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Rightful ownership through image adaptive DWT-SVD watermarking algorithm and perceptual tweaking

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Abstract In this paper, a tailored blended image adaptive watermarking scheme has been presented, which is based on DWT and SVD. Through this paper an attempt has been made to solve the problem of false positive while maintaining the robustness and imperceptibility with the help of principal component and perceptual tuning of the image. Perceptual tuning is a non-blind technique and based on the objective quality of image. The embedding strength is made dependent on watermark features as well as of host in wavelet domain by using tuning parameter which is user specific. The idea of embedding the principal component of intermediate frequency sub-bands of watermark image into singular values of perceptually tuned intermediate frequency sub-bands of host image have been exploited. The proposed algorithm is providing the adaptive behavior towards the image content for perceptual transparency and at the same time avoiding the possibility of false watermark extraction well supported by a private key, which is necessary at the time of extraction. Thus the proposed watermarking algorithm is a kind of non-blind, image adaptive and suitable for rightful ownership. Various comparative results make the algorithm superior in terms of intentional and non-intentional attacks. Also the algorithm is strong against the print and scan attack.

Keywords Singular value decomposition · False positive problem · Principal component · Tuning matrix · Adaptive and blended watermarking

1 Introduction

Economic development of the internet technologies and associated services has been augmented significantly leading to the problem of rightful ownership and associated copyright to be protected. This has led to a chance of a new opportunity in developing new copy prevention and enrichment mechanisms giving the digital watermarking as an obvious

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solution [2, 15, 27, 32]. By using the technology as a robust covert communication channel, digital watermarks could have a wide range of applications in the sectors like defense and intelligence, where traditional data hiding techniques have been used for centuries. Digital watermarking is the process of embedding information into digital, while embedding must be ended in such a way so that, perceptual degradation is nil, at the same time non-removable by unauthorized parties and must be robust against various intentional and non-intentional attacks [36]. All the reported watermarking algorithms can be broadly divided into two categories namely spatial and transform-domain. The algorithms used for spatial domain watermarking to directly modify the pixel values of the host image while the transformed coefficients of the host images have been modified to embed the watermarks in transform domain routines. Unluckily the reported watermarking routines suffer from a variety of malicious and non-malicious attacks. Some routines are resistant to one kind of attacks then, on the other side, its robustness may suffer for other kind of attacks. Spatial domain algorithms are easier to implement, however not robust, while the transform domain techniques are relatively more reliable and robust to various attacks [14, 32]. The frequency domain algorithms are resistant to filtering and compressions attacks and are generally, rotation, translation and scale invariant. Discrete Cosine Transform (DCT) [5, 8, 9, 13] and Discrete Wavelet Transform (DWT) [6, 11, 22, 23, 33] are commonly used frequency domain techniques. The watermark can be embedded in various sub-bands (either low frequency or high ones) after wavelet decomposition of host and/or watermark image. Watermarks inserted in the low frequencies are robust against the attack having low pass characteristics e.g. filtering, lossy compression, and geometric distortions in contrast to high frequency embedding which is robust to attack having high pass response like histogram equalization, gamma correction and brightness adjustments [16]. Lin et al. [25] have been proposed a copyright protection scheme based on 1/T forward error correction for gray-level digital images. In this scheme feature value has been generated by its corresponding gray-level of the image and XORed with the embedding bits. Consequently Lin et al. [26–28] have been proposed a blind watermarking algorithm by applying the concept of wavelet coefficient quantization for copyright protection. In this scheme watermark has been embedded into the local maximum wavelet coefficient of host image.

Recently singular value decomposition (SVD), a new transform for watermarking has been introduced and the first algorithm has been proposed by Liu et al. [29] in 2002. The main feature of SVD-based image watermarking is the stability of singular values, which contain most of the image energy. In this algorithm the singular values of the host image are modified by directly adding the gray scale watermark image of the same size as of host image. SVD was again applied to the resultant matrix for finding the modified singular values. These modified singular values were combined with the known component to get the watermarked image. Similarly for the watermark extraction inverse process was adopted. The algorithm proposed by Liu et al. [12] is fundamentally imperfect and encompasses the watermark ambiguity/false-positive problem. In false positive problem it was possible to extract a watermark which was not actually the embedded one [35, 37, 38]. The problem of rightful ownership has been addressed by few authors through hybrid DWT-SVD based algorithms [3, 4, 7, 10, 12, 16, 17, 19, 24, 29, 39]. Jain et al., *2008* [21] reported reliable SVD-based image watermarking algorithms which were capable of dealing the false positive problem. The authors embed the principal component of watermark into the host image rather than only the singular value of the watermark. These algorithms were based on the fact that SVD subspaces (left and right singular vectors) can preserve a significant amount of information about an image. Lai et al. [12] suggested a hybrid DWT-SVD watermarking procedure in which two halves of the watermark image are embedded into the two singular value matrices of intermediate frequency sub-bands obtained while taking one level DWT of host image. After embedding the watermark, the two halves are combined to get the watermarked image. At the time of the extraction reverse procedure is adopted to get the extracted watermark image. This particular watermarking technique has shown the significant improvement over the other parallel watermarking approaches in terms of imperceptibility and robustness under an assortment of attacks but at the same time it suffers from the problem of false positive. The SVD-based watermarking and its variations which have been reported through literature [3, 4, 7, 10, 12, 16, 17, 19, 24, 29, 39] mainly deals with robustness and impeccability issues while overlooking the problem of false positive associated copyright ownership. However Run et al. [34] suggested a watermarking scheme that solves the ambiguities and false positive problem but at the same time it suffers from the robustness and Imperceptibility of watermarked Image.

Through this paper an attempt has been proposed to highlight the problem of false positive occurring in Lai et al. [12] while maintaining the robustness and imperceptibility against a variety of attacks. The proposed approach is a hybrid one and based on DWT based transparent image watermarking algorithm through perceptual tuning and principal component of the watermark. The approach of perceptual tuning is based on the objective quality evaluation of watermarked images, which is essentially PSNR. Through the proposed algorithm the user can adjust the minimum required PSNR for watermarked images for maintaining the objective quality of images as well as watermark. The embedding strength will be modified on the basis of watermark and host image features in the wavelet domain as well as the tuning parameter. The principal component of intermediate frequency sub-bands of watermark image into singular values of intermediate frequency sub-bands of host image has been embedded. SVD subspaces contain the structural information of the decomposed image and are having a potential to be used for watermarking in juxtaposition with DWT. To avoid the possibility of false watermark extraction a concept private key has been adopted, which is necessary at the time of extraction. Thus the proposed watermarking algorithm is a kind of non-blind, mostly suitable for rightful ownership and also provides the adaptive behavior toward the image content for perceptual transparency.

Towards further organization, Section-2 gives the concise overview of the SVD, DWT and DWT-SVD based hybrid watermarking algorithm. Section-3 demonstrates the problem of false positive occurring in the hybrid DWT-SVD based algorithm proposed by Lai et al. [12] along with the theoretical and experimental support. The proposed watermarking embedding and extraction algorithm has been elaborated in section-4. Various experiments have been performed to make obvious robustness and reliability of the proposed algorithm in section-5. Section-5 also provides the graphical representation of comparative performance analysis on the basis of robustness and imperceptibility among various existing routines. Various discussions about the obtained results and associated conclusion have been accounted in section-6.

2 DWT-SVD based watermarking

2.1 Singular value decomposition

From the discernment of image processing an image can be viewed as a matrix with nonnegative scalar entries. SVD is an effective numerical analysis tool from linear algebra to decompose a rectangular matrix “A” into an orthogonal matrix U, diagonal matrix S, and the transpose of an orthogonal matrix V [3, 4, 7, 10, 12, 16, 17, 19, 24, 29, 32, 39]. SVD decomposes a given image A of size M×N as

$$A = USV^T$$

$$A = \begin{bmatrix} u_{1,1} & \cdots & u_{1,m} \\ u_{2,1}, & \cdots & , u_{2,m} \\ \vdots & \ddots & \vdots \\ u_{m,1}, & \cdots & u_{m,m}, \end{bmatrix} \begin{bmatrix} \sigma_{1,1} & 0 & 0 \\ 0, & \sigma_{2,2} & , 0 \\ \vdots & \ddots & \vdots \\ 0, & \cdots & \sigma_{m,n}, \end{bmatrix} \begin{bmatrix} v_{1,1} & \cdots & v_{1,n} \\ v_{2,1}, & \cdots & , v_{2,n} \\ \vdots & \ddots & \vdots \\ v_{n,1}, & \cdots & v_{n,n}, \end{bmatrix}^T$$

U and V are orthogonal matrices of size MxM and NxN, respectively. S is a diagonal matrix of size MxN having singular values and satisfy the property $\sigma_{1,1} > \sigma_{2,2} > \sigma_{3,3} > \ldots\ldots\ldots > \sigma_{n,n}$.

It is worth noting that, the singular vectors of an image specify the image "geometry" similarly left singular vectors represent horizontal details and right singular vectors represent the vertical details of an image, while the singular values specify the "luminance" (energy) of the image[18, 20]. Slight variations in the singular values do not affect the visual perception of the quality of the image. It is this property, based on psycho-visual effect that allows one to embed the Watermark bits in the original image through minor modification of the singular values of the original image. Singular value decomposition exhibits the properties of transpose, flip, rotation, scale and translation invariance, which are common geometric distortion attacks. These geometric invariance properties make SVD a very favorable tool for watermarking.

