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Choosing The Right Technique For The Robust Watermark

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Abstract---In this paper, the proposed approach for digital image watermarking raises the combination of Redundant Discrete Wavelet Transform (RDWT) and Contourlet Transform (CT_RDWT and RDWT_CT). It is expected from this combination to cover multi-scale, time-frequency, localization, shift invariance of RDWT and offers directionality and anisotropy supported by Contourlet Transform (CT) that will lead to improve resistance to most of the attacks, and protect copyright and repository. Based on the results of these two methods, we can choose the best to achieve the watermarking objectives. In both methods; RDWT_CT and CT_RDWT, two-level decomposition is applied to the host image, and one-level decomposition is applied to the watermark image. Embedding the two high frequency mid-bands of the watermark image in the two high frequency mid-bands of the host is tested, and then best is chosen for watermarking. Watermarked image is exposed to different types of attacks; Peak Signal-to-Noise Ratio (PSNR) value which represents imperceptibility and CORR value which represent robustness are calculated before and after attacks. Results showed that the combination CT_RDWT is better than the combination RDWT_CT.

Keywords- Watermark; Robustness; Imperceptibility; Attacks; Contourlet Transform and Redundant Discrete Wavelet Transform.

1. INTRODUCTION

There are wide range of software and programs that modulate and modify media, so that one can claim that a certain image or video clip or audio is his/her and produced by him/her when it is not. Publishers, artists, and photographers, however, may be unwilling to distribute pictures over the internet due to a lack of security, this raised the need for copy protection and file encryption and research on development of digital watermarking is coming up continuously [1,2,4]. Digital watermarks have been proposed as a way to tackle this tough issue. This digital signature could discourage copyright violation, and may help determine the authenticity and ownership of an image [1,2]. Within the field of watermarking, image watermarking has attracted the attention mainly for three reasons; ready availability of test images, image carries a lot of redundant information that they provide a good opportunity to embed watermarks easily, and it is assumed that any embedding algorithm may be upgraded for videos [2, 4, 8, 12]**.** Watermarks are very useful and are mainly used for insuring security and repository. They are used in banknotes, certificates, postage stamps, official documents, passports to prevent counterfeiting. Moreover, a watermark is very useful in paper examinations because it can be used for dating, identifying sizes, mill trademarks and locations, and the quality of a paper [1].

Over the past years researches were conducted to find a watermarking technique that have the ability to trade off Robustness, Imperceptibility and capacity. Different watermarking techniques were found and experimented such as those based on Discreet Wavelet Transform (DWT) [3, 4,8,12], Discrete Cosine Transform (DCT) [14], DWT_DCT [13,15], Singular Value Decomposition (DWT_SVD) [10], Redundant Discreet Wavelet (RDWT) [3,8,16] , (RDWT_SVD) [9], Contourlet Transform (CT)

[5,7,12] and RDWT_CT [17] each has some advantages and shortages. The proposed work raises a new watermarking technique using combining RDWT and CT to generate a watermark with maximum robustness, invisibility and with best degree of capacity, since this combination expected to cover multi-scale, time-frequency, localization, shift invariance of DWT, and also offers directionality and anisotropy supported by CT, which would help to resist attacks, and improve repository and copyright protection [17].

2. The Proposed Approach

Discrete Wavelet Transform (DWT) is sensitive to the translation/shift of input signals, so its effectiveness could be negatively impacted when we encounter translation among signals. To deal with such drawbacks, redundant DWT (RDWT) method is used to achieve image registration, translation invariant wavelet feature extraction. The RDWT removes the down sampling operation from the DWT to produce an over complete and shift-invariant transform. From a mathematical perspective, the RDWT is a frame expansion, and frame expansions have long been known to be robust to added noise. The Contourlet Transform (CT) is a geometrical image based transform.

The main idea in the proposed approach is the combination of two main watermarking methods; RDWT and CT, by which it is expected to optimize watermarking efficiency through exploiting the desired features of each of them, and then choosing the right one for robust watermark.

