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SVD-based digital image watermarking using complex wavelet transform

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Abstract. A new robust method of non-blind image watermarking is proposed in this paper. The suggested method is performed by modification on singular value decomposition (SVD) of images in Complex Wavelet Transform (CWT) domain while CWT provides higher capacity than the real wavelet domain. Modification of the appropriate sub-bands leads to a watermarking scheme which favourably preserves the quality. The additional advantage of the proposed technique is its robustness against the most of common attacks. Analysis and experimental results show much improved performance of the proposed method in comparison with the pure SVD-based as well as hybrid methods (e.g. DWT-SVD as the recent best SVD-based scheme).

Keywords. Digital image watermarking; complex wavelet transform; singular value decomposition.

1. Introduction

Digital data utilization along with the increased popularity of the internet has facilitated information sharing and distribution. Watermark, which is usually some information related to original data or the owner, is embedded in the original data; then the watermarked data is distributed throughout computer networks. Considering the applications of such systems, the watermark can be extracted from the media.

Watermark can be applied to the spatial domain (Darmstaedter *et al* 1998; Nikolaidis & Pitas 1998) or transform domain watermarking (Cox *et al* 1997; Guo & Georganas 2003; jung *et al* 2003; Guitart *et al* 2004 and Ho *et al* 2003). Modifying the singular value decomposition of the image is one of the most prevalent technique in transform domain watermarking (Liu & Tan 2002), (Chandra 2002) and (Gorodetskii & Samoilov 2003). SVD as a general linear algebra technique is used in a variety of applications. SVD is an optimal matrix decomposition in a least square sense packing the maximum signal energy into a few coefficients as possible (Ganic *et al* 2003) and (Liu & Tan 2002). The SVD theorem decomposes a digital image A of size $M \times N$, as:

$$A = USV^T, \tag{1}$$

where U and V are of size $M \times M$, and $N \times N$ respectively. S is a diagonal matrix containing the singular values. In watermarking trial, SVD is applied to the image matrix; then watermark resides by altering singular values (*SVs*).

In transform domain, the discrete wavelet transform (DWT) has been used in some researches. However, the results of DWT have tended to be disappointing (Wang *et al* 2004). Although the separable 2D wavelet transform represents efficiently point singularities, but it is less capable for line and curve singularities (edges).

Dual Tree-Complex Wavelet Transform (DT-CWT) has been introduced as an efficient approach to shift invariant properties. This transform gives much better directional selectivity when it uses the multi-dimensional signal filtering. Some useful properties of DT-CWT have been emphasized as:

- Approximate shift invariance.
- Good directional selectivity in two-dimensions (2D) with Gabor-like filters (also true for higher dimensionality, m-D).
- Perfect reconstruction (PR) using short linear-phase filters (Selesnick & Li 2003).

The separable DT-CWT produces the oriented wavelets, consider the 2D wavelet function as $\varphi(x, y) = \varphi(x)\varphi(y)$ where $\varphi(x)$ is a complex (Hilbert transform) wavelet given by$\varphi(x) = \varphi_h(x) + j\varphi_g(x)$, (Selesnick *et al* 2005). Since the spectrum of (approximately) analytic 1D wavelet is supported by only one side of the frequency axis hence the spectrum of the complex 2D wavelet φ(x, y) is also supported in just one quadrant of the 2D frequency plane, (Selesnick 2002) and (Kingsbury 2005).

In case of solving checkerboard artifact, two versions of dual tree wavelet transforms have been introduced, real and complex. So, while the separable 2D Wavelet Transform is characterized by three wavelets, the dual-tree 2D real Wavelet Transform can be identified by six wavelets as can be seen in figure 1.

Although real oriented 2D dual tree-Wavelet Transform benefits from sufficient capability to solve the checkerboard artifact problem, the oriented complex 2D dual tree-Wavelet Transform with additional advantages has been also introduced. This transform is four-times extensive, but it has the benefit of being both oriented and approximately analytic. Figure 2 illustrates the related sub-band using DT-CWT (Selesnick & Li 2003).

As the main idea, we embed (*SVs*) into CWT domain, in order to use the properties of frequency domain and SVD simultaneously. Hence the paper is organized in the following manner. In section 2, the previous work especially those based on singular value decomposition and complex wavelet transform are reviewed. Then, details of new proposed method using singular value decomposition technique have been presented in section 3. Section 4 is dedicated to analyse the results of the performed implementation.

2. Previous works

In this section, an overview of the important existing SVD-based and also CWT domain watermarking will be explained briefly. Three methods were proposed by Chandra (2002) while the most popular of them combines *SVs* of the original image with *SVs* of the watermark image by a constant scaling factor.

