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An Improved Discrete Wavelet Transform Technique for Enhancing Digital Image Watermarking

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Abstract— *An improved Discrete Wavelet Transform technique(IM-DWT) presented in this paper offers better imperceptibility, decreases execution time, and improves robustness in comparison to combined method Improved DWT/DCT (IMD-WC-T), Discrete Cosine Transform (DCT) and hybrid fusion technique (HFT) digital watermarking techniques. The proposed IM-DWT spread the watermark with PN-sequence with a certain key in a certain region coefficient of level 2 after decomposing the host image to generate the final watermarked image. Results obtained from IM-DWT technique showed improved performance in terms of imperceptibility, execution time and certain aspect in robustness such as Gama Correction and Histogram Equalization; than that of IMD-WC-T, DCT, and HFT, in addition to the quality of recovered watermark image as well. Comparing with HFT, the IM-DWT technique guarantees additional imperceptibility, reduced execution time and gave more robustness against Gama Correction and Histogram Equalization.*

Keywords— Digital image; watermarking; data hiding; image combination; discrete wavelet transforms; discrete cosine transform; image fusion; hybrid fusion technique

1. Introduction

Digital watermarking is widely common as a technique for tag multi-media data, including digital images, video clips, text documents and audio, by hiding confidential information in the data [1-3]. There are many watermarking techniques that can be categorized into two major categories: spatial-domain and frequency-domain watermarking techniques [4].

In the spatial domain techniques, the values of the image pixels are directly modified on the watermark which is to be embedded. The least significant bits (LSB) technique [5], is one of the earliest such techniques, which is implemented by changing the least significant bits of the image's pixel data.

On the other hand, in frequency-domain, the transform coefficients are modified instead of directly changing the pixel values. To detect the existence of a watermark, the inverse transform is used. Some of the frequently used frequency-domain transforms include the Discrete Wavelet Transform (DWT), Discrete Fourier Transform (DFT) and the Discrete Cosine Transform (DCT) [6]. Nevertheless, due to its high performance in spatial localization, DWT [7] is frequently used in digital image watermarking.

Exploiting this objective, our proposed technique offers improved and enhanced robustness, a key benefit of DWT methods, while also providing better imperceptibility to some certain attacks.

The outline of the remainder of this paper is as follows: the details of the watermark embedding, and extraction procedures required to accomplish it are presented in Section 2. In Section 3, the discussion and analysis of experimental results obtained using the proposed technique. Section 4 concludes the paper.

2. THE PROPOSED IMD-WC-T TECHNIQUE

The proposed improved Discrete Wavelet Transform (IM-DWT) technique including its watermark embedding and extraction processes are presented in this section. The most widely used 'Lena' test image has been used as the cover (or host) image. A simple 20×50 binary image has been used as the watermark signal (or image).

In the beginning, the IM-DWT method, the content of the host image is decomposed using the DWT with Haar filter. To make the resulting image more robust against attacks, the watermark signal is then inserted into the second level sub-band of the cover image [8] with help of the Key, the PN-Sequence of the watermark will embed in the detail coefficients of the LL2 after applying the second level DWT for the host image.

In IM-DWT method, a key is used to embed the watermark in the detailed wavelet coefficients of the host image [8]. This is useful to improve robustness against several kinds of attacks. The trio of the host image, the watermark image, and the key is simply referred as I, W, and K respectively. These images are presented in Figure 1. The proposed procedures for watermark embedding and extraction are summarized and presented in Figures 2 and 3, respectively.

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Fig. 1. *(a) the host Lena image, (b) the 'Copyright' watermark image and (c) the key*

2.1 Watermark Embedding Algorithm

The watermark embedding process consists of four steps as enumerated. In addition to improve the robustness of the other watermarking techniques and keep the watermarked image imperceptible. So that LL2 region In HH1 is chosen as a region to embed the watermark in it as mentioned in step 2.

- Decompose the host image into four multi-resolution sub-bands, perform DWT on the host image: LL1, HL1, LH1, and HH1,
- Get other four smaller sub-bands and choose the LL2 sub-band, perform DWT again on sub-band HH1 [8],
- Spread the watermark with PN-sequence with a certain key in the LL2 sub-band,
- Use IDWT to get the watermarked image on the DWT transformed image, including the modified sub-band.

