A hybrid watermarking scheme using contourlet transform and singular value decomposition

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Abstract
In this paper, we propose a new robust hybrid watermarking technique based on recently introduced contourlet transform and singular value decomposition. After applying the contourlet transform for the original image, we select the low frequency directional sub band coefficients and apply singular value decomposition. The singular values of the original image are then modified by the singular values of contourlet transformed binary logo watermark image. Combination of these two transforms on image improves the performance of watermarking algorithm. It has been observed that, in comparison with other contourlet based and wavelet based methods, the proposed method shows the higher imperceptibility and robustness against common image processing attacks such as Jpeg compression, Jpeg 2000 compression, resizing, median filtering, histogram equalization, sharpening, and Gama correction.
Key words:
Image watermarking, contourlet transform, singular value decomposition, Binary logo.

1. Introduction

Digital image watermarking is a process of embedding a low energy image into a original image such that it does not perceptibly degrade its quality. The watermark should adhere to the original image such that it can not be removed by common signal processing operations. Watermark also is detectable from the watermarked / distorted watermarked (attacked) image by using finite number of computing steps. This helps to make assertions about the data authenticity. The watermarking algorithm consists of watermark structure, an embedding algorithm and an extraction or detection algorithm.
Watermarking techniques may be classified in different ways. The classification may be based on the type of watermark being used, i.e., the watermark may be a visually recognizable logo or sequence of random numbers. A second classification is based on whether the watermark is applied in the spatial domain or the transform domain. In spatial domain, the simplest method is based on embedding the watermark in the least significant bits (LSB) of image pixels. However, spatial domain techniques are not resistant enough to image compression and other image processing operations.

Transform domain watermarking schemes such as those based on the discrete cosine transform (DCT),the discrete wavelet transform (DWT), contourlet transforms along with numerical transformations such as Singular value Decomposition (SVD) and Principle component analysis (PCA) typically provide higher image fidelity and are much robust to image manipulations.
Of the so far proposed algorithms, wavelet domain algorithms perform better than other transform domain algorithms since DWT has a number of advantages over other transforms including time frequency localization, multi resolution representation, superior HVS modeling, linear complexity and adaptivity and it has been proved that wavelets are good at representing point wise discontinuities in one dimensional signal. However, in higher dimensions, e.g. image, there exists line or curve-shaped discontinuities. Since, 2D wavelets are produced by tensor products of 1D wavelets, they can only identify horizontal, vertical, diagonal discontinuities (edges) in images, ignoring smoothness along contours and curves. Curvelet transform was defined to represent two dimensional discontinuities more efficiently, with least square error in a fixed term approximation. Curvelet transform was proposed in continuous domain and its discretisation was a challenge when critical sampling is desired. Contourlet transform was then proposed as an improvement of curvelet transform. The contourlet is a directional multi resolution expansion, which can represent images containing contours efficiently. [2] Contourlet transform possess all features of wavelets and also shows a high degree of directionality and anisotropy. One of the unique properties of contourlet transform is that we could have any number of directional decompositions at every level of resolutions [5].
In this paper, proposed method is compared with another which is based on discrete wavelet transform and singular value decomposition (DWT-SVD).The peak signal noise ratio (PSNR) between the original image and watermarked image and the normalized correlation coefficients (NCC) after different attacks were calculated. The results show high improvement detection reliability using proposed method.
The rest of this paper is organized as follows. Section2 describes the contourlet transform, section 3 describes

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singular value decomposition, section 4 illustrates the details of proposed method, in section 5 experimental results are discussed without and with attacks, conclusion and future scope are given in section 6.

2. Contourlet Transform:

Contourlet transform is a multi resolution and multidirectional transformation technique which is used in image analysis for capturing contours and fine details in images [2].The contourlet transform is composed of basis functions oriented at different directions in multiple scales with flexible aspect ratios. This frame work should form a basis with small redundancy unlike other transform techniques in image processing, Contourlet representation contains basis elements oriented at variety of directions much more than few directions that are offered by other separable transform technique. One way to obtain a sparse expansion for images with smooth contours is first apply a multistage wavelet like transform to capture the edge points, and then local directional transform to gather the nearby edge points into contour segments. With this insight, one can construct a double filter bank structure shown in figure 1(a) where the laplacian pyramidal (LP) filter is used to capture the point discontinuities, followed by a directional filter bank (DFB) to link point discontinuities into linear structures. The overall result is an image expansion using basic elements like contour segments, and thus it is named contourlet transform. The combination of this double filter bank is named pyramidal directional filter bank (PDFB). An example of frequency partitioning of a PDFB is shown in fig1 (b) [5].