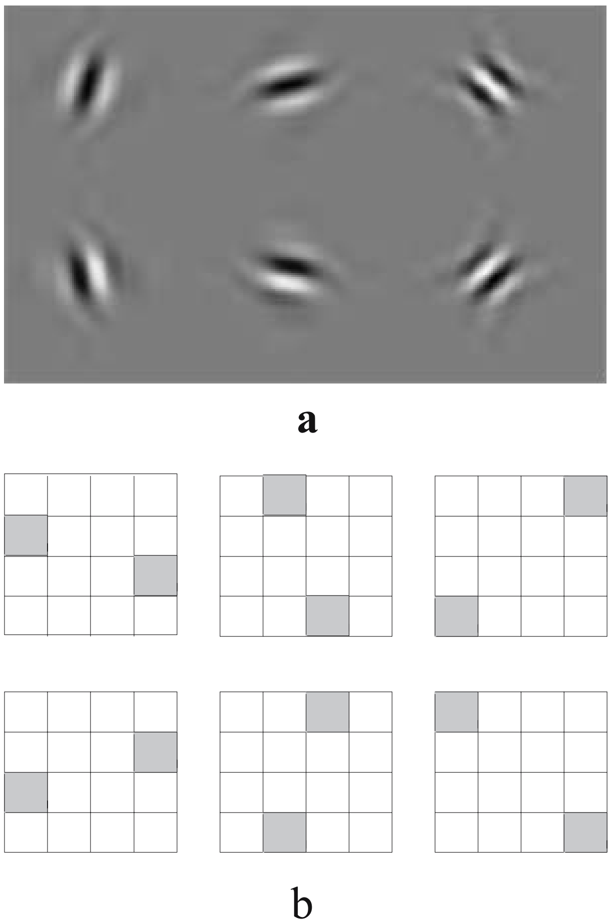


Figure 1. Typical wavelets associated with the real oriented 2D dual-tree wavelet transform, **(a)** in the space domain. **(b)** The Fourier spectrum of each wavelet in the 2D frequency plane.

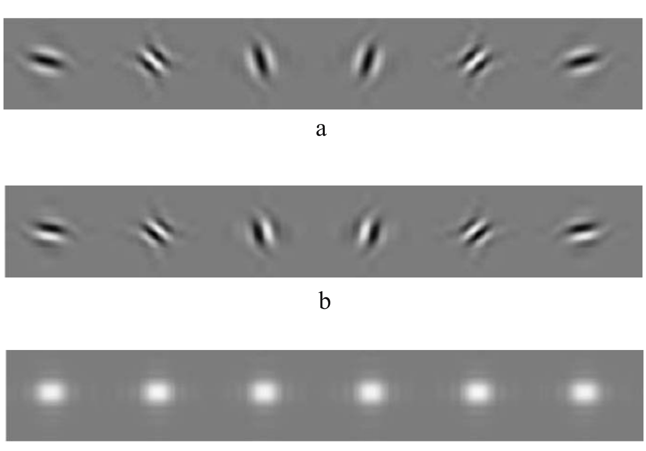


Figure 2. Typical wavelets associated with the oriented 2D dual tree-CWT. **(a)** Illustrates the real part of each complex wavelet; **(b)** illustrates the imaginary part; and **(c)** illustrates the magnitude.

In Ganic *et al* (2003) watermark has been embedded to the original image in two layers. In the first layer, the host image is divided into smaller blocks then *SVs* of the watermark image is scaled by a variable scaling factor and distributed over the image blocks. In the second layer, all *SVs* of the image are scaled by using a constant scaling factor and combined with the *SVs* of the watermarked image then the resultant values are substituted with the original image *SVs*.

Ganik and Eskicioglu have proposed a SVD-based watermarking technique using Discrete Wavelet Transform (DWT-SVD). In this scheme, after decomposing of the host image into four sub-bands, the SVD of the watermark image is embedded into the mentioned sub-bands. Although the most beneficial point of this algorithm is its robustness since modification is applied to all sub-bands but, this fact leads to quality degradation of watermarked image (Ganic & Eskicioglu 2005).

Since in this paper the watermarking algorithm is presented in CWT domain, a brief overview of the important existing CWT watermarking technique is presented. However, only few watermarking methods have been developed in this domain till now.