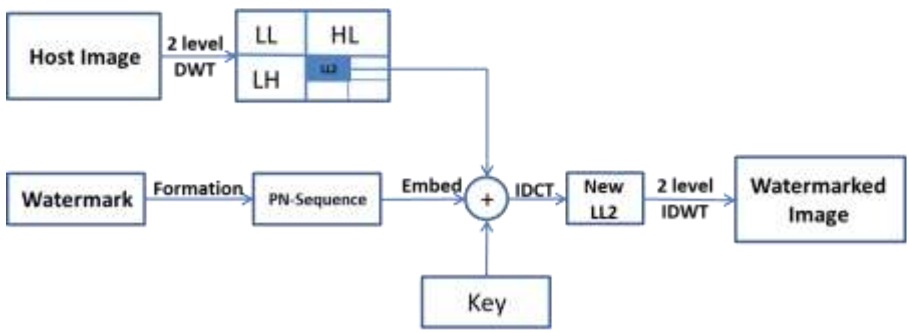

Fig. 2. *Watermark embedding procedure for the proposed improved Discrete Wavelet Transform (IM-DWT) technique*

2.2 Watermark Reconstruction Algorithm

To recover the watermark image from an already watermarked image, three simple steps, as enumerated below, are required.

- Use DWT to decompose the cover host image into four non-overlapping multi-resolution sub-bands: LL1, HL1, LH1, and HH1.
- Use DWT again to sub-band HL1 to get other four smaller sub-bands and use DWT to sub-band HH1 to get other four smaller sub-bands and choose the LL2 sub-band [8].
- With the helping of the key, it is easily to generate the recovered watermark bits and reconstruct it.

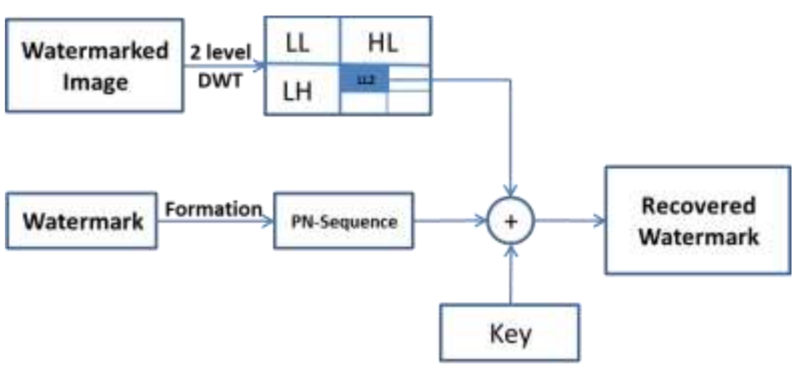

Fig. 3. *Watermark extraction procedure for the proposed improved Discrete Wavelet Transform (IM-DWT) technique*

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Figure 3 shows the watermark extraction process for an improved Discrete Wavelet Transform (IM-DWT) technique. In this figure, with help of the Key and the PN-Sequence of the watermark, the recovered watermark will be extracted from the detail coefficients of the LL2 after applying the second level DWT for the watermarked image.

A proposed extracting process which is used by finding the correlation in the components of watermarked image by employing the command "correlation ( )=corr2(LL2,pn_sequence)", then compare the correlation with mean correlation by using command " if (correlation(bit) > mean(correlation)) make the watermark (bit) = 0 else make it = 1.

The resulting watermarked Lena images presented in Figures 4 and 5; and specifically the peak-signal-to-noise-ratio (PSNR) values, confirm that the quality of the watermarked Lena image obtainable using the proposed improved Discrete Wavelet Transform (IM-DWT) technique is better than those DCT, improved technique (IMD-WC-T) technique and the hybrid fusion technique (HFT) [9]. At the Same Time, the proposed improved technique (IMD-WC-T) technique offers better recovery of the watermark than that obtained from both the separated (IM-DWT and DCT methods alone) and the hybrid fusion technique (HFT). The recovered 'Copyright' text watermark image for the separate IM-DWT, DCT, the hybrid fusion (HFT) techniques [10], and the improved (IMD-WC-T) technique, are presented in Figure 6.

