A Novel Algorithm for Watermarking and Image Encryption

Rakesh S[1], Ajitkumar A Kaller[2], Shakshari B C[3] and Annappa B[4]

Department of Computer Science and Engineering, National Institute of Technology Karnataka, Surathkal

[1]rakeshsmysore@gmail.com
[2]ajitkaller@gmail.com
[3]shadsbellekere@gmail.com
[4]annappa@ieee.org

ABSTRACT

Digital watermarking is a method of copyright protection of audio, images, video and text. We propose a new robust watermarking technique based on contourlet transform and singular value decomposition. The paper also proposes a novel encryption algorithm to store a signed double matrix as an RGB image. The entropy of the watermarked image and correlation coefficient of extracted watermark image is very close to ideal values, proving the correctness of proposed algorithm. Also experimental results show resiliency of the scheme against large blurring attack like mean and gaussian filtering, linear filtering (high pass and low pass filtering) , non-linear filtering (median filtering), addition of a constant offset to the pixel values and local exchange of pixels .Thus proving the security, effectiveness and robustness of the proposed watermarking algorithm.

KEYWORDS

Image Watermarking, Contourlet Transform, singular value decomposition, Correlation, Image Entropy.

1. Introduction

Digital watermarking primarily means inserting a copyright information into a cover work and is proposed as a solution to illegal copying and tampering of the original data. The digital watermark embedded need not be hidden and should be robust against intentional and non-intentional attacks. The existing transform domain techniques locate regions of high frequency or middle frequency to embed information. The transforms usually selected for digital watermarking are Discrete Cosine Transform (DCT), Discrete Fourier Transform (DFT) and Discrete Wavelet Transform (DWT) [4][5]. Of the proposed algorithms so far wavelet domain algorithms perform better than DCT based algorithms. It has been proved that wavelets are good at representing discontinuities in one dimension or point singularities [2]. But, since in higher dimensions there are more types of singularities which wavelets fail to represent, we need to go for transforms like curvelets and contourlets for better performance. Curvelet transform was defined in the continuum space R2 and its discretization is a challenge when critical sampling is desired . Contourlet transform was proposed as an improvement on curvelet transform using a double filter bank structure. [1] Contourlet transform possess all features of wavelets and also shows a high

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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 [3]. Thus making it a one of the suitable technique for watermarking [8][9],[10].

The paper also proposes a novel method of image encryption, which is just an optional intermediate layer for multimedia data security. Also the normalized correlation coefficients (NCC) between the original watermark image and the extracted image after different attacks were calculated. The results show high improvement detection reliability using proposed method. The rest of the paper covers a brief introduction to contourlet transform and SVD in Section 2 and 3. Section 4 explains the proposed algorithm. Experimental results and conclusion are included in Section 5 and 6 respectively.

2. Contourlet Transform

It is transformation technique which is used in image analysis for capturing contours and fine details in images. The contourlet transform is composed of basic functions oriented in multiple scales at different directions with flexible aspect ratios, making it a multi resolution and multi directional transformation. This frame work forms 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 filter is used to capture the point discontinuities, followed by a directional filter bank to link point discontinuities into linear structures. The result is an image expansion using basic elements like contour segments, and thus it is named contourlet transform.

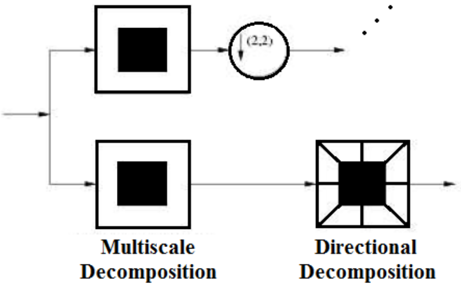


Figure 1.Block Diagram of Contourlet Filter Bank

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.

3. Singular Value Decomposition

Singular value decomposition (SVD) is a technique to obtain low dimensional representation for high dimensional data, which can be further processed for data compression and data de-noising. If A is any M x N matrix, it is possible to find a decomposition of the form $A=U\ S\ V^T$, Where U and V are orthogonal matrices of order M x M and N x N, and the diagonal matrix S is of order M x N having positive elements λ_i (i=1,2,3,..n) called singular values. Even though the matrix A is subjected to transpose, scaling, flipping, rotation or translation the singular values still remain the same as that of matrix A, making singular values of an image have very good stability i.e. when a small perturbation is added to an image, the values do not change significantly. Thus it was employed for image watermarking [8], [9].