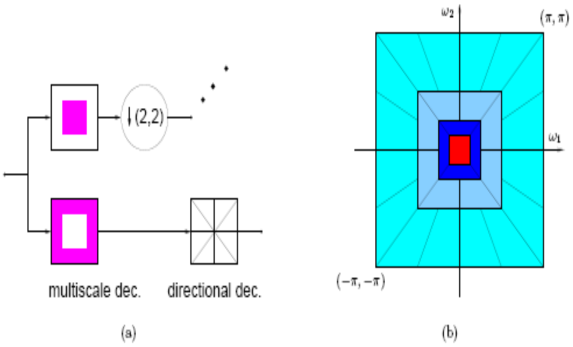


Fig1 (a). Block diagram of the contourlet filter bank. Fig. 1(b). Resulting frequency division where the no. of directions is increased with frequency.

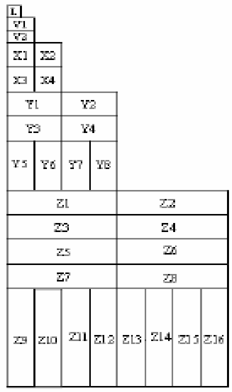


Fig 2: Contourlet transform decomposition

The directional decomposition is implemented through an l-level tree structured decomposition that leads to 2l sub bands with wedge shaped frequency partition .

Fig. 2 shows the directional decomposition at every level obtained using contourlet transform. The no. of directional decompositions can be chosen different and it makes this transform unique. From fig. 2, it is apparent that L is the low pass version of the image and W, X, Y and Z are the directional detail bands at different levels. Directional bands in four levels of multi resolutions are divided into 2, 4, 8 and 16 directional sub bands from coarse to fine scales respectively. In this method, low frequency version sub band 'L' is selected for watermark embedding as discussed in section 4. [9]

3. Singular value decomposition:

Singular value decomposition (SVD) is a popular technique in linear algebra and it has applications in matrix inversion, obtaining low dimensional representation for high dimensional data, for data compression and data denoising. If A is any N x N matrix, it is possible to find a decomposition of the form

$A=USV^T$

$A=[\, u_1\, u_2\, ..u_n] \, [\lambda \, [v_1 \, v_2 .\, v_n]^T \, {}_2 \lambda_{n\,]}$

Where U and V are orthogonal matrices of order N x N and N x N such that UTU=I,VTV=I , and the diagonal matrix S of order N x N has elements λi (i=1,2,3,..n) Which are positive and called singular values of S. [7]
The general properties of SVD are [4]

a) **Transpose:** *A* and its transpose A^T have the same non-zero singular values.
b) **Flip**: *A*, row-flipped *Arf*, and column-flipped ***Acf*** *have* the same non-zero singular values.

c) **Rotation:** *A* and *Ar* (*A* rotated by an arbitrary degree) have the same non-zero singular values.
d) **Scaling:** *B* is a row-scaled version of *A* by repeating every row for *L*1 times. For each non-zero singular value *λ* of *A*, *B* has $\sqrt{L1}\lambda$. *C* is a column-scaled version of *A* by repeating every column for *L*2 times. For each nonzero singular value *λ* of *A*, *C* has $\sqrt{L2}\lambda$. If *D* is row-scaled by *L*1 times and column-scaled by *L*2 times, for each non-zero singular value *λ* of *A*, *D* has $\sqrt{L1L2}\lambda$.
e) **Translation:** *A* is expanded by adding rows and columns of black pixels. The resulting matrix *Ae* has the same Non-zero singular values as A

The important properties of SVD from the view point of image processing applications are:

1. The singular values of an image have very good stability i.e. When a small perturbation is added to an image, their singular values do not change significantly.
2. Singular value represents intrinsic algebraic image properties.

