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Robust Digital Watermarking Technique for Satellite Images

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Abstract

To overcome the copyright-protection issue, digital watermarking techniques have received considerable attentions and have been under development for several years. Therefore, this paper proposed a new watermarking scheme based on Discrete Wavelet Transform (DWT) and Discrete Cosine Transform (DCT) for satellite images. This will improve both the robustness and imperceptibility requirements of the watermarking algorithm. Firstly, the original image is transformed using DWT prior to the DCT. Then, the gray-level watermark is embedded into the first five AC-DCT coefficients of the selected DWT bands. Simulation results show that the proposed technique has better imperceptibility and higher robustness against various image processing attacks.

الخلاصـــة

للتغلب على معوقات حماية حقوق التأليف والنشر ،حظيت تقنية البصمة المائية باهتمام كبير وكانت قيد التطوير منذ عدة سنوات. لذلك في هذا البحث تم اقتراح تقنية جديدة للبصمة المائية تعتمد على اساس التحويل المويجي وتحويل الجيب تمام الرقمي لصور الاقمار الصناعية، وهذا من شانه تحسين كل من متطلبات القوة والاخفاء لخوارزمية البصمة المائية. ان الصورة الاصلية يتم تحويلها اولاً باستخدام تحويل المويجة الرقمي ثم تحويل الجيب تمام الرقمي ، وبعد ذلك يتم اخفاء القيم الرمادية للبصمة المائية في الخمس معاملات الاولى للـ AC-DCT للحزم المختارة من الـ DWT . ان نتائج المحاكاة بينت ان الطريقة المقترحة لها قابلية اخفاء جيدة وقوة عالية ضد مختلف انواع المعالجات الصورية .

1. Introduction

With the advancement of multimedia and networking technologies it becomes easy to copy, manipulate and distribute the digital media (e.g. audio, images, video). These create problems for parties who own digital media and want to protect it from illegal multiplication and distribution. Because of that, there is a need for protecting the intellectual property rights. Digital watermarking has been proposed as a solution for the copyright protection [1].

A digital image watermark is a signal permanently embedded into a digital image that can be detected or extracted later by means of some operations for authentication purposes [2]. For any watermarking technique to be valid, it must satisfy three important requirements namely[3]:

1. **Robustness:** the watermarks embedded into images must be hard to destroy under the common image processing operations such as image compression, blurring, noising, sharpening, etc.
2. **Imperceptibility:** the watermark must be embedded without affecting the perceptual quality of the original image. That is, a user can not distinguish between the original and watermarked version. As a result, human eye should not perceive the existence of the watermark.

3.**Unambiguity:** the watermark extracted or detected from the watermarked image must identify the ownership unambiguously. This implies that the error of the extracted watermark must be as low as possible.

There exist several methods to classify all the digital watermarking techniques [4,5,6]. First, according to what kind of watermark is embedded, they can be divided into two classes: *robust* and *fragile* watermarking. A watermark is said to be fragile if the watermark hidden within the host signal is destroyed as soon as the watermarked signal undergoes any manipulation. Secondly, according to the strategy adopted for hidden watermark extraction, there are two categories referred to as *blind* and *non-blind* watermarking respectively. Blindness means that the hidden data is restored in the absence of the original host without hidden data embedded.

2. Related Works

Several techniques have been proposed for the watermarking of digital images that can be accomplished in either the spatial or transform domain. **Spatial domain** techniques are generally simple and easily performed, but are not resistant to lossy compression and common signal processing operations. In contrast, **transform domain** (i.e. DCT or DWT) techniques are more robust in comparison to spatial domain techniques. DWT has been used in digital image watermarking more frequently due to its excellent spatial localization and multi-resolution characteristics, which are similar to the theoretical models of the human visual system [7].

Darmstaedter et al. [8] presented a low computational cost watermarking technique for pictures and video sequences. The embedding process consists in embedding redundantly copyright information (typically 64 bits) in a digital picture with the use of a secret key. The retrieval process allows to retrieve the copyright information without the use of the original image.

Santi and Malay [9] described a computationally efficient block based spatial domain watermarking technique for a two level watermark symbol. The selection of the required block is based on variance of the block and watermark insertion exploits average brightness of the blocks.