Reasons for choosing this combination are: Firstly, DWT performs down sampling of its bands; it does not provide shift invariance which causes a major change in the wavelet coefficients of the image and inaccurate extraction of the cover and watermark image [3, 4]. Secondly, wavelet based transform provide insufficient information like curve shape, edge representation and also lack of directional selectivity [6, 8, 12]. Thirdly the RDWT is shift invariant and its redundancy introduces an over complete frame expansion, where frame expansions add numerical robustness when adding white noise, also RDWT is successful in noise reduction and features detection [3,8,14]. Finally, Contourlet Transform is multi-geometric analysis that analyzes signals consisting of lines, curves and edges that wavelet transform does not support [5, 12]. So the combination between both methods is expected to cover, multi-scale, time-frequency, localization of shift invariance of RDWT and also offers directionality and anisotropy supported by CT.

Working Process

Work process follows the following stages:

Embedding

For embedding the watermark into the host image, the following algorithm is used.

1. One level decomposition is applied to the host image Eq. 1(either RDWT or CT).
2. One level CT is applied to the watermark image and resized to match the size of the host subbands.
3. Embedding LL,HH subband of watermark into LL, HH subabands of the host are experimented according to Eq. 1 $F' = F + k*W$ ......(1)

   Where F is original image, F' is watermarked image, w is watermark, and k is a gain factor for trading imperceptibility and robustness.
4. Best sub-band of host image for watermarking is selected for the second decomposition (RDWT or CT).
5. The subbands of the second level decomposition (LH1, HL1) are tested again for watermarking and the best

subband is chosen for the watermarking.

6. Reconstruct sub-bands of the host twice generating the watermarked image.
7. Similarity between original image and watermarked image (PSNR) is calculated representing imperceptibility.

Extraction

1. Two-level decomposition is applied to the original host image and the watermarked image, selecting the sub-band that was used for watermarking from the original image and its corresponding sub-band from the watermarked image (same as described in Embedding part).
2. Extract the watermark sub-band coefficients by using Eq. 2:

$$W = (F'-F) / k \quad \text{---- (2)}$$

3. Extracted coefficients matrix is reconstructed with the other sub-bands of the watermark generating the extracted watermark.
4. Correlation between original watermark and extracted watermark is evaluated (CORR) representing robustness.

Attacks

1. Apply different types of attacks with different values for each attack to the watermarked image.
2. Calculate PSNR.
3. Apply extraction algorithm after each attack.
4. Results are reported in notes (tables).

This process is repeated multiple times testing multiple watermarks that differ in size and capacity. The proposed approach RDWT_CT is tested and for more accuracy CT_RDWT is also tested to determine which of them performs better.

Analysis

After reporting results, maximum and minimum preservation value is calculated for PSNR and CORR for each technique. Preservation values for PSNR for each technique are compared to each, determining the order of the techniques in resisting each attack. The same is done for CORR, and then determining best technique that has higher performance in resisting attacks.

Experimental Results of Watermarking Techniques

Summary of results are shown in the following tables, last two columns represents amount of imperceptibility and robustness conserved by each technique. The range of conservation is calculated by (maximum value of PSNR after attacks/watermarked image PSNR), and (minimum value of PSNR after attacks/watermarked image PSNR), then results are compared to find most efficient watermarking technique. Finally, determine if the proposed method has provided any improvement. Comparing the results of the three techniques before attacks, the best technique for robust watermark is RDWT_CT, but for imperceptibility RDWT was the best as shown in Table (1).

It is important to insinuate that watermarking techniques from RDWT to RDWT_CT were tested using the three watermarks. Results improved by using watermarks that have more capacity (Baboon, Partnership-logo), so for more accurate results CT_RDWT was tested using these two watermarks see Fig. 1.

Fig. 1. a) Host image: Lena.bmp b) watermark image

Table 1. PSNR, CORR values after Gaussian noise on [Lena.bmp] and watermark [Copyright.bmp] for each technique.

Method		Before Attacks	Gaussian noise				Conservation Percentage	
			0.2	0.4	0.6	0.8	Max	Min
RDWT	PSNR	99.9359	68.2141	62.6665	60.4102	59.5662	68.26%	59.60 %
	CORR	0.9973	0.9961	0.9973	0.9973	0.9973	100.00 %	99.88 %
CT	PSNR	99.7656	68.2135	62.6665	60.4098	59.5664	68.37%	59.71 %
	CORR	0.9993	0.9981	0.9753	0.9286	0.8858	99.88%	88.64 %
RDWT_CT	PSNR	98.5092	68.2133	62.6663	60.4104	59.5666	69.25%	60.47 %
	CORR	0.9995	0.9994	0.9975	0.9926	0.9874	99.99%	98.79 %

a) For Gaussian noise; best resistance was provided by RDWT followed by RDWT_CT. RDWT provided more robustness by [0.01%-0.9%] on the account of imperceptibility which was reduced by [0.07%] ,

b) For Rotation attack, it appears that best resistance to rotation was provided by RDWT, then RDWT_CT. RDWT provided more robustness by [1.61- 2.5%] but reduced imperceptibility by [0.93% - 0.95%] which leads to overbalance RDWT technique. We conclude that best performance is provided by RDWT.