In an algorithm which was proposed by Loo and Kingsbury, pseudo-random string used as a watermark and embedded in all sub-bands of CWT coefficients of the original image (Loo & Kingsbury 2000). It is noticeable that the robustness of this method against the watermarking attacks was not investigated by the authors. In a similar method which was presented by Loo, the embedding algorithm used the (32, 6) error correction Hadamard code (Loo & Kingsbury 2000). In another attempt (Loo 2002), the block based CWT approach employed the basis of Chen & Wornell (2001) quantization based algorithm. Other researchers also selected the third and fourth levels of CWT decomposition of the original image. In such cases, the watermark was added to embedding channel using the additive spread spectrum technique in spatial domain Terzija & Geisselhardt (2004). In the entire CWT based method the bit stream or binary image has been used as the watermark.

3. New suggested watermarking technique

As clarified earlier, most of the previous SVD-based watermarking techniques treat different parts of the image in the same way. Therefore, the edges and the smooth areas of the image, related to different sub-bands, accept similar effects. By considering the human visual system which is less sensitive to noise on edges, making similar changes to perceptually significant and insignificant areas of the image consequently lead to noticeable alternation in smooth areas, hence the quality degradation of the image increases. Additionally, the previous techniques employ bit streams or binary images as watermark in most cases. Obviously in such conditions the watermark is more vulnerable to intentional or unintentional attacks. Moreover, the most important drawbacks of SVD-based algorithms is the watermarked image quality degradation. In addition, the extracted watermark is not robust enough against common attacks in both mentioned techniques Thus, the authors of the present paper have been motivated to propose a simple image watermarking technique with imperceptible image quality alteration. Additional advantages of the presented technique could be highlighted as high capacity and robustness of the method against different types of common attacks. Since CWT provides high redundancy in transform domain, the high capacity of the transformed host could utilize as the beneficial point to scatter the watermark data. Disseminating data in the whole image considering the best sub-band is the main privilege of using CWT. In other word, CWT gives the potential to obtain suitable areas in which the information could be

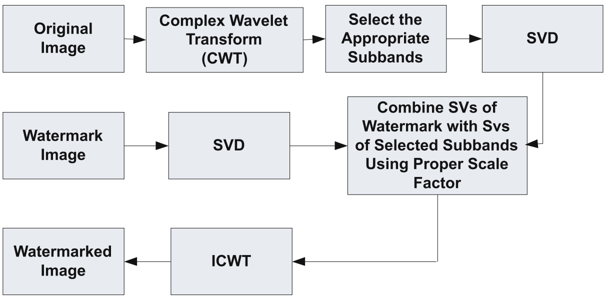


Figure 3. Diagram of embedding watermark.

embedded. This is based on the fact that CWT provides approximate shift invariance and good directional selectivity in comparison with other popular transforms specially DWT (Loo & Kingsbury 2000). For example, DWT does not have separate sub-bands for two opposing diagonal direction, while this is simply available in CWT. Finally, approximate shift invariance property of the CWT leads to get better robustness against applying the common attacks.

We suggest the following steps of the embedding phase method and the related diagram is shown in figure 3.

(i) Consider a host image of size $N \times N$.
(ii) The Complex Wavelet Transform of the host image is calculated according to the selected decomposition level (L), sub-bands of size $\frac{N}{2^L} \times \frac{N}{2^L}$ can be achieved.
(iii) To select the more suitable sub-bands, to embed the *SVs* of the watermark, both robustness against the attacks and the best quality of the watermarked image should be considered. Choosing the LL sub-band causes less quality fidelity. Since the high frequency components such as edges and the other image details are located in the HH sub-band, just selecting the HH sub-band decreases the robustness of the watermarked image against different types of attacks. To choose the appropriate sub-bands for embedding watermark, the intensity variance of each sub-band is calculated, then the sub-bands with the midst values are selected as the best ones.
(iv) Combine *SVs* of the watermark with the *SVs* of the selected sub-bands using appropriate scaling factor; a, as illustrated in Equation (2)

$$S^k_{wkd} = S^k_{org} + aS_w, \tag{2}$$

in which S^k_{org} and S^k_{wkd} are singular values of k^{th} sub-band of the host and watermarked images and S_w shows the singular values of the watermark image. The criterion for selection of appropriate scaling factor will be explained later.
(v) Using inverse complexes wavelet transform, the watermarked image will be constructed.

Since the *SVs* of the original image are needed in the extraction phase, the suggested method is deemed as non-blind watermarking technique using singular vector matrices as the keys. The extraction steps are considered as follow:

(i) Calculate the complex wavelet transform of the watermarked image to the decomposition level (L), consider the appropriate sub-bands, and compute the corresponding *SVs*.
(ii) Compute the *SVs* of the mentioned sub-bands.