Thus SVD is one of the numerical techniques that have been employed for image watermarking [4], [7], [8]

4. Proposed method:

In this paper, contourlet and SVD based transform technique is proposed for watermarking of gray scale image along with binary watermark logo. The robustness and perceptuality of watermarked image is tested for two quantifiers such as PSNR and NCC. It is investigated whether the contourlet-SVD advantages over DWT-SVD with their extra features would provide any significant in terms of watermark robustness and invisibility. 4.1 And 4.2 explains the watermark embedding and extraction algorithm.

4.1 Watermark Embedding algorithm

The proposed watermark embedding algorithm is shown in figure 3. The steps of watermark embedding algorithm are as follows

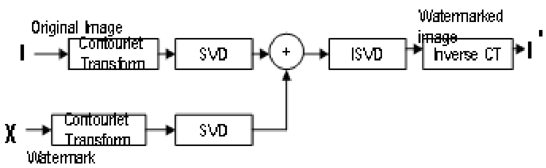


Fig.3. watermark embedding algorithm

1.**A**pply contourlet transform to the original image to decompose into sub bands.

2. Apply SVD to low frequency sub band of contourlet transformed original image.

3. Apply contourlet transform to binary logo watermark to decompose into sub bands.

4. Apply SVD to low frequency sub bands of contourlet transformed to binary logo watermark image.

5. Modify singular values of original image with the singular values of binary image watermark. i.e.
$\lambda^I = \lambda_I + \alpha\, \lambda_W$
α is scaling factor,[4] λ_I is singular value of original image, λ_W is singular value of binary logo watermark.

6. Apply inverse SVD of transformed original image with modified singular values in step 5.

7. Apply inverse contourlet transform using the modified coefficients of the low frequency bands to obtain the watermarked image.

4.2 Watermark Extraction algorithm

The watermark extraction algorithm is shown in fig. 4. The Steps of watermark extraction algorithm are as follows.

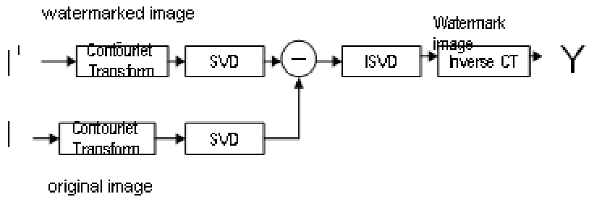


Fig. 4. Watermark extraction algorithm

1. Apply contourlet transform to the watermarked image to decompose into sub bands.

2. Apply SVD to low frequency sub band of transformed watermarked image.

3. Extract the singular values from low frequency sub band of watermarked and original image i, e

$$\lambda_W = (\lambda^I - \lambda_I)/ \alpha$$

Where λI is singular value of watermarked image.

4. Apply inverse SVD to obtain low frequency coefficients of transformed watermark image using step 3.

5. Apply inverse contourlet transform using the coefficients of the low frequency sub band to obtain the binary logo watermark image.

5. Experimental results:

In the experiments that we have tested, we used the original image I as shown in the figure (5) .The binary logo watermark X that is used in the experiments is shown in figure (6). The size of the original image 'LENA' is 512 x 512 pixel gray scale image where as the size of the binary logo watermark 'TI' is also 512x512 pixels. Results show that there are no perceptibly visual degradations on the watermarked image shown in Fig. (7) With a PSNR of 38.6712dB for the "Lena" image. The normalized correlation coefficient without attack is obtained unity as shown in figure (8). MATLAB 7.6 version is used for testing the robustness of the proposed method. Various attacks is used to test robustness of the proposed watermark are JPEG,JPEG2000,low pass filtering, resizing, rotation, manual and automatic cropping, histogram equalization, median filtering, grace scale inversion, soft thresholding, Gaussian noise, Mosaic, Contrast adjustment, blurring, sharpening, rescaling, wiener filter, Gamma correction and Alpha mean.