c) After Crop attack; RDWT_CT provided more imperceptibility by [0.99% - 1.12%] on the account of robustness which was reduced by [0.25% - 0.58%. Therefore, best performance is provided by RDWT_CT followed by RDWT.

d) For Dither; comparing CT with RDWT_CT, CT provides better imperceptibility but degraded robustness by a great noticeable amount [31.17% - 4.36%] which lead us to overbalance RDWT_CT. Comparing RDWT_CT with RDWT, RDWT improved robustness by [0.07% - 6.01%] while reduced imperceptibility by [0.86% - 1.01%] which led to overbalance the RDWT.

e) For Compression; Comparing RDWT_CT with CT, it appears that RDWT_CT provides better performance in robustness, but comparing RDWT with RDWT_CT, the last improved imperceptibility by [1.03 - 1.45%] while robustness was swaying between improvement and degradation; increased maximum preservation by [0.31%] and decreased minimum preservation by [0.14%] which lead to overbalance RDWT_CT. So, best performance is provided by RDWT_CT, then RDWT.

The following table includes results of watermarking host image [Lena.bmp] by watermark [Baboon.bmp in Fig. 2] which is higher in texture and details. Before attacks; best imperceptibility and robustness values were debuted by CT_RDWT followed by RDWT as shown in Table 2.

Fig. 2. Watermark image [Baboon.bmp]

Table 2. PSNR, CORR values after Gaussian noise on watermarked image [Lena.bmp] and watermark [Baboon.bmp] for all watermarking methods.

Method		Before Attacks	Gaussian noise				Conservation Percentage	
			0.2	0.4	0.6	0.8	Max	Min
RDWT	PSNR	99.5276	68.2142	62.6668	60.4102	59.5662	68.538 %	59.849 %
	CORR	0.9931	0.9930	0.9918	0.9880	0.9837	99.990 %	99.053 %
CT	PSNR	99.433	68.2138	62.6670	60.4106	59.5662	68.603 %	59.906 %
	C	0.9	0.9	0.9	0.9	0.9	99.8	91.1

	ORR	911	893	723	333	036	18%	71%
RDWT_CT	PSNR	99.2509	68.2139	62.6668	60.4103	59.5662	68.729%	60.016%
	CORR	0.9923	0.9917	0.9781	0.9768	0.9701	99.940%	97.763%
CT_RDWT	PSNR	99.8326	68.2142	62.6666	60.4102	59.5662	68.33%	59.67%
	CORR	0.9983	0.9980	0.9955	0.9874	0.9805	99.97%	98.22%

a) For Gaussian noise; RDWT_CT showed more imperceptibility [0.4%] and less robustness [0.45% - 0.03] than CT_RDWT, but we can say that results are nearby to each other overbalancing CT_RDWT. Comparing CT_RDWT with RDWT; RDWT provided more robustness and imperceptibility. Therefore, best techniques debuted resistances to Gaussian noise are RDWT, CT_RDWT, and then RDWT_CT.

b) The best of the techniques that showed more resistance to Rotation before attacks are CT_RDWT then RDWT. After attack, CT_RDWT in comparison with RDWT_CT provided more robustness by [2.01% - 2.05%] but provided less imperceptibility by [0.38%]. When comparing CT_RDWT with RDWT, it appears that RDWT provided more robustness and more imperceptibility. Therefore, the best performance is provided by RDWT, CT_RDWT, and then RDWT_CT.

c) For Crop; RDWT_CT improved imperceptibility but reduced robustness in comparison with CT_RDWT, so CT_RDWT is considered better in performance. On the other hand RDWT showed more imperceptibility and robustness than CT_RDWT. Therefore, best performance is achieved by RDWT, CT_RDWT, and then RDWT_CT.

d) For Dither; CT_RDWT provided more robustness by [13.62% - 0.51%] than RDWT_CT but reduced imperceptibility by [0.35% - 0.42%] which proved better performance. Comparing CT_RDWT with RDWT, it is clear that RDWT proved the best performance in both robustness and imperceptibility.

e) **For Compression;** CT_RDWT increased robustness by [1.1% - 1.01%] but reduced imperceptibility by [0.7% - 0.84%] in comparison with RDWT_CT which directs to overbalance the CT_RDWT. Comparing CT_RDWT with RDWT, the last provided more robustness and imperceptibility, so the best performance is deputed by RDWT, CT_RDWT, and then RDWT_CT.