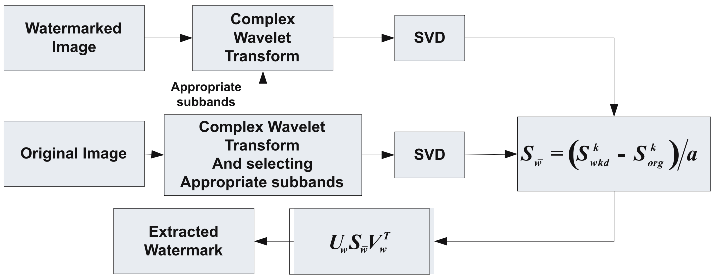


Figure 4. Diagram of the watermark extraction.

(iii) Obtain the *SVs* of watermark through Equation (3):

$$S_{\bar{w}} = (S^k_{\text{wkd}} - S^k_{\text{org}})/a. \tag{3}$$

(iv) Combine the *SVs*, achieved from each sub-band, to extract the watermark.

The extraction diagram is illustrated in figure 4. To evaluate the performance of suggested method, some experiments have been performed with pure SVD-based method (Chandra 2002) and also DWT-SVD (Ganic & Eskicioglu 2005) watermarking scheme. The respective results are visually and numerically compared.

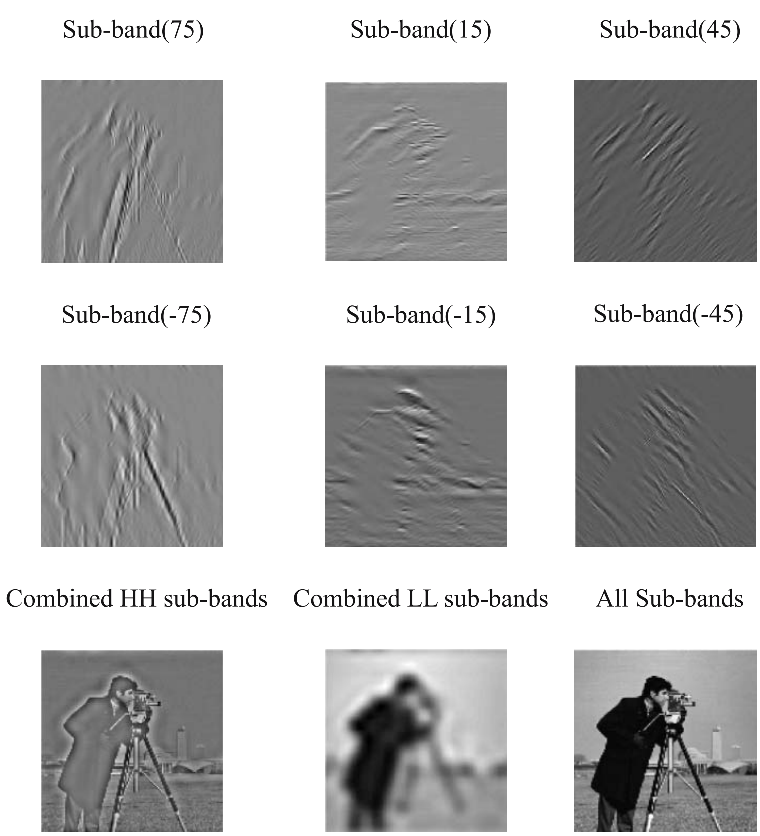


Figure 5. Typical wavelets associated with the oriented 2D dual tree-CWT illustrate the six real parts of each complex wavelet and also the combination of HH and LL sub-bands.

