A Blind Adaptive Color Image Watermarking Scheme Based on Principal Component Analysis, Singular Value Decomposition and Human Visual System

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1. Introduction

The enormous usage and afford-ability of Internet across the world, has made it easy to access online literature in the form of pictures, audios, videos, books, etc. The data available online can be downloaded, and then can be redistributed its copies multiple times, without any distinguishable difference between original and copied material. This illegal distribution and copyright violation results in the form of millions of dollars loss [1]. To overcome this illicit distribution and copyright violation digital watermarking is proposed as a prominent solution [2–7].

Watermarking is the way of embedding some information (image, audio, strings) into another data (image, audio, video, pdf file). The embedded data can later be extracted to prove the ownership. If the data which is being protected by embedding information in it is image, then this type of watermarking is called image watermarking. The information which is being hidden is called watermark, and the image in which watermark is hidden is called host image, and the resultant image is known as watermarked image. In terms of information required at the time of watermark extraction, watermarking is divided into blind and non-blind [2]. In later case, original image is required (and may be key) at the time of watermark extraction, whereas in former watermarking type there is no need of original image for extraction of watermark [3]. Therefore, blind watermarking is considered to be more secure and convenient, hence in this paper blind watermarking schemes are proposed.

The watermarking scheme for gray scale [2], [4], [5] and for color images [1], [3], [6], [7] are available in literature. One additional challenge of color image watermarking is that the three channels R, G, and B are highly correlated [3], [8], hence modification of one channel affects other channels severely and as a result the quality of whole image is compromised. This adverse effect can be avoided if Principal Component Analysis (PCA) [9] is used. In the proposed scheme PCA is used to decorrelate the three channels. In most cases either the same amount of information is em-

Abstract. A blind adaptive color image watermarking scheme based on principal component analysis, singular value decomposition, and human visual system is proposed. The use of principal component analysis to decorrelate the three color channels of host image, improves the perceptual quality of watermarked image. Whereas, human visual system and fuzzy inference system helped to improve both imperceptibility and robustness by selecting adaptive scaling factor, so that, areas more prone to noise can be added with more information as compared to less prone areas. To achieve security, location of watermark embedding is kept secret and used as key at the time of watermark extraction, whereas, for capacity both singular values and vectors are involved in watermark embedding process. As a result, four contradictory requirements; imperceptibility, robustness, security and capacity are achieved as suggested by results. Both subjective and objective methods are acquired to examine the performance of proposed schemes. For subjective analysis the watermarked images and watermarks extracted from attacked watermarked images are shown. For objective analysis of proposed scheme in terms of imperceptibility, peak signal to noise ratio, structural similarity index, visual information fidelity and normalized color difference are used. Whereas, for objective analysis in terms of robustness, normalized correlation, bit error rate, normalized hamming distance and global authentication rate are used. Security is checked by using different keys to extract the watermark. The proposed schemes are compared with state-of-the-art watermarking techniques and found better performance as suggested by results.

Keywords

Image watermarking, principal component analysis, singular value decomposition, human visual system, imperceptibility, robustness
2. Proposed Scheme

In this paper two watermarking schemes are proposed. In proposed scheme 1, HVS and FIS are used together to find the areas where more information can be embedded, and regions where less data should be concealed. In this way two contradictory requirements of watermarking techniques; imperceptibility and robustness can be achieved simultaneously. For this purpose Human Visual System (HVS) and Fuzzy Inference System (FIS) are used to find adaptive scaling factor so that the amount of information is embedded according to the perceptual quality of host image.

In addition to perceptual quality of watermarked image and robustness, an other concern is that neither original nor false watermark should be extracted even by untrained eyes. Where, with the help of fake keys (singular vectors) a watermark different than the embedded watermark is extracted, which completely destroys the purpose of copyright protection. Therefore in designing proposed scheme, special attention is given to security and it is ensured that neither original nor false watermark is extracted as suggest by results in Sec. 5.3. The proposed scheme is discussed in detail in the following sections.

2.1 Human Visual System

Given an image $I$ of size $M \times N$, the luminance masking [15] $M_L$, is calculated as follows:

$$M_L(x, y) = \text{max}[f_1(bg(x, y), mg(x, y)), f_2(bg(x, y))]$$  \hspace{1cm} (1)

where

$$f_1(bg(x, y), mg(x, y)) = mg(x, y)\alpha(bg(x, y)) + \beta(bg(x, y)),$$

$$f_2(bg(x, y)) = \begin{cases} 
T_0 \left(1 - \left(\frac{bg(x, y)}{127}\right)^{0.5}\right)^{0.5} + 3, & bg(x, y) \leq 127, \\
(y(bg(x, y) - 127) + 3, & bg(x, y) > 127.
\end{cases}$$

$$\alpha(bg(x, y)) = \begin{cases} 
0.001bg(x, y) + 0.115, & 1 \leq x \leq H, 1 \leq y \leq W, \\
1, & \text{otherwise}.
\end{cases}$$

