A Robust Digital Image Watermarking Scheme Using Hybrid DWT-DCT-SVD Technique

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Abstract
Protection of digital multimedia content has become an increasingly important issue for content owners and service providers. As watermarking is identified as a major technology to achieve copyright protection, the relevant literature includes several distinct approaches for embedding data into a multimedia element (primarily images, audio, and video). In this paper, we present a hybrid watermarking scheme based on Discrete Wavelet Transform – Discrete Cosine Transform – Singular Value Decomposition (DWT-DCT-SVD). Robustness is achieved by taking DCT of the DWT coefficients of the HL band of DWT. After applying DCT we map the DCT coefficients in a zig – zag order into four quadrants and apply the SVD to each quadrant. These four quadrants represent frequency bands from the lowest to the highest. The singular values in each quadrant are then modified by the singular values of the DWT-DCT transformed visual watermark. We show that embedding data in lowest frequencies is resistant to most of the attacks and some attacks are resistant to other frequency bands.

Keywords
multimedia, DWT , DCT, zig – zag , SVD.

1. Introduction

There are several types of digital watermarking, with different goals, and many schemes to accomplish those types of watermarking. Digital watermarking is the process of embedding information into an image that can identify where the image came from or who has rights to it. In some watermarking schemes, a Watermarked image has a logo or some other information embedded into the image so that it is readily visible. However, these watermarks can be easily corrupted or removed using simple image processing techniques. Other schemes use invisible watermarking, in which the information is virtually invisible after it is embedded. Watermark embedding can be achieved in a number of different ways. Some techniques embed a binary pattern into the spatial domain of an image. Usually, the information can be embedded while taking into account which areas of the original image can hold more information while remaining undetectable [1]-[6]. The watermark is embedded by directly modifying pixel values in the spatial domain. Correlation based approach [7,8] is another spatial domain technique in which the watermark is converted to a PN sequence which is then weighted & added to the host image with a gain factor k. For detection, the watermark image is correlated with the watermark image. Watermarking in transform domain is secure and robust to various attacks. However, the size of the watermark that can be embedded is generally 1/16 of the host image. Image watermarking algorithms using Discrete Cosine Transform (DCT) [9, 10], Discrete Wavelet Transform (DWT) [11, 12, 13, 14], Singular Value Decomposition (SVD) [15, 16, 17, 18, 19, 20, 21, 22, 23, 24] are available in the literature. The basic philosophy in majority of the transform domain watermarking schemes is to modify transform coefficients based on the bits in watermark image. Domain transformation watermarking schemes, in general, first use DCT and DWT and then transform the image into the spatial domain. Watermarking schemes usually focus on watermarking black and white or grayscale images. The data hiding capacity is high in spatial domain and frequency domain algorithms based on DCT, SVD. However, these algorithms are hardly robust against various attacks, prone to tamper and degrade the quality of the watermarked image. The algorithms based on DWT provide high image quality but are less robust to various attacks. In this paper, we propose a hybrid digital marking scheme based on DWT-DCT-SVD which overcomes the above draw backs. The rest of the paper is organized as follows: Section 2 briefly describes various domain transforms while Section 3 proposes our hybrid DWT-DCT-SVD technique. Section 4 contains our experimental results followed by conclusions in Section 5.

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2. The Dwt, Dct and Svd Transforms

The DWT, DCT and SVD transforms have been extensively used in many digital signal processing applications. In this section, we introduce these transforms briefly, and outline their relevance to the implementation of digital watermarking.

The DCT transform:

The discrete cosine transforms is a technique for converting a signal into elementary frequency components. It represents an image as a sum of sinusoids of varying magnitudes and frequencies. With an input image, x, the DCT coefficients for the transformed output image, y, are computed according to Eq. 1 shown below. In the equation, x, is the input image having N x M pixels, x(m,n) is the intensity of the pixel in row m and column n of the image, and y(u,v) is the DCT coefficient in row u and column v of the DCT matrix.

$$C(u,v)=\alpha(u)\alpha(v)\sum_{x=0}^{N-1}\sum_{y=0}^{N-1}f(x,y)\cos\left[\frac{(zx+1)u\pi}{2N}\right]\cos\left[\frac{(2y+1)v\pi}{2N}\right] \quad \text{-- [1]}$$

for $u,v = 0,1,2........N-1$

Where

$$\alpha(u) = \begin{cases} \frac{1}{\sqrt{2}} & u=0 \\ 1 & u=1,2,.......N-1 \end{cases}$$

$$\alpha(v) = \begin{cases} \frac{1}{\sqrt{2}} & v=0 \\ 1 & v=1,2,.......N-1 \end{cases}$$

