A Hybrid Algorithm for Image Watermarking against Signal Processing Attacks

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Abstract. In this paper, we have presented a hybrid image watermarking technique and developed an algorithm based on the three most popular trans form techniques which are discrete wavelet transforms (DWT), discrete cosine transforms (DCT), and singular value decomposition (SVD) against signal processing attacks. However, the experimental results demonstrate that this algorithm combines the advantages and remove the disadvantages of these three transform. This proposed hybrid algorithm provides better imperceptibility and robustness against various attacks such as Gaussian noise, salt and pepper noise, motion blur, speckle noise, and Poisson noise etc.

Keywords: mage watermarking, steganography, discrete wavelet transforms, discrete cosine transforms, singular value decomposition.

1 Introduction

Recently, with the explosive growth of information and communication technologies (ICT), various new opportunities emerged for the creation and delivery of content in the digital form which includes applications such as real time video and audio delivery, electronic advertising, digital libraries, telemedicine, e-commerce, e-governance, media forensics and web publishing [1]. However, these advantages have the consequent risks of data piracy, which motivate for the development of new protection mechanisms. One such effort that has been attracting interest is based on the digital watermarking techniques, which is a technique for inserting information into an image and later extracted or detected for variety of purposes including identification and authentication. With this technique, we can recognize the source, owner, distributor or creator of a document or an image. Simmons [2] has demonstrated a sample scenario where watermarking can be thought of in terms of the "Prisoner's problem". The data hiding technique in which the message signal is hidden in the cover signal without any perceptual distortion is a form of communication that depend on the channel used to transfer the host content. It is classified in to two categories: 1) steganography and 2) digital watermarking [3]. However, the former refers to hiding of a secret message inside another message in order to avoid the detection

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and/or decoding it by others. It is used for spying in corporate and intelligence industries like for copyright purposes in entertainment industry [4]. On the other hand in later technique, a watermark signal is embedded into a host signal (image, audio, video or a text document) robustly and invisibly at the same time [5]. However, the watermarking techniques based on the type of document have been divided into the several categories such as text, image, audio and video watermarking [6]. Further, the image watermarking techniques are divided into two domain methods: spatial domain method and transform domain method [7]. In the spatial domain methods [8, 9], the data is embedded directly by manipulating the pixel values and bit stream or code values of the cover image. These methods are less complex, very simple and computationally straightforward, however, they are not robust against signal processing attacks, whereas on the transform domain watermarking techniques are more robust. In this method, the data has been embedded by modulating the wavelet coefficients of the image in transform domain such as DCT, DFT and DWT [10]. The wavelet transforms provides excellent spatial-frequency localization properties as discussed in detail in [11-13].

Jiansheng et al. [14] proposed an algorithm for the digital image watermarking based on two transform method (DCT and DWT). In embedding process, the host image is decomposed into *3rd* level wavelet transform and the watermark information is embedding only in high frequency band information of DWT image. However, it has been DCT transformed before embed the watermark information. This algorithm has strong capability of embedding signal and anti-attack but the computing speed is lower. Lai and Tsai [15] proposed a watermarking scheme based on DWT and SVD. In embedding process, the cover image is decomposed into four subband and the SVD is applied to diagonally (H and V subband) only. After dividing the watermark image into two parts, singular values in H and V sub-band are modified with the half of the watermark image and then apply SVD to them, respectively.

Ahire and Kshirsagar [16] proposed a blind watermarking algorithm based on DCT and DWT that embeds a binary image into the gray image. In embedding process, DWT first applied to the cover image and it decomposed into 3rd level and DCT is applied on four selected subband of DWT. Now, the watermark information is embedded in all four selected DWT sub-band, where all four selected sub-band has been DCT. Umaamaheshvari and Thanushkodi [17] proposed a frequency domain watermarking method to check the integrity and authenticity of the medical images. In the embedding process, DCT first applied to original image to generate a resultant transformed matrix and a hybrid transformed image is obtained when Daubechies 4 wavelet transform applied on the resultant transformed matrix. The Daubechies 4 wavelet transform are useful for local analysis but it has higher computational overhead and is more complex.