$$\beta(bg(x, y)) = \lambda - 0.01bg(x, y),$$

$f_1$ is the spatial masking function, $bg(x, y)$ is the background luminance, $mg(x, y)$ is the maximum weighted average of luminance differences around the pixel at location $(x, y)$, $W = M/2$ and $H = N/2$. $f_2$, $\alpha$ and $\beta$ are the background luminance dependent functions. The value of some other parameters are: $T_0 = 17$, $\gamma = 3/128$, and $\lambda = 1/2$. In order to know about the selection of parameter’s values readers may refer [15]. $mg(x, y)$ and $bg(x, y)$ are calculated as follows:

$$mg(x, y) = \max_{k=1,2,3,4} [||\text{grad}_k(x, y)||],$$

$$\text{grad}_k(x, y) = \frac{1}{16} \sum_{i=1}^{5} \sum_{j=1}^{5} I(x - i, y - j)G_k(i, j),$$

$$bg(x, y) = \frac{1}{32} \sum_{i=1}^{5} \sum_{j=1}^{5} I(x - i, y - j)B(i, j).$$

The values of $G_1, G_2, G_3, G_4$ and $B$ are shown below:

$$G_1 = \begin{bmatrix} 
0 & 0 & 0 & 0 & 0 \\
1 & 3 & 8 & 3 & 1 \\
0 & 0 & 0 & 0 & 0 \\
-1 & -3 & -8 & -3 & -1 \\
0 & 0 & 0 & 0 & 0 
\end{bmatrix}, \quad G_2 = \begin{bmatrix} 
0 & 0 & 1 & 0 & 0 \\
1 & 3 & 0 & -3 & -1 \\
0 & 0 & -3 & -8 & 0 \\
0 & 0 & -1 & 0 & 0 
\end{bmatrix},$$

$$G_3 = \begin{bmatrix} 
0 & 0 & 1 & 0 & 0 \\
0 & 0 & 3 & 0 & 0 \\
-1 & -3 & 0 & 3 & 1 \\
0 & -8 & -3 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 
\end{bmatrix}, \quad G_4 = \begin{bmatrix} 
0 & 1 & 0 & -1 & 0 \\
0 & 3 & 0 & -3 & 0 \\
0 & 3 & 0 & -3 & 0 \\
0 & 1 & 0 & -1 & 0 
\end{bmatrix},$$

$$B = \begin{bmatrix} 
1 & 1 & 1 & 1 \\
1 & 2 & 2 & 2 \\
1 & 2 & 0 & 2 \\
1 & 2 & 2 & 2 \\
1 & 1 & 1 & 1 
\end{bmatrix}.$$
In order to choose $B_1$ and $D_1$, following condition must be satisfied:

$$C_1 - B_1 = D_1 - C_1.$$  

The membership function for adaptive scaling factor $\alpha_{M_L}$ is shown in Fig. 2.

The rules used for calculating $\alpha_{M_L}$ are as follows:

1. $Ru^1$: IF $M_L$ is large, THEN $\alpha_{M_L}$ is large,
2. $Ru^2$: IF $M_L$ is medium, THEN $\alpha_{M_L}$ is medium,
3. $Ru^3$: IF $M_L$ is small, THEN $\alpha_{M_L}$ is small.

The detailed procedure of watermark embedding and extraction are discussed in following sections.

### 3. Proposed Scheme 1

In proposed scheme 1, human visual system is used to find the areas of image which are more prone to alterations, and areas which are less prone to disturbances. The information of HVS is then used in FIS to find adaptive scaling factor for watermark embedding, so that the areas which are more prone to noise, can be embedded with more information as compared to areas which are less prone. In this way both; imperceptibility and robustness can be achieved as suggested by results in Sec. 5. The detailed procedure of watermark embedding and extraction are discussed in Sec. 3.1 and 3.2 respectively.

#### 3.1 Watermark Embedding

1. Let the original image $I$ is decomposed into three channels $R$, $G$, and $B$

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1N} \\ r_{21} & r_{22} & \cdots & r_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ r_{M1} & r_{M2} & \cdots & r_{MN} \end{bmatrix},$$

$$G = \begin{bmatrix} g_{11} & g_{12} & \cdots & g_{1N} \\ g_{21} & g_{22} & \cdots & g_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ g_{M1} & g_{M2} & \cdots & g_{MN} \end{bmatrix},$$

$$B = \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1N} \\ b_{21} & b_{22} & \cdots & b_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ b_{M1} & b_{M2} & \cdots & b_{MN} \end{bmatrix}.$$  

$M$ and $N$ defines the size of image.

2. Let a covariance matrix $C$ can be computed as

$$C = \frac{1}{MN}(AA^T) = Q \wedge Q^{-1} \tag{5}$$

where

$$A = \begin{bmatrix} r_{11} & \cdots & r_{1N} & r_{21} & \cdots & r_{2N} & \cdots & r_{M1} & \cdots & r_{MN} \\ g_{11} & \cdots & g_{1N} & g_{21} & \cdots & g_{2N} & \cdots & g_{M1} & \cdots & g_{MN} \\ b_{11} & \cdots & b_{1N} & b_{21} & \cdots & b_{2N} & \cdots & b_{M1} & \cdots & b_{MN} \end{bmatrix},$$

$$Q = \begin{bmatrix} q_{11} & q_{12} & q_{13} \\ q_{21} & q_{22} & q_{23} \\ q_{31} & q_{32} & q_{33} \end{bmatrix}, \quad \Lambda = \begin{bmatrix} \lambda_{11} & 0 & 0 \\ 0 & \lambda_{22} & 0 \\ 0 & 0 & \lambda_{33} \end{bmatrix},$$

$\lambda_{11} \geq \lambda_{22} \geq \lambda_{33}$ are eigenvalues in descending order.