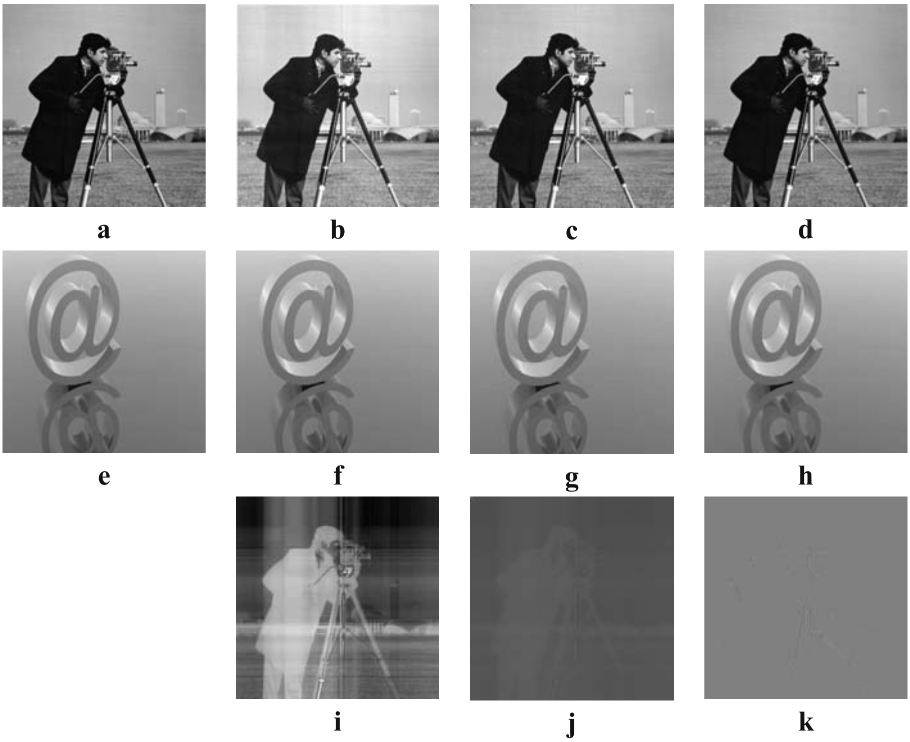


Figure 6. Experimental result: **(a)** original image, watermarked image, **(b)** pure SVD-based method, **(c)** DWT-SVD, **(d)** the proposed method, **(e)** original watermark, extracted watermark, **(f)** pure SVD-based method, **(g)** DWT-SVD, **(h)** and the proposed method, difference between original and watermarked images, **(i)** pure SVD-based, **(j)** DWT-SVD, and **(k)** the proposed method.

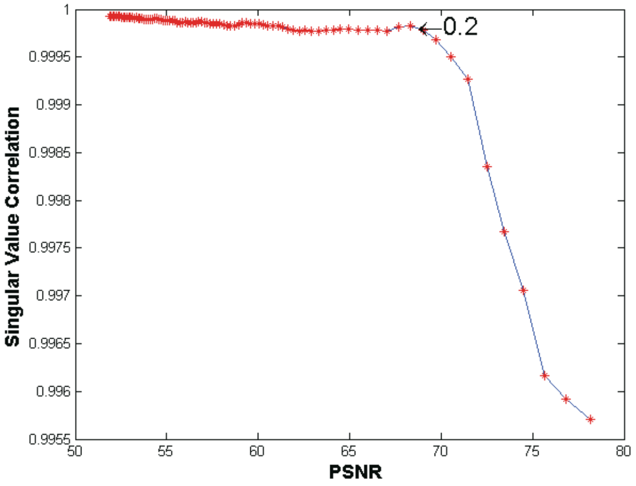


Figure 7. Trade-off between PSNR of the watermarked and the extracted watermark correlation related to variant alpha of level one.

Table 1. Comparison of PSNR in three methods.

Algorithm		PSNR(dB)
The proposed method	$L = 1$	68·33
	$L = 2$	55·28
Pure SVD-Based		18·92
DWT-SVD		24·65

4. Experimental results

In the performed experiments, the famous cameraman of size 512 × 512 has been selected as the host image and for the watermark, @ picture of size 512 × 512 has been used. Considering the selected level (L), firstly, 2^L sub-bands are chosen by calculating the sub-bands variance. Figure 5 shows the results after applying one level of CWT to the cameraman image.

Figure 6 relates the results of the experiment for the proposed pure SVD-based (Chandra 2002) and DWT-SVD (Ganic & Eskicioglu 2005) methods. In this figure the original host, watermarked image, and the difference of the original and watermarked images respected to each method are depicted too. As it can be seen, the watermarked image generated by the pure SVD-based method is much brighter than the original image; that is, the image quality is obviously degraded due to the usage of constant value in combining watermark with the original image. Considering figure 6i–j, the different parts of the image i.e. edges and smooth areas, are treated in the same manner without considering the human visual system characteristics.

In the suggested method, however, the difference between the original and watermarked images highly depends on the selected sub-bands in which the *SVs* of watermark are embedded (figure 6a–k).

