A Bi-Dimensional Empirical Mode Decomposition Based Watermarking Scheme

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Abstract: An invisible robust, non blind watermarking scheme for digital images is presented. The proposed algorithm combines the Discrete Wavelet Transform (DWT) and the Bi-dimensional Empirical Mode Decomposition (BEMD). Unlike previous works where the watermark bits are embedded directly on the wavelet coefficients, the proposed scheme suggests rather the embedding of the wavelet coefficients of the mean trend results by performing the BEMD on the host image, using Singular Value Decomposition (SVD). The watermarked image has a very good perceptual transparency. The extraction algorithm is a non-blind process, which uses the original image as a reference for retrieving the watermark. The proposed algorithm is robust against rotation, translation, compression and noise addition. It has also a superior Peak Signal to Noise Ratio (PSNR) for the watermarked image. The obtained results, tested on different images by various attacks, are satisfactory in terms of imperceptibility and robustness.

Keywords: Watermarking, DWT, BEMD, SVD.

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1. Introduction

In recent years, the use of digital data has reached a phenomenal level. This trend was mainly driven by the widespread of a variety of intelligent portable devices (smart phones, multimedia internet enabled tablets and game consoles etc.,), as well as the extensive use of social networks. With the ever growing IT infrastructure, it is now very common to upload any digital information to the net almost on the fly. Once published and unless protected, the information remains vulnerable to malicious attacks. On daily basis, thousands of digital images are posted online either by individuals or corporations and the issue of protecting the copyrights of their owners has become very critical [8, 33].

Watermarking techniques can be broadly classified into two categories: Spatial and transform domain based methods. Spatial domain methods [7, 31] are less complex but not robust against various attacks [6]. Frequency-domain watermarking techniques are more effective in achieving the imperceptibility and robustness requirements of digital watermarking algorithms [6]. This is due to the fact that when an image is inverse transformed, the watermark is distributed irregularly over the image making it difficult to be modified or to be read. The commonly used frequency-domain transforms consist of the Discrete Cosine Transform (DCT), the Discrete Fourier Transform (DFT), and the Discrete Wavelet Transform (DWT) among others. An overview of frequency domain watermarking is reported in [22].

However, the DWT has been used in digital image watermarking more frequently in comparison to other transforms [23]. In fact, the DWT based watermarking approach has been used by many groups to generate watermarking schemes for images and videos [1, 29, 31, 32]. The superiority of the DWT is mainly due to its excellent spatial localisation and multi-resolution characteristics, which are similar to the theoretical model of the Human Visual System (HVS) [23].

Barni *et al.* [3] exploited the wavelet domain based texture and luminance characteristics of all image subbands to embed the watermark using the HVS. Later, Barni's work was used by Reddy and Chaterji [30] to calculate the weight factors for the wavelet coefficients of the host image. Unfortunately, these schemes are vulnerable to a relatively high compression and consequently, the embedded watermark coefficients may be destroyed in the compression process [37]. The SVD based watermarking algorithm was firstly introduced by Liu and Tan [20]. To achieve high robustness against attacks like compression, Gaussian noise or cropping, the DWT is combined with SVD. Since then, many other schemes based on this combination have been proposed [2, 6, 10, 11, 34, 36].

Empirical Mode Decomposition (EMD) is another technique for digital image watermarking. It is based on direct extraction of the image energy associated with various intrinsic time scales [25]. The technique adaptively decomposes non stationary images into a set of intrinsic oscillatory modes. The mean trend-the coarsest component-of the image is highly robust under noise attack and JPEG compression [15, 24, 26, 35]. Geometric attacks remain one of the major problems to combat in image watermarking since synchronisation errors between the extracted and the embedded watermarks can be very important. To deal with this problem, several approaches have been developed. They can be classified into four distinct categories; invariant-domain [17], template [28], moment [14] and feature based watermarking [4].