3. The principal components [18] of covariance matrix $C$ are calculated as

$$P = \begin{bmatrix} P_1 \\ P_2 \\ P_3 \end{bmatrix} = Q^TA = \begin{bmatrix} p_{11} & \cdots & p_{1N} & p_{21} & \cdots & p_{2N} & \cdots & p_{M1} & \cdots & p_{MN} \\ p_{R1} & \cdots & p_{RN} & p_{G1} & \cdots & p_{G2N} & \cdots & p_{M1} & \cdots & p_{MN} \\ p_{B1} & \cdots & p_{BN} & p_{B21} & \cdots & p_{B2N} & \cdots & p_{M1} & \cdots & p_{MN} \end{bmatrix}.$$  

**Remark 2:** Since $R$, $G$ and $B$ components are highly correlated [3], [7] and [8], modification in one channel causes alteration in other two channels, as a result imperceptibility is affected severely. However, this can be avoided if PCA [9] is used to decorrelate these $R$, $G$ and $B$ components.
4. Let matrix $P_{rn}$ is formed from row vector $P_r$ of matrix $P$ as shown below

$$P_{rn} = \begin{bmatrix} P_{r11} & P_{r12} & \cdots & P_{r1N} \\ P_{r21} & P_{r22} & \cdots & P_{r2N} \\ \vdots & \vdots & \ddots & \vdots \\ P_{rM1} & P_{rM2} & \cdots & P_{rMN} \end{bmatrix}.$$

Remark 3: Since $P_{rn}$ is composed of components from $P_r$ and contains most of the information [9], therefore it is chosen for watermark embedding.

5. Let $P_{rn}$ is divided into non-overlapping blocks $A_1, A_2, \ldots, A_{pq}$. Where the size of each block is $4 \times 4$, $p \leq M/4$ and $q \leq N/4$.

6. Let each block is decomposed using SVD as follows

$$A_i = U_iS_iV_i^T, \quad i = 1, 2, \ldots, pq$$

where $S$ is a diagonal matrix containing singular values in descending order, whereas, $U$ and $V$ represent the left and right singular vectors respectively.

Remark 4: Small perturbation in image does not cause large variation in singular values and vice versa [5], [7].

Remark 5: Singular values contain intrinsic properties of image, whereas geometric information is maintained by corresponding singular vectors [5], [7].

7. Compute the covariance matrix of each block $A_i$. Select the column number with lowest covariance (variance) value, and then location of two values with lowest covariance values within that selected column from covariance matrix of each block. In this way three numbers are selected for each block, and those selected locations will later be used as key at the time of watermark extraction. For instance $(f, e, g)$ are selected, where, 'f' represents the column number with lowest covariance value, 'e' and 'g' denoting the locations of two values with lowest covariance values from selected columns. These three numbers are used to select two numbers from $U$ and $V$ for modifications. For example in case of $(f, e, g)$, tow numbers at location $(e, f)$ and $(g, f)$ from $U$, similarly two values from location $(f, e)$ and $(f, g)$ from $V$ are selected for watermark embedding. In addition to that singular values either at location $(e, f)$ or $(g, f)$ based on embedding bits are modified as shown in (7)–(10). It is shown in result in Sec. 5 that the procedure described above for choosing two numbers for modifications gives better results in terms of imperceptibility.

8. Let the luminance masking $M_L$, for each block $A_i$, where $i = 1, 2, 3, \ldots, pq$ is calculated using (1).

9. The adaptive scaling factor $\alpha_{ML}(g, f), \alpha_{ML}(e, f), \alpha_{ML}(f, g)$ and $\alpha_{ML}(f, e)$ of each block $A_i$ for values of selected positions are calculated by utilizing luminance masking values $M_L$ of block ‘i’.

10. Given a watermark $W$ of size $M/4 \times N/4$, the watermarking bits $W_i$ are embedded as described below in (7)–(10).