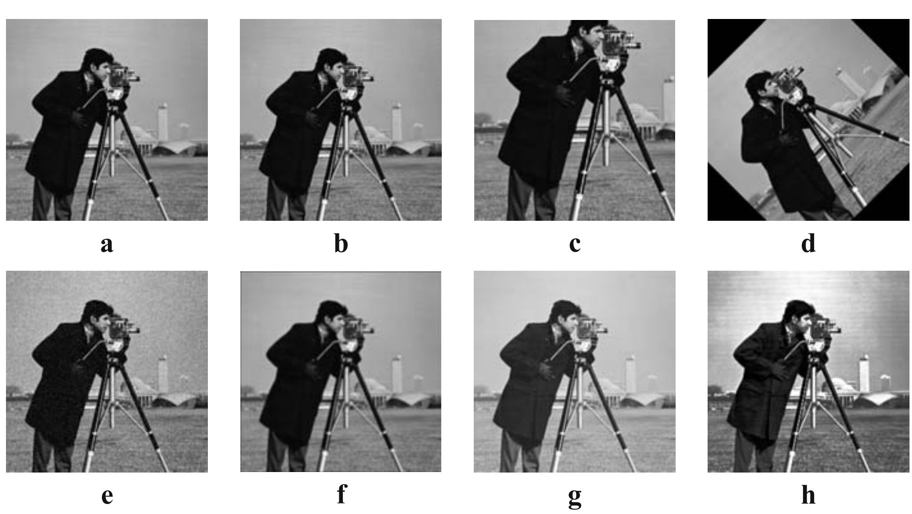


Figure 8. Watermarked image with different attacks, **(a)** Watermarked image, **(b)** JPEG 87%, **(c)** Cropping 100 pixels from up and right + scaling, **(d)** Rotation 45 + scaling, **(e)** Gaussian noise, **(f)** Gaussian blurred, **(g)** Gamma correction 0·6, **(h)** Histogram equalization.

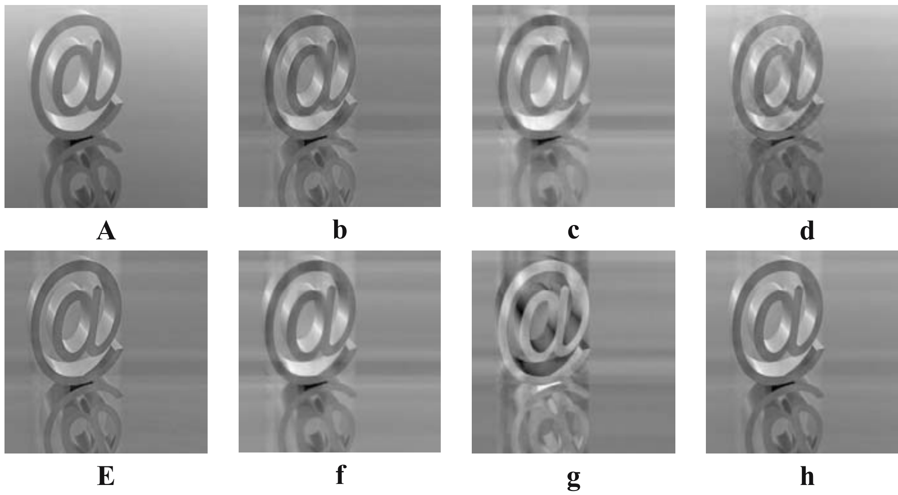


Figure 9. Extracted watermark by the new algorithm due to different attacks of figure 8.

Since, the efficiency of new method is highly dependent on the way through which the scaling factor has been selected; several experiments have been conducted for testing. Using variant scaling factor for each sub-band can lead to the appropriate result. In this phase, we can choose 2^L types of scaling factors. In each sub-band, this coefficient is grown up according to Equation (4):

$$a_i = a_{\text{sub-band}} \times \frac{i \times 2^L}{\text{Image Size}}. \tag{4}$$

In this equation, a_i indicates the appropriate scaling factor which corresponds with the i^{th} *SV* of each sub-band. $a_{\text{sub-band}}$ has been chosen as appropriate sub-band coefficient based

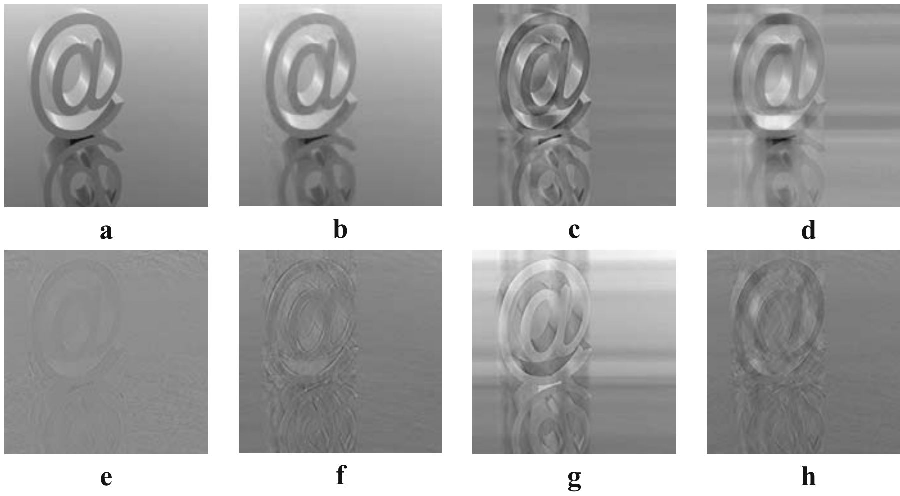


Figure 10. Extracted watermark by the Pure-SVD due to different attacks of figure 8.