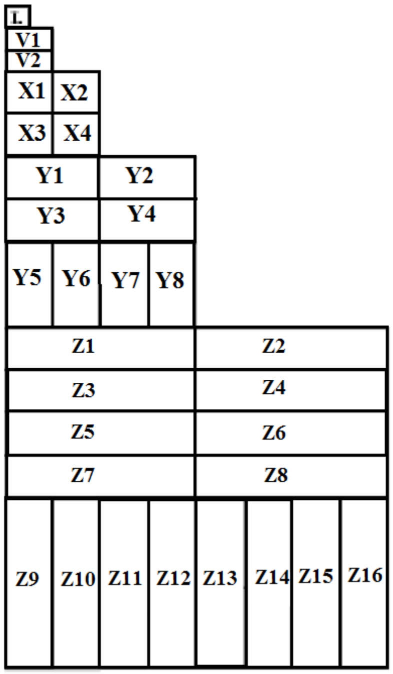


Figure 2.Contourlet Transform Decomposition

4. Proposed Algorithm

The proposed approach for watermarking of still images is based on a hybrid combination of contourlet transform and singular value decomposition. Also the intermediate image is encrypted to ensure additional security. The detailed steps involved are explained below.

4.1. Watermark Embedding

Embedding the watermark image is a four step procedure. First the watermark image is camouflaged onto the original image, followed by encoding the intermediate double image into an RGB image. This image is prone to various statistical attacks, so the image is shuffled and scrambled to reduce correlation. Further individual pixel values are encrypted to increase entropy.

4.1.1. Step 1

In this step watermark image is embedded to the original image to get the transformed watermarked image

Step i. Apply contourlet transform to the original image to decompose into sub bands (CTO).

Step ii. Do the same with the watermark image to decompose into sub bands (CTW).

Step iii. Apply SVD to low frequency sub band (CTO{1}) of contourlet transformed original image.

$$[U\ S\ V^T] = SVD(CTO\{1\}) \quad (1)$$

Step iv. Modify matrix S so obtained, by salting it with the values of low frequency sub band of contourlet transformed watermark image.

$$S' = S + \alpha\, CTW\{1\} \quad (2)$$

Where α being the scaling factor.

Step v. Reverse the operation in 3 to get the low frequency sub band of watermarked image.

$$CTT\{1\}=U*S'*V^T \quad (3)$$

Step vi. To get other of other sub bands of the watermarked image, add the corresponding sub bands of CTW to that of CTO, with the same scaling factor

$$CTT\{i\}\{j\}=CTO\{i\}\{j\}+ \alpha\, CTW\{i\}\{j\} \quad (4)$$

where i=2 to 5 and j=3 if i=2 else 2^(i-1).

Step vii. Apply inverse contourlet transform using the modified coefficients (CTT) to obtain the watermarked image.

4.1.2. Step 2

The watermarked image so obtained is prone to attacks (resizing, median filtering, histogram equalization, sharpening, etc..), also as its values range from [-1000.000 +1000.000], it has to be converted to suitable format for storage and data transfer. So we propose the following novel image encryption algorithm, which results in low correlation and high entropy. Here, we convert the signed double watermarked image (IW) into an RGB unsigned 8 bit image (IW'), by the following:

```
If IW(x1,y1) < 0
        s = sqrt(IW(x1,y1)*(-1))
else
        s = sqrt(IW(x1,y1))
end

f = floor((sim-floor(sim))*100)
d = floor(sim)
r  = round(IW(x1,y1)-(d+f)^2)*100)
IW'(x1,y1,1) = d
IW'(x1,y1,3) = r

If IW(x1,y1) < 0
        IW'(x1,y1,2) = 100+f
else
        IW'(x1,y1,2) = f
end
```

Here, IW'(: , : , i) represents R,G,B as i=1,2,3 respectively. Now if we can notice, square root of positive pixel values of IW is calculated and the decimal part is stored in red component of IW' and the fraction part rounded to two decimal places (storing 3 decimal places would require more than 8 bits, so we stick to 2) is stored in green component, also its clear that these values do not exceed 100, so if the original pixel values in IW was negative, 100 is added, which acts as a sign indicator and later can be subtracted during decryption. Since we are considering only square root rounded to 2 decimal places, there will always be fractional error part, which is stored in blue component.