3. RESULTS AND ANALYSIS

In analyzing the performance of image-hiding techniques, many parameters have been proposed. These parameters include visual quality (i.e., imperceptibility), complexity, payload capacity, execution time, robustness and a few others depending on the objective of the watermarking strategy [10,11]. Among them, we will select some of them for measuring the performance of our technique alongside other image hiding methods to the trio of watermarked image quality known as a.k.a. imperceptibility, the execution time (i.e., in terms of computing resources) and, finally, the ability of the watermarked image to withstand attacks, i.e. robustness.

3.1 Measuring Imperceptibility (Perceptual Quality)

3.1.1 PSNR

The heart measure here is the numerical PSNR values obtained using each of the four methods under analysis (and the visual quality of the watermarked images themselves). But due to brevity, the inherent distortions in the watermarked versions obtained using each of the four methods are not easily visible, hence, we constrain the comparison to the numerical PSNR values. The PSNR is given by

$$PSNR(I_{org}, I_w) = 10 \times \log\left(\frac{255^2}{MSE\ (I_{org}, I_w)}\right) \quad (1)$$

Form using the results that presented in Figure 4, IM-DWT gives the best result. This is attributed to the fact that the method of embedding watermarks, such as in CDMA [8], involves inserting the watermark in the second level of DWT image sub-band (i.e. in the LL2 of HH sub-band). It has been proven that embedding the watermark in this region does not affect the quality of the watermarked image.

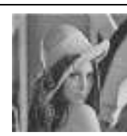
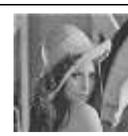
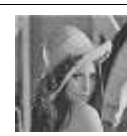
Original image	Watermarked image			
	IM-DWT	DCT	HFT	IMD-WC-T
				
	PSNR = 49.29 dB	PSNR = 29.589 dB	PSNR = 37.27 dB	PSNR = 41.28 dB

Fig. 4. *The watermarked Lena image as realized from the IM-DWT, DCT, HFT and IMD-WC-T*

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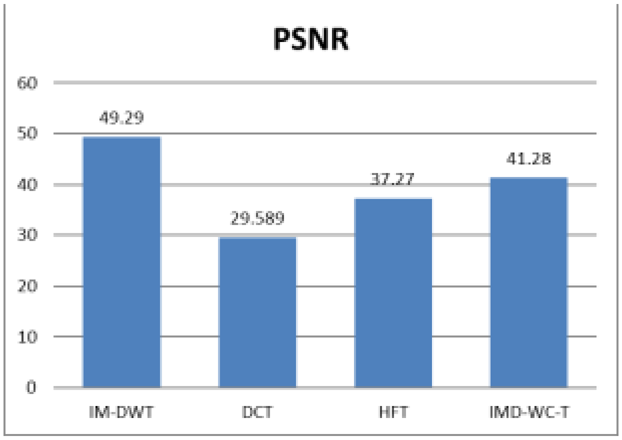

Fig. 5. *The PSNR for the separate IM-DWT, DCT, HFT and IMD-WC-T*

The proposed improved Discrete Wavelet Transform (IM-DWT) technique came in the first place with 49.29 dB, notwithstanding the combined (IMD-WC-T) method, in second position with 41.28 dB, fares better than the other two methods under analysis. Interestingly, after varying the dimensions of the image and watermark signal we saw that the PSNR values obtained using the HFT method is approximately the average of the values obtained using the separate IM-DWT and DCT [9] methods but our proposed method is better than HFT.

These results prove that, the main advantage of using IM-DWT methods, while also giving some assaults a stronger imperceptibility. A lot of efficiency improvements in DWT-based digital image watermarking systems could be accomplished by pairing, for instance, more than one method, DWT with DCT like the HFT and IMD-WC-T method, which is clear from the PSNR value of using the DCT alone that is 29.59 dB.

Recovered (Copyright) Watermark image			
IM-DWT	DCT	HFT	IMD-WC-T
			
PSNR=23.97 dB	PSNR=19.21 dB	PSNR=25.23 dB	PSNR=30.00 dB

Fig. 6. *The text 'Copyright' watermark images as recovered from the IM-DWT, DCT, HFT IMD-WC-T*

As shown in Figure 6, the IMD-WC-T achieved the first place in the PSNR for the recovered (copyright) watermark image with 30 dB and come in the second position HFT with 25.23dB.

