PSNR value is higher.

**Figure 7**  Cover images (a) boat, (b) airplane, (c) tiffany, (d) splash, (e) peppers, (f) Lena and (g) baboon (see online version for colours)

Bit error rate (BER) and normalised correlation (NC) assess the robustness of digital watermark. BER can be computed as equation (19):

$$\text{BER} = \frac{\sum_{i=1}^{l} \sum_{j=1}^{k} W(i, j) \oplus W'(i, j)}{l \times k}$$  

(19)
where $W(i, j)$ and $W'(i, j)$ represent original watermark and extracted watermark respectively, $\otimes$ denotes the exclusive-OR operation. $l$ and $k$ are the maximum size of the watermark. The closer to 0 the BER is, the better the robustness performs. The definition of NC is shown in equation (20):

$$NC = \frac{\sum_{i=1}^{l} \sum_{j=1}^{k} W(i, j) \times W'(i, j)}{\sum_{i=1}^{l} \sum_{j=1}^{k} (W(i, j))^2}$$  \hspace{1cm} (20)

where $W_{ij}$ and $W'_{ij}$ denote the $(i, j)$th pixel value of the original and the extracted watermark respectively. $l, k$ are the row and column maximum values of the image. They should be very similar when NC between two images is in close proximity to one.

### 5.1 Parameters selection

$K$ and $\alpha$ are two important parameters in the proposed watermark algorithm. $K$ is secret key of Arnold scrambling, $\alpha$ is the embedding strength:

#### 5.1.1 Secret key $K$ of Arnold scrambling

2D Arnold scramble is a periodic transformation, the cycle ($T$) is associated with the matrix dimension $N$ of the watermark image, Table 1 shows the relationship between $T$ and $N$ (Wu et al., 2009). From Table 1, it can be seen that there is a nonlinear relationship between the period $T$ of Arnold transform and the matrix dimension $N$ of the scrambled image. As the size of the watermark image in this paper is $32 \times 32$, the period $T$ of Arnold transform is selected with 24. In this paper, $K$ is chosen as five randomly.

<table>
<thead>
<tr>
<th>$N$</th>
<th>2</th>
<th>4</th>
<th>5</th>
<th>8</th>
<th>10</th>
<th>16</th>
<th>32</th>
<th>64</th>
<th>100</th>
<th>128</th>
<th>256</th>
<th>512</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period ($T$)</td>
<td>3</td>
<td>3</td>
<td>10</td>
<td>6</td>
<td>30</td>
<td>12</td>
<td>24</td>
<td>48</td>
<td>150</td>
<td>96</td>
<td>192</td>
<td>384</td>
</tr>
</tbody>
</table>

#### 5.1.2 Embedding strength $\alpha$

The calculating results of PSNR and NC under different embedding strengths $\alpha$ are shown in Figures 8 and 9. We can draw that with the increasing of $\alpha$, the values of PSNR are falling, and the corresponding values of NC are increasing gradually. Figure 9 shows that when $\alpha$ belongs to $[0.1, 0.5]$, the values of NC are small but with a high increasing speed; when $\alpha \in [0.6, 1]$ the NC values increase smoothly. In order to balance the imperceptibility and robustness of the proposed watermark scheme, embedding strength $\alpha$ is chosen as 0.7.
5.2 Imperceptibility analysis

Parah et al. (2016), Priyanka and Maheshkar (2016), Hu and Hsu, (2015) and Kalra et al. (2015) are important blind and robust watermarking techniques, they are adopted for comparisons. The selected frequency domains include DCT, DWT-SVD, DWT-DCT, DWT-DCT-SVD, respectively. Table 2 shows the PSNR values from the proposed scheme and four methods above mentioned. PSNR value of 34 dB is generally considered as acceptable level. According to Table 2, the PSNR values of the proposed scheme are larger than 42 dB and higher the other four’s, so the imperceptibility of the proposed scheme is superior to those (Parah et al., 2016; Priyanka and Maheshkar, 2016; Hu and Hsu, 2015; Kalra et al., 2015).
Table 2  
PSNR comparison

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cover image</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lena</td>
<td>DCT</td>
<td>35.93</td>
<td>42.01</td>
<td>39.83</td>
<td>43.85</td>
</tr>
<tr>
<td>Baboon</td>
<td>-</td>
<td>33.65</td>
<td>36.11</td>
<td>39.42</td>
<td>44.02</td>
</tr>
<tr>
<td>Peppers</td>
<td>41.84</td>
<td>-</td>
<td>42.64</td>
<td>39.48</td>
<td>42.99</td>
</tr>
<tr>
<td>Airplane</td>
<td>41.17</td>
<td>34.56</td>
<td>-</td>
<td>39.59</td>
<td>42.99</td>
</tr>
<tr>
<td>Average value</td>
<td>41.43</td>
<td>34.71</td>
<td>40.19</td>
<td>39.58</td>
<td>43.97</td>
</tr>
</tbody>
</table>

5.3 Robustness analysis

Robustness refers to the capacity of extracting watermark bits under noise pollution which can authenticate copyright of digital information.

5.3.1 Robustness of the proposed method

In this experiment, we demonstrate the visual quality of watermarked images. Figure 10 shows the watermarked images with different types of attacks and the corresponding extracted watermark images. It can be seen that the proposed watermark method can resist different types of attacks effectively and extract watermark images with high visual perceptual quality.