2.2 Discrete wavelet transform

Recently DWT has received significant attention in various signal processing applications, including image watermarking due to its ability to provide sufficient information both for analysis and synthesis of the original signal, with a significant reduction in the computation time. The wavelet transform decomposes the image into three spatial directions, i.e. horizontal, vertical and diagonal and reflect the anisotropic properties of Human Visual System (HVS) [6, 11, 22, 33]. DWT-based watermarking schemes follow the same guidelines as DCT-based schemes, i.e. the underlying concept is the same; however, the process to transform the image into its transform domain varies hence the resulting coefficients are different. Wavelet transforms use wavelet filters to transform the image, i.e. Haar Wavelet Filter, Daubechies Orthogonal Filters and Daubechies Bi-Orthogonal Filters. Each of these filters decomposes the image into several frequencies. Single level harr decomposition gives four frequency representations of the images called as *LL*, *LH*, *HL* and *HH* sub-bands. The watermark can be embedded in a variety of sub-bands (either low frequency, mid frequency and high frequency) after wavelet decomposition of host and/or watermark image. Watermarks inserted in low frequency sub-bands are robust against various types of image processing attacks but at the same time it compromises with the perceptual quality of image. If mid frequency sub-bands (LH and HL) of host image are used to embed the watermark then the perceptual quality of embedded watermarked is superior, whereas not much robust against a wide range of attacks. The problem of reliability also exists if the watermark is embedded either by any or all mid and high frequency sub-bands.

2.3 DWT-SVD based hybrid watermarking

Lai et al. [12], proposed a watermarking scheme in which the watermark is divided into two parts and directly embedded into the singular values of LH and HL sub bands. After that the inverse of wavelet transform was performed to reconstruct the watermarked Image. Let A (x, y) and W (x, y) be the original host Image and watermark image respectively while α is embedding strength. The watermark embedding procedure according to Lai et al. [12] is given below.

2.4 Watermark embedding

Step 1 One level Discrete Haar wavelet transform (DWT) was applied on $A(x,\ y\ )$ to get the four sub bands $(\ LL, LH, HL, HH)$

Step 2 Apply the SVD to wavelet coefficients of LH and HL sub bands

$$[U_{LH}, S_{LH}, V_{LH}] = SVD(A_{LH})$$
$$[U_{HL}, S_{HL}, V_{HL}] = SVD(A_{HL})$$

Step 3 Divide the watermark

$$W(x,\ y) = W_1(x1,\ y1) + W_2(x2,\ y2)$$

Step 4 Modify the singular values of HL and LH sub bands with half of the watermark and apply SVD to them

$$S^1{}_{LH} = S_{LH} + \alpha * W_1(x1,\ y1)$$
$$S^2{}_{HL} = S_{HL} + \alpha * W_2(x2,\ y2)$$

Step 5 Apply SVD to S_{LH} and S_{HL}

$$[U_{W1}, S_{W1}, V_{W1}] = SVD(S^1{}_{LH})$$
$$[U_{W2}, S_{W2}, V_{W2}] = SVD(S^2{}_{HL})$$

Step 6 Now two set of modified coefficients has been obtained for LH and HL sub bands

$$A^*{}_{LH} = (U_{LH}\ )(S_{W1})(V_{LH})^T$$
$$A^*{}_{HL} = (U_{HL}\ )(S_{W2})(V_{HL})^T$$

Step 7 Obtained the watermarked image $A^*(x,\ y\ )$ by applying the inverse DWT using the modified wavelet coefficients

Suppose $A^*(x,\ y\ )$ is the distorted watermarked Image then the watermark extraction procedure according to Lai et al. [12] is given below.

Watermark Extraction:

Step 1 One level Harr DWT was applied to $A^*(x,\ y\ )$ to get the four distorted sub bands (*LL*, *LH*, *HL*, *HH*)

Step 2 Apply SVD to LH and HL sub bands

$$\left[U_{LH}{}^*, S_{LH}{}^*, V_{LH}{}^*\right] = SVD\left(A^*_{LH}\right)$$
$$\left[U_{HL}{}^*, S_{HL}{}^*, V_{HL}{}^*\right] = SVD\left(A^*_{HL}\right)$$

Step 3 Now compute the

$$D_1 = (U_{W1})(S_{LH}^{\ *})(V_{W1})^T$$
$$D_2 = (U_{W2})(S_{HL}^{\ *})(V_{W2})^T$$

Step 4 Extract the part of watermark from both sub bands

$$W_1^{\ *}(x1, y1) = (D_1 - S_{LH})/\ \alpha$$
$$W_2^{\ *}(x2, y2) = (D_2 - S_{HL})/\ \alpha$$

Step 5 Now combine the two watermarks to get the exact watermark

$$W^* = W_1^{\ *}(x1,\ y1) + W_2^{\ *}(x2,\ y2)$$

Figures 1 and 2 respectively shows a block diagram of watermark embedding and the watermark extraction algorithm using Discrete Wavelet Transform-SVD (DWT-SVD) scheme as reported by Lai et al. [12].

3 Problem with SVD based watermarking

3.1 Problem of false positive

Due to the fact that in SVD based watermarking, the watermark image is embedded only in the singular values of the host image causes the false positive problem [35, 38]. One can show the presence of any watermark by using its left singular matrix (U) and right singular matrix (V) in place of embedded ones; such method cannot be used for rightful ownership and proper authentication of host image. It is well known fact that in SVD left singular matrix (U) and right singular matrix (V) preserve the major information about an image.

The detection of the watermark is mainly determined by these matrices not by diagonal matrix. By using the method given by Lai et al. [12], cameraman image of 128×128 dimensions has been embedded into the Lena image of 256×256 and asked for Pirate

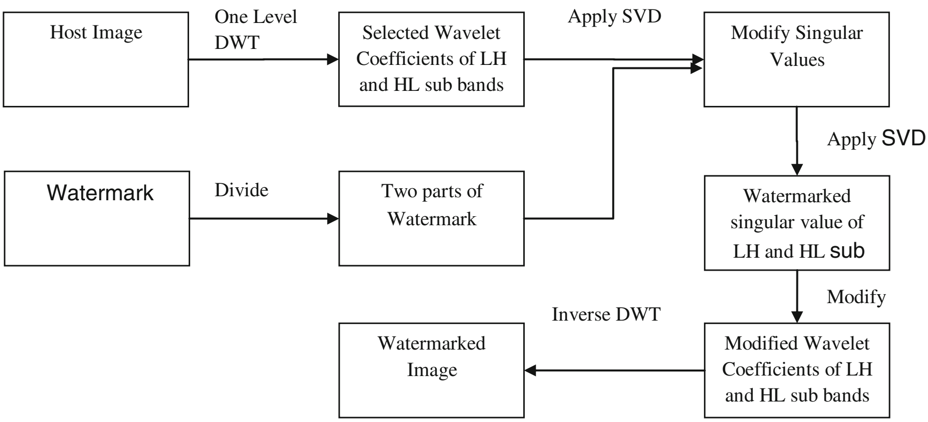

Fig. 1 Block diagram of watermark embedding technique given by Lai et al. [12]

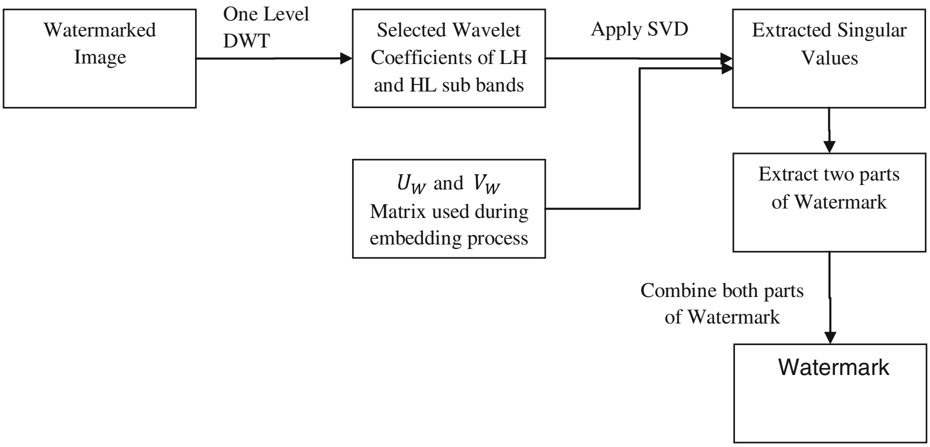

Fig. 2 Block diagram of watermark extraction technique given by Lai et al. [12]

image. The correlation coefficient of the constructed watermarks to pirate image is 0.9805, causing the false positive problem.

Suppose $A(x,\ y\ )$ is a host image and W1 and W2 is two watermarks. After embedding these two watermarks into host image, we got two watermarked Image $A_1(x,\ y)$ and $A_2(x,\ y)$.

Following algorithm has been used to embed and extract the false watermark from two different watermarked Images.