3.1.2 Normalized Cross-Correlation

The second perceptual performance test is the correlation scores acquired using each of the four methods being analyzed. The metric used to assess difference between the host image and the watermarked image is Normalized Cross-Correlation (NCC) which measure of similarity between the original and watermarked images, that is illustrated in Equation. (3.2).

$$NCC = \frac{\sum_{j=1}^{M}\sum_{K=1}^{N}(X_{j,k})(X`_{j,k})}{\sum_{j=1}^{M}\sum_{K=1}^{N}X_{j,k}^{2}} \qquad (2)$$

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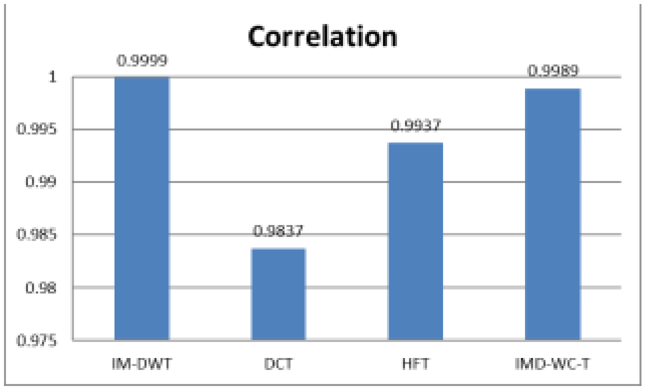

Fig. 7. *The Correlation for the IM-DWT, DCT, HFT and IMD-WC-T*

It is clear from Figure 7 that with the same order likes PSNR. As shown in the previous figure, the correlation of the HFT is approximately the average between the correlation of DWT and DCT and the correlation of our proposed method is better than HFT. The magnitude range of r is [−1, 1], and the unity holds if the image extracted perfectly matches the original. The minus sign indicates the extracted image is a reverse version of its original image.

3.1.3 MSE

The third measure for the perceptual quality is MSE which is mean square error between the two of host image $X_{j,k}$ and watermarked image $X`_{j,k}$, as shown in equation (3).

$$MSE = \frac{1}{MN} \sum_{j=1}^{M} \sum_{k=1}^{N} (X_{j,k} - X'_{j,k})^2 \qquad (3)$$

Where M and N are the image dimensions.

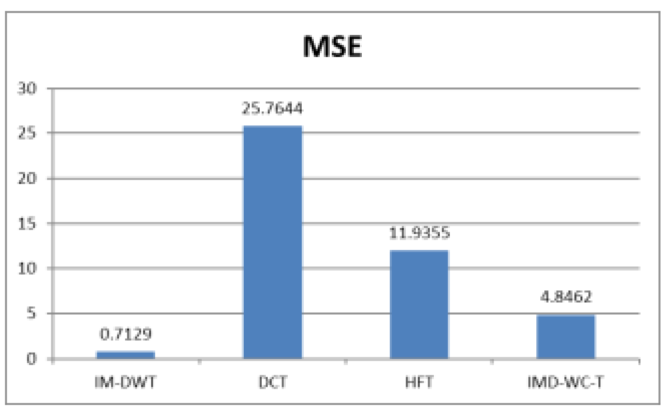

Fig. 8. *The MSE for the IM-DWT, DCT, HFT and IMD-WC-T*

From equations (1) and (3), there is an inverse relationship between PSNR and MSE, which is also reflected on the figure, as shown in Figure 8.

3.1.4 WDR

The fourth measure for the perceptual quality metric is Watermark to Document Ratio (WDR) which is defined by the ratio of watermark energy to the cover image energy. Its metric is defined in equation (4).

The WDRs are positively correlated to the image quality in which a high WDR represents high quality of image since the host image is slightly distorted by the watermarking process.

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$$WDR = 10\log\frac{\sum_{i=1}^{N}\sum_{j=1}^{N}[X(i,j) - X_w(i,j)]^2}{\sum_{i=1}^{N}\sum_{j=1}^{N}X(i,j)^2} \quad (4)$$

where X(i,j) is the host image and XW(i,j) is the watermarked image.