In this paper, it will be shown that the BEMD is an efficient tool to address the geometrical attacks issue. It is proposed a non blind, hybrid algorithm in which the mark is inserted in the mean trend. The proposed algorithm combines the DWT with both the SVD and the BEMD leading to a more robust approach for combating geometrical attacks. Initially, the BEMD algorithm is applied to the host image to get different Intrinsic Mode Functions (IMFs), as well as, the mean trend. The IMFs are then decomposed into four subbands using the DWT. The SVD is then applied to the middle frequency band and the same watermark data is embedded by modifying the singular values.

This paper is organised as follows: Section 2 briefly reviews the DWT and SVD transformations. An overview of the BEMD is presented in section 3. The proposed watermarking algorithm is introduced in section 4. The experimental results are highlighted in section 5. The conclusion, in section 6 closes the paper.

2. Wavelet Transform and SVD

2.1. Wavelet Transform

The DWT is obtained by filtering the signal through a series of digital filters at different scales. The scaling operation is done by changing the resolution of the signal by the process of sub sampling. In bidimensional DWT, each level of decomposition produces four bands of data denoted by LL, HL, LH, and HH. The LL sub band can further be decomposed to obtain another level of decomposition. This process is continued until the desired number of levels, determined by the application is reached. The hierarchical image representation due to the multiresolution characteristics of the DWT domain allows the insertion of the watermark in any band. Generally, if the watermark is embedded in the low resolution sub-band LL, it is robust to attacks but it causes a degradation of the image quality. On the other hand, a small modification in the HH sub-band is not perceived by human eyes, but the robustness is compromised. Based on these considerations, the embedding is usually performed in the HL and LH sub-bands [5, 9]. The proposed algorithm in this paper uses this characteristic.

2.2. SVD Technique

The SVD belongs to the category of orthogonal transforms. It consists in the decomposition of a given matrix into three matrices of either the same or different dimensions under certain conditions. The

SVD technique compacts the maximum energy available into a minimum number of coefficients. Therefore, SVD techniques are widely used in digital image watermarking schemes. Let us denote the image as matrix A. The SVD decomposition of A is given by the following equation:

$$A = USV \tag{1}$$

The rank of the matrix A of dimension (m, n) is given by r=min (m, n). The first r columns of V are the right singular vectors and the first r columns of U are the left singular vectors. These singular values (λ_i) are such that it satisfies $\lambda_1 \ge \lambda_2 \ge \dots \ge \lambda_r$. Singular values in a digital image are less affected if general image processing is performed. This is due to the fact that bigger singular values do not only preserve most energy of an image, but also resist against attacks. Generally, the matrix Shas many small singular values. It is important to note that each singular value specifies the luminance of an image layer while the corresponding pair of singular vectors specifies the geometry of the image layer [6]. In this work, we will use the singular values of the middle sub-bands of both the original image and the watermark to obtain the watermarked image.

3. Empirical Mode Decomposition

The Huang's data-driven EMD method was initially proposed in the study of ocean waves [25] and found immediate applications in image processing. The major advantage of EMD is that the basic functions are derived directly from the signal itself. In comparison to Fourier analysis, where the basic functions are fixed as sine and cosine, the EMD method is more adaptive. The central idea of this method is an iterative sifting process that decomposes a given signal into a sum of IMFs.

For signal to be an IMF, it must satisfy two criteria: The number of extrema and the number of zero crossings are either equal or differ at most by one; and the mean of its upper and lower envelopes equals zero. The second criterion modifies a global requirement to a local one and is necessary to ensure that the instantaneous frequency will not have unwanted fluctuations as induced by asymmetric waveforms [16]. Nunes *et al.* [26] extended this method to two-dimensional space for image processing. It was then adopted for de-noising [21], texture analysis [27], compression [18, 19] and fusion [12].