Applying, DCT to an image results in three frequency sub-bands: low-frequency, mid-frequency and high-frequency sub-bands. DCT-based watermarking is based on two facts. The first is that much of the signal energy lies at low-frequency sub-bands containing the most important visual parts of the image. The second is that high frequency component of the image can usually be removed through compression and noise attacks. The watermark is therefore embedded by modifying the coefficients of the middle frequency sub-band so that the visibility of the image will not be affected at the same time the watermark cannot be removed by compression.

The DWT transform:

Wavelets are special functions which, in a form analogous to sines and cosines in Fourier analysis, are used as basal functions for representing signals. For 2-D images, applying DWT corresponds to processing the image by 2-D filters in each dimension. The filters divide the input image into four non-overlapping multi-resolution sub-bands LL1, LH1, HL1 and HH1. The sub-band LL1 represents the coarse-scale DWT coefficients while the sub-bands LH1, HL1 and HH1 represent the fine-scale of DWT coefficients. To obtain the next coarser scale of wavelet coefficients, the sub-band LL1 is further processed until some final scale N is reached. When N is reached we will have 3N+1 sub-bands consisting of the multi-resolution sub-bands LLN and LHx, HLx and HHx where x ranges from 1 until N. 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. In particular, this property allows the exploitation of the masking effect of the human visual system such that if a DWT coefficient is modified, only the region corresponding to that coefficient will be modified. In general most of the image energy is concentrated at the lower frequency sub-bands LLx and therefore embedding watermarks in these sub-bands may degrade the image significantly. Embedding in the low frequency sub-bands, however, could increase robustness significantly. On the other hand, the high frequency sub-bands HHx include the edges and textures of the image and the human eye is not generally sensitive to changes in such sub-bands. This allows the watermark to be embedded without being perceived by the human eye. The compromise adopted by many DWT-based watermarking algorithm, is to embed the watermark in the middle frequency sub-bands LHx and HLx where acceptable performance of imperceptibility and robustness could be achieved.

Singular Value Decomposition

In linear algebra, the singular value decomposition (SVD) is an important factorization of a rectangular real or complex matrix, with several applications in signal processing and statistics. The spectral theorem says that normal matrices can be unitarily diagonalized using a basis of Eigen vectors. The SVD can be seen as a generalization of the spectral theorem to arbitrary, not necessarily square, matrices. Suppose M is an m-by-n matrix. Then there exists a factorization for M of the form where, U is an m-by-m unitary matrix, the matrix Σ is m-by-n with nonnegative numbers on the diagonal and zeros on the off diagonal, and VTVUMΣ=T denotes the conjugate transpose of V, an n-by-n unitary matrix. Such a factorization is called a singular-value decomposition of M.

- The matrix V thus contains a set of orthonormal input vector directions for the matrix M.
- The matrix U contains a set of orthonormal output basis vector directions for the matrix M
- The matrix Σ contains the singular values, which can be thought of as scalar "gain controls" by which each corresponding input is multiplied to give a corresponding output.

3. The Proposed Scheme

Watermark Embedding Procedure

1. Let 'A' be the cover image of size N X N and 'W' be the watermark image of size N/2 X N/2.
2. Apply a two level DWT to the cover image.
3. Then apply DCT to the second level DWT HL coefficients.
4. Map the DCT coefficients into four quadrants: B_1, B_2, B_3 and B_4 as shown in Figure 1 using the zig-zag sequence.

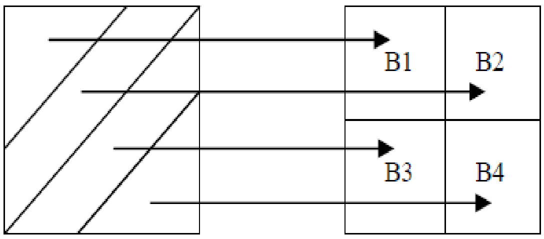


Figure 1: Mapping of DCT coefficients into 4 blocks.