Frank et al. [10] presented a robust image adaptive watermarking scheme. The watermark is embedded into the middle-frequency coefficients of block DCT domain for the host image. The robustness of the proposed scheme is enhanced with the aid of artificial neural networks.

John [11] introduced a robust watermarking algorithm using the wavelet transform and edge detection. The efficiency of an image watermarking technique depends on the preservation of visually significant information. This is attained by embedding the watermark transparently with the maximum possible strength. The watermark embedding process is carried over the subband coefficients that lie on edges, where distortions are less noticeable, with a subband level dependent strength. Also, the watermark is embedded to selected coefficients around edges, using a different scale factor for watermark strength, that are captured by a morphological dilation operation.

In this paper, a new digital image watermarking scheme is adopted by applying Discrete Wavelet Transform (DWT) and Discrete Cosine Transform (DCT) respectively. This will improve both the robustness and imperceptibility properties of the watermarking scheme. Then, the embedding process is done by modifying some AC coefficients of the DCT domain in the selected bands of the DWT domain. The strength of the adopted watermarking scheme is achieved by embedding watermark over **details** bands that lie on edges where the distortions are less noticeable.

3. The DCT and DWT Transforms

This section gives a brief introduction on the DCT and DWT transforms that have been extensively used in many digital signal processing applications. Also, it outlines their relevance to the implementation of digital watermarking.

3.1 The DCT transform:

The discrete cosine transforms is a technique for converting a signal into elementary frequency components [10]. It represents an image as a sum of sinusoids of varying magnitudes and frequencies. The DCT coefficients for the transformed output image are computed according to Eq.(1).

$$Y(u,v)=\sqrt{\frac{2}{M}}\sqrt{\frac{2}{N}}\alpha_u\alpha_v\sum_{m=0}^{M-1}\sum_{n=0}^{N-1}X(m,n)\cos\frac{(2m+1)\pi u}{2M}\cos\frac{(2n+1)\pi v}{2N} \qquad \text{………..(1)}$$

Where

$$\alpha_u=\begin{cases}\frac{1}{\sqrt{2}} & u=0\\ 1 & u=1,2,\dots M-1\end{cases}$$

$$\alpha_v=\begin{cases}\frac{1}{\sqrt{2}} & v=0\\ 1 & v=1,2,\dots N-1\end{cases}$$

In eq.(1) X(m,n) is the original image pixel, Y(u,v) is the corresponding DCT coefficient values, and M×N is the image dimension.
The image is reconstructed by applying inverse DCT operation according to Eq.(2):

$$X(m,n)=\sqrt{\frac{2}{M}}\sqrt{\frac{2}{N}}\alpha_u\alpha_v\sum_{u=0}^{M-1}\sum_{v=0}^{N-1}Y(u,v)\cos\frac{(2u+1)\pi m}{2M}\cos\frac{(2v+1)\pi n}{2N} \qquad \text{…….(2)}$$

The popular block-based DCT transform segments an image non-overlapping blocks and applies DCT to each block. This results in giving three frequency sub-bands: low frequency sub-band, mid-frequency sub-band and high frequency sub-band. DCT-based watermarking is based on two facts. The first fact is that much of the signal energy lies at low-frequencies sub-band which contains the most important visual parts of the image. The second fact is that high frequency components of the image are usually 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 and the watermark will not be removed by compression [12].

3.2 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 [8]. 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 LL, LH, HL and HH.

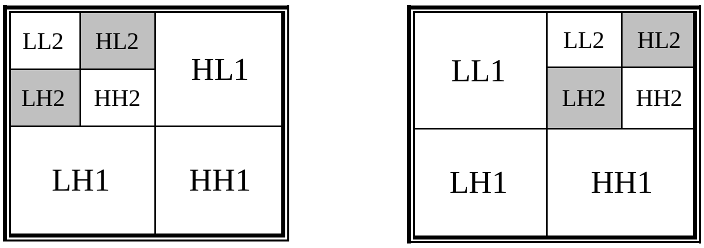
The sub-band LL represents the coarse-scale (approximation) sub-band while the bands LH, HL and HH represent the fine-scale (details) sub-bands.
Due to its excellent spatio-frequency localization properties, the DWT is very suitable to identify the areas in the host image where a watermark can be embedded 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-band LL and therefore embedding watermarks in this sub-band 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-band HH includes 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 LH and HL where acceptable performance of imperceptibility and robustness could be achieved [13,14].