Case 1: If embedding bit is 1 i.e. $(W_i = 1)$.

$$
\begin{align*}
\hat{u}_{wi(e,f)} &= \text{sgn}(u_{wi(e,f)}) \times (\hat{U}_i + (\beta M_{L_i}(e,f))/2) \\
\hat{u}_{wi(g,f)} &= \text{sgn}(u_{wi(g,f)}) \times (\hat{U}_i - (\beta M_{L_i}(g,f))/2) \\
\hat{v}_{wi(f,e)} &= \text{sgn}(v_{wi(f,e)}) \times (\hat{V}_i + (\beta M_{L_i}(f,e))/2) \\
\hat{v}_{wi(f,g)} &= \text{sgn}(v_{wi(f,g)}) \times (\hat{V}_i - (\beta M_{L_i}(f,g))/2) \\
\hat{s}_{wi(e,g)} &= 3 \times s_{wi(e,g)}
\end{align*}
$$

If $e < g$

(7)

Case 2: If embedding bit is 0 i.e. $(W_i = 0)$.

$$
\begin{align*}
\hat{u}_{wi(e,f)} &= \text{sgn}(u_{wi(e,f)}) \times (\hat{U}_i - (\beta M_{L_i}(e,f))/2) \\
\hat{u}_{wi(g,f)} &= \text{sgn}(u_{wi(g,f)}) \times (\hat{U}_i + (\beta M_{L_i}(g,f))/2) \\
\hat{v}_{wi(f,e)} &= \text{sgn}(v_{wi(f,e)}) \times (\hat{V}_i - (\beta M_{L_i}(f,e))/2) \\
\hat{v}_{wi(f,g)} &= \text{sgn}(v_{wi(f,g)}) \times (\hat{V}_i + (\beta M_{L_i}(f,g))/2) \\
\hat{s}_{wi(e,g)} &= 3 \times s_{wi(e,g)}
\end{align*}
$$

If $e > g$

(9)

$$
\begin{align*}
\hat{u}_{wi(e,f)} &= \text{sgn}(u_{wi(e,f)}) \times (\hat{U}_i - (\beta M_{L_i}(e,f))/2) \\
\hat{u}_{wi(g,f)} &= \text{sgn}(u_{wi(g,f)}) \times (\hat{U}_i + (\beta M_{L_i}(g,f))/2) \\
\hat{v}_{wi(f,e)} &= \text{sgn}(v_{wi(f,e)}) \times (\hat{V}_i - (\beta M_{L_i}(f,e))/2) \\
\hat{v}_{wi(f,g)} &= \text{sgn}(v_{wi(f,g)}) \times (\hat{V}_i + (\beta M_{L_i}(f,g))/2) \\
\hat{s}_{wi(e,g)} &= 3 \times s_{wi(e,g)}
\end{align*}
$$

If $e < g$

(10)

where

$$\hat{U}_i = \frac{|u_{wi(e,f)} + u_{wi(g,f)}|}{2}, \quad \hat{V}_i = \frac{|v_{wi(f,e)} + v_{wi(f,g)}|}{2}.$$

$W_i$ represents the watermark bit, where $1 \leq i \leq MN/16$. In (7)–(10), $\beta$ represents the threshold defining the amount of change in values, whereas, $u_{wi(e,f)}$, $u_{wi(g,f)}$, $v_{wi(f,e)}$, $v_{wi(f,g)}$, $s_{wi(e,g)}$ and $s_{wi(g,e)}$ represents the modified (watermark added) values at locations $(e, f)$, $(g, f)$, $(f, e)$, $(f, g)$ and $(e, g)$ respectively for block $i$. For (7) and (9) the key would be
11. Let the modified blocks are formed as follows

\[ A_{\text{watermarked}} = U_{\text{watermarked}} V_{\text{watermarked}}^T, \quad i = 1, 2, \ldots, pq, \]  

where, the subscript ‘watermarked’ is representing the modified (or watermark added) blocks.

12. The modified blocks \( A_{\text{watermarked}} \) are combined to form modified first principal component \( P_{\text{watermarked}} \), where

\[
P_{\text{watermarked}} = \begin{bmatrix}
P_{r11} & P_{r12} & \cdots & P_{r1N} \\
P_{r21} & P_{r22} & \cdots & P_{r2N} \\
\vdots & \vdots & \ddots & \vdots \\
P_{rM1} & P_{rM2} & \cdots & P_{rMN}
\end{bmatrix}.
\]

13. The modified principal components are obtained as

\[
P_{\text{watermarked}} = \begin{bmatrix}
P_{r1} \\
P_{r2} \\
P_{b}
\end{bmatrix}
\]

where \( P_{\text{watermarked}} \) is a row vector, obtained from \( P_{\text{watermarked}} \).

14. The matrix \( A_{\text{watermarked}} \) is obtained as

\[
A_{\text{watermarked}} = Q P_{\text{watermarked}} =
\]

\[
\begin{bmatrix}
r_{w11} & \cdots & r_{w1N} & r_{w21} & \cdots \\
q_{11} & \cdots & q_{1N} & q_{21} & \cdots \\
\vdots & \cdots & \vdots & \vdots & \ddots \\
r_{w2N} & \cdots & r_{wM1} & \cdots & r_{wMN} \\
q_{2N} & \cdots & q_{M1} & \cdots & q_{MN} \\
\vdots & \cdots & \vdots & \vdots & \ddots \\
b_{2N} & \cdots & b_{M1} & \cdots & b_{MN}
\end{bmatrix}.
\]

15. Finally, \( R_{\text{watermarked}} \), \( G \) and \( B \) channels are combined to form the watermarked image \( I_{\text{watermarked}} \), where

\[
R_{\text{watermarked}} = \begin{bmatrix}
r_{w11} & r_{w12} & \cdots & r_{w1N} \\
r_{w21} & r_{w22} & \cdots & r_{w2N} \\
\vdots & \vdots & \ddots & \vdots \\
r_{wM1} & r_{wM2} & \cdots & r_{wMN}
\end{bmatrix}.
\]

