FABEMD Based Image Watermarking in Wavelet Domain

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Abstract. In this work, we aimed to further improve the commonly used DCT-DWT based watermarking method by combining the DCT-DWT with the FABEMD method. Rather than embedding the watermark in the whole image, in our approach, the image is decomposed using FABEMD method into a series of BIMFs and residue, while the watermark takes place into one of BIMFs. The experiments indicate that our developed FABEMD-DCT-DWT technique can achieve high imperceptibility while showing good robustness. Furthermore, the proposed method is compared with the DCT-DWT based method, and the experiment results confirm that the proposed method shows better performances.

Keywords: Watermarking, DCT, DWT, FABEMD, BIMF, Residue.

1 Introduction

Nowadays, Due to the fast development of the internet and wireless networks, there are new challenges raised in protecting the digital materials. Data security is one of the main concerns these days. In this context, watermarking has been introduced to deal with the issue of data security. The idea of watermarking is to embed a secret message (watermark) inside an image, either audio or video file to increase the digital data security. Different techniques have been proposed. Watermarking techniques can be classified into two categories: Spatial and Transform domain methods. The most popular techniques for the image watermarking are the frequency domain approaches. In these techniques, the image is being transformed via some common frequency transform. The transforms that are usually used are the DCT, DFT, SVD, DWT or their mixing algorithms such us DWT-DCT, DCT-SWD and so on.

Among the proposed frequency based watermarking approaches, DCT based (Discrete Cosine Transform) techniques have gained interest among watermarking researchers[8].

Due to its excellent spatio-frequency localization properties, the DWT is very suitable to identify the areas in the host image where a watermark can be embedded effectively. Furthermore, some ownership protection schemes which combine DWT and DCT have also been proposed, and they achieved good results [5-7].

The compromise adopted by those watermarking schemes is to embed the watermark in the middle frequency sub-bands where acceptable performance of imperceptibility and robustness could be achieved.

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In this paper, we propose a new watermarking scheme which integrates Discrete Cosine Transform (DCT), FABEMD and Discrete Wavelet Transform (DWT). Hence, by combining the advantages of the three methods, we can make a good balance between invisibility and robustness of the watermark. Our main contribution consists of embedding watermark logo information inside the BIMF2, which correspond to the middle frequency of the host image, in order to achieve better performance in terms of perceptually invisibility and the robustness of the watermark.

Therefore, section 2 briefly introduces the FABEMD decomposition method for readers unfamiliar with this method. Then, section 3 goes into details about the scheme. The experimental results and discussion is given in Section 4 followed by conclusion in section5.

2 FABEMD (Fast and Adaptive Bidimensional Empirical Mode Decomposition)

2.1 FABEMD Overview

Empirical Mode Decomposition (EMD) is first developed by Huang et al. [1, 2] and has shown to be a powerful tool for decomposing nonlinear and nonstationary signals. The concept of EMD is to decompose the signal into a set of zero mean functions called Intrinsic Mode Functions (IMF) and a residue. This decomposition technique has also been extended to analyze two-dimensional (2D) data/images, which is known as bidimensional EMD (BEMD). In EMD or BEMD, extraction of each IMF or BIMF requires several iterations. Hence, the extreme detection and interpolation at each iteration makes the process complicated and time consuming. The situation is more difficult for the case of BEMD, which requires 2D scattered data interpolation at each iteration. For some images it may take hours or days for decomposition. To overcome these limitations of BEMD, a novel approach called Fast and Adaptive BEMD (FABEMD) was proposed recently by Bhuiyan et al. [3, 4]. It substitutes the 2D scattered data interpolation step of BEMD by a direct envelop estimation method and limits the number of iterations per BIMF to one. In this technique, spatial domain sliding order-statistics filters, namely, MAX and MIN filters, are utilized to obtain the running maxima and running minima of the data. Application of smoothing operation to the running maxima and minima results in the desired upper and lower envelopes respectively. The size of the order-statistics filters is derived from the available information of maxima and minima maps.