3.1.1 Watermark embedding algorithm

Step 1 One level Harr DWT was applied on $A(x,\ y\ )$ to get the four sub bands $(\ LL, LH, HL, HH)$

Step 2 Apply the SVD to wavelet coefficients of LH and HL sub bands

$$[U_{LH1}, S_{LH1}, V_{LH1}] = SVD(A_{LH})$$
$$[U_{HL2}, S_{HL2}, V_{HL2}] = SVD(A_{HL})$$

Step 3 Divide the watermark W_1 and W_2

$$W_1(x,\ y) = W_1^a(x1,\ y1) + W_1^b(x2,\ y2)$$
$$W_2(x,\ y) = W_2^a(x1, y1) + W_2^b(x2, y2)$$

Step 4 Modify the singular values of HL and LH sub bands with half of the watermark and apply SVD to them

$$S^a{}_{LH} = S_{LH1} + \alpha * W_1^a(x1, y1)$$
$$S^b{}_{HL} = S_{HL2} + \alpha * W_1^b(x2,\ y2)$$
$$S^c{}_{LH} = S_{LH1} + \alpha * W_2^a(x1,\ y1)$$
$$S^d{}_{HL} = S_{HL2} + \alpha * W_2^b(x2,\ y2)$$

Step 5 Apply SVD on Sa_{LH},Sb_{HL}, Sc_{LH} and Sd_{HL}.

$$\begin{aligned}[U_{W1}, S_{W1}, V_{W1}] &= SVD(S^a{}_{LH})\\ [U_{W2}, S_{W2}, V_{W2}] &= SVD\left(S^b{}_{HL}\right)\\ [U_{W3}, S_{W3}, V_{W3}] &= SVD(S^c{}_{LH})\\ [U_{W4}, S_{W4}, V_{W4}] &= SVD\left(S^d{}_{HL}\right)\end{aligned}$$

Step 6 Now obtained two set of modified coefficients for LH and HL sub bands

$$\begin{aligned}A^1{}_{LH} &= (U_{LH1})(S_{W1})(V_{LH1})^T\\ A^1{}_{HL} &= (U_{HL2})(S_{W2})(V_{HL2})^T\\ A^2{}_{LH} &= (U_{LH1})(S_{W3})(V_{LH1})^T\\ A^2{}_{HL} &= (U_{HL2})(S_{W4})(V_{HL2})^T\end{aligned}$$

Step 7 Now obtained the two watermarked images $A_1(x,\ y)$ and $A_2(x,\ y)$ by applying the inverse DWT using the modified wavelet coefficients $A^1{}_{LH}$, $A^1{}_{HL}$, $A^2{}_{LH}$, $A^2{}_{HL.}$

Suppose $A_1(x,\ y)$ and $A_2(x,\ y)$ are two different watermarked Images then by using the following algorithm we can extract the false watermark from Lai et al. [24].

3.1.2 Watermark extraction algorithm

Step 1 One level Haar DWT has been applied to $A_1(x,\ y)$ and $A_2(x,\ y)$ to get the four sub bands (*LL*, *LH*, *HL*, *HH*)

Step 2 Apply SVD on possibly distorted LH and HL sub bands

$$\begin{aligned}\left[U_{LH1}{}^*, S_{LH1}{}^*, V_{LH1}{}^*\right] &= SVD\left(A^{1^*}{}_{LH}\right)\\ \left[U_{HL2}{}^*, S_{HL2}{}^*, V_{HL2}{}^*\right] &= SVD\left(A^{1^*}{}_{HL}\right)\\ \left[U_{LH3}{}^*, S_{LH3}{}^*, V_{LH3}{}^*\right] &= SVD(A^{2^*}{}_{LH})\\ \left[U_{HL4}{}^*, S_{HL4}{}^*, V_{HL4}{}^*\right] &= SVD\left(A^{2^*}{}_{HL}\right)\end{aligned}$$

Step 3 Now D_1, D_2, D_3, D_4 has been computed by using U_W and V_W matrices used during embedding process.

$$\begin{aligned}D_1 &= (U_{W1})\left(S_{LH1}{}^*\right)(V_{W1})^T\\ D_2 &= (U_{W2})\left(S_{HL2}{}^*\right)(V_{W2})^T\\ D_3 &= (U_{W3})\left(S_{LH3}{}^*\right)(V_{W3})^T\\ D_4 &= (U_{W4})\left(S_{HL4}{}^*\right)(V_{W4})^T\end{aligned}$$

Step 4 Extract different parts of watermark from both LH and HL sub bands

$$\begin{aligned}W_1^{a^*}(x1,\ y1) &= (D_1 - S_{LH1})/\alpha\\ W_1^{b^*}(x2, y2) &= (D_2 - S_{HL2})/\alpha\\ W_2^{a^*}(x1, y1) &= (D_3 - S_{LH3})/\alpha\\ W_2^{b^*}(x2, y2) &= (D_4 - S_{HL4})/\alpha\end{aligned}$$

Step 5 Now different parts of watermark have been combined to get the exact watermark

$$W_1^* = W_1^{a*}(x1, y1) + W_1^{b^*}(x2, y2)$$
$$W_2^* = W_2^{a*}(x1, y1) + W_2^{b^*}(x2, y2)$$

Step 6 Now we can extract the false watermark by using U_{W3}, U_{W4}, $V_{W3}$and V_{W4} matrix of watermark W_2 and $S_{LH1}{}^*$ and $S_{HL2}{}^*$ matrix of watermark W_1.

$$D^1{}_{false} = (U_{W3})(S_{LH1}{}^*)(V_{W3})^T$$
$$D^2{}_{false} = (U_{W4})(S_{HL2}{}^*)(V_{W4})^T$$
$$W^1{}_{false}(x1,\ y1) = (D^1{}_{false} - S_{LH1})/\alpha$$
$$W^2{}_{false}(x2, y2) = (D^2{}_{false} - S_{HL2})/\alpha$$
$$W_{false} = W^1{}_{false}(x1, y1) + W^2{}_{false}(x2, y2)$$
$$W_{false} \Rightarrow W_2$$

Figure 3 shows the false positive problem of DWT-SVD based image watermarking proposed by Lai et al. [12]. Figure 3(a) and (b) are the host image of size 256×256 and watermark of size 128×128 respectively. Figure 3(c) is a watermarked image with the cameraman image and Fig. 3(d) depicts the desired watermark of pirate by using U_W and V_W matrix of pirate and singular value of watermarked image with cameraman.

4 Proposed watermarking process

The proposed scheme is based on the facts and observations about the various DWT-SVD based watermarking systems that to show the resistive behavior to normal signal and image processing and other attacks but suffers from the false positive problem. It's well known to all that the robustness and imperceptibility are contradictory requirements for any efficient watermarking system. The embedding strength is selected similar or same for the all types of images, irrespective of the image contents. If the images to be inserted are different then they may pose perceptual distortions. Different watermark images will show totally indifferent performance in terms of visual transparency and robustness. Through the proposed approach the watermarking strength is modified according to the content of the image to be watermarked, hence showing an adaptive behavior in the DWT-SVD domain. Figures 4 and 5 has been consequently used to represent the block diagram of proposed watermark embedding and extraction algorithm.

The following sub-sections are describing the perceptual tuning matrix formulation, principal component and watermark embedding/extraction algorithm.

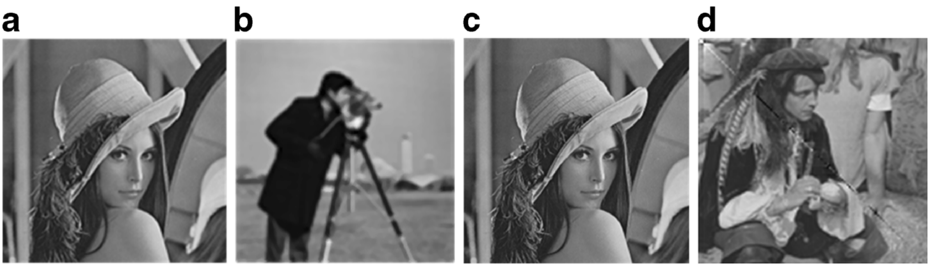

Fig. 3 **a** Host image **b** Original watermark **c** Watermarked Image **d** Extracted false watermark from Lai & Tsai [12]

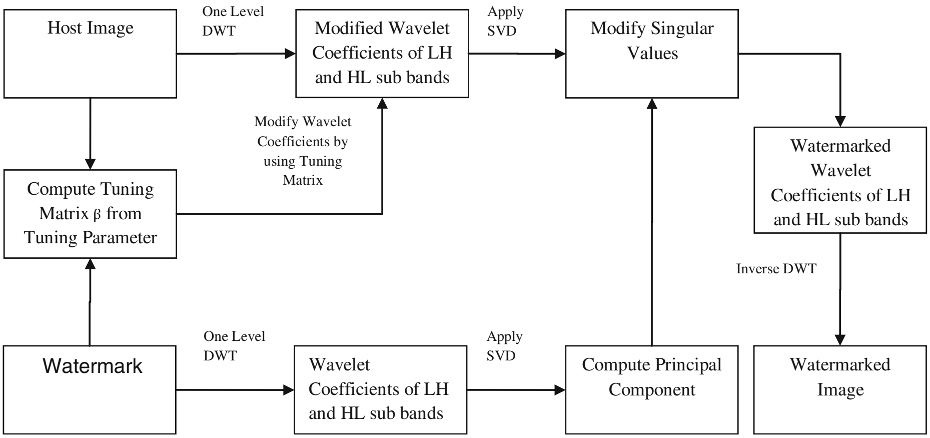

Fig. 4 Block diagram of proposed watermark embedding technique

4.1 Perceptual tuning and formulation of embedding strength matrix

The proposed algorithm is based on perceptual tuning of embedding strength while considering the pixel-by-pixel mean square error after modification in approximate wavelet coefficients. Let the adopted watermarking algorithm be additive in nature and A, W and A_w be original-host, watermark and watermarked images of same size $N \times N$ respectively. After taking the one level wavelet transform, the approximation, horizontal, vertical and diagonal details A_{LL}, A_{LH}, A_{HL}, A_{HH} and W_{LL}, W_{LH}, W_{HL}, W_{HH} of host and watermark image, has been obtained respectively. Similarly the approximation, horizontal, vertical and diagonal details for watermarked image are given as $A^w_{LL}, A^w_{LH}, A^w_{HL}, A^w_{HH}$. Assuming the pixel-by-pixel embedding of approximation of watermark image into approximate part of host image, the pixel wise square error $e(i,j)^2$ is given by,