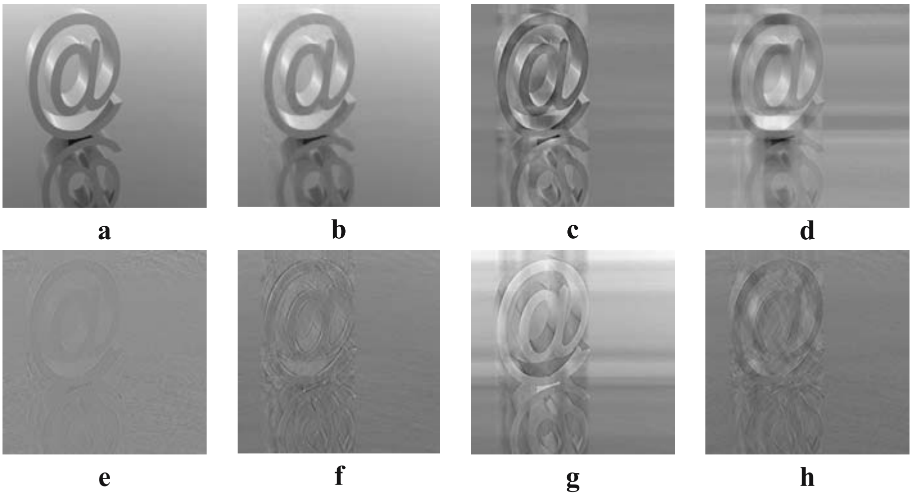


Figure 11. The best extracted watermark results by DWT-SVD due to different attacks of figure 8.

on the trade off between PSNR of watermarked images and the correlation between the original watermark and the extracted one. The relationship between these two values is clearly identifiable in figure 7.

PSNR results of the watermarked image of the proposed algorithm and the two other methods are shown in table 1. In the following, the results of evaluating the proposed method against wide range of the common attacks are displayed. Figure 8 shows the watermarked image with different kinds of image manipulation.

The corresponding extracted watermarked images obtained through using the mentioned method, the pure SVD-based, and also DWT-SVD watermarking techniques are shown in figures 9–11. Considering figure 9, all of the extracted watermarks are visually recognizable. However in all watermarking systems, it is recommended to compare the results objectively using an acceptable visual quality metric. Since in many cases the poor results of the numerical metric may be qualified by subjective tests (which is evaluated by humans) (wang *et al* 2004),

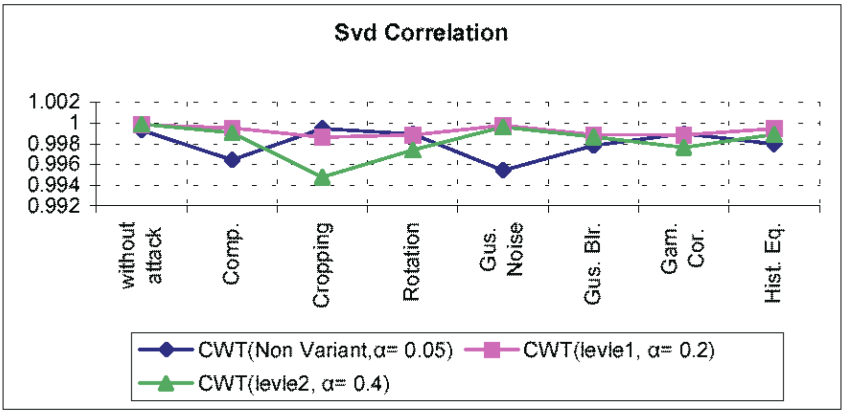
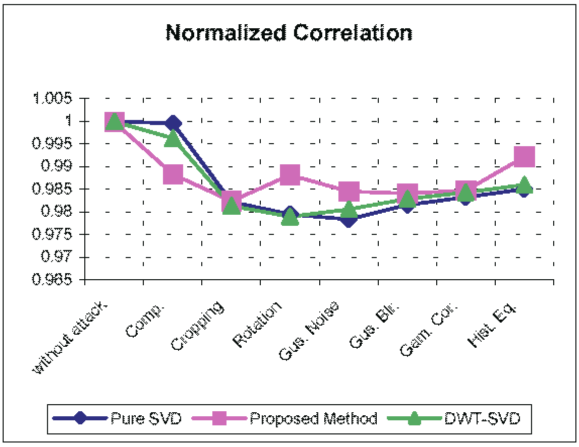
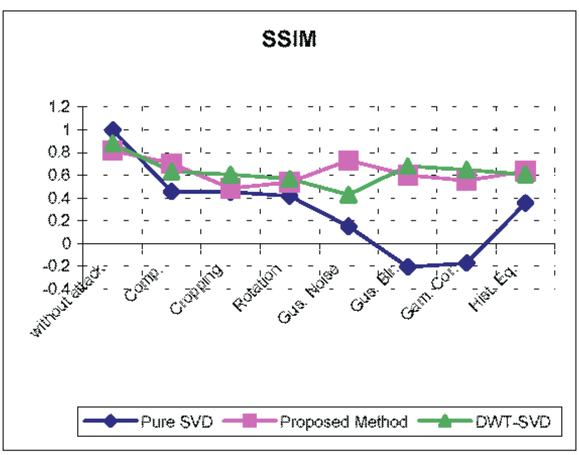