5. Now apply SVD to each quadrant.
6. Implement the two-level DWT to the watermark image.
7. Then implement a DCT to the second level DWT coefficients of HL band.
8. Now apply SVD to the DCT transformed visual watermark.
9. Modify the singular values in each quadrant B_k, K=1, 2, 3, 4 with the singular values of the DCT transformed visual watermark given in Eq. 2:

$$\lambda^{*k}{}_i = \lambda^k{}_i + \alpha_k \lambda_{wi}, i = 1.....,n \quad \text{-- [2]}$$

10. Obtain the 4 sets of modified DCT coefficients.
11. Map the modified DCT coefficients back to their original positions.
12. Perform inverse DCT.
13. And finally, inverse DWT to produce original cover image.

The following description describes the watermark extraction procedure which is the inverse of embedding.

1. Implement the two-level DWT to the watermarked image.
2. Apply DCT to the second level DWT coefficients.
3. Now map DCT coefficients into four quadrants: B_1, B_2, B_3 and B_4 using the zig-zag sequence.
4. Extract the singular values from each quadrant B_k, K = 1, 2, 3, 4.

$$\lambda^k{}_{wi} = (\lambda^{*k}{}_i - \lambda^k{}_i) / \alpha_{k,}, i = 1.....,n \quad \text{---- [3]}$$

5. Construct the DCT coefficients of the four visual watermarks using the singular vectors.
6. Apply the inverse DCT to each set to construct the four visual watermarks.
7. Finally, implement the inverse DWT to each set to construct the four visual watermarks.

4. Experimental Results

To test the robustness of the scheme, experiments are conducted using a 512 x 512 host image of 'Lena' (Figure 3) and 256 x 256 of 'cameraman' as the watermark image (Figure 4). Figure 5 shows the watermarked Lena and xtracted watermarks without any attacks. .

Figure 2: Original Image

Figure 3: Watermark image

Fig 4: watermarked lena and extracted watermarks

Table 1 depicts a host of attacks such as Gaussian Blur, Gaussian Noise, Pixelate-2, JPEG, JPEG 2000, Sharpen, Rescale, Rotation, Symmetrical Crop, Contrast, Histogram Equalization and Gamma Correction. All attacks were implemented in XnView and Matlab to test robustness of the watermark embedded by our proposed method (DWT-DCT-SVD). The perceptibility of the watermarked image was excellent with a Signal to Noise ratio (PSNR) of 42 db. The extracted watermarks after applying various attacks are shown in Table 2 with Normalized Cross Correlation values as a metric for robustness. The Gaussian Blur of mask 5 x 5 is applied to the watermarked image. The recovered watermarks show good similarity with original watermark. Resizing operation first reduces or increases the size of the image and then generates the original image by using an interpolation technique. This operation is a lossy operation and hence the watermarked image also losses some watermark information. In this experiment, first the watermarked image is reduced from 512 to 256 by using Bi-cubic interpolation and then again increased its dimensions to its original size i.e. from 256 to 512. The extracted watermarks are clearly visible. The recovered watermarked image looks good even after Gaussian Noise attack with 0.3. Likewise, we tested with Pixelate-2, Sharpen 80, Contrast 20, Gamma Correction of 0.6 and Histogram Equalization attacks. In all of the above attacks, we recovered good visual watermarks. Recovered watermarked image showed a good similarity with the original watermark image even after rotating 200 to the right. The watermarked image is compressed using lossy JPEG compression with a compression index of ranging from 0 to 100, where 0 is the best compression and 100 is the best quality. Similarly, JPEG 2000 compression is used to test robustness with a quality factor 50. While in all of the tests our method yielded a better recovered watermark image, except in the case of JPEG 2000 attack. In JPEG 2000 Alexander Sverdlov [24] method's is superior to ours. The proposed algorithm is also best for symmetrical crop attack. Table 3 compares our algorithm with Alexander Sverdlov's algorithm. Values in bold indicate the best results for a particular attack.