As it has been mentioned above, the signal must have at least one maximum and one minimum to be successfully decomposed into IMFs. For a signal s(t), n IMFs and a residue are obtained at the end of the decomposition. The signal could be then decomposed as follows:

$$s(t) = \sum_{j=1}^{n} c_{j} + r_{n}$$
 (2)

In terms of basic functions, the data-driven basic functions c_j , obtained by EMD, are completely different from those of either the Fourier or the Wavelet decompositions, respectively. As it is adaptive and un-supervised, the multi-scale EMD decomposition method improves the efficiency of a signal and could be then applied to both non-linear and non-stationary signal processing. More details about EMD could be found in [25].

The BEMD is similar in essence to one-dimensional EMD, however, the extrema detection and the surface interpolation of envelopes are more complicated. A BIMF component is obtained using a bi-dimensional sifting process in which neighbouring windows are exploited to detect the extrema. To find the first IMF, the image $inp_{lk}(m, n)=x(m, n)$ is considered as the input signal, where l=1,...,L and k=1,...,K.

In the sifting process, m and n represent the two spatial dimensions. The same notation as indicated in [18] has been adopted. The sifting process consists of the following steps:

- a. Identify the extrema (both maxima and minima) of the image using morphological reconstruction and based on nearest 8-connected neighbours.
- b. Generate the 2D 'envelope' by connecting maxima points (respectively, minima points) with a B-spline function [19]. The upper envelopes of the local maxima and minima are denoted $e_{max}(m, n)$ and $e_{min}(m, n)$, respectively.
- c. Determine the local mean (*denoted* $em_{l,k}$) by averaging the two envelopes:

$$em_{l,k}(m,n) = \frac{e_{max}(m,n) + e_{min}(m,n)}{2}$$
 (3)

d. Since, an IMF has a zero local mean, subtract out the mean from the image:

$$h_{l,k}(m,n) = inp_{l,k}(m,n) - em_{l,k}(m,n)$$
(4)

This process constitutes the first iteration of the sifting process. The next step is to check if the signal $h_{l,k}(m, n)$ obtained after step d is an IMF or not. The process stops when the envelope mean signal is closed enough to zero according to:

$$\left|em_{l,k}\left(m,n\right)\right| < \varepsilon \tag{5}$$

e. If Equation 5 is not fulfilled, then repeat the process from step a using the resulting IMF from step *d* as the input signal:

$$inp_{L(k+1)}(m, n) = h_{Lk}(m, n)$$
(6)

Once the stop criterion is met, then set k=K. The IMF is defined as the last result from *d*:

$$c_{l}(m,n) = h_{lk}(m,n)$$
 (7)

After the IMF $c_i(m, n)$ is found, define the residue $r_i(m, n)$ as the result of subtracting this IMF from the input image:

$$r_{l}(m, n) = inp_{ll}(m, n) - c_{l}(m, n)$$
(8)

The residue becomes a monotonic function when no IMF can be extracted. By summing up the sifting process as depicted in the previous steps, the decomposed image into *N*-empirical modes and a residue is obtained:

$$x(m,n) = \sum_{j=1}^{N} \inf_{j} (m,n) + r_{N}(m,n)$$
(9)

The residue can be either the mean trend or a constant. In this study and to illustrate the decomposition process, 3 IMFs, calculated by repeating the sifting process were sufficient to obtain a satisfactory residue, which is used to insert the watermark. The decomposition process as shown in Figure 1. As it is reported in [13] it is important to note here that there is no systematic method for each step and that the successive IMFs are just considered as appropriately orthogonal.

4. Proposed Algorithm

In the proposed scheme of this work, the watermark is inserted by use of the obtained residue from BEMD of the image. Because the mean trend (residue) of the signal is highly robust against noise attack and JPEG compression [15], the DWT is applied on it and the obtained middle sub bands are used to embed the watermark in the image by means of SVD tool. The watermark used for embedding is a uniform random image of the same size of the cover one. The proposed scheme is given by the following algorithm and its flowchart is shown in Figure 2.