### 3.2 Watermark Extraction

1. Let received watermarked image \( I_{\text{watermarked}} \) be decomposed into its components \( \hat{R}_{\text{watermarked}}, \hat{G}, \) and \( \hat{B} \), where

\[
\hat{R}_{\text{watermarked}} = \begin{bmatrix}
r_{\text{watermarked}11} & r_{\text{watermarked}12} & \cdots & r_{\text{watermarked}1N} \\
r_{\text{watermarked}21} & r_{\text{watermarked}22} & \cdots & r_{\text{watermarked}2N} \\
\vdots & \vdots & \ddots & \vdots \\
r_{\text{watermarked}M1} & r_{\text{watermarked}M2} & \cdots & r_{\text{watermarked}MN}
\end{bmatrix}.
\]

2. Let a covariance matrix \( \hat{C} \) be computed as

\[
\hat{C} = \frac{1}{MN} (\hat{A}^T \hat{A}) = \hat{Q} \hat{\lambda} \hat{Q}^{-1}
\]

where

\[
\hat{A} = \begin{bmatrix}
r_{w11} & \cdots & r_{w1N} & r_{w21} & \cdots \\
q_{11} & \cdots & q_{1N} & q_{21} & \cdots \\
\vdots & \vdots & \vdots & \vdots & \ddots \\
r_{w2N} & \cdots & r_{wM1} & \cdots & r_{wMN} \\
q_{2N} & \cdots & q_{M1} & \cdots & q_{MN} \\
\vdots & \vdots & \vdots & \vdots & \ddots \\
b_{2N} & \cdots & b_{M1} & \cdots & b_{MN}
\end{bmatrix}.
\]

\[
\hat{\lambda} = \begin{bmatrix}
\hat{\lambda}_{11} & 0 & 0 \\
0 & \hat{\lambda}_{22} & 0 \\
0 & 0 & \hat{\lambda}_{33}
\end{bmatrix}
\]

\( \hat{\lambda}_{11} \geq \hat{\lambda}_{22} \geq \hat{\lambda}_{33} \) are eigenvalues in descending order.

3. The principal components of covariance matrix \( \hat{C} \) are calculated as

\[
\hat{P}_{\text{w}} = \begin{bmatrix}
\hat{P}_{r1} \\
\hat{P}_{r2} \\
\hat{P}_{b}
\end{bmatrix} = \hat{Q}^T \hat{A} =
\]

\[
\begin{bmatrix}
\hat{P}_{r11} & \cdots & \hat{P}_{r1N} & \hat{P}_{r21} & \cdots \\
\hat{P}_{r21} & \cdots & \hat{P}_{r2N} & \hat{P}_{b1} & \cdots \\
\vdots & \vdots & \vdots & \vdots & \ddots \\
\hat{P}_{rM1} & \cdots & \hat{P}_{rM2} & \cdots & \hat{P}_{bM}
\end{bmatrix}.
\]

4. Let matrix \( \hat{P}_{\text{watermarked}} \) obtained by converting row vector \( P_{\text{watermarked}} \) into a matrix of size \( M \times N \) as shown below

\[
\hat{P}_{\text{watermarked}} = \begin{bmatrix}
\hat{P}_{r11} & \hat{P}_{r12} & \cdots & \hat{P}_{r1N} \\
\hat{P}_{r21} & \hat{P}_{r22} & \cdots & \hat{P}_{r2N} \\
\vdots & \vdots & \ddots & \vdots \\
\hat{P}_{rM1} & \hat{P}_{rM2} & \cdots & \hat{P}_{rMN}
\end{bmatrix}.
\]

5. The \( \hat{P}_{\text{watermarked}} \) is divided into non-overlapping blocks \( \hat{A}_{\text{watermarked}}, \hat{A}_{\text{watermarked}2}, \ldots, \hat{A}_{\text{watermarked}pq} \), each of size \( 4 \times 4 \). Using SVD, each block is decomposed as follows:

\[
\hat{A}_{\text{watermarked}} = \hat{O}_{\text{watermarked}} \hat{S}_{\text{watermarked}} \hat{V}_{\text{watermarked}}^T, \quad i = 1, 2, \ldots, pq.
\]
6. Based on keys: $\Xi_{i} = \{k_{1}, k_{2}, k_{3}\}$, the watermarking bits are extracted as follows:

$$\xi = \begin{cases} 1, & \text{if } \tilde{u}_{wi}(k_{2}, k_{1}) \leq \hat{u}_{wi}(k_{2}, k_{1}), \\ 0, & \text{otherwise.} \end{cases}$$

(14)

$$\zeta = \begin{cases} 1, & \text{if } \tilde{v}_{wi}(k_{2}, k_{1}) \leq \hat{v}_{wi}(k_{2}, k_{1}), \\ 0, & \text{otherwise.} \end{cases}$$