Gaussian blur 5x5	Gaussian noise 0.3	Pixelate 2
		
JPEG 30:1	JPEG2000 50:1	Sharpen 80
		

Rescale 512->256->512	Rotate 20^0	Symmetric Crop (25%)
		
Contrast-20	Histogram equalization	Gamma correction 0.6
		

Table 1: Attacks on the watermarked image

Gaussian blur 5X5		**Gaussian noise-0.3**		**Pixelate-2**	
					
0.9912	**0.9572**	**0.9976**	**0.9628**	**0.9948**	**0.9806**
0.9687	**0.9390**	**0.9621**	**0.9635**	**0.9850**	**0.9693**

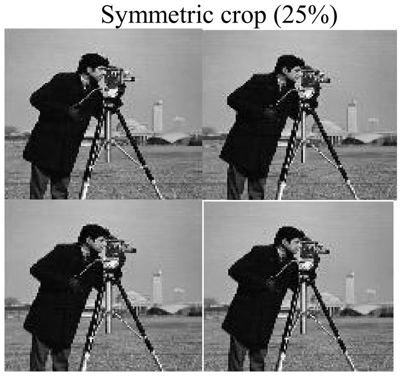
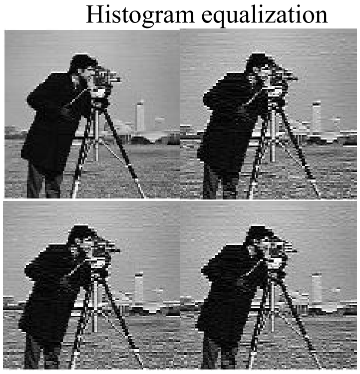
JPEG 30:1  0.9999 0.9993 0.9995 0.9993	JPEG2000 50:1  **0.9962 0.9982** **0.9962 0.9957**	Sharpen 80  0.9646 0.8927 0.8805 0.8632
Rescale 512->256->512  0.9961 0.9926 0.9893 0.9833	Rotate 20^0  0.9988 0.9597 0.9774 0.9993	Symmetric crop (25%)  0.9998 0.9990 0.9991 0.9992
Contrast -20  0.9984 0.9869 0.9870 0.9865	Histogram equalization  0.9899 0.9429 0.9462 0.9417	Gamma Correction 0.6  1.0000 0.9998 0.9995 0.9998

Table 2: Extracted watermarks with proposed algorithm

Table 3: Comparison of experimental results with existing algorithm

Type of Attack	NC values from DCT-SVD by Alexander Sverdlov in 4-blocks				NC values from our proposed method (DWT-DCT-SVD) in 4-blocks			
	B1	B2	B3	B4	B1	B2	B3	B4
Gaussian blur(5 x 5)	0.9894	-0.2173	-0.2261	-0.2136	**0.9912**	0.9572	0.9687	0.9390
Gaussian noise-0.3	0.9942	0.2318	0.2199	0.2083	**0.9976**	0.9628	0.9621	0.9635
Pixelate-2	0.9939	0.3629	0.4833	-0.2035	**0.9948**	0.9806	0.9850	0.9693
JPEG 30:1	0.9998	-0.2662	-0.0874	-0.1036	**0.9999**	0.9993	0.9995	0.9993
JPEG 2000 50:1	**0.9994**	-0.1568	0.0437	-0.1852	0.9962	0.9982	0.9962	0.9957
Sharpen 80	0.9275	0.5974	0.7303	0.8117	**0.9646**	0.8297	0.8805	0.8632
Rescale 512-256-512	0.9957	-0.2114	-0.0450	-0.1458	**0.9961**	0.9926	0.9893	0.9833
Rotate 20	-0.8977	0.7617	0.6095	0.4426	**0.9988**	0.9597	0.9774	0.9993
Symmetric crop 25%	-0.9813	0.4790	0.9990	0.9990	**0.9998**	0.9990	0.9991	0.9992
Contrast 20	0.9883	0.9687	0.9845	0.9941	**0.9984**	0.9869	0.9870	0.9865
Histogram equalization	0.5870	0.8045	0.8800	0.9148	**0.9899**	0.9429	0.9462	0.9417
Gamma correction 0.6	-0.9857	0.9918	0.9975	0.9993	**1.0000**	0.9998	0.9995	0.9998

5. Conclusion

In this paper, a watermarking algorithm based on hybrid technique is proposed. The proposed method (DWT-DCT-SVD) is highly robust and can resist many image processing attacks. The quality of the watermarked image is good in terms of perceptibility and PSNR (42 db). The proposed algorithm is shown to be robust to all the attacks mentioned earlier except for JPEG 2000 attack. But in other remaining three quadrants, comparing with existing method, we get good NC values. In our future work, we will investigate in embedding multiple watermarks in D and U matrices so that the watermark image can resist an increased number of image attacks.

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