4.1.3. Step 3

Image Scrambling and Shuffling -

Step i. Divide the whole image IW' into 16x16 size blocks, B1, B2, . . ., Bn.

Step ii. Apply Cat map within block Bi by the following equation:

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 1 & 2 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \tag{5}$$

Where (x,y) are original coordinates of IW' and (x',y') are new shuffled coordinates . After repeating this step for n times we get partially shuffled image IW'' (x, y).

Step iii. Then uniform scrambling is applied onto the image IW'' where the pixels in the same block of original image is distributed into all the blocks of scrambled image and the every block has one pixel at least, without regarding to the order of the pixels appearance, accordingly all the pixels in the same block of scrambled image come from different blocks of original image. Figure below shows that all the pixels in the first block of the original image are distributed into all the blocks of the scrambled image. Thus, the ideal block numbers is N for an original image of size NxN. After scrambling, the resultant would be a new image IW'''.

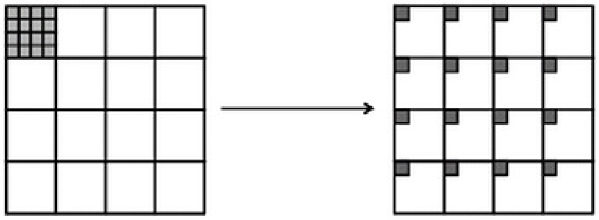


Figure 3. Uniform Image Scrambling

Step iv. Apply Cat map to IW''' to shuffle the pixels of the whole image. Steps i to iv are repeated n times to get the finally shuffled image IS. In our case we performed 3 iterations were performed to get the shuffled image.

4.1.4. Step 4

Image so shuffled is encryption to increase entropy. Encryption is performed on the image IS of size NxN using secret keys Z and L, to get the encrypted image IE using the following proposed algorithm-

```
for x = 1 to N
  for y = 1 to N
    KB1=mod(10^14*Z,256)
    Z=L*Z*(1-Z)
    KB2=mod(10^14*Z,256)
    Z=L*Z*(1-Z)
```

```
        IE(x,y)= mod(IS(x,y)+KB1,256)
        IE(x,y)= xor(IE(x,y),KB2)
    end
end
```

In our case, the keys Z and L were taken to be 0.3915 and 3.9985 respectively. The above method uses modulus operation, restricting the encrypted values less than 256 and thus making it 8 bit encrypted image. The above steps ie., shuffling, scrambling and encryption had to be performed separately for the three RGB components of the image IW'. Also the proposed approach results in very high entropy close to the ideal value 8.

4.2. Water Mark Extraction

The encrypted image IE first has to be decrypted then the watermark image is extracted, the following three steps explain the decryption process and step 4, the watermark extraction process.

4.2.1. Step1

The image IE is decrypted by the following snippet, using the same keys Z and L used during encryption (0.3915 and 3.9985 respectively) -

```
for x = 1 to N
    for y = 1 to N
        KB1=mod(10^14*Z,256)
        Z=L*Z*(1-Z)
        KB2=mod(10^14*Z,256)
        Z=L*Z*(1-Z)
        ID(x,y)= xor(IE(x,y),KB2)
        ID(x,y)= mod(ID(x,y)-KB1,256)
    end
end
```

The resultant would be the decrypted image ID, having the pixel values same as that of original image, but correlation between adjacent pixel still not being the same due shuffling.

4.2.2. Step 2

Now the shuffling and scrambling performed during watermark embedding process has to be nullified to get back the intermediate RGB watermarked image.

Step i. Apply inverse of the transformation matrix used in embedding process to shuffle the pixels of the whole image. During watermark embedding, Arnold Cat transformation used $\begin{bmatrix} 1 & 1 \\ 1 & 2 \end{bmatrix}$ as mapping matrix, thus here its inverse $\begin{bmatrix} 2 & -1 \\ -1 & 1 \end{bmatrix}$ is used as transformation matrix to get the partially de-shuffled image ID'.

Step ii. Now the block wise shuffling and scrambling effect on the pixels performed during process has to be nullified. For this Then divide the whole image ID' into 16x16 size blocks, B1, B2, . . ., Bn. And the pixels uniformly scattered across the image amongst different blocks has to be brought back to their respective block. This is reverse of image scrambling operation performed in step 3.ii of watermark embedding mechanism.