4. The Proposed Digital Watermarking Technique

The main purpose for inserting the watermark in the transform domain is the resulting dispersion of the watermark in the spatial domain; hence it becomes very difficult to remove the watermark from the image. In the proposed technique, the DWT is combined with DCT to provide the embedded watermark higher imperceptibility yet more energy. The suggested watermark embedding and extracting processes are described in the following sub-sections.

4.1 The Watermark Embedding Process

The embedding process involves the following steps:
Step 1: Apply DWT to decompose the cover host image into four non-overlapping sub-bands: LL1, HL1, LH1, and HH1 using Haar filter.
Step 2: Apply DWT again to sub-band LL1 or HL1 to get four smaller sub-bands and choose the HL2 and LH2 sub-band as shown in fig.(1) (a) and (b).



(a) ***(b)***

Fig.(1) (a): 2nd level DWT decomposition of the LL1 band, (b) 2nd level DWT decomposition of the HL1 band.

Step 3: Divide the sub-band HL2 and LH2 into 4×4 non-overlapping blocks.
Step 4: Apply DCT to each block in the chosen sub-band (HL2 and LH2).
Step 5: Estimate the first five DCT AC coefficients of each block in a zigzag order, using its neighbor blocks. Gonzales et al. [15] proposed a technique for estimating low frequency AC DCT coefficients of a block using the DC values of its 3×3 neighbor blocks using the following equations:

$$AC'(0,1) = 1.13884\times(DC4 - DC6)/8$$
$$AC'(1,0) = 1.13884\times(DC2 - DC8)/8$$
$$AC'(0,2) = 0.27881\times(DC4 + DC6 - 2\times DC5)/8 \qquad \ldots\ldots.(3)$$
$$AC'(2,0) = 0.27881\times(DC2 + DC8 - 2\times DC5)/8$$
$$AC'(1,1) = 0.16213\times(DC1 + DC9 - DC3 - DC7)/8$$

Where, DC_i represents the DC coefficient of the i-th block in fig.(2).

Block1 DC_1	Block1 DC_2	Block1 DC_3
Block1 DC_4	Central Block DC_5	Block1 DC_6
Block1 DC_7	Block1 DC_8	Block1 DC_9

Fig.(2): The central block and its neighbor blocks

Step 6: Embed the gray-level value of the watermark by replacing each low frequency AC value in the central block with its estimated modified value according to the following formula:

$$AC_k = AC'_k + \alpha \times w(i,j) \qquad \ldots\ldots\ldots(4)$$

Where, AC_k is one of the five AC components: AC(0,1), AC(1,0), AC(0,2), AC(2,0) and AC(1,1) (fig.(3)). AC'_k is the value of AC_i predicted with equation (3), w(i,j) is the current pixel value in the watermark image and α is a scaling factor.

If α is very small, the watermark will be very weak to attack. On the other hand, a large value of α will degrade the quality of the watermarked image.

Step 7: Apply inverse DCT (IDCT) to each block after some its AC coefficients have been modified.

Step 8: Apply the inverse DWT (IDWT) on the DWT transformed image, including the modified sub-band, to produce the watermarked image.

DC	AC(0,1)	AC(0,2)	AC(0,3)
AC(1,0)	AC(1,1)	AC(1,2)	AC(1,3)
AC(2,0)	AC(2,1)	AC(2,2)	AC(2,3)
AC(3,0)	AC(3,1)	AC(3,2)	AC(3,3)

Fig.(3): DCT coefficients of 4×4 block

4.2 The Watermark Extracting Process

In the proposed technique, the original input image is not needed at the watermark detector. The watermarked image is sufficient for the extraction. The extraction is done on the DCT of the selected DWT bands as follows:

Step 1: Apply DWT to decompose the watermarked image into four non-overlapping sub-bands: LL1, HL1, LH1, and HH1.
Step 2: Apply DWT again to sub-band LL1 or HL1 to get four smaller sub-bands and choose the HL2 and LH2 sub-band as shown in fig. (1) (a) and (b).
Step 3: Divide the sub-band HL2 and LH2 into 4×4 blocks.
Step 4: Apply DCT to each block in the chosen sub-band (HL2 and LH2).
Step 5: Compute the estimated first five AC-DCT coefficients of each block as described in step (5) of the embedding process.
Step 6: Compute the gray-level value of the watermark by calculating the difference between the AC_k and its estimated AC'_k value as follows:

$$w(i,j) = \frac{AC_k - AC'_k}{\alpha} \qquad \text{.........(5)}$$

5. Simulation Results

In order to test the performance of the proposed watermarking technique, two host satellite images of 512×512 pixels with 8 bits gray levels were used. Also, two grayscale images of size 64×64 were selected as watermarks. Figs.(4 and 5) show the original host images, the watermarks images, the watermarked images, and the extracted watermarks. The proposed watermarking algorithm is implemented: firstly, by applying the 2nd level decomposition of DWT on the LL band (DCT-DWT (LL)); secondly, by applying 2nd level decomposition of DWT on the HL band (DCT-DWT (HL)). The quality of the watermarked image, compared to the original image, is measured based on the Peak Signal to Noise Ratio (PSNR) [3,9,12] which is defined by:

$$PSNR = 10 \log_{10} \frac{255^2}{\frac{1}{M \times N} \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} X(i,j) - X'(i,j)} \qquad \text{..........(6)}$$

Where, M×N is the image size, X(i,j) is the original host image pixel, and **X′**(i,j) is the watermarked image pixel. Table (1) shows the results of PSNRs values for the watermarked images using the proposed technique: the embedded watermark does not degrade the quality of host images seriously, and the watermarked images have best quality using second method.

Table (1): PSNR for the watermarked images

Images	DCT-DWT (LL)	DCT-DWT (HL)
Airel	40.5690	43.2624
Kohnon	36.0323	41.0210

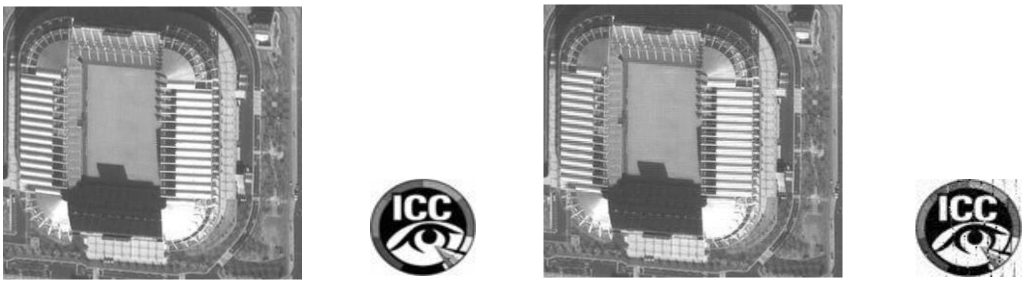
To show robustness of the proposed techniques, the watermarked images were attacked using different image processing operations such as histogram equalization, contrast adjustment, high-pass filtering, blurring, sharpening, lossy JPEG compression, cropping, salt & peppers noise, and Gaussian noise. The Normalized Cross Correlation (NCC) was computed for the extracted watermark after these attacks to measure the amount of a similarity between the original watermark (**w**) and the extracted watermark (**w′**). The NCC can be written as [9] :

$$\text{NCC} = \frac{\sum_{i=0}^{M-1}\sum_{j=0}^{N-1} w(i,j)\cdot w'(i,j)}{\sum_{i=0}^{M-1}\sum_{j=0}^{N-1} w(i,j)^2} \qquad \text{.........(7)}$$

If the NCC equals one, this means the extracted watermark is the same as the original watermark. On the other hand, if the NCC equals zero, then the extracted watermark and original watermark is totally different. So, success of the watermarking process means higher values of the NCC.

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

Fig.(4): (a) The original Airel image, (b) the first watermark, (c) the watermarked image, and (d) the extracted watermark.



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

Fig.(5): (a) The original Kohnon image, (b) the second watermark, (c) the watermarked image, and (d) the extracted watermark.