Figure 1. Example of applying BEMD on Lena image.

4.1. Watermark Embedding

Initially, the BEMD is performed on the cover image I (image under consideration). Three levels of decomposition are required leading to 3 IMF functions and a residue of order 3 (refer to Figure 1 for details). Then, one level DWT is applied on the obtained residue of image I and on the watermark image W to

generate the necessary four sub-bands LL, LH, HL and HL.

In the proposed algorithm, only the HL band has been used as it is explained in sub section 2.1. Finally, the SVD decomposition is applied on the two obtained HL sub-bands. The singular values of watermark (λ_W) are added to those of the cover image residue (λ_I) as follows:

$$\lambda_{IW} = \lambda_I + \lambda_W \tag{10}$$

 λ_{IW} represents the singular values of the watermarked image.



Figure 2. Watermark embedding.

On the modified sub-band, the inverse DWT is applied to achieve the embedded residue. The modified residue is summed with the 3 IMFs to achieve the watermarked image. The watermark embedding algorithm is presented in Figure 2.

4.2. Watermark Extraction

The watermark extraction algorithm is shown in Figure 3. The extraction algorithm uses the cover and the original watermark images to extract the watermark. It is a non blind proposed scheme. On the residue RIW of the watermarked image, the one level DWT is applied to generate the four sub-bands. The SVD

decomposition is applied on the sub-band HL. The singular values of watermark $(\lambda_{w'})$ are extracted from the singular values of the DWT transformed residue of the watermarked image:

$$\lambda_{w'} = \lambda_{IW} + \lambda_I \tag{11}$$

The extracted singular values formed the S matrix. This latter is combined with other matrices U and V according to Equation 1 to generate the watermark image 'W' as illustrated in Figure 3.



Figure 3. Watermark extraction.

5. Simulation Results

To evaluate the performance of the proposed watermarking scheme, the MATLAB V7.10 platform is used. Numerous tests have been conducted on the popular test images of Figure 5 with different textures and the same size of 256*256 (Lena, Peppers, Barbara and Baboon). Generally, the elapsed time of calculus varies from one image to another and depends on its size.

Various experiments are performed on the watermarked image to test the robustness of the algorithm against various attacks such as JPEG compression, rotation and noise addition. The watermark image is a binary image of the same size of the cover image. The quality of the extracted watermark is compared with the original watermark using the pearson's Correlation Coefficient (CC):

$$CC(w,w') = \frac{\sum_{i=l}^{m} \sum_{j=l}^{n} (w(i,j) - \tilde{m}_{w})(w'(i,j) - \tilde{m}_{w'})}{\sqrt{\sum_{i=l}^{m} \sum_{j=l}^{n} (w'(i,j) - \tilde{m}_{w'})^{2}} \sqrt{\sum_{i=l}^{m} \sum_{j=l}^{n} (w(i,j) - \tilde{m}_{w})^{2}}} \quad (12)$$

Where, w(i, j) and w'(i, j) are the original and extracted watermarks, respectively.

 \tilde{m}_w and \tilde{m}_w , are the mean values of the original and extracted watermarks, respectively. $-1 \le CC \le 1$. CC = 1

indicates perfect correlation, while an extremely low value reveals that the watermarks are dissimilar.

Table 1. Values of correlation coefficient obtained under common image processing.