Step iii. The transformation matrix used in step i, is applied once again on each of the blocks B1, B2,.., Bn to de-shuffle the image block wise. Steps i to iii are repeated the same number of iterations performed during embedding process to finally remove all the shuffling and scrambling, fetching image IWD. Also the above 2 steps of de-shuffling and decrypting has to be performed separately on the RGB components of the encrypted image to get the original RGB watermarked image.

4.3.3. Step 3

Now the RGB watermarked image IWD so obtained has to be converted back to intermediate signed double watermarked image. According to the encoding algorithm, the red component of image represents decimal part of square root of required double value, green component the fractional part and blue component represents fractional error. This information is used to decode as shown by the following algorithm,

```
If IWD(x,y,2) >= 100
        IWD’(x,y)=-1;
        IWD(x,y,2)=IWD(x1,y1,2)-100;
else
        IWD’(x,y)=1;
end
        // Above takes care of sign
IWD’(x,y)=IWD’(x,y)*((IWD(x,y,1)+IWD(x,y,2)/100)^2+IWD(x,y,3))
```

Here x and y are pixel coordinated of the image and they range from 1 to N, since assuming IWD is of size NxNx3. Thus finally IWD’ is the decrypted watermarked image obtained, also NCC (Normalized Correlation Coefficient) between IW (watermarked image during embedding process) and IWD’ is very close to 1, proving correctness of the proposed encryption-decryption algorithm.

4.4.4. Step 4

Watermark Extraction is done by the following steps

Step i**.** Apply contourlet transform to the watermarked image to decompose into sub bands (CTT).

Step ii. Do the same with the original image to decompose into sub bands (CTO).

Step iii. Apply SVD to low frequency sub band (CTO{1}) of contourlet transformed original image.

$$[U\ S\ V^T] = \mathrm{svd}(CTO\{1\}) \tag{6}$$

Step iv. To extract the values of low frequency sub band of contourlet transformed watermark image, originally salted during embedding we perform the following operations

$$S'' = \mathrm{inv}(U) * CTT\{1\} * \mathrm{inv}(V^T) \tag{7}$$

$$CTW'\{1\} = (S'' - CTO\{1\}) / \alpha \tag{8}$$

Here CTW’ is the extracted low frequency sub band.

Step v. Extracting the other frequency sub bands follows the following equation

$$CTW'\{i\}\{j\} = (CTT\{i\}\{j\} - CTO\{i\}\{j\}) / \alpha \tag{10}$$

where i=2 to 5, j=3 if i=2 else 2^(i-1)

Step vi. Finally apply inverse contourlet transform using the extracted coefficients (CTW') to obtain the extracted watermark image.

5. Experimental Results

In the experiments that we have tested, we used the original image as shown in the figure(4)(a) and watermark shown in figure(4)(b). Both are gray scale images of size 512 x 512 pixels. The normalized correlation coefficient without attack is obtained to be 0.9919, which very close to ideal value 1 as shown in figure(4)(c). Also the intermediate encrypted RGB watermarked image shown in figure(4)(d) has an ideal entropy of 8, which is the required. Normalized Correlation Coefficient is calculated using the equation (11) and entropy by the equation (12). MATLAB was used for testing the robustness of the proposed approach. Various attacks that was used to test robustness of the proposed watermark algorithm are erode, dilate, open, close, const value added and subtracted, motion filter, gaussian blur, sharpening, weiner filter, high pass filter, low pass filter and mean filter. The results of the various above attacks are shown in table 1.

Entropy is calculated by the equation below

$$\text{Entropy} = \sum(\mathrm{p(k)} * \log(1/\mathrm{p(k)})) \qquad (11)$$

where p(k) is the probability of occurrence of a pixel with gray scale value k.