(15)

$$\psi = \begin{cases} 1, & \text{if } \tilde{\delta}_{wi}(k_{2}, k_{1}) \leq \hat{\delta}_{wi}(k_{2}, k_{1}), \\ 0, & \text{otherwise.} \end{cases}$$

(16)

Once three values $\xi$, $\zeta$, and $\psi$ are calculated for each block, then watermarking bits are extracted as follows.

$$\hat{W}_{i} = \begin{cases} \psi, & \text{if } (\xi = \psi) \lor (\zeta = \psi), \\ \theta, & \text{otherwise} \end{cases}$$

(17)

where

$$\theta = \text{Mode}\{\xi, \psi, \zeta\}.$$

4. Proposed Scheme 2

The only difference in proposed scheme 1 and 2 is that, in scheme 2 neither HVS nor FIS used to find adaptive factor $\alpha_{ML}$ for watermark embedding. Instead only constant scaling factor $\beta$ having values from 0.1 to 0.9 with a step size of 0.2 is used. The watermark embedding and extraction procedure are described in following sections.

4.1 Watermark Embedding

Eliminating step 8 and step 9, and the terms $\alpha_{ML}(g, f)$, $\alpha_{ML}(e, f)$, $\alpha_{ML}(f, g)$ and $\alpha_{ML}(f, e)$ from (7)–(10) of Sec. 3.1 will reduce to watermark embedding procedure of proposed scheme 2.

4.2 Watermark Extraction

The watermark extraction procedure of proposed scheme 2 is same as of proposed scheme 1 which is described in Sec. 3.2.

5. Experimental Results

In order to test the performance of proposed schemes a number of experiments were performed. For this purpose six different images shown in Fig. 3, each of size $512 \times 512$ were used as host images. Whereas for watermark a binary image shown in Fig. 4(a) of size $64 \times 64$ was used. The performance of proposed schemes is evaluated in terms of imperceptibility, robustness, security and capacity, which are discussed in following sections.

5.1 Imperceptibility

To end user the original and watermarked image should look similar, in other words, there should be no visible difference between original and watermarked images [3], this is referred as imperceptibility. For qualitative analysis watermarked images are shown in Fig. 3, whereas, for quantitative evaluation Peak-Signal-to-Noise-Ration (PSNR) [7] shown in (18) is used to measure imperceptibility. The PSNR for proposed scheme 1 for different images and for distinct constant scaling factor is shown in Tab. 1. The use of constant scaling factor here is only for reference, otherwise, proposed scheme 1 performs well without constant scaling factor.

The watermarked images are shown for proposed scheme 1, however, the watermarked images obtained from proposed scheme 2 also have good perceptual quality.

$$PSNR(dB) = 10 \log_{10} \left( \frac{G^{2}}{H} \right)$$

(18)

where

$$G = \max(I(m, n) : 1 \leq m \leq M, 1 \leq n \leq N),$$

$$H = \frac{1}{M \times N} \sum_{m=1}^{M} \sum_{n=1}^{N} (I(m, n) - I_{w}(m, n))^{2}.$$
Information Fidelity (VIF) and Normalized Color Difference (NCD) also used to examine the quality of watermarked images, quantitatively. Therefore, in this paper in addition to PSNR, SSIM, VIF and NCD are also utilized for evaluation [3]. SSIM [19] utilizes luminance ($L$), contrast ($C$) and structural information ($S$) to find the distortion introduced in watermarked images. Given original $I$ and watermarked $I_w$ images, the SSIM can be calculated using (19).

\[
SSIM(I, I_w) = L(I, I_w)^{\gamma_L} \times S(I, I_w)^{\gamma_S} \times C(I, I_w)^{\gamma_C}
\]  

where $\gamma_L > 0$, $\gamma_S > 0$ and $\gamma_C > 0$, are constant used to describe the dependency of each component. For equal contribution of $L$, $S$ and $C$ in the calculation of SSIM, $\gamma_L = \gamma_S = \gamma_C = 1$ are set equal to 1. The $L$, $C$ and $S$ defined in (19) are calculated as follows.

\[
L(I, I_w) = \frac{2\mu_I \mu_{I_w} + C_1}{\mu_I^2 + \mu_{I_w}^2 + C_1}, 
C(I, I_w) = \frac{2\rho_I \rho_{I_w} + C_2}{\rho_I^2 + \rho_{I_w}^2 + C_2}, 
S(I, I_w) = \frac{\rho_{I_w}}{\rho_I^2 \rho_{I_w}^2 + C_3}
\]

(20)

where $\mu_I$, $\mu_{I_w}$, $\rho_I$ and $\rho_{I_w}$ denotes the mean and covariance of host and watermarked images respectively. $C_1$, $C_2$ and $C_3$ are small constants used to avoid the situations where the sum of means or covariances can be zero. Using (20) and setting $C_3 = C_2/2$ in (19), will result in the form of equation shown below

\[
SSIM = \frac{(2\mu_I \mu_{I_w} + C_1) \times (2\rho_I \rho_{I_w} + C_2)}{(2\mu_I^2 + \mu_{I_w}^2 + C_1) \times (2\rho_I^2 + \rho_{I_w}^2 + C_2)}.
\]

(21)
The comparison of proposed schemes with existing techniques in terms of SSIM shown in Tab. 3, clearly demonstrates the improvement of proposed schemes over present watermarking techniques.