$$e(i,j)^2 = (A_I(i,j) - A_{wI}(i,j))^2 : 0 \leq i \,\&\, j \leq N/2 \tag{1}$$

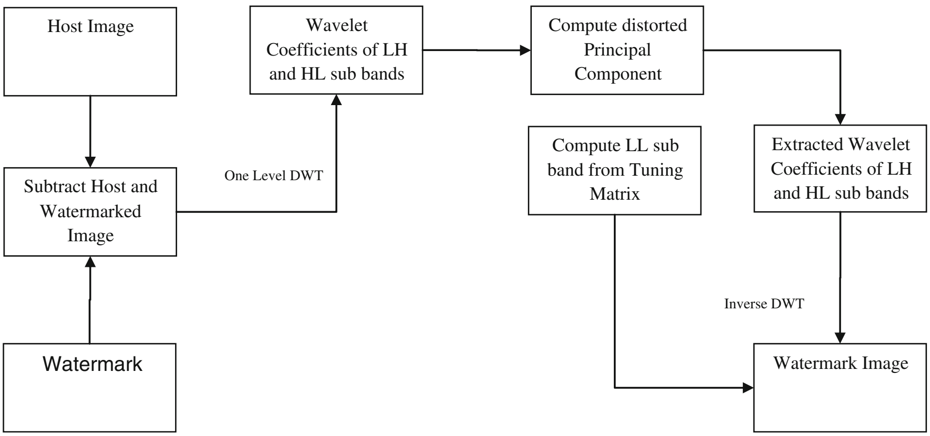

Fig. 5 Block diagram of proposed watermark extraction technique

Similarly the pixel-by-pixel PSNR is calculated using the following relation,

$$psnr(i,j) = 10log_{10}\left[\frac{P^2}{e(i,j)^2}\right] \tag{2}$$

Where, P is the maximum possible gray scale pixel value, 255 for typical 8-bit images.

The pixel-wise *PSNR* is being related to the approximation coefficients, which is a low pass version of the watermark image, obtained as follows,

$$psnr(i,j) = 10log_{10}\left[\frac{P^2}{[\beta(i,j).\mathrm{W}_{\mathrm{LL}}(i,j)]^2}\right] \tag{3}$$

Simplifying the (3) to find the β_1, which is a function of pixel-wise *PSNR* and approximation coefficients of watermark image.

$$\begin{aligned} psnr(i,\ j) &= 20log_{10}\left[\frac{P}{\beta(i,j).\mathrm{W}_{\mathrm{LL}}(i,j)}\right] \\ \Rightarrow \frac{psnr(i,j)}{20} &= log_{10}\left[\frac{P}{\beta(i,j).\mathrm{W}_{\mathrm{LL}}(i,j)}\right] \\ \Rightarrow 10^{\left(\frac{psnr(i,j)}{20}\right)} &= \frac{P}{\beta(i,j).\mathrm{W}_{\mathrm{LL}}(i,j)} \end{aligned} \tag{4}$$

$$\Rightarrow \beta_1(i,\ j) = \left[\frac{P}{\mathrm{W}_{\mathrm{LL}}(i,\ j).10^{\left(\frac{psnr(i,\ j)}{20}\right)}}\right] \tag{5}$$

Once more simplifying the (3) to find the β_2, which is a function of pixel-wise *PSNR* and approximation coefficients of Host Image.

$$\Rightarrow \beta_2(i,j) = \left[\frac{P}{\mathrm{A}_{\mathrm{LL}}(i,j).10^{\left(\frac{psnr(i,\ j)}{20}\right)}}\right] \tag{6}$$

The value of β matrix has been obtained by averaging the β_1 andβ_2, which is of dimension $(N/2)\times(N/2)$. So, instead of taking a fixed value of embedding factor a tuning matrix has been taken, adapting the watermark image content as well as host image content. Furthermore the horizontal and vertical details of host image have been modified with the tuning matrix β, obtained by considering the approximation coefficients of Host Image as well as Watermark Image.

4.2 Principal components of watermark

In order to overcome the problem of false positive the idea of embedding singular vectors matrix U along with the singular value matrix S has been exploited, because majority of image structural information is contained by left and right singular vectors, while energy by singular values . The principal component of the watermark [26] is calculated as multiplying U vector with singular value S of the Images. Let A and W be the original and watermark images respectively and corresponding SVD's are given as,

$$\begin{aligned} A(i,j) &= U(i,j)S(i,j)V(i,j)^T \\ W(i,j) &= U_w(i,j)S_w(i,j)V_w(i,j)^T \end{aligned}$$

The principal component of watermark image has been computed as,

$$A(i,j)^{wa} = U_w(i,j)S_w(i,j).$$

The host as well as watermark image has been decomposed by applying the one level DWT to get the LL, LH, HL, HH sub-bands. Now the principal component of wavelet coefficients of LH and HL sub bands of watermark is calculated. These principal components are embedded with the singular value of the modified wavelet coefficient of LH and HL sub bands with a tuning matrix of Host image to improve perceptual quality of embedded watermarked, whereas the problem of robustness against a wide range of intentional and non-intentional attacks have been improved by using the principle components.

4.3 Secret Key generation

To secure the approximation details of the watermark idea of the private key has been exploited. The secret key has been generated at the time of watermark embedding with help of tuning matrix β. This key is generated while considering the standard deviation and the mean value of tuning matrix β and the tuning matrix β^1 that is generated by considering the watermark only. We have computed the $W_{key}(i,j)$ matrix given as

$$W_{key}(i,j) = \left(\sqrt{\sigma_\beta + \mu_\beta} * \sqrt{\beta}\right)/\beta^1(i,j) \tag{7}$$

This key is supposed to be used at the time of ownership verification by the actual owner hence of private nature. The key will act as a private key because it necessitates the requirement of host image as well as the watermark image. The key will be used to extract approximation details that will be used to generate the watermark. We can extract the approximation details of watermark by using Eq. (7) as

$$\Rightarrow \beta^1(i,j) = \left(\sqrt{\sigma(\beta) + m(\beta)} * \sqrt{\beta}\right)/W_{key}(i,j)$$
$$\Rightarrow \mathrm{W_{LL}}(i,j) = \frac{P}{\beta^1(i,\ j).10^{\left(\frac{psnr(i,\ j)}{20}\right)}}$$

4.4 Watermark embedding algorithm

Input [Host Image (A), *Minimum Required Quality of Watermarked Image in terms of* $PSNR_{min}$, Watermark Image (W)]

Step 1 Perform 1-level haar wavelet decomposition to the host image $A^l(i, j)$ and watermark image $W^l(i, j)$ where $l \in \{LL, LH, HL, HH\}$

Step 2 Take the minimum value $PSNR_{min}$ to compute the tuning matrix β expressed as

$$\beta^1(i,j) = \left[\frac{P}{W^J(i,j).10^{\left(\frac{psnr(i,j)}{20}\right)}}\right]$$
$$\beta^2(i,j) = \left[\frac{P}{A^J(i,j).10^{\left(\frac{psnr(i,j)}{20}\right)}}\right]$$
$$\beta(i,j) = \frac{\beta^1(i,j)+\beta^2(i,j)}{2}$$

Where $J \in \{LL\}$

$$W_{key}(i,j) = \left(\sqrt{\sigma(\beta) + m(\beta)} * \sqrt{\beta}\ \right)/\beta^1(i,j)$$

Step 3 The vertical and horizontal details of wavelet coefficients of $A^l(i, j)$ are modified with the tuning matrix β

$$A^{LH^*}(i,j) = A^{LH}(i,j)/\beta(i,j)$$
$$A^{HL^*}(i,j) = A^{HL}(i,j)/\beta(i,j)$$

Step 4 Perform the SVD to perceptually tune wavelet sub bands $A^{LH^*}(i,j)$ and $A^{HL^*}(i,j)$ of host Image,

$$A^K(i,j) = U^K(i,j)S^K(i,j)V^{K^T}(i,j),$$

Where K =1, 2 represents two sub bands LH^* & HL^*

Step 5 Perform the SVD to wavelet sub bands $W^{LH}(i,j)$ and $W^{HL}(i, j)$ of watermark image

$$W^K(i,j) = U_w^K(i,j)S_w^K(i,j)V_w^{K^T}(i,j)$$

Where K = 1, 2 represents two sub bands LH & HL

Step 6 To generate the principal component of watermark multiply the left singular vector and the singular value of the watermark sub-bands

$$A^{waK}(i,j) = U_w^K(i,j)S_w^K(i,j)$$

Step 7: Add the principal component of the watermark sub-bands (*LH*, *HL*) into the singular value of the host image sub-bands (*LH*, *HL*).

$$S_{new}^K(i,j) = S^K(i,j) + \alpha * A^{waK}(i,j)$$

Where α refers to watermark strength and computed with help of tuning matrix β by considering host image as well as the watermark image.