And Normalized Correlation Coefficient is calculated by the equation

$$\text{NCC} = \frac{\sum_{y=0}^{M} \sum_{x=0}^{N} I^{'}(x,y) I(x,y)}{\sqrt{\sum_{y=0}^{M} \sum_{x=0}^{N} I^{'}(x,y)^{2} \sum_{y=0}^{M} \sum_{x=0}^{N} I(x,y)^{2}}} \qquad (12)$$

where I is the mean centred watermark image, I' is the extracted mean centred watermark image, and both are of size MxN

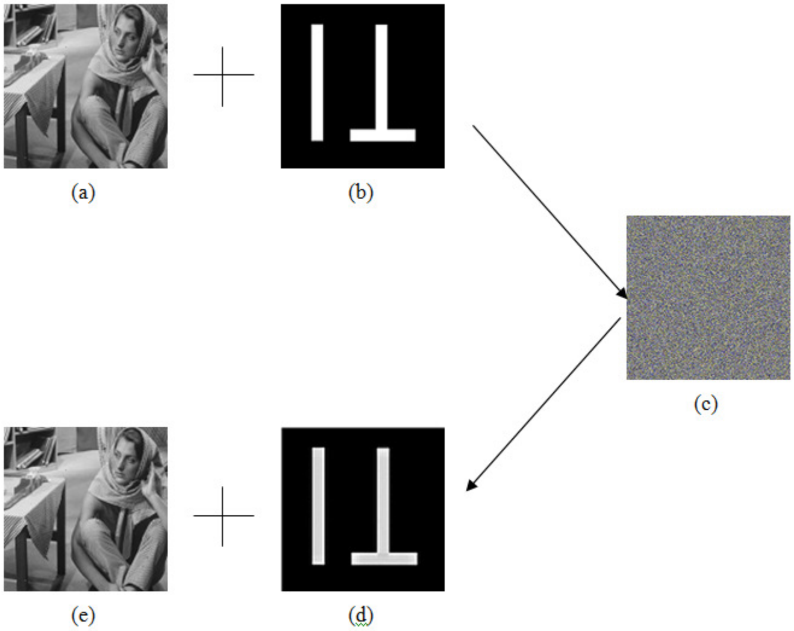
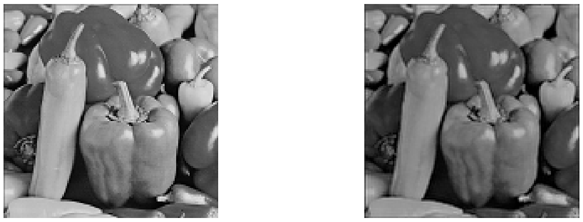


Figure 4. Step involved in Watermark Embedding and Extraction

Table 1. NCC for various Attacks

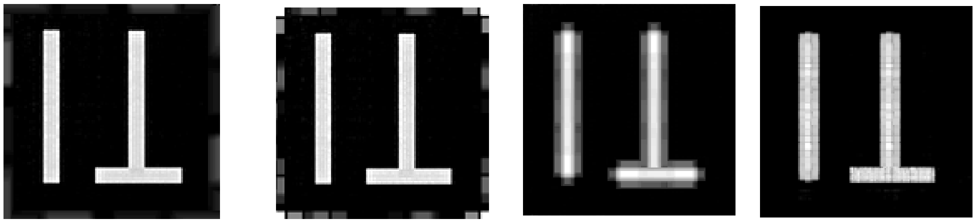
Attack	**NCC**	**Attack**	**NCC**
Erode	0.9821	Dilate	0.9627
Open	0.9886	Close	0.9899
Const value added	0.9898	Const value subtracted	0.9905
Motion filter	0.9893	Gaussian blur	0.9865
Sharpening	0.9818	Weiner filter	0.9906
Low pass filter	0.9904	High pass filter	0.9897
Mean filter	0.9899		

The proposed algorithm works well for more complicated watermark images also, as shown in figure(5). The extracted watermark image has a NCC of 0.9717 which is appreciable. Also the quality of extracted watermark survives after several attacks, but in some cases the quality and texture degrades as shown in the figure(6)



(a) (b)

Figure 5. (a) Original Watermark Image (b) Extracted Watermark Image



(a) **(b)** **(c)** **(d)**

Figure 6.Extracted Watermark after (a)Erode (b) Dilate (c) Gaussian blur (d) Low pass filter

6. Conclusion

We proposed a new approach for watermarking of still images based on a hybrid combination of contourlet transform and singular value decomposition concepts, also imparting a novel image encryption for multi-media data security. The proposed method of embedding the copyright information is robust and the experimental results show that it has survived various attacks like large blurring by mean and Gaussian filtering, linear filtering (high pass filtering and low pass filtering), non-linear filtering (median filtering), addition of constant offset to the pixel values, local exchange of pixels and more. Future work will concentrate to extend the same to video and audio watermarking, also making the method more practical that can be implemented in real life applications.

7. References

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