The values of the NCC and PSNR for the extracted watermarks after different attacks are shown in tables (2 and 3). It can be noted that the proposed techniques can effectively resist different attacks. Also, the second method (DCT-DWT (HL)) is more robust for histogram equalization, blurring, sharpening, and JPEG compression according to the values of NCC The visual results for Airel image after different attacks using the second method are shown in fig.(6). The results show that there is a meaningful correlation between the extracted and original watermarks. Also, the extracted watermarks are still recognizable.

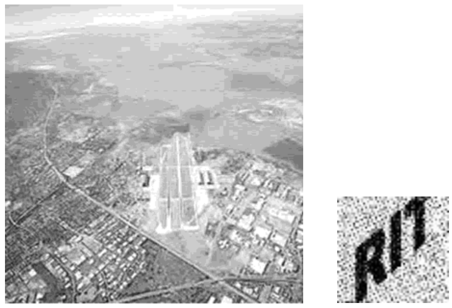
Table (2): PSNR values for the extracted watermarks

Attack	DCT-DWT (LL)		DCT-DWT (HL)	
	Airel	Kohnon	Airel	Kohnon
No attack	44.5350	43.5285	43.2624	41.0210
Histogram Equalization	34.9794	33.0279	35.6673	33.6593
Contrast Adjustment	44.9519	38.8141	43.8654	37.3788
High-pass Filter	32.1165	29.5611	32.1145	28.9456
Blurring	25.3115	26.0346	24.8808	25.0127
Sharpening	35.9937	33.2478	41.0559	37.3228
JPEG Compression	27.0764	27.2327	27.5526	27.3108
Cropping on both sides	30.7285	29.6549	30.8655	30.4873
Salt & Peppers Noise	28.1080	28.3823	28.1006	28.0293
Gaussian Noise	32.8691	28.5564	27.9693	27.9149

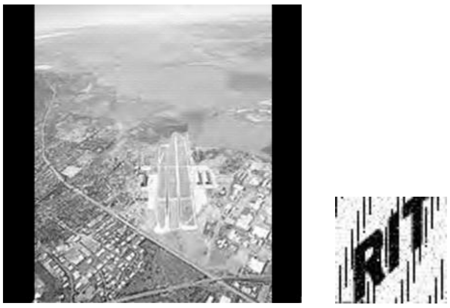
Table (3): NCC values for the extracted watermarks

Attack	DCT-DWT (LL)		DCT-DWT (HL)	
	Airel	Kohnon	Airel	Kohnon
No attack	0.9970	0.9790	0.9967	0.9823
Histogram Equalization	0.8503	0.7623	0.8919	0.8067
Contrast Adjustment	0.9820	0.9674	0.9815	0.9578
High-pass Filter	0.9954	0.9810	0.9953	0.9779
Blurring	0.8848	0.8051	0.9446	0.8635
Sharpening	0.9288	0.8004	0.9628	0.9153
JPEG Compression	0.8343	0.8283	0.8685	0.8354
Cropping on both sides	0.8013	0.8648	0.8025	0.8653
Salt & Peppers Noise	0.6102	0.6121	0.6229	0.6298
Gaussian Noise	0.8102	0.7815	0.8094	0.7768

(1) Histogram Equilization



(2) JPEG Compression (50%)



(3) Cropping on both sides

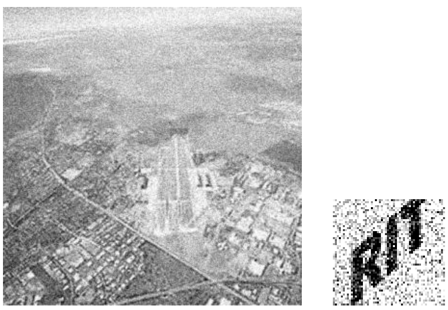
(4) Contrast Adjustment

(5) High Pass Filter

(6) Blurring

(7) Sharpening

(8) Impulse Noise



(9) Gaussian Noise

Fig.(6): The results of some image processing operations with their extracted watermarks for the Airel image using proposed technique (DCT-DWT (HL)).

6. Conclusion

This paper illustrates the effectiveness of combining two different transform domains (DWT and DCT) for satellite image watermarking scheme. The simulation results show the imperceptibility and high robustness capabilities to different image processing operations and geometric distortions for the proposed watermarking technique. The extracted watermark is meaningful and still recognizable.

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