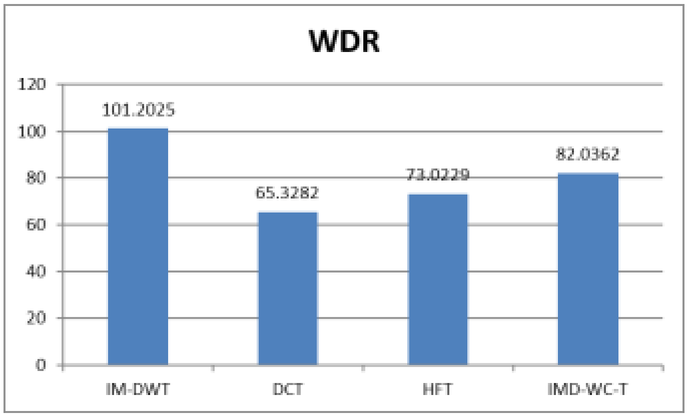

Fig. 9. *WDR the separate IM-DWT, DCT, HFT and IMD-WC-T*

As shown in the Figure 9, the ordering is the same as that of the PSNR. This is clear since the equation of WDR depends on the same factors, the difference between the host and the watermarked image.

3.2 Measuring Execution Time

This test is implemented to determine the computational execution time for each watermarking method. The simulation is carried out using a desktop computer fitted with the required software, i5 2.67 GHz CPU, 4 GB Ram. CPU timings are predicted for the introduction and removal of watermarks for each image for each method.

The DCT method Occupies the least computational time for the execution time, as shown in the Figure 10. While IM-DWT occupies the second longer time, in which the watermark is embedded in LL2, after which the correlation is made between the extracted watermarks.

Figure 10 shows that the IMD-WC-T was marginally lower than the IM-DWT and DCT methods. It takes the sum of time required for the distinct IM-DWT and DCT methods. The IMD-WC-T is slightly quicker than the Hybrid Fusion Technique (HFT) because the HFT has a correlation that takes more time to execute.

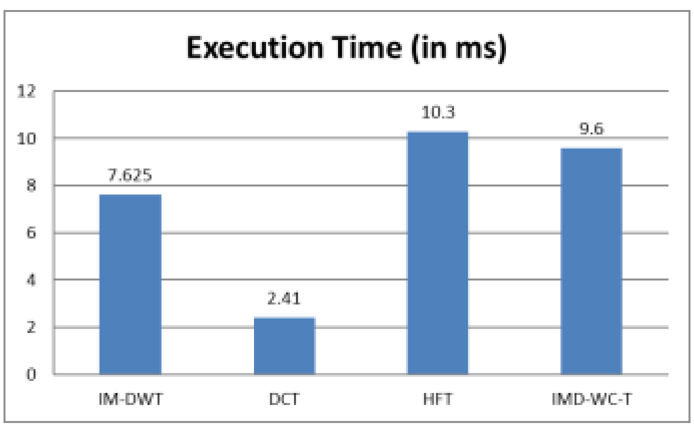

Fig. 10. *Comparison of the execution time for the IM-DWT, DCT, HFT and IMD-WC-T*

3.3 Measuring Robustness

The latest study uses the binary robustness metric, which could result in two distinct results, whether the watermark is robust or not. However, using other metrics allows meaning, which would lead in many concentrations of robustness. The Bit-correct rate

(BCR) method is one of the recent robustness metrics. BCR is defined as the correct ratio of extracted bits to the total number of embedded bits as shown in the next formula:

$$BCR = \frac{100}{l}\sum_{n=0}^{l-1}\begin{cases}1, & W'_n = W_n \\ 0, & W'_n \neq W_n\end{cases} \quad (5)$$

Where l is the distance of the watermark, W_N is associated with the nth bit of the watermark inserted and is associated with the n^{th} fraction of the watermark recovered. High BCR values indicate that the algorithm is more robust.

3.3.1 BCR of Histogram Equalization

The embedding procedure was performed for each method, accompanied by histogram equalization, and after the attack the recovery method is implemented to obtain the watermark.

The process of adjusting intensity values can be done automatically using histogram equalization. Histogram equalization involves transforming the intensity values so that the histogram of the output image approximately matches a specified histogram. By default, the histogram equalization function (i.e., histeq) adjusts the contrast using histogram equalization. Specify the gray scale transformation return value, h, which is a vector that maps gray levels in the intensity image I to gray levels in J.