Step 8 Compute the modified wavelet coefficients horizontal and vertical details as

$$A_w{}^K(i,j) = U^K(i,j)S_{new}^K(i,j)V^{K^T}(i,j)$$

Step 9 Carry out the inverse discrete wavelet transform (IDWT) on the modified coefficients to obtain the watermarked image, A_w

Output [Watermarked Image (A_w), W_{key}]

4.5 Watermark extraction algorithm

Input [Host Image (A), Distorted Watermarked Image ($A_w{}^*$), Watermark Image (W), Key (W_{key})]

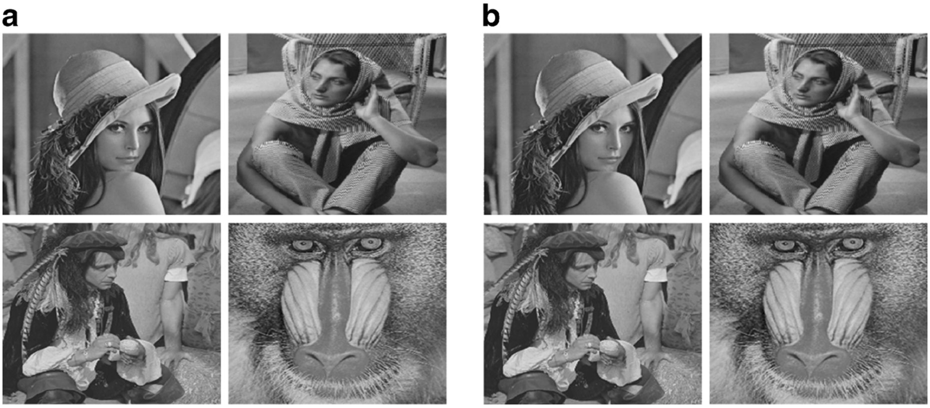

Fig. 6 **a** Host image **b** Watermarked Image

Step 1 Subtract the possibly attacked watermarked image with the original host image

$$\left(A_w{}^*(i,j) - \mathrm{A(i,j)}\right) \Rightarrow B_1(\mathrm{i,j})$$

Step 2 Perform 1-level discrete wavelet transform (DWT) on the subtracted image $B_1(i, j)$ to get the $\{LL, LH, HL, HH\}$ sub bands

Step 3 Compute the distorted principal components for LH & HL sub bands

$$A^{wa\mathrm{K}*}(i,j) = \left[inverse\left(U^K(i,j)\right)B_1{}^K(i,j)inverse\left(V^{K^T}(i,j)\right)\right]/\beta(i,j)$$

Where K=1, 2 represents two sub bands LH & HL

Step 4 Extract wavelet coefficient of watermark for LH & HL sub-band

$$A^{wa\mathrm{K}*}(i,j)V_w^{K^T}(\mathrm{i,j})$$

Step 5 Compute the LL sub band of Watermark from the key W_{key} as given below

$$\beta^{*1}(i,j) = \left(\sqrt{\sigma(\beta) + m(\beta)} * \sqrt{\beta}\right)/W_{key}(i,j)$$
$$W^{J*}(i,j) = \frac{P}{\beta^{*1}(i,j)\ .10^{\left(\frac{psnr(i,j)}{20}\right)}}$$

Step 6 Apply one level inverse discrete wavelet transform (IDWT) on the distorted coefficients to recover watermark.

Table 1 Comparison of peak signal to noise ratio for each host image

Test images	Proposed method	Run et al.[34]	Lai et al. [12]	Jain et al. [21]
Lena	64.57	32.54	36.11	19.66
Barbara	68.66	31.47	36.24	18.35
Pirate	55.01	33.93	32.18	17.42
Mandril	63.32	31.72	35.86	18.75

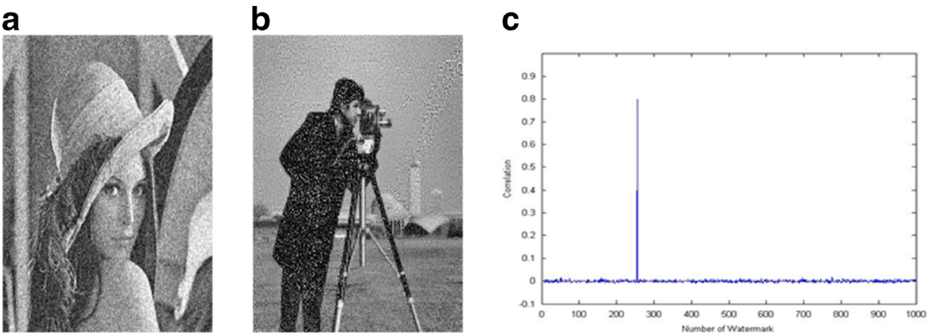

Fig. 7 **a** Watermarked Lena Image after adding additive Gaussian noise of density 0.01 **b** Extracted Watermark **c** Correlation coefficient

5 Experiment results and discussion

Through a variety of experiments attempt has been made to establish the effectiveness of the proposed watermarking algorithms. Several experiments have been performed on grayscale images "Lena" of size 256×256 and "Cameraman" of size 256×256 which are used as the cover image and the watermark, respectively. The capacity of a watermark and host image is same. Figure 6(a)–(b) has been given to show the host, watermark images respectively. In this section, the proposed scheme has been demonstrated for its robustness against a variety of attacks namely Average and Median Filtering, Gaussian noise addition, JPEG Compression, Cropping, Resize, Rotation, Histogram Equalization, Contrast Adjustment. The aforementioned experiments have been performed on watermarked image, while taking the Tuning Parameter=30. The experimental results for specified tuning parameter have been shown in Fig. 6(a)–(b). Figure 6 provides clear evidences for the imperceptibility of the watermarked image, while $\forall \alpha \in [\beta(i,j)]$ the PSNR value obtained is up to standard. To verify the presence of watermark, different measures can be used to show the similarity between

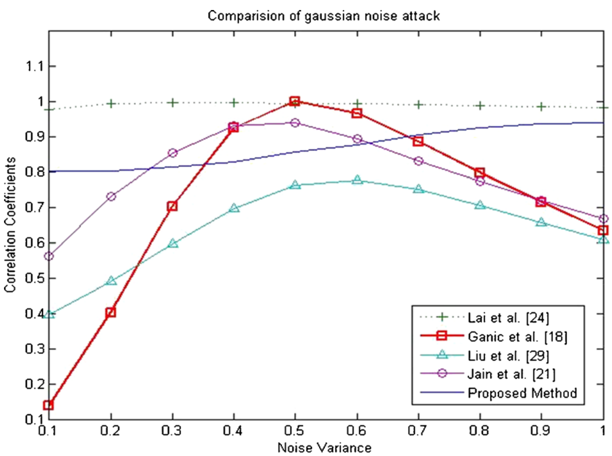

Fig. 8 Performance of proposed watermarking method for different Gaussian noise parameters

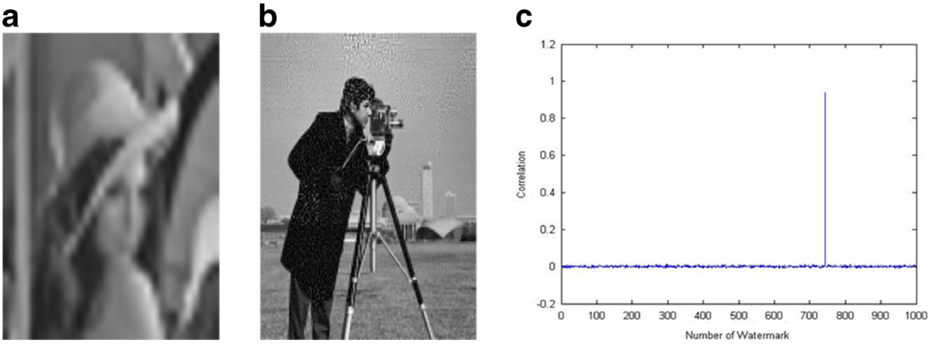

Fig. 9 **a** Watermarked Lena Image after rescaling to 256-32-256 **b** Extracted Watermark **c** Correlation coefficient

the original and the extracted singular values. In our proposed algorithm, normalized correlation coefficient (NCC) is used which is defined as,

$$NCC(W, W^*) = \frac{\sum_{I=1}^{N}\sum_{j=1}^{N}\left(W_{ij} - \overline{W}\right)\left(W_{ij}^* - \overline{W}_{ij}^*\right)}{\sqrt{\sum_{I=1}^{N}\sum_{j=1}^{N}\left(W_{ij} - \overline{W}\right)^2}.\sqrt{\sum_{I=1}^{N}\sum_{j=1}^{N}\left(W_{ij}^* - \overline{W}_{ij}^*\right)^2}}$$

Where W is the original watermark, W* is the extracted watermark from distorted image. Normalized Correlation coefficient (NCC) is the number that lies between [−1, 1].If the value of NCC is equal to 1 then the extracted watermark is just equal to the original one. To show the imperceptibility of watermarked image we have used the peak signal-to-noise ratio (PSNR) [1] given by following equations

$$PSNR(W, W^*) = 10\log_{10}\left(\frac{L_{\max}}{RMSE}\right)^2$$

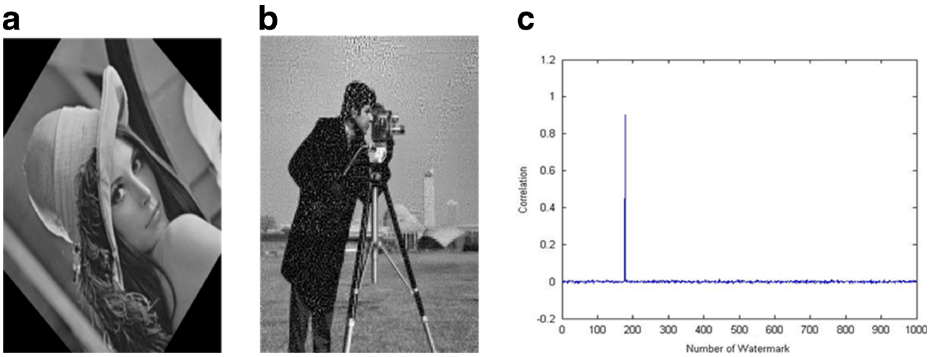

Fig. 10 **a** Watermarked Lena Image after rotating 50° **b** Extracted Watermark **c** Correlation coefficient