5.3.2 Comparative analysis

The scheme proposed by Parah et al. (2016) could resist common attacks while weak performance in JPEG compression. Two methods presented by Preda and Vizireanu (2015) and Su et al. (2013) are better in imperceptibility but not well in resisting some attacks. Although Hu and Hsu (2015) and Takore et al. (2016) utilised the hybrid domain including DWT, DCT and SVD, but their ability of resisting noise addition is poor. This paper evaluates the robustness by BER and NC values.

5.3.2.1 JPEG compression attack

Figure 11(a) shows the NC values in different JPEG quality factors (QF). Figure 11(b) shows the BER values in different JPEG QFs. It can be seen that BER is smaller than 0.035, and NC is larger than 0.90 when QF is greater than or equal to 50, which show that our method have excellent robustness. The NC values of Preda and Vizireanu (2015), Su et al. (2013) and Kalra et al. (2015) grow as the compression factors rise, while the values of the proposed algorithm are larger than them all. The BER values of Kalra et al. (2015), Takore et al. (2016) and Fu (2013) all are greater than the proposed method. In addition to QF > 70, the BER of the method (Fu, 2013) is smaller than the proposed method. When QF is equal to 20, the NC value of the proposed algorithm can reach 0.84, which
means that the extracted watermark can still be used. Experimental results show that the proposed watermark scheme has stronger resistance to JPEG compression attack than the other methods (Preda and Vizireanu, 2015; Su et al., 2013; Kalra et al., 2015; Takore et al., 2016; Fu, 2013).

5.3.2.2 Other attacks

The specific attacks include six attacks: median filtering (3×3), Gaussian filtering (3×3), average filtering (3×3), salt and pepper noise (1%), Gaussian noise (1%), histogram equalisation. Table 3 represents the BER and NC values of five methods under different attacks severally, the proposed algorithm has higher NC values under different attacks, which means it performs well and has stronger robustness than the other two methods (Parah et al., 2016; Takore et al., 2016). The BER values of the proposed algorithm are smaller than those (Parah et al., 2016; Hu and Hsu, 2015; Kalra et al., 2015), showing high robustness. Table 3 can be graphed as Figure 12 intuitively.

Figure 10 Watermarked images attacked and the corresponding extracted watermark images, (a) no attack (b) JPEG QF (30) (c) JPEG QF (40) (d) JPEG QF (50) (e) Gaussian filtering (3×3) (f) Gaussian noise (1%) (g) average filtering (3×3) (h) median filtering (3×3) (i) histogram equalisation (j) cropping (25%) (k) Gaussian filtering (3×3) (l) salt and pepper noise (1%) (see online version for colours)
Figure 11  (a) NC comparison (b) BER comparison (see online version for colours)

Nevertheless, there is certainly room for improvement on resisting geometric attacks such as scale and rotation. Based on print-scan, print-photo and other practical applications environment, the robustness of existing digital watermarking methods against geometric attacks are very weak, including this proposed method. Further research will continue to explore a watermarking scheme against geometric attacks combining the hybrid domain and the invariant features.
Table 3  NC and BER values under different attacks

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NC</td>
<td>BER</td>
<td>NC</td>
<td>BER</td>
<td>BER</td>
</tr>
<tr>
<td>Median filtering</td>
<td>0.971</td>
<td>0.017</td>
<td>0.945</td>
<td>0.099</td>
<td>0.0926</td>
</tr>
<tr>
<td>Gaussian filtering</td>
<td>1</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>0.0041</td>
</tr>
<tr>
<td>Average filtering</td>
<td>0.910</td>
<td>0.054</td>
<td>0.916</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Salt and pepper noise</td>
<td>0.992</td>
<td>0.016</td>
<td>0.860</td>
<td>0.156</td>
<td>0.226</td>
</tr>
<tr>
<td>Gaussian noise</td>
<td>0.969</td>
<td>0.042</td>
<td>0.938</td>
<td>0.086</td>
<td>0.1624</td>
</tr>
<tr>
<td>Histogram equalisation</td>
<td>0.990</td>
<td>0.004</td>
<td>0.967</td>
<td>0.039</td>
<td>-</td>
</tr>
</tbody>
</table>

6 Conclusions

This paper explored a novel robust and invisible blind watermark algorithm of colour images for copyright protection by combining DWT, DCT and SVD transform and using modulation method to embed watermark bits jointly. The proposed algorithm obtains a preferable trade-off between the imperceptibility and the robustness while these methods (Preda and Vizireanu, 2015; Su et al., 2013; Parah et al., 2016; Priyanka and Maheshkar, 2016; Hu and Hsu, 2015; Kalra et al., 2015; Takore et al., 2016; Fu, 2013) above mentioned have merely single advantage. In other words, it improves the robustness under the premise of good imperceptibility. In view of the most common attacks the robustness is enhanced, especially in case of JPEG compression. The BER value of the proposed method can still achieve 0.09 and the corresponding NC value can also reach the available condition of 0.84 even when QF is equal to 20.

Acknowledgements

This work is supported by Scientific Research Program Funded by Shaanxi Provincial Education Department (Program No. 15JK1504).

References


Exploring robust and blind watermarking approach of colour images