2.2 FABEMD Algorithm

Let the original image be denoted as I, a BIMF as BIMFi, and the residue as R. In the decomposition process ith BIMF BIMFi is obtained from its source image Si, where Si is a residue image obtained as Si=Si-1-BIMFi-1and S1=I. It requires one or more iterations to obtain BIMFi, where the intermediate temporary state of BIMF in jth iteration can be denoted as FTj. With the definition of the variables, the steps of the FABEMD process can be summarized as follows:

1. Set i=1. Take I and set Si(m,n)=I(m,n).
2. Obtain the local maxima and minima maps of Si(m,n) denoted as (LMMAX) and (LMMIN) respectively using the neighboring window method. In this method a data point is considered as a local maximum (minimum) if its value is strictly higher (lower) than all of its neighbors within a window.
3. Calculate the size of the order statistics filters and smoothing averaging filters from (LMMAX) and (LMMIN).
4. Form the upper envelope UEi(m,n) and lower envelope LEi(m,n) from Si using the order statistics filter and then form smoothed upper envelope and smoothed lower envelope using smoothing averaging filters
5. Find the mean/average envelope MEi(m,n) as
   MEi(m,n) =(UEi(m,n) + LEi(m,n))/2
6. Calculate BIMFi(m,n)=Si(m,n)-MEi(m,n)
7. Set Si+1(m,n)=Si(m,n)-BIMFi(m,n)
8. if the source image Si+1(m,n) has less than three extrema points, and if so, this is the residue of the image(R(m,n)=Si(m,n)+1) and the decomposition is complete, otherwise, set i=i+1 and go to step (2) and continue to step (8) to obtain the subsequent BIMFs.

Figure 1 shows an example of FABEMD decomposition.

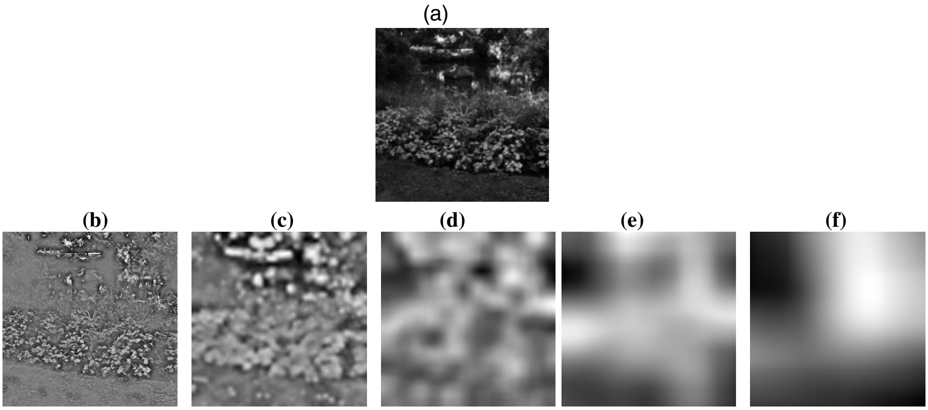


Fig. 1. (a) The original image is decomposed into BIMFs (b-e) and residue (f)

3 Proposed Algorithm

3.1 Watermark Embedding

To insert the watermark in the host image, the first step is to decompose the image into BIMFs and residue using the FABEMD decomposition and then, embedding watermark logo information inside the BIMF2. Watermarked image is obtained by adding all the BIMFs and the residue (Figure3).

The watermark embedding procedure can be described as follows:

1. Perform DWT on the host image to decompose it into four non-overlapping multi-resolution coefficient sets: LL, HL, LH and HH.
9. Divide the sub-band LL into 8 x 8 blocks and apply DCT to each block. The watermark is not applied to all block DCT values, but is applied only to the midfrequency DCT coefficients using the mask shown in Figure 2.

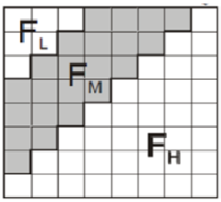


Fig. 2. Definition of DCT Regions

FL is used to denote the lowest frequency components of the block, FM is used to denote the middle frequency components of the block while FH is used to denote the higher frequency components.

10. Reshape the watermark image into a vector of zeros and ones
11. Generate two uncorrelated pseudorandom sequences by a key. One sequence is used to embed the watermark bit 0 (PN_0) and the other sequence is used to embed the watermark bit 1 (PN_1).
12. Embed the two pseudorandom sequences, PN_0 and PN_1, with a gain factor k in the DCT coefficients. If we donate X' as the matrix of the midband coefficients of the DCT transformed block, then embedding is done as follows:
    If the watermark bit is 0 then
    X' =X+k* PN_0
    If the watermark bit is 1 then
    X' = X + k * PN_1
13. Perform inverse DCT (IDCT) on each block after its mid-band coefficients have been modified to embed the watermark bits as described in the previous step.
14. Perform the inverse DWT (IDWT) on the DWT transformed image, including the modified coefficient sets, to produce the watermarked image.