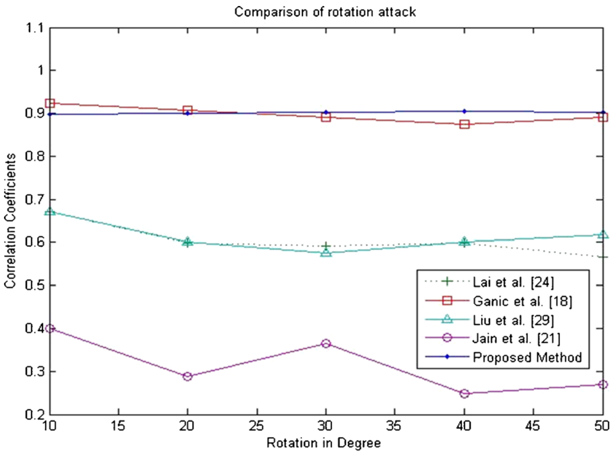

Fig. 11 Performance of the proposed watermarking method by varying the degree of rotation

Where RMSE is the root mean square error defined as

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}\sum_{i=1}^{M}\left(X(i,j) - X^*(i,j)\right)^2}{N \times M}}$$

The objective quality of the embedded host image has also been evaluated on the basis of *wPSNR* and the resultant watermarked images have been shown for variable values of embedding strength, where $\forall \alpha \in [0,\ 1]$. The imperceptibility of the proposed watermarking algorithm has also been compared with the other reported parallel algorithms (Lai et al. [12], Jain et al. [19], Run et al. [34]), shown in Table 1. Addition of noise is a very common attack that is responsible for the degradation and distortion of the image. The watermark information is also degraded by noise addition and results in difficulty in watermark extraction. Robustness against additive noise is estimated by Gaussian noise of density 0.01. Figure 7(a), (b) & (c) shows the watermarked Lena Image after addition of Gaussian noise,

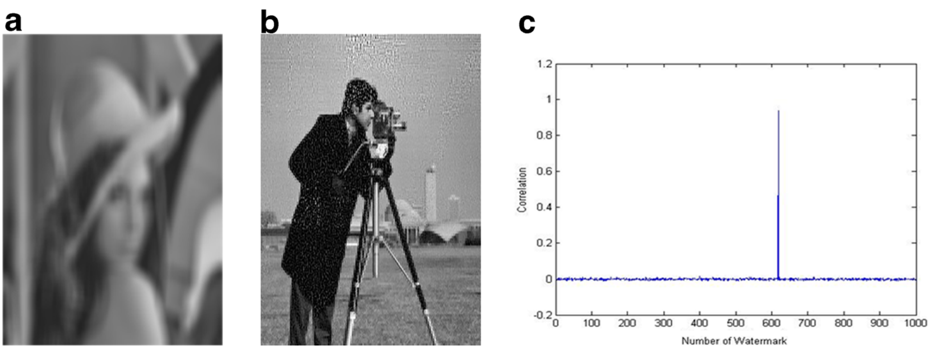

Fig. 12 **a** Watermarked Lena Image after 13×13 Average Filtering **b** Extracted Watermark **c** Correlation coefficient

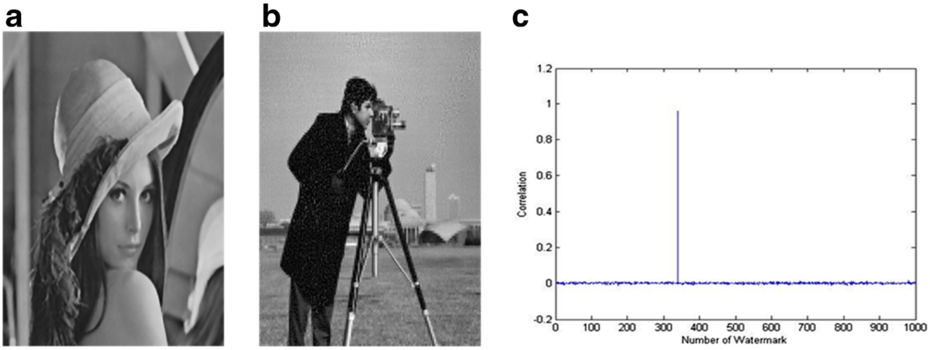

Fig. 13 **a** Watermarked Lena Image after Median Filtering **b** Extracted Watermark **c** Correlation coefficient

extracted watermark and corresponding correlation coefficient. Figure 8 provides a performance comparison of the proposed method for Gaussian noise by adjusting the value of noise variance.

The performance of proposed watermarking algorithms against the Gaussian noise attack is in close proximity of the Lai and Tsai, 2010 and far better than the other three algorithms.

Enlargement or reduction of an image is commonly performed and images may lose the required information including embedded watermark. For this attack, first the size of the watermarked image is reduced to 32×32 and again brought to its original size 256×256. Figure 9(a), (b) & (c) shows the Watermarked Lena Image after resizing to 256-32-256, extracted Watermark and corresponding correlation coefficient. Figure 10(a), (b) & (c) demonstrate the 50° rotated watermarked Lena image, extracted watermark and corresponding correlation coefficient of cameraman images respectively.

The effect of rotation has been evaluated and compared for varying degrees of rotation between 10 and 50 and shown through Fig. 11. The proposed algorithm is quite resistant against rotation attack and proves superiority over the other existing algorithms.

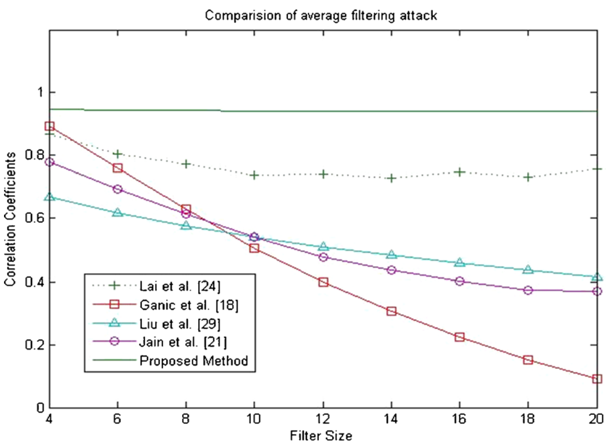

Fig. 14 Performance of proposed watermarking method by varying the filter size

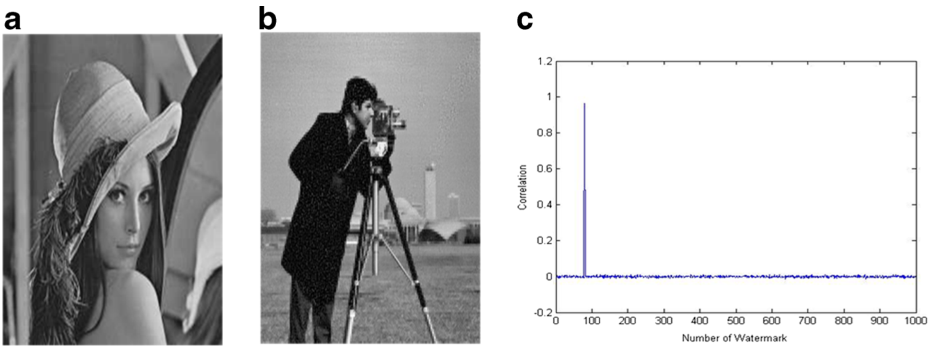

Fig. 15 **a**-**d** Watermarked Lena Image at quality factor =50 **b** Extracted Watermark **c** Correlation coefficient

Filtering is most common manipulation in digital image processing. The degraded image and extracted watermarks, after applying 13 × 13 averaging filter and median filter are shown in the Figs. 12 and 13 respectively.

It can be observed that after applying these filters, watermarked image gets degraded and lot of data is lost but the extracted watermark is in good stipulation. Figure 14 provides a performance comparison for Average filtering attack by varying the filter size and the proposed method confirms the improvement over the existing methods.

To check the robustness of the watermark against Image Compression, the watermarked image is tested with JPEG compression attacks.

The extracted watermark and correlation coefficient of the cameraman from compressed images of Lena at quality factor =50 is shown in Fig. 15(a–c). Figure 16 provides a performance comparison of the proposed method for JPEG compression attack by varying the quality factor. It has been derived that the performance of the proposed algorithm is close to the algorithm proposed by Lai et al. [12] and Ganic et al. [16] while superior over the algorithm proposed by Jain et al. [21] and Liu et al. [29].

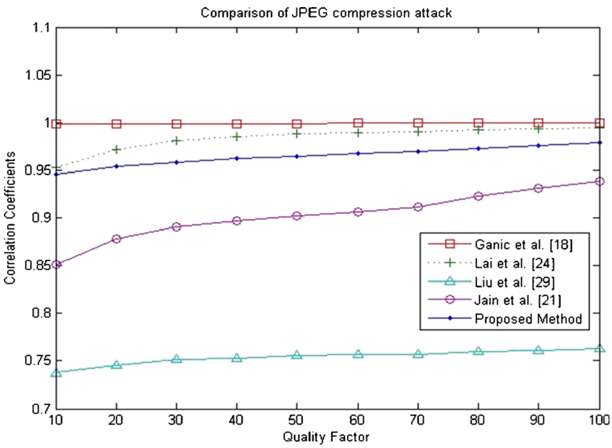

Fig. 16 Performance of proposed watermarking method by varying the value of quality factor

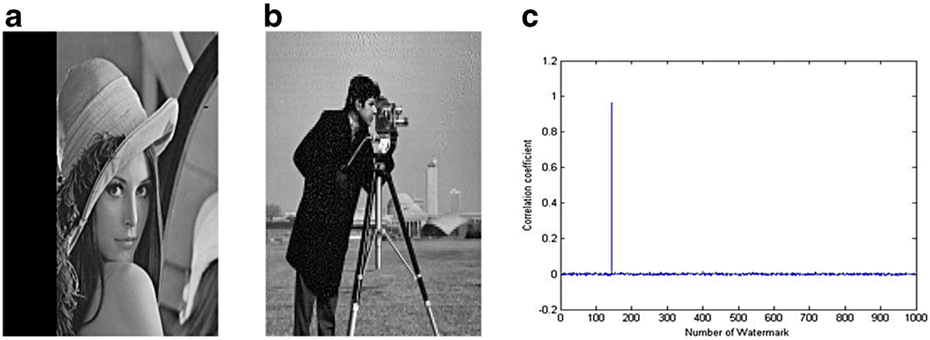

Fig. 17 **a** Watermarked Lena Image after cropping **b** Extracted Watermark **c** Correlation coefficient

Image cropping is frequently used process of selecting and removing a portion of an image to create focus or strengthen its composition.