2 Theoretical Background

The proposed work based on DWT, DCT, and SVD, which required certain theoretical considerations related to their application in image processing. Hence, a brief description of these concepts is discussed as follows.

2.1 Discrete Wavelet Transform (DWT)

Discrete wavelet transform is a system of filters that decomposes an image into a set of four sub bands that are non-overlapping multi-resolution [18], A (approximation/lower frequency sub-band), H (horizontal sub-band), V (vertical sub-band) and D (diagonal sub-band). The process can be repeated to obtain multiple scale wavelet decomposition.

2.2 Discrete Cosine Transform (DCT)

The discrete cosine transform (DCT) works by separating image into parts of different frequencies, low, high and middle frequency coefficients [19], makes it much easier to embed the watermark information into middle frequency band that provide an additional resistance to the lossy compression techniques, while avoiding significant modification of the cover image. The DCT has a very good energy compaction property. For the input image, I, of size N x N the DCT coefficients for the transformed output image, D, are computed using Equation (1). The intensity of image is denoted as I (x, y), where the pixel in row x and column y of the image. The DCT coefficient is denoted as D (i, j) where i and j represent the row and column of the DCT matrix.

$$D(i,j) = \frac{1}{\sqrt{2N}} C(i)C(j)\sum_{x=0}^{N-1}\sum_{y=0}^{N-1} I(x,y) cos\frac{(2x+1)i\pi}{2N} cos\frac{(2y+1)i\pi}{2N} \quad (1)$$

$$C(i), C(j) = \frac{1}{\sqrt{N}}\ for\ i,j = 0\ and \quad C(i), C(j) = \sqrt{\frac{2}{N}}\ for\ i,j = 1,2, \ldots \ldots . N-1$$

2.3 Singular Value Decomposition (SVD)

The singular value decomposition of a rectangular matrix A is as follows:

$$A = USV^T \quad (2)$$

where A is an $M \times N$ matrix, U and V are the orthonormal matrices. S is a diagonal matrix which consists of singular values of A. The singular values s1≥s2≥………≥sn≥0 appear in the descending order along with the main diagonal of S. However, these singular values have been obtained by taking the square root of the eigenvalues of AA^T and A^TA. These singular values are unique, however the matrices U and V are not unique. The SVD has two main properties from the viewpoint of image processing applications are: 1) the singular values of an image have very good stability, when a small perturbation is added to an image, its singular values do not change significantly, and 2) singular values represent the intrinsic algebraic image properties [20].

3 Performance Measures

However, the performance of the watermarking algorithm has been evaluated on the basis of its robustness and imperceptibility. A larger Peak Signal to Noise Ratio (PSNR) indicate that the watermarked image more closely resembles the original image meaning that the watermark more imperceptible. In general, the watermarked image with PSNR value greater than 28 is acceptable [21]. The PSNR is defined as:

$$PSNR = 10\log\frac{(255)^2}{MSE} \quad (3)$$

where the Mean Square Error (MSE) is defined as:

$$MSE = \frac{1}{X\times Y}\sum_{i=1}^{X}\sum_{j=1}^{Y}(I_{ij} - W_{ij})^2 \quad (4)$$

where I_{ij} is a pixel of the original image of size X×Y and W_{ij} is a pixel of the watermarked image of size X×Y. The robustness of the algorithm is determined in term of correlation factor. However, the similarity and differences between the original watermark and extracted watermark is measured by the Normalized Correlation (NC). It value is generally 0 to 1. However, ideally its should be 1 but the value 0.7 is acceptable [21].

$$NC = \sum_{i=1}^{X}\sum_{j=1}^{Y}(W_{original\ ij} \times W_{recovered\ ij}) / \sum_{i=1}^{X}\sum_{j=1}^{Y} W_{original\ ij}^2 \quad (5)$$

where $W_{original\ ij}$ is a pixel of the original watermark of size $X \times Y$ and $W_{recovered\ ij}$ is a pixel of the recovered watermark of size $X \times Y$.