Original "Lena" — Watermark — Watermarked 'Lena' (PSNR= 38.6712dB) — Extracted watermark (NCC=1)

Fig 5 Fig 6 Fig 7 Fig 8

A size of 256x256 watermark is embedded in "LENA" by using DWT-SVD.PSNR is reported as 34.42dB and the No of attacks are tested as only 12 [4]. In the proposed method 512x512 size watermark is embedded and PSNR obtained is 38.6712dB Watermark image can survive to 20 attacks compared to Emir Ganic and Ahmet M.Eskicioglu.

In table 1, the normalized correlation coefficient values for different attacks are shown with extracted watermark Y and watermarked image I'.

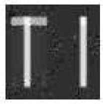
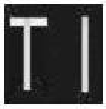
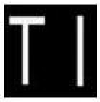
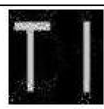
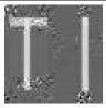
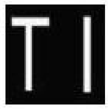
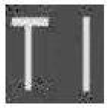
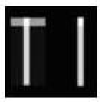
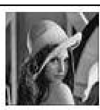
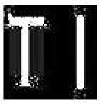
The quality and imperceptibility of watermarked image is measured by using peak signal noise ratio (PSNR) which can be obtained using eq. (1) [3] with respect to original image I. The similarity of extracted watermark(Y) with original watermark (X) embedded is measured using normalized correlation coefficient (NCC) which is given in eq. (2). Performance of proposed method is compared with Emir Ganic's method is shown in table 2 [6]

$$PSNR = 10\log\left[\frac{\max(I(i,j))^2}{\sum_{N,M}(I'(i,j)-I(i,j))^2}\right] \quad (1)$$

Normalized Correlation Coefficient:

$$NCC = \frac{\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}(X-X')(Y-Y')}{\left[\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}(X-X')^2(Y-Y')^2\right]^{1/2}} \quad (2)$$

Table 1: extracted watermark with NCC For different attacks

Guassion noise			0.9375
Mosaic			0.9865
Contrast Adjustmen t			0.9976
Blurring			0.8628
Sharpening			0.7610
Image rescaling			0.9976
Wiener filter			0.9628
Gamma Correction			0.9865
Alpha mean			0.9498

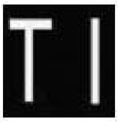
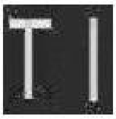
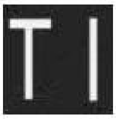
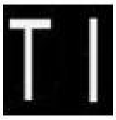
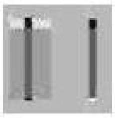
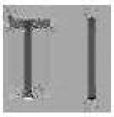
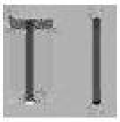
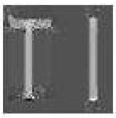
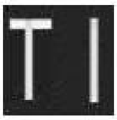
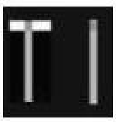
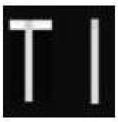
Name of the attack	Watermarked image	Extracted Watermark	NCC
JPEG Compression			0.9974
JPEG, 2000			0.9735
LPF			0.9901
Resize			0.9915
Rotation			0.3404
Manual Cropping			0.1281
Automatic croping			0.1330
Histogram Equlation			0.8312
Median Filter			0.9848
Gray scale inversion			0.9778
Soft Thersholding			0.9949

Table 2 Comparison of proposed method with Emir Ganic and Ahmet M.Eskicioglu

Characteristic	Proposed method	Emir Ganic and Ahmet M.Eskicioglu
No of watermark bits embedded	2,62,144 (512x512)	65,536 (256x256)
PSNR in DB	38.6712	34.42
No of attacks tested	20	12

6. Conclusion:

In this paper, we proposed a new approach for watermarking of still images based on both contourlet transform and singular value decomposition concepts. The proposed method is highly robust to JPEG and JPEG2000 compression, low pass filter, Resize, histogram equalization, median filtering, soft Thresholding, mosaic, contrast adjustment, rescaling and gamma correction. In fact, the images are almost completely destroyed, yet the watermark can be extracted fairly accurately. This approach is also quite resilient to histogram equalization, grayscale equalization, weiner filtering, Gaussian noise, sharpening and alpha mean.

Future work will concentrate on making the method more practical by modifying the technique such that the orginal image is not required to extract the watermarking and this approach may also be extended to video and audio watermarking.

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