VIF [20] introduced in 2006 is also used to assess the quality of images. In this paper VIF shown in (22), is also used to examine the quality of watermarked images with respect to original host images

$$\text{VIF} = \frac{\sum_{j=1}^{C} I_{C,N,j}^{2} \sum_{j=1}^{C} I_{C,N,j}^{2}}{\sum_{j=1}^{C} I_{C,N,j}^{2} \sum_{j=1}^{C} I_{C,N,j}^{2}}$$

where \(I_{C,N,j}^{2}\) and \(I_{C,N,j}^{2}\) represent the information that a brain can extract from images using HVS of original and watermarked images respectively, \(\overline{C}_{N,j}\) represents the \(N\) elements of random field \(C_{j}\) for \(j\) \(th\) sub-band. For detailed description of parameters and calculation of information \(I\) from host and watermarked images, [20] can be referred.

The comparison in terms of VIF of proposed schemes with that of state-of-the-art techniques is shown in Tab. 4. The better visual quality of watermarked images obtained from proposed schemes is clearly visible from the results shown in Tab. 4.

Finally, NCD [3] shown in (23), is also used to evaluate the quality of watermarked images.

$$\text{NCD} = \frac{\sum_{i=1}^{M} \sum_{j=1}^{N} \sqrt{\sum_{i=1}^{M} \sum_{j=1}^{N} \sum_{i=1}^{M} \sum_{j=1}^{N} (h_{i,j} - a_{i,j})^2 + (b_{i,j} - a_{i,j})^2}}{\sum_{i=1}^{M} \sum_{j=1}^{N} \sum_{i=1}^{M} \sum_{j=1}^{N} (h_{i,j} + b_{i,j})^2}$$

where \(L\) represents the luminance, \(a\) and \(b\) denote the chrominance. It should be noted that in order to calculate NCD, the RGB color model must be converted to Lab color space.

The performance of proposed scheme is calculated in terms of NCD and compared with existing schemes as shown in Tab. 5.

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5.2 Robustness

Robustness refers to the ability of watermarking scheme to withstand against intentional or unintentional attacks, that may be applied on watermarked images either to remove or to destroy the hidden information [7], [21]. Robustness is measured using normalized correlation [6] shown in (24). In order to check the robustness of proposed schemes different attacks like rotation (RO), translation (TR), y-shearing (YSH), x-shearing (YSH), scaling (SC), cropping (CR), affine transformation (AFT), Gaussian noise (GN), salt & pepper noise

<table>
<thead>
<tr>
<th>Images</th>
<th>Proposed in</th>
<th>Presented in</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lena</td>
<td>0.9859</td>
<td>0.8543</td>
</tr>
<tr>
<td>Baboon</td>
<td>0.9118</td>
<td>0.8796</td>
</tr>
<tr>
<td>Autumn</td>
<td>0.9439</td>
<td>0.9279</td>
</tr>
<tr>
<td>Airplane</td>
<td>0.9428</td>
<td>0.8921</td>
</tr>
<tr>
<td>Peppers</td>
<td>0.9653</td>
<td>0.9130</td>
</tr>
<tr>
<td>Crane</td>
<td>0.9259</td>
<td>0.9033</td>
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</table>

<table>
<thead>
<tr>
<th>Images</th>
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<th>Presented in</th>
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</thead>
<tbody>
<tr>
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<tr>
<td>Baboon</td>
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<tr>
<td>Autumn</td>
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</tr>
<tr>
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<td>0.0364</td>
</tr>
<tr>
<td>Peppers</td>
<td>0.0448</td>
<td>0.0758</td>
</tr>
<tr>
<td>Crane</td>
<td>0.0268</td>
<td>0.0496</td>
</tr>
</tbody>
</table>

Fig. 4. Extracted watermarks from attacked watermarked images (proposed scheme 1 (\(\beta = 0.5\)): (a) Original watermark (b) RO, (c) TR, (d) XSH, (e) YSH, (f) AFT, (g) SC, (h) CR, (i) GN, (j) S&P (k) SN, (l) MB, (m) SB, (n) AF, (o) HE, (p) JQ (q) JQ+AF, (r) JQ+GN, (s) JQ+SC (t) RO+SC.

Tab. 3. SSIM for different techniques.

Tab. 4. VIF for different techniques.