4 Proposed Algorithm

In this paper, we have proposed a hybrid image watermarking algorithm, where second level DWT is performed on the cover image and first level DWT on watermark image. The two level DWT results in decomposition of the host image into four sub-bands $(A_{c1}, H_{c1}, V_{c1}, and\ D_{c1})$. However, among these four sub-bands, the H_{c1} sub-bands are chosen for watermark embedding. The decomposition of the watermark image into four sub-bands$(A_w, H_w, V_w, and\ D_w)$. Now, with the help of DCT and SVD, the singular value of theH_w is embedded into the singular value of H_{c1}. The watermark extraction process is same as the embedding process but in reverse order. The proposed algorithm has two parts, one is the watermark embedding and other is watermark extraction method as follows:

4.1 Watermark Embedding Algorithm

start:
STEP 1: Variable Declaration
Medical Image(Thorax): cover image
Leena: watermark image
C_w: read the cover image
W_w: read the watermark image
α : scale factor
DWT, DCT and SVD: Transform Domain Techniques
Wavelet filters: Haar

A_c, H_c, V_c *and* D_c : First level DWT coefficients for cover image
A_{c1}, H_{c1}, V_{c1} *and* D_{c1}: Second level DWT coefficients for cover image
A_w, H_w, V_w *and* D_w: First level DWT coefficients for watermark image
D_c^1: DCT coefficients matrix for H_{c1}
H_w^1: DCT coefficients matrix for H_w
U_c *and* V_c^T: orthonormal matrices for D_c^1
S_c: diagonal matrix for D_c^1
U_w *and* V_w^T: orthonormal matrices for H_w^1
S_w: diagonal matrix for H_w^1
W_w^k: modified value of S_c
U_{ww} *and* V_{ww}^T: orthonormal matrices for W_w^k
S_{ww}: diagonal matrix for W_w^k
W_{modi}: Modified DWT coefficient
W_{idct}: InverseDCT coefficients matrix
W_d: Watermarked Image

STEP 2: Read the Images
C_w← Thorax.bmp (Cover image of size 512*512)
W_w← Leena.bmp (Watermark image of size 256*256)

STEP 3: Perform DWT on Cover and Watermark image
Apply second level DWT on cover image and first level DWT on Watermark image
$[A_c, H_c, V_c, and\ D_c]$ ← DWT (C_w, wavelet filter);
$[A_{c1}, H_{c1}, V_{c1}, and\ D_{c1}]$ ←DWT (H_c, wavelet filter);
$[A_w, H_w, V_w, and\ D_w]$ ← DWT (W_w, wavelet filter);

STEP 4: Choice of subands in Cover and Watermark image and obtain the DCT coefficients for the same
//Choose subband $H_{c1}$from cover image and H_w from watermark image
if (DCT on H_{c1})**then**
D_c^1 ← DCT (H_{c1});
endif;
if (DCT on H_w)**then**
H_w^1 ← DCT (H_w);
endif;

STEP 5: Compute the singular values of DCT coefficients for Cover and Watermark image
if (SVD on D_c^1)**then**
$U_c S_c V_c^T \leftarrow SVD\ (D_c^1)$
endif;
if (SVD on (H_w^1) **then**
$U_w S_w V_w^T \leftarrow SVD\ (H_w^1)$
endif;
STEP 6: Watermark Embedding
for $\propto \leftarrow 1{:}\,5$
$S_c + \propto S_w = W_w^k;$
end;

STEP 7: Compute the singular values for W_w^k and obtain the modified DWT coefficients

if $(SVD\ on\ W_w^k)$**then**
$[U_{ww}S_{ww}V_{ww}^T \leftarrow SVD(W_w^k)$
endif;
//modified DWT coefficient
$W_{modi} \leftarrow U_c S_{ww} V_c^T$
Step 8: Obtain the Watermarked Image