Figure 17(a), (b) &(c) shows the watermarked image after cropping, extracted watermark and correlation coefficient. Cropping an image is a lossy operation where we remove either rows or columns. In our approach 50 % of the watermarked image is cropped and then a watermark is extracted and obtained NCC is 0.9665. For Contrast Adjustment, the contrast of the watermarked image is increased by 20 % shown in Fig. 18(a), extracted watermark in Fig. 18(b) and corresponding correlation coefficient in Fig. 18(c).

Figure 19 illustrates a performance comparison by adjusting the contrast of watermarked image and proposed method shows the similar results as shown by Lai et al. [12] for$CA \leq 1$.

The proposed scheme has been tested against forging of image to detect the tamper and localization in watermarked Image. Figure 20(a), (b) & (c) shows the watermarked image after forging at the right bottom, extracted watermark and corresponding correlation coefficient in that order. It can be observed that the proposed scheme is not suitable for temper detection and localization of error in watermarked Image as we have extracted watermark with high correlation value.

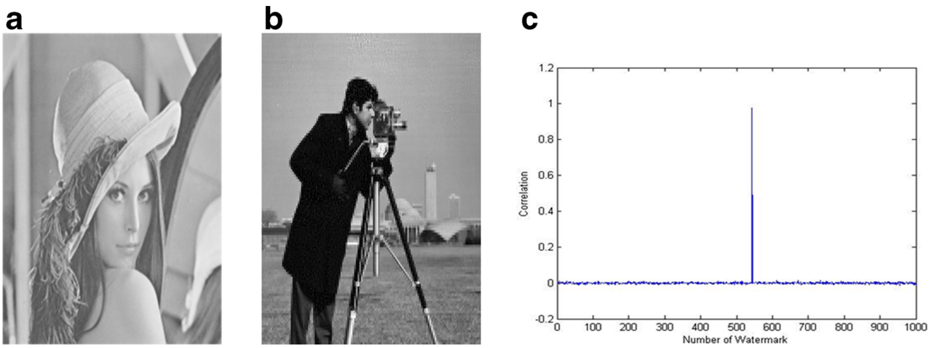

Fig. 18 **a** Watermarked Lena Image after contrast adjustment **b** Extracted Watermark **c** Correlation coefficient

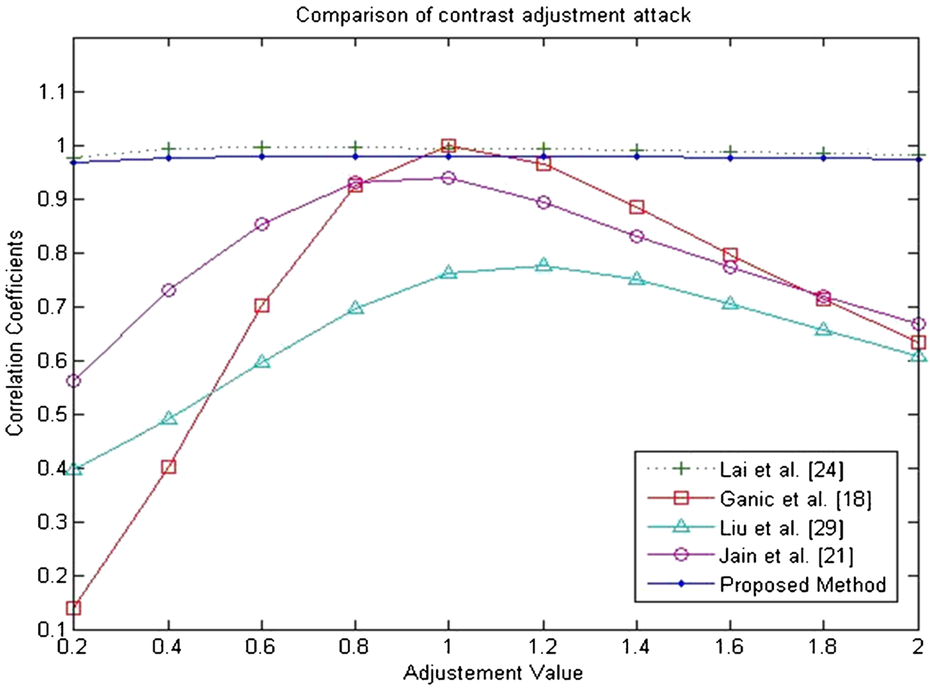

Fig. 19 Performance of proposed watermarking method with varying the Contrast

Printing of an Image is a most useful application that is being used in our daily life. To demonstrate the effectiveness against this attack, first the watermarked Image has been printed on an A4 sheet and then scanned the same by using 200dpi. Figure 21(a) & (b) shows the watermarked image after printing & scanning and extracted watermark. The NCC value for the extracted watermark is 0.64.

The performance of a proposed watermarking algorithm has been reported in Table 2. It represents the value of Normalized Correlation Coefficient (NCC) against numerous attacks as reported in Run et al. [34], Matty et al. [30], Ahahmad et al. [31] and Bao et al. [4] . It can be observed that the proposed algorithm outperforms in comparison to various other mentioned watermarking algorithms.

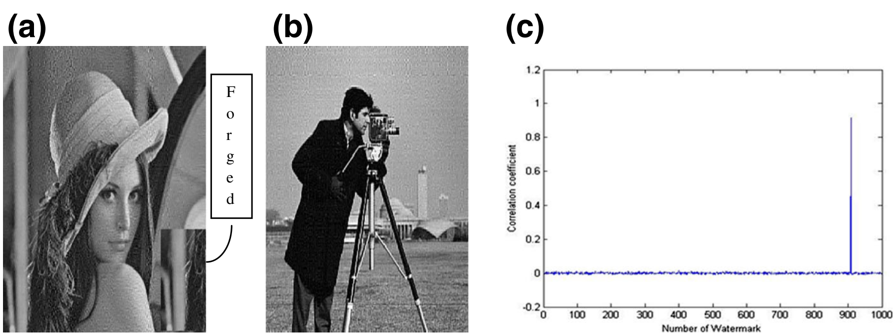

Fig. 20 **a** Watermarked Lena Image after forging **b** Extracted Watermark **c** Correlation coefficient

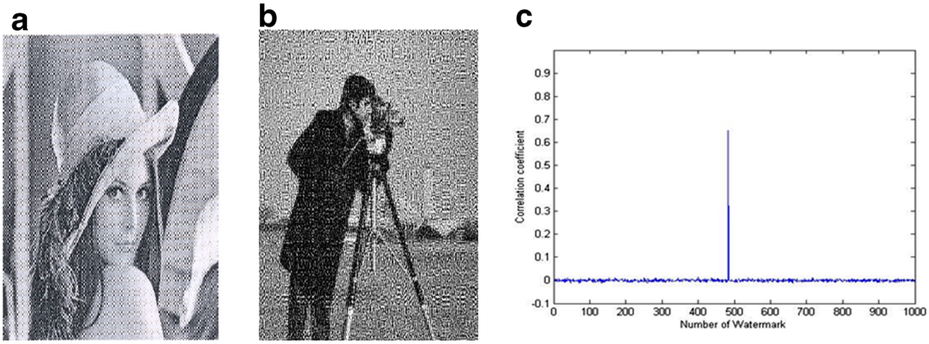

Fig. 21 **a** Watermarked Lena Image after Printing & Scanning **b** Extracted Watermark **c** Correlation coefficient

5.1 Reliability test against false positive problem

The experiment has been conducted to test the reliability of the proposed algorithm. Figure 22(a), (b) and (c) shows the watermarked image, original watermark and the distorted reference watermark having NCC value 0.42 by using pirate image. Since a secret key has been used, at the time of extraction to secure the low frequency component, due to this reason watermark extraction without knowing the tuning matrix β is not possible. Suppose any one try to extract the approximation details of the watermark by their own false $W^{*}_{key}(i,j)$ that is generated by different watermark image. The generation of $W^{*}_{key}(i,j)$ will be same as Eq. (7)

$$W^{*}_{key}(i,j) = \left(\sqrt{\sigma_{\beta*} + \mu_{\beta*}} * \sqrt{\beta^{*}}\right)/\beta^{*1}(i,j)$$

Where $\beta^{*1}(i,j)$ is the tuning matrix calculated through false watermark and β^{*} is computed by averaging the $\beta_2(i,j)$ and $\beta^{*1}(i,j)$ matrix. Consequently it can be observed that $W^{*}_{key}(i,j) \neq W_{key}(i,j)$. Hence, no reference image can be extracted from any arbitrary image using our proposed algorithm.