	Peppers	Barbara	Baboon	Lena
Filter (3x3)	0.8260	0.8747	0.9327	0.9552
DWT-SVD	0.5384	0.5296	0.0938	0.6369
Filter (5x5)	0.6741	0.8763	0.8964	0.7962
DWT-SVD	0.2889	0.2779	0.0121	0.3703
Salt and Pepper Noise 0.1	0.8157	0.8032	0.9245	0.8051
DWT-SVD	0.0833	0.0881	0.0942	0.0893
Gaussian Noise 75%	0.8506	0.8297	0.9183	0.9183
DWT-SVD	0.0683	0.0727	0.0725	0.0731
JPEG 80:1	0.9969	0.9969	0.9969	0.9969
JPEG 80 DWT-SVD	0.9429	0.9008	0.9969	0.9580
JPEG 40 DWT-SVD	0.6457	0.7235	0.7031	0.7786
JPEG 10 DWT-SVD	0.2131	0.4523	0.0665	0.3511
	Peppers	Barbara	Baboon	Lena

The performance of the proposed algorithm (PM) is measured using Peak Signal to Noise Ratio (PSNR) metric. Without any attacks, the watermark can be extracted with a PSNR superior to 40 db from all images. The invisibility of the embedding process is then guaranteed as it can be seen in Figure 4.



c) Watermarked image

Figure 4. Example of applying the proposed method on peppers image.

5.1. Robustness Against Common Image Processing

In order to, approve the results obtained by using BEMD and determine the effect of using this tool, we have simulated the same algorithm in DWT-SVD domain only (without use of the mean trend of BEMD decomposition). The obtained results from the cited images under common image processing are reported in Table 1.

As it is shown, the CC values of the proposed method are practically superior than 0.9 for all attacks. The difference of the obtained CC values between the two methods is clear as shown in Table 1. These results confirm that the insertion in the residue of BEMD decomposition make the scheme more robust against noise addition, filtering and JPEG compression.

The extracted watermark is still recognizable after applying 13*13 averaging filtering with a CC value correspondent to 0.6281. In [6] the CC value after applying the same attack is equal to -0.3696 under the same image (peppers). From the same reference, we compare the results of robustness under noise addition. The watermark image is degraded by randomly adding 75% Gaussian noise. The CC from our method is 0.8506 and the obtained CC value in [6] is 0.2843 for peppers image. Attacked watermarked Peppers image and extracted watermark are shown in Figure 6.





Figure 5. Used images.

b) Lena



a) Peppers.

c) Barbara



a) Watermarked attacked Peppers by noise





b) Extracted watermark



Watermarked attacked Peppers by filtering

Figure 6. Results of adding noise (75% additive gaussian noise) and 13*13 median filtering attacks respectively.

5.2. Robustness Against Geometrical Attack

Since the wavelet transformation is not rotational invariant, we will not compare our algorithm like in previous section. The obtained CC values under some geometrical attacks are given in Table 2. An affine transformation has been performed under the conditions: Scale= 1, rotation= 5° , translation x= -40 and y=30. Figure 7 shows the obtained Lena image under this kind of attack and other attack with the correspondent extracted watermark. The best results are obtained from Peppers image which is not textured image. The extracted watermark still recognizable under different geometrical attacks but the values of CC are low than 1. In our case, the obtained PSNR values for all extracted watermarks from the attacked images are greater than 40 db.

Table 2. Values of correlation coefficient under desynchronization attacks.

	Peppers	Barbara	Baboon	Lena
Rotation 30°	0.9787	0.6114	0.5435	0.7190
Rotation 45°	0.5567	0.5280	0.3270	0.3754
Translation x-40	0.9633	0.9658	0.9716	0.8655
Translation y-40	0.6128	0.5929	0.3417	0.5899
Affine Transformation	0.6635	0.8774	0.7377	0.7891



c) Watermarked attacked Lena by translation.

d) Extracted watermark.

Figure 7. Results of affine transformation and translation attacks respectively.

6. Conclusions

In this work, a BEMD-DWT-SVD based non-blind watermarking scheme is presented and tested. The mark is inserted in the mean trend by means of the SVD tool. The extraction is tested on various images under attacks by use of the correlation coefficient. After simulation, it has been found that the proposed scheme is more robust against JPEG compression, filtering and noise addition. The use of the BEMD has been approved for common image processing. As a future work, it will be very interesting to elaborate a blind scheme in this domain.

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