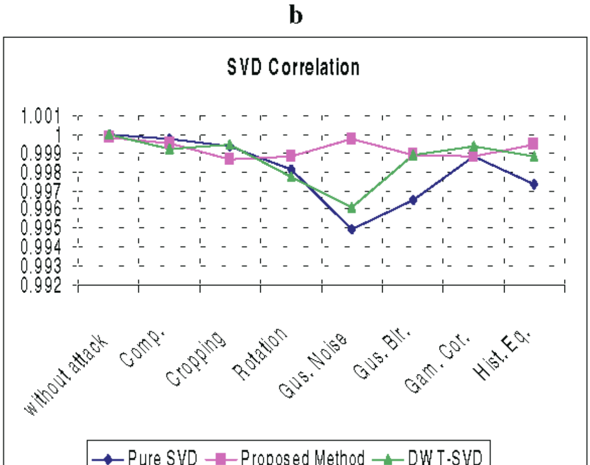
Figure 12. Comparison between different types of CWT implementation.



a



b



c

Figure 13. Extracted results of the proposed method, pure SVD and DWT-SVD using **(a)** normalized correlation, **(b)** SSIM (Wang *et al* 2003) and SVD correlation (Papas & Safranek 2000).

(Papas & Safranek 2000), (Kutter & Petitcolas 2000), (Petitcolas & Anderson 1999), (Wu & Rao 2006), (Wang & Bovic 2002) and (Wang *et al* 2003) in this paper three common visual quality assessments have been applied to testify the extracted watermark similarity to the original one.

In figure 12, the results of the extracted watermark with different types of scaling factors in the proposed method are illustrated. By considering the results summarized in figure 12, it can be concluded that the implementation in level one with variant scaling factor can be treated as the best result of the proposed method; therefore, in figure 13, this implementation of the proposed method is compared with the best existing methods.

Although the normalized correlation shows the acceptable performance (figure 13a), extracted watermark after applying Gaussian noise and Gaussian blur attacks (figures 9–11) shows better visual results. Since the watermarking method is SVD-based, in the last graph (identified as figure 13c), the SVD correlation quality assessment was used (Papas & Safranek 2000). This measure is more consistent with HVS criteria. As it has been referred to in the mentioned figure, the proposed method have shown better performance in most of the cases, especially by applying non geometrical attacks like Gaussian noise and Gaussian blur in which the SVD-based methods are less efficient to extract the related watermark. Consequently, both PSNR values of watermarked and the robustness against attacks show considerable improvement using the proposed algorithm.

5. Conclusion

A new non-blind SVD-based watermarking method in CWT domain was introduced. Modifying *SVs* of the host image in CWT domain provides high robustness against the common attacks. High PSNR of watermarked image is another beneficial point of the algorithm as the result of CWT implementation. Making trade off between PSNR of the watermarked image and correlation between extracted watermark and the original data lead to selecting the best value of the scaling factor in both variant and non-variant implementations of our method. Although all SVD-based watermarking algorithms are enough robust against the geometrical attacks such as cropping and rotation, they are less robust against some distortions like Gaussian noise, blurring and histogram equalization. Since the proposed algorithm takes the advantages of the Wavelet Transform and SVD methods simultaneously, the extracted watermarks are more robust against all mentioned attacks. The additional privilege of suggested algorithm is its compatibility with human visual system characteristics to embed the watermark by selecting the best sub-bands in CWT domain. In this way, high capacity of CWT domain is applied to embed the watermark information along with preserving the quality of the watermarked image.

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