$W_{idct} \leftarrow inverseDCT(W_{modi});$
//Apply InverseDWT to $A_{c1}, H_{c1}, V_{c1}, and\ D_{c1}$ with modified coefficient
$H_c \leftarrow inverseDWT(A_{c1}, W_{idct}, V_{c1} and\ D_{c1}, wavelet\ filter);$
//Apply InverseDWT to $A_c, H_c, V_c, and\ D_c$ with modified coefficient
$W_d \leftarrow inverse\ (A_c, H_c, V_c, D_c, wavelet\ filter);$
end:

4.2 Watermark Extraction Algorithm

start:
STEP 1: Variable Declaration
α : scale factor
$A_c, H_c, V_c\ and\ D_c$: subbands for watermarked image
D_w^*: DCT coefficients matrix for H_c
$U_w^*\ and\ V_w^{*T}$: orthonormal matrices for D_w^*
S_w^*: diagonal matrix for D_w^*
S_c^k: diagonal matrix for DCT coefficients of cover image
S^{*k}: modified values
$U_w^{*1}\ and\ V_w^{*1T}$: orthonormal matrices for S^{*k}
S_w^{*1}: diagonal matrix for S^{*k}
I_{cc}^*: modified DWT coefficients
I_{Wcc}^*: InverseDCT coefficients matrix
W_{EW}: Extracted watermark image

STEP 2: Perform DWT on Watermarked image (possibly distorted)

$[A_c, H_c, V_c, and\ D_c] \leftarrow$ DWT (W_d, wavelet filter);

STEP 3: obtain the DCT coefficients for H_c
if (DCT on H_c)**then**
$D_w^* \leftarrow$ DCT (H_c);
endif;
STEP 4: Compute the singular values for D_w^*
$U_w^* S_w^* V_w^{*T} \leftarrow SVD(D_w^*)$
end;

STEP 5: Perform the operation and then apply SVD
for $\propto \leftarrow \mathbf{1{:}5}$

$$S^{*k} = \frac{S_w^* - S_c}{\propto}$$

end;

$U_w^{*1} S_w^{*1} V_w^{*1T} \leftarrow SVD(S^{*k})$

STEP 6: Compute modified DWT coefficients

$I_{cc}^{*} \leftarrow U_w S_w^{*1} V_w^{T}$

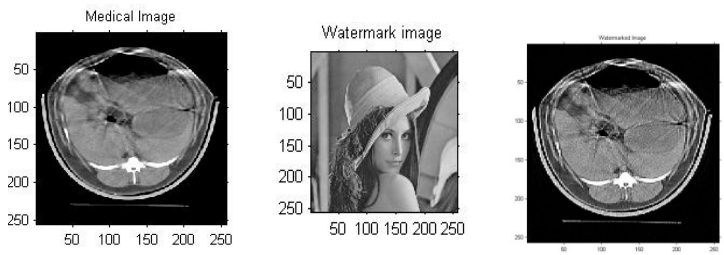
STEP 7: Extract the watermark image

$I_{Wcc}^{*} \leftarrow inverse(I_{cc}^{*});$
$W_{EW} \leftarrow inverseDWT(A_w, I_{Wcc}^{*}, V_w, D_w, wavelet\ filter);$

end:

5 Experimental Results

We have discussed the performance of the combined DWT-DCT-SVD watermarking algorithm. The gray–level images "Medical image (Thorax)" and "Lena" of size 256 ×256 are used as cover and watermark image as shown in figure 1(a) and 1(b), respectively. We have evaluated the quality of watermarked image (as shown in figure 1(c)) and robustness of the proposed algorithm by the parameter PSNR and Normalized Correlation (NC) respectively. Also, we have compared the performance of the proposed algorithm with reported techniques by Jiansheng et al. [14], Lai et al. [15] and Nidhi et al. [22] against various kinds of attacks. The hybrid of DWT, DCT and SVD give the better results (see Table 1). However, our method needs less SVD computation than other methods. The effects of the attacks are shown in fig 2 to fig. 11. In the experiments, the value of the scale factor (α) are carried out from 1 to 5 and taking the average value of the PSNR and Normalized Correlation (NC), and the results are illustrated in Table 1. Without any noise attack the average PSNR obtained is 38.61dB and the NC value is 1. We found that the larger the scale factor, stronger the robustness and smaller the scale factor, better the image quality.