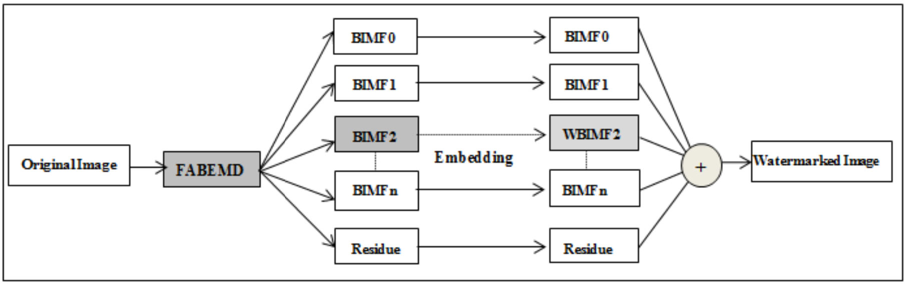


Fig. 3. Embedding scheme of our method

3.2 Watermark Extraction

The watermark extraction process is represented in Figure4, and can be described as follows:

1. Read in the watermarked image
2. Apply DWT to decompose the watermarked image into four non-overlapping sub-bands: LL, HL, LH, and HH.
3. Divide the sub-band LL into 8x8 blocks, and apply DCT to each block in the chosen sub-band LL.
4. Extract the middle band coefficients from each block.
5. Regenerate the two pseudorandom sequences (PN_0 and PN_1) using the same key which used in the watermark embedding procedure.
6. For each block calculate the correlation between the mid-band coefficients and the two generated pseudorandom sequences (PN_0 and PN_1). If the correlation with the PN_0 was higher than the correlation with PN_1, then the extracted watermark bit is considered 0, otherwise the extracted watermark is considered 1.
7. The watermark is reconstructed using the extracted watermark bits, and compute the similarity between the original and extracted watermarks.

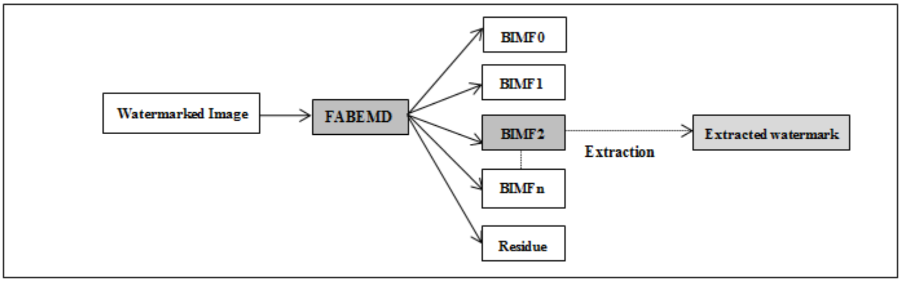


Fig. 4. Extraction scheme of our method

4 Results and Discussions

In order to verify the efficiency of our proposed method, we have applied our embedding algorithm to a database of 1000 512x512 grey scale images [9].

The performance of the watermarking methods is investigated by measuring their imperceptible and robust capabilities.

For the imperceptible index, Peek Signal-to-Noise Ratio (PSNR), is employed to evaluate the difference between an original image I and a watermarked image Iw.

The PSNR is defined by the following equation :

$$PSNR = 10\log_{10}\frac{255^2}{MSE} \quad (1)$$

$$MSE = \sum_{i=0}^{M-1}\sum_{j=0}^{N-1}\left(\frac{(I_w(i,j)-I(i,j))^2}{MxN}\right) \quad (2)$$

For the robust capability, a measure of Normalized Correlation (NC) between the original watermark W and the corresponding extracted watermark W' is done.

The Normalized Correlation (NC) is defined by the following equation:

$$NC = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N} W(i,j)xW\prime(i,j)}{\left(\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N} W(i,j)\hat{}2}\right)\left(\sqrt{\sum_{i=}^{M}\sum_{j=1}^{N} W\prime(i,j)\hat{}2}\right)} \tag{3}$$

NC value is generally 0 to 1. Ideally NC should be 1.

4.1 Robustness in Attack Free Case

The performance of our proposed technique, which embeds the watermark in the BIMF2 only, is compared with that of the traditional technique, which embeds the watermark in the whole image [7]. The results obtained are reported in figure5. They are presented in terms of Peak Signal –to- Noise Ratio (PSNR) and Normalized Correlation(NC). Each point on a curve is the averaged value over 1000 images from the BOWS database.