The following table includes results of watermarking host image [Lena.bmp] by watermark [Partnership-logo.bmp as in Fig. 3].

Fig. 3. Watermark image [partnership-logo.bmp]

RDWT_CT improved imperceptibility by 0.52% - 0.84% while it reduced robustness by [1.1% - 1.01%] in comparison with CT_RDWT, so CT_RDWT is better in performance according to robustness. RDWT provided more imperceptibility and robustness than CT_RDWT. As a result, best performance is provided by RDWT, and then RDWT_CT as shown in Table 3.

Table 3. PSNR, CORR values after Gaussian noise on watermarked image [Lena.bmp] and watermark [Partnership-logo.bmp] for all watermarking methods.

Method		Before Attacks	Gaussian noise				Conservation Percentage	
			0.2	0.4	0.6	0.8	Max	Min
RDWT	PSNR	99.6761	68.2141	62.6667	60.4101	59.5659	68.44%	59.76%
	CORR	0.9999	0.9998	0.9993	0.9979	0.9966	99.99%	99.67%
CT	PSNR	99.8438	68.2140	62.6666	60.4100	59.5662	68.32%	59.66%
	C	0.9	0.9	0.9	0.9	0.9	99.	99.

	ORR	997	996	986	966	951	99%	54%
RDWT_CT	PSNR	99.9424	68.2145	62.6668	60.4101	59.5660	68.25%	59.60%
	CORR	0.9997	0.9996	0.9989	0.9970	0.9954	99.99%	99.57%
CT_RDWT	PSNR	99.8719	68.2142	62.6667	60.4101	59.5659	68.30%	59.64%
	CORR	0.9999	0.9998	0.9997	0.9991	0.9986	99.99%	99.87%

f) For Gaussian noise; CT_RDWT in comparison with RDWT_CT improved robustness by [0.3%] and the imperceptibility by [0.04% - 0.05%]. Comparing CT_RDWT with RDWT, RDWT provided [0.12% - 0.14%] more imperceptibility, but reduced robustness by 0.2% which means that CT_RDWT is better in performance, followed by RDWT, and then RDWT_CT.

g) For Rotation; CT_RDWT provided more robustness and imperceptibility in comparison with RDWT_CT, but comparing CT_RDWT with RDWT, CT_RDWT reduced imperceptibility by [0.13%] while increased robustness by [0.28% - 0.4%], therefore CT_RDWT provided better performance than RDWT. Also when comparing RDWT with RDWT_CT the first reduced imperceptibility by [0.33% - 0.82%] while increased robustness by [2.19% - 1.45%] which implies that RDWT performance is better than RDWT_CT. As a result, best performance is provided by CT_RDWT followed by RDWT, and then RDWT_CT

h) For Crop attack; Robustness and imperceptibility were noticeably improved by CT_RDWT, it provided better performance over RDWT_CT. CT_RDWT in comparison with RDWT, improved robustness by [0.02% - 0.08%] while degraded imperceptibility by [0.13% -0.14%] which implies that RDWT is better in performance. Also comparing RDWT_CT with RDWT, their performance is nearby. As a result best performance is provided by CT_RDWT, RDWT, and then RDWT_CT.

i) For Dither; robustness and imperceptibility were improved by CT_RDWT in comparison with RDWT_CT, But when comparing CT_RDWT with RDWT we find that CT_RDWT improved robustness by [0.03% - 1.22%] on the account of imperceptibility which was reduced by [0.12 - 0.15%]. Also comparing RDWT with RDWT_CT, we find that RDWT reduced imperceptibility by [0.17% - 0.20%], while increased robustness by [18.3% - 0.67%]. As a result, best performance is deputed by CT_RDWT, RDWT, and then RDWT_CT.

j) For compression; CT_RDWT versus RDWT_CT, CT_RDWT provided more robustness, while the imperceptibility are nearby in both techniques. Comparing CT_RDWT with RDWT, The first provided more robustness by [0.16% - 0.05%] while reduced imperceptibility by [0.17% - 0.13%], as for robust watermark CT_RDWT is overbalanced. Also comparing RDWT with RDWT_CT, we find that RDWT is better in performance than RDWT_CT. As a result, Best performance is deputed by CT_RDWT, RDWT, and then RDWT_CT.