[J,h] = histeq (I);

Histogram equalization distributes the image histogram to complete scale for an even distribution of brightness of pixels. Image contrast is reasonable improved in most cases. The effect of histogram equalization of watermark is mainly based on histogram distribution of image before the test. A plot of the Histogram Equalization (BCR) as a function of percentage quality is presented in Figure 11 below.

Therefrom, we see that the IMD-WC-T method fares better than the separate IM-DWT and HFT but fares slightly worse than the DCT method. This suggests that the proposed method is slightly fragile to Histogram Equalization while the DCT method outperforms all the other methods because it is the core component of the Histogram Equalization. The results of this experiment are shown in Figure 11.

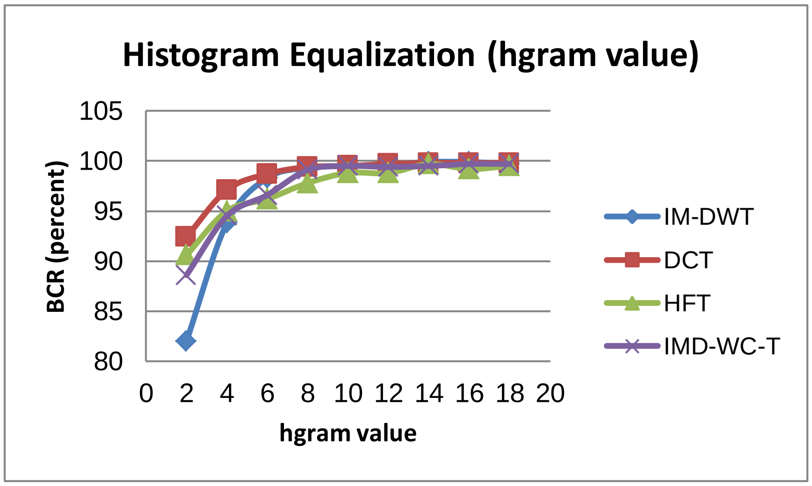

Fig. 11. *Bit correct ratio due to histogram equalization for the watermarked images for the four methods IM-DWT, DCT, HFT and IMD-WC-T*

3.3.2 BCR of Gama Correction

Gamma correction is a very frequently used operation that is used to enhance images or adapt images for display. Gamma correction is performed to adjust the brightness of image. Value of gamma exponent is varied to affect the quality of watermark. By default, “imadjust” function in MATLAB uses a gamma value of 1, which means that it uses a linear mapping between intensity values in the original image and the output image. A gamma value less than 1 weights the mapping toward higher (brighter) output values. A gamma value of more than 1 weights output values toward lower (darker) output values. The results of this experiment are shown in this figure 12.

J = imadjust (I,[ ],[ ],Gamma value);

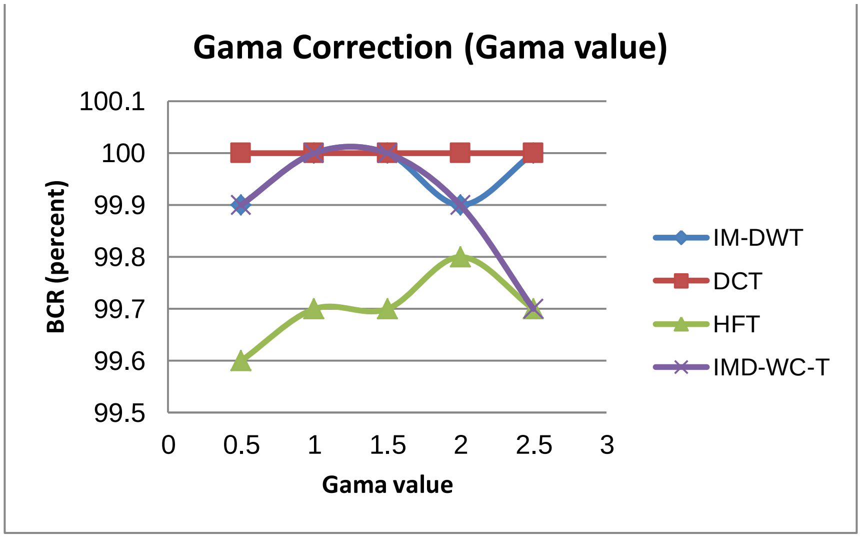

Fig. 12. *The Gama value Comparison of watermarked images for the four methods IM-