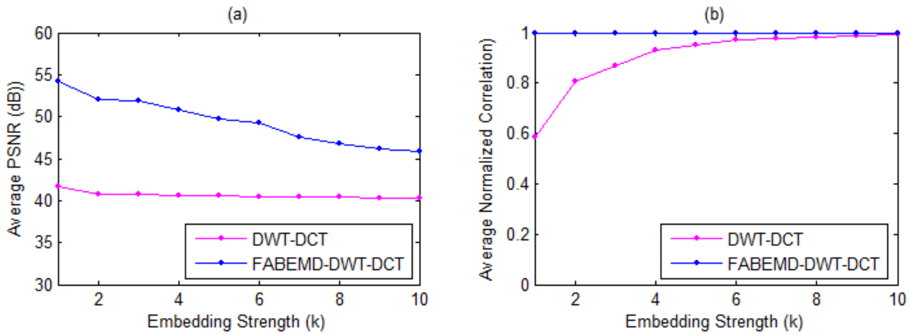


Fig. 5. The comparison between our method and DCT-DWT based method in attack free case (a) Curve of Peak Signal to Noise Ratio (PSNR) in dB Against varying embedding Strength (k) for different cover images via using DCT based method, (b) Curve of Normalized Correlation against varying embedding Strength (k) for different cover images

Invisibility of the Watermark

The PSNR is popularly used to measure the similarity between the original image and the watermarked image. While higher PSNR usually implies higher fidelity of the watermarked image. The watermarking performance of the proposed technique, is compared with that of the DCT-DWT technique on the basis of PSNR for different values of k (gain factor). The results obtained are plotted in Figure 5 (a).

As can be seen from figure5(a), the quality of watermarked images degrades as the value of k increases. Note particularly that the value of PSNR degrades at higher k values. For the DCT-DWT method, the highest PSNR value reached over 1000 images is 68,22 dB, while the lowest PSNR value is 30,56 dB. However our method shows higher PSNR value compared to traditional method. The higher PSNR value obtained for our method is 75,50 dB, while the lowest PSNR value obtained is 41,48 dB.

Robustness of the Watermark

To check the robustness of the extracted watermark, the Correlation (NC) between the original watermark and the corresponding extracted watermark for different values of k (gain factor) using our method and DCT-DWT method is computed. The results are shown in figure 5 (b) .

As can be seen from figure 5 (a) and figure 5 (b), for DCT-DWT method, we observe that as the value of k increases, the robustness of extracted watermark increases, but that affects the imperceptibility of watermarked image. Thus with marginal reduction in perceptibility of watermarked image it is possible to achieve better robustness. On the other hand, it is clear from figure 5 (a) and figure 5 (b) that even with low value of k, the proposed scheme provides highest NC and highest PSNR value compared to traditional method. Thus the results clearly indicate the imperceptibility and the robustness of the present method in attack free case.

4.2 Robustness against Attacks

In order to demonstrate, the robustness of the proposed method (PM) against the DCT-DWT method[7], the watermarked images are attacked by a variety of attacks. The results obtained are plotted in figure6. In this experiment, the embedding strength k=1. Each point on a curve is the Normalized Correlation (NC) averaged over 1000 images from the BOWS database.

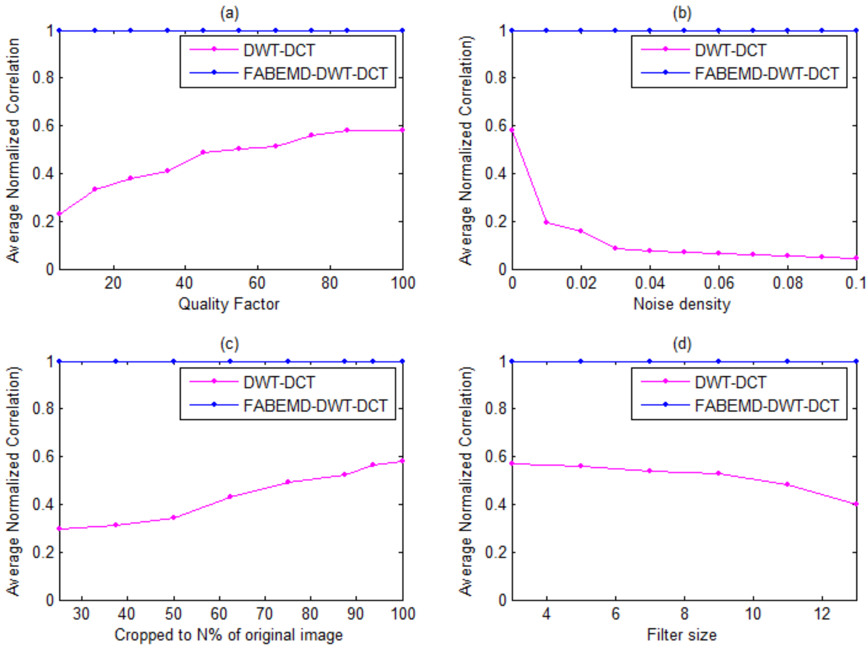


Fig. 6. The comparison between our method and DCT-DWT based method (a) Against JPEG Compression attack. (b) Against Salt&Pepper noise attack. (c) Against cropping attack (d) Against Filtering attack. (e) Against rotation attack. (f) Against Gaussian noise attack.