Tab. 5. NCD for different techniques.
(S&P), speckle noise (SN), motion blurring (MB), simple blurring (SB), average filtering (AF), histogram equalization (HE) and JPEG compression (JQ) were applied on watermarked image. In addition to conventional watermarking attacks, combined attacks are formed by combining two or more conventional attacks. For instance, watermark is tried to be extracted form a watermarked images that has been subjected to JPEG compression and filtering attack. In this way five additional attacks – JPEG compression plus filtering (JQ+AF), JPEG compression plus Gaussian noise (JQ+GN), JPEG compression plus scaling (JQ+SC), translation plus x and y shearing (TR+SH), and rotation plus scaling (RO+SC) – are also used to check robustness of proposed schemes.

\[
NC = \frac{\sum_{p=1}^{P} \sum_{q=1}^{Q} W(p,q) \times \tilde{W}(p,q)}{\sqrt{\sum_{p=1}^{P} \sum_{q=1}^{Q} W^2(p,q) \times \sqrt{\sum_{p=1}^{P} \sum_{q=1}^{Q} \tilde{W}^2(p,q)}}}, \tag{24}
\]

For qualitative assessment of extracted watermarks after applying above mentioned attacks on watermarked image, Fig. 7 can be referred. It can be seen that in all cases the extracted watermarks are clearly visible hence can be used to prove ownership. The performance of proposed scheme 1 in terms of robustness for different scaling factors is shown in Tab. 6. In general with increasing scaling factor the robustness is increased [3], whereas, the change in NC values shown in Tab. 6, is random and that is due to the adaptive scaling factor (\(\alpha_{ML}\)).

The comparison of proposed schemes in terms of NC with existing technique [3], [6], [13] and [14] is shown in Tab. 7. Robustness of watermarking techniques are also measured using Bit Error Rate (BER) [3], shown in (25). The comparison of proposed schemes in terms of BER with [3], [6], [13] and [14] is shown in Tab. 8. From Tab. 7 and Tab. 8, it is clear that the proposed schemes give better results in terms of robustness as well.

\[
BER = \frac{\text{Number of wrong bits extracted}}{\text{Total number of bits embedded}}. \tag{25}
\]

The extracted watermarks shown in Fig. 4 are for proposed scheme 1, however, the quality of watermarks obtained using proposed scheme 2 is also good. This can be seen from Tab. 7 that there is not significant difference between NC
values of both proposed schemes. The recognizable watermarks can be extracted as long as the distorted watermarked image are visually identifiable.

Besides NC and BER, there are other ways to calculate the credibility of extracted watermarks quantitatively. For instance, Normalized Hamming Distance (NHD) [6] shown in (26), where, $w$ and $\hat{w}$ represent embedded and extracted watermark respectively, can be used to calculate the similarity (or difference) between embedded and extracted watermarks.

$$H_D = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} h_{w,\hat{w}}(i, j)}{m \times n}$$  \hspace{1cm} (26)

where

$$h_{w,\hat{w}}(i, j) = \begin{cases} 1, & \text{if } w(i, j) = \hat{w}(i, j), \\ 0, & \text{otherwise.} \end{cases}$$

Similarly, Global Authentication Rate (GAR) [22] shown in (27) is also used to check the quality of extracted watermark. It should be noted that GAR and NHD are almost same just different form of representations

$$\rho_{\text{GAR}} = \left(1 - \frac{1}{m \times n} \sum_{i=1}^{m} \sum_{j=1}^{n} (w(i, j) \oplus \hat{w}(i, j)) \right) \times 100 \%.$$  \hspace{1cm} (27)

The performance of proposed schemes is examined using both NHD and GAR in terms of robustness and also compared with other watermark techniques.

The comparision of proposed and existing watermarking schemes in terms of NHD is shown in Fig. 5(a) and in terms of GAR in Fig. 5(b). Both figures clearly demonstrate the improvement of proposed scheme over existing watermarking techniques.
5.3 Security

Security refers to the resistance against false positive or true negative extraction of watermark [5]. In designing the proposed schemes security is given high importance and it was ensured to nullify the chances of false positive or true negative detection or extraction of hidden information. To test the security ample number of fake keys were used to extract the watermark neither true nor false watermark was extracted. In Fig. 6 the extracted watermarks with false keys are shown. It is evident that no watermark was extracted.

5.4 Capacity

Capacity refers to the amount of data that can be embedded into the host image without degrading the quality of watermarked image. The capacity of proposed schemes is \((64 \times 64 \times 3 = 12288)\), since watermark of size \(64 \times 64\), and all three components (\(U\), \(S\) and \(V\)) of SVD decomposition are used. This is considered to be good capacity for a watermarking scheme. The capacities of proposed schemes are 3 times more than the capacities of [3] and [6].

6. Conclusion

In this paper, two watermarking schemes are proposed. In order to achieve four conflicting requirements for a good watermarking scheme, HVS, FIS, PCA and SVD are used together. The perceptual quality is improved by using PCA to decorrelate the three channels of color image, afterwards HVS and FIS are used to find adaptive scaling factor so that the amount of information embedded is subject to the acceptability of host image. For instance, the areas which are less prone to modifications are modified to lesser extent as compared to areas which are open to changes. In this way imperceptibility is further improved, and can be seen from results that the imperceptibility of proposed scheme 1 is much better than proposed scheme 2 (HVS and FIS are not employed in proposed scheme 2, otherwise it is same as proposed scheme 1). To achieve robustness, SVD is used, as changes in singular values does not change the image and vice versa. Whereas to obtain security, based on correlation certain elements from SVD components are selected for modification, and then those locations served as key at the time of watermark extraction. In this way not only security and capacity are achieved but this method also helped to improve the imperceptibility as suggested by results. The proposed schemes are compared with state-of-the-art watermarking techniques and obtained better results.

References


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