Finally, the following table describes the order of the techniques according to their performance (robustness in balance with Imperceptibility).

Table 4. Order of watermarking technique according to performance

Attack	Copyright	Baboon	Partnership
Gaussian Noise	RDWT, RDWT_CT, CT	RDWT, CT_RDWT, RDWT_CT CT	CT_RDWT, RDWT, RDWT_CT CT
Crop	RDWT_ CT, RDWT, CT	RDWT, CT_RDWT, RDWT_CT, CT	CT_RDWT, RDWT, RDWT_CT, CT
Rotation	RDWT, RDWT_CT, CT	RDWT, CT-RDWT, RDWT_CT, CT	CT_RDWT, RDWT, RDWT_CT, CT
Dither	RDWT, RDWT_ CT, CT	RDWT, CT-RDWT, RDWT_CT, CT	CT_RDWT, RDWT, RDWT_CT, CT
Compression	RDWT-CT, RDWT, CT	RDWT, CT-RDWT, RDWT_CT, CT	CT_RDWT, RDWT, RDWT_CT, CT

Reading results in Table 4:

Comparing RDWT_CT with CT_RDWT; results showed that CT_RDWT provides better imperceptibility and robustness.

When we used less capacity watermark image [Copyright.bmp], RDWT proved best performance in resisting Gaussian noise, Rotation, and Dither attacks, while RDWT_CT showed better performance in resisting Crop and Compression attacks.

As we used more capacity watermark image (Baboon.bmp), RDWT proved its better performance in resisting attacks. CT_RDWT provided better performance when a more capacity watermark (partnership.bmp) was used.

Summary

Watermarking is based on embedding one of the high frequency mid-bands of watermark image into one of the high frequency mid-band of the host image. It was not selected randomly, but experimentally by embedding each high frequency mid-band of watermark into each of high frequency mid-band of host image, and then the best for watermarking is chosen according to the experimental results.

Two-level decomposition is applied to the host image, and one-level decomposition on the watermark image.

Host image is of size 512x512, while the watermark images are [copyright.bmp] of size 20x50, [Baboon.bmp] of size 512x512, and [Partnership-logo.bmp] of size 480x526. Resizing the watermark to a suitable size is needed depending on the technique used.

Embedding is based on Eq. 1 while extraction is based on Eq. 2.

Original image and watermarked image are compared to each other to estimate imperceptibility using the measure PSNR. Also embedded watermark is extracted from the watermarked image and compared to the original watermark to estimate robustness using the measure CORR. This is applied before and after attacks for each technique. It was found that the efficiency of the watermarking techniques becomes more clear and accurate when watermark image is higher in capacity (details and texture); that is when we used black and white with low capacity watermark image [copyright.bmp] all techniques results were very close and nearby, while using higher capacity gray-scaled watermark image [Baboon.bmp] and [Partnership-logo.bmp] gave more accurate and varying results.

The new approach showed more robustness and imperceptibility than RDWT, but this depends on the capacity of the watermark image. RDWT provides shift-invariance by eliminating down-sampling and up-sampling of coefficients during each filter-bank iteration, also it provides frame expansion which proved robustness to attacks. CT offers multi-scale, multi resolution, and directional decomposition and applies Laplasian Pyramidal decomposition and Directional Filter Bank decomposition that made it robust to noise. Experimentally results proved the expectations but with a little amount. Why? This is because CT uses LP decomposition; which is a technique to cover shift-invariance by; firstly the signal is smoothed by Gaussian filter, then down-sampled by a factor of 2. This approximation signal is then up-sampled using nearest neighbor interpolation and then subtracted from original signal. The difference signal represents the information lost during the smoothing down-sampling and up-sampling process. This process can be iterated number of times generating low-pass signal and a number of error signals equal to the number of levels of iteration.

So, as a result both RDWT and CT provided shift-invariance, the new technique provided good results in resisting attacks and imperceptibility.

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