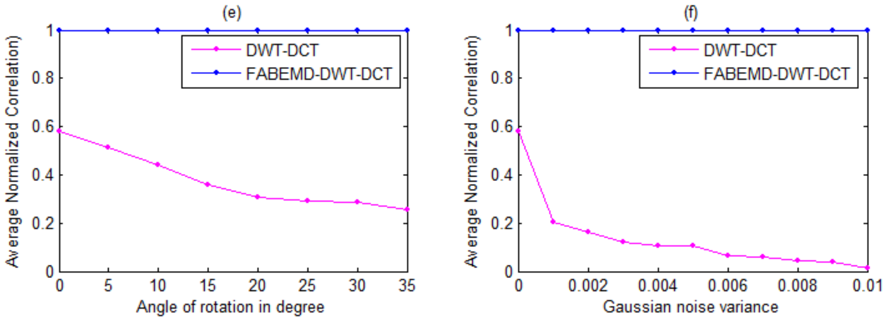


Fig. 6. (*Continued*)

Besides the quantitative results in terms of the PSNR and correlation, experiments also provide visual comparison results (Table1). In this experiment, a 16x64 binary image is taken as the watermark of images.

Table 1. Affect of Attacks

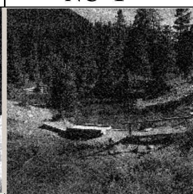
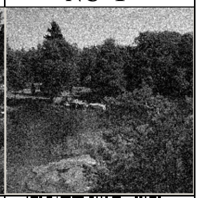
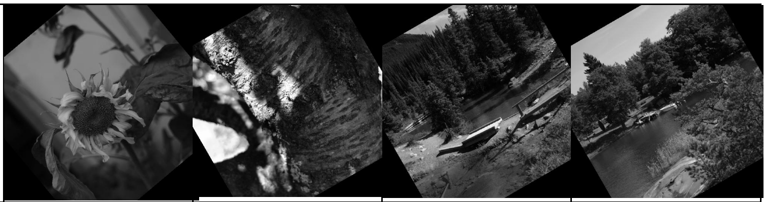
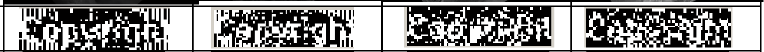
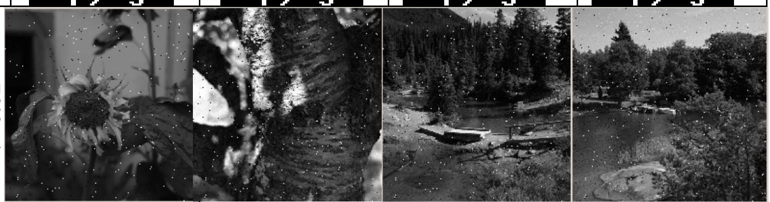
Attacks free				
[7]	**PSNR=43.4931**  **NC=0.84023**	**PSNR=37.3792**  **NC=0.72039**	**PSNR=35.1916**  **NC=0.49164**	**PSNR=36.0559**  **NC=0.55967**
PM	**PSNR=59,0627**  **NC=1**	**PSNR=54,4114**  **NC=1**	**PSNR=56,7599**  **NC=1**	**PSNR=50,9637**  **NC=1**
Gaussian Noi-sev=0.01				
[7]				
PM				

Table 1. (*Continued*)

Rotation 30^0	
[7]	
PM	
JPEG compression Q=5	
[7]	
PM	
Cropping 50 %	
[7]	
PM	
Median Filter (13x13)	
[7]	
PM	
Salt& Pepper V=0.01	
[7]	
PM	

5 Conclusion

We have presented a new robust digital image watermarking scheme based on joint DWT, DCT and FABEMD decomposition. Our scheme is shown to be resistant against several signal processing techniques, including rotation, Gaussian noise, JPEG compression and so on. Furthermore, we show that our algorithm lead to better performance in terms of invisibility of the watermark compared with classical and state of the art watermarking methods[5] [6] [7].

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