Table 2 Normalized correlation coefficient

Attacks	Proposed method	Run et al.[34]	Matty et al. [30]	Ahahmad et al. [31]	Bao et al. [4]
Median filter	0.9595	0.9564	0.2114	Not Given	Not Given
Histogram equalization	0.9583	0.9615	Not Given	Not Given	Not Given
Rotation(50)	0.9031	Not Given	0.2245	0.4972	0.3906
Average filter(13×13)	0.9414	0.9530	Not Given	0.3537	0.4526
Contrast adjustment	0.9765	0.7716	0.1886	Not Given	Not Given
Resizing(256-32-256)	0.9421	0.9322	0.1283	0.4279	0.5264
Gaussian noise	0.7989	0.7566	Not Given	0.5376	0.3881
JPEG compression (50:1)	0.9643	0.9512	0.1378	0.5156	0.4618
Cropping	0.9665	Not Given	0.2134	0.4255	0.5806

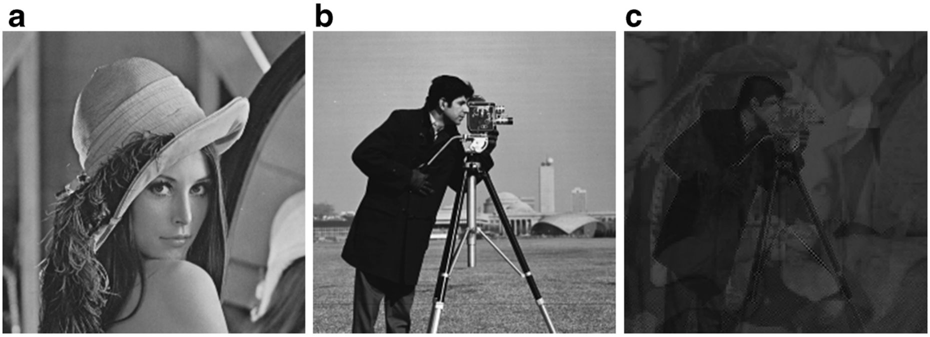

Fig. 22 **a** Watermarked Lena Image **b** Extracted original Watermark **c** Extracted false watermark from proposed method

6 Conclusion

Through this paper, a modified hybrid wavelet-based transparent image watermarking algorithm through perceptual tuning has been presented, which is based on DWT and SVD, where the principal component of the watermark is added on the singular values of the cover image's DWT sub bands. Due to the embedding of only principal components of watermark the information about the entire watermark is not available without a prior knowledge of the original watermark. The proposed algorithm avoids the pitfall encountered by Lai et al. [12] and improves the imperceptibility in comparison to the method proposed by Run et al. [35]. By conducting several experiments, the conclusion has been derived; that the proposed method can solve the false positive problem and it also shows a good PSNR value as reported through Table 1. The use of a key has been suggested which is a combination of perceptually tuned matrices of DWT coefficients of watermark image as well as host image at the time of watermark extraction and ensures copy right of ownership. Results of the proposed technique indicate that it preserves the imperceptibility and the robustness under various types of image processing attacks. The algorithm is also robust against the print and scan attack while lacking in case of forging and morphing attack hence requires improvement in future. Moreover the algorithm is adaptive and having the capability of producing the targeted quality of watermarked image and user/application oriented.

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References

1. Abdel-Aziz B and Chouinard J-Y (2003) On perceptual quality of watermarked images—An experimental approach. In: Proc. Digital Watermarking: 2nd International Workshop, IWDW, pp 277
2. Adhipati RA, Chatterji BN (2005) A new wavelet based logo-watermarking scheme. Pattern Recogn Le 26:1019–1027
3. Agarwal R, Santhanam MS (2008) Digital watermarking in the singular vector domain. Int J Image Graph 8(3):351–368
4. Bao P, Ma X (2005) Image adaptive watermarking using wavelet domain singular value decomposition. IEEE Trans Circ Syst Video Technol 15(1):96–102

5. Barni M, Bartolini F, Piva A (1998) A DCT domain system for robust image watermarking. IEEE Trans Signal Process 66:357–372
6. Barni M, Bartolini F, Piva A (2001) Improved wavelet based image watermarking through pixel wise masking. IEEE Trans Image Process 10(5):783–791
7. Chandra D (2002) Digital image watermarking using singular value decomposition. In: Proceedings of the IEEE 45th Midwest Symposium on Circuits and Systems, Oklahoma State University, USA, Vol. 3, pp. 264–267, August 4–7
8. Chang CC, Chuang JC, Chen TS (2002) Recognition of image authenticity using significant DCT coefficients quantization. Informatica 26(4):359–366
9. Chang CC, Hsiao JY, Yeh JC (2002) A color image copyright protection scheme based on visual cryptography and discrete cosine transform. Image Sci J 50:133–140
10. Chang CC, Tsai P, Lin CC (2005) SVD-based digital image watermarking scheme. Pattern Recogn Lett 26:1577–1586
11. Chen TH, Hrong G, Lee WB (2005) A publically verifiable copyright-proving scheme resistant to malaises attacks. IEEE Trans Ind Electron 52(1):327–334
12. Chih-Chin L, Cheng-Chih T (2010) Digital image watermarking using discrete wavelet transform and singular value decomposition. IEEE Trans nstrum and Meast 59(11):3060–3063
13. Chu WC (2003) DCT based image watermarking using sub sampling. IEEE Trans Multimedia 5:34–38
14. Cox I, Kilian J, Leighton T, Shamoon T (1997) Secure Spread Spectrum Watermarking for Multimedia. IEEE Trans Image Process 6(12):1673–1687
15. Cox I, Miller ML, Bloom JA (2001) Digital watermarking. Morgan Kaufmann
16. Ganic E & Eskicioglu AM (2004) Robust DWT-SVD domain image watermarking: embedding data in all frequencies. In: Proceedings of the ACM Multimedia and Security workshop, Magdeburg, Germany, pp. 166–174, 19
17. Ganic E, Eskicioglu AM (2005) Robust embedding of visual watermarks using DWT-SVD. J Electron Imaging 14(4):043004
18. Gaurav B, Balasubramanian R (2009) A new robust reference logo watermarking scheme. Multimed Tools Appl 52(2–3):621–640
19. Gaurav B, Balasubramanian R (2009) A new robust reference watermarking scheme based on DWT-SVD. Comput Stand Interfaces 31(5):1002–1013
20. Gaurav B, Wu QMJ, Balasubramanian R A new aspect in robust digital watermarking. Multimed Tools Appl. doi:10.1007/s11042-011-0788-z, April, 2011
21. Jain C, Arora S, & Panigrahi PK (2008) A reliable SVD based watermarking scheme, http://arxiv.org/abs/0808.0309v1
22. Kim WS, Hyung OH, Park RH (1999) Wavelet based watermarking method for digital images using human visual system. Electron Lett 35(6):466–468
23. Kundur D, Hatzinakos D (2004) Towards robust logo watermarking using multi resolution image fusion. IEEE Trans Multimed 6:185–197
24. Li Q, Yuan C, Zong YZ (2007) Adaptive DWT-SVD domain image watermarking using human visual model. ICACT, pp 1947–1951
25. Lin W-H, Horng S-J, Kao T-W, Chen R-J, Chen Y-H, Lee C-L, Terano T (2009) Image copyright protection with forward error correction. Expert Syst Appl (SCI 1/64, 2596) 36(9):11888–11894
26. Lin WH, Horng SJ, Kao T, Fan WP, Lee CL, Pan Y (2008) An efficient watermarking method based on significant difference of wavelet coefficient quantization. IEEE Trans Multimed (SCI 12/86, 2288) 10(5):746–757
27. Lin W-H, Wang Y-R, Horng S-J (2009) A wavelet-tree-based watermarking method using distance vector of binary cluster. Expert Syst Appl (SCI 1/64, 2596) 36(6):9869–9878
28. Lin W-H, Wang Y-R, Horng S-J, Pan Y (2009) A blind watermarking method using maximum wavelet coefficient quantization. Expert Syst Appl (SCI 1/64, 2596) 36(9):11509–11516
29. Liu R, Tan T (2002) An SVD-based watermarking scheme for protecting rightful ownership. IEEE Trans Multimed 4(1):121–128
30. Maity Santi P, Kundu Malay K (2011) Perceptually adaptive spread transform image watermarking scheme using Hadamard transform. Inform Sci 181:450–465
31. Mohammad AA, Alhaj A, Sameer S (2008) An improved SVD-based watermarking scheme for protecting rightful ownership. Sig Process 88:2158–2180
32. Podilchuk CI and Delp EJ (2001) Digital watermarking: algorithms and applications. IEEE Signal Proc Mag 33–46, July
33. Qi H, Zheng D, Zhao J (2008) Human visual system based adaptive digital image watermarking. Signal Process 88:174–188

34. Ray-Shine R, Shi-Jinn H, Jui-Lin L, Kao T-W, Chen R-J (2012) An improved SVD-based watermarking technique for copyright protection. Expert Syst Appl 39(1):673–689
35. Rosiyadi D, Horng S-J, Fan P, Wang X, Khan MK, Yi P (2012) An efficient copyright protection scheme for e-government document images. IEEE Multimed 19(3):62–73
36. Singh SK, Shishir K (2011) Novel adaptive color space transform and application to image compression. Signal Process Image Commun 26:662–672
37. Wu Y (2005) On the security of an SVD-based ownership watermarking. IEEE Trans Multimed 7(4):624–627
38. Xiao-Ping Z, Kan L (2005) Comments on "an SVD-based watermarking scheme for protecting rightful ownership". IEEE Trans Multimed 7(2):593–594
39. Yavuz E, Telatar Z (2007) Improved SVD-DWT based digital image watermarking against watermark ambiguity. In: Proc. ACM Symposium on Applied Computing, pp 1051–1055

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