(a) (b) (c)

Fig. 1. (a) Cover Image (b) Watermark Image(c) Watermarked Image

Table 1. Comparison of robustness for Jiansheng [14], Lai [15], Nidhi [22] and our method

Various Attack	**PSNR (Avg. Value) of proposed method**	**Jiansheng Method [14] Using DWT and DCT**	**Lai Method [15] Using DWT and SVD**	**Nidhi & Jani Method [22] Using DWT DCT and SVD**	**Proposed Method Using DWT, DCT and SVD**
Gaussian Noise	18.51	Not Shown	0.97	0.9992	0.9997
Salt and Pepper Noise	17.94	0.8643	Not Shown	0.9995	0.9996
Motion Blur	17.02	Not Shown	Not Shown	Not Shown	0.9998
Low pass filter	18.88	0.9132	0.9597	0.9996	0.9996
Median filter	19.81	Not Shown	Not Shown	0.9995	0.9998
Speckle Noise	19.78	Not Shown	Not Shown	Not Shown	0.9996
Poisson Noise	25.61	Not Shown	Not Shown	Not Shown	0.9999
Contrast adjustment	18.84	Not Shown	0.9958	0.9995	0.9998
JPEG compression	18.12	0.8518	0.9761	0.9996	0.9996
Histogram equalization	19.21	Not Shown	0.9890	0.9991	0.9994

(a) (b)

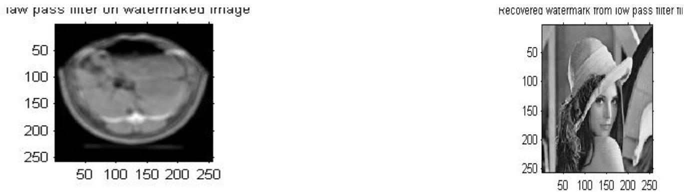
Fig. 2. (a) Gaussian Noise on Watermarked Image (b) Recovered Watermark Image from Gaussian Noise

(a) (b)

Fig. 3. (a) Salt & Pepper Attack on Watermarked Image (b) Recovered Watermark Image from Salt & Pepper Attack

(a) (b)

Fig. 4. (a) Motion Blurred on Watermarked Image (b) Recovered Watermark Image from Motion Blurred



(a) (b)

Fig. 5. (a) Low pass filter on Watermarked Image (b) Recovered Watermark Image from Low pass filter

(a) (b)

Fig. 6. (a) Median filter on Watermarked Image (b) Recovered Watermark Image from Median filter

(a) (b)

Fig. 7. (a) Speckle Attack on Watermarked Image (b) Recovered Watermark Image from Speckle Attack

(a) (b)

Fig. 8. (a) Poisson Attack on Watermarked Image (b) Recovered Watermark Image from Poisson Attack

(a) (b)

Fig. 9. (a) Histogram equalization on Watermarked Image (b) Recovered Watermark Image from Histogram equalization

(a) (b)

Fig. 10. (a) Contrast adjustment on Watermarked Image (b) Recovered Watermark Image from Contrast adjustment

(a) (b)

Fig. 11. (a) JPEG Compression on Watermarked Image (b) Recovered Watermark Image from JPEG Compression

6 Conclusion

The three important parameters such as robustness, imperceptibility and capacity measure the quality of watermarking method, which need to be considered in the methods. There is some tradeoff between the imperceptibility, robustness and capacity, so there must be some balance among these requirements according to the applications.

The performance of watermarking methods depends on the overall watermarking method as well as embedding and detection techniques. In the transform domain, several efficient image watermarking techniques based on DFT, DCT, DWT and SVD have been developed. However, they do not have the directional information such as directional edges of the image. The discrete contourlet transform [23] is capable of capturing the directional information with multi-resolution representation. It makes use of Laplacian Pyramid for multi-resolution representation of the image followed by a directional decomposition on every band pass image using directional filters. However, this proposed hybrid scheme is robust and keeps the image quality very well. We would like improve the performance, which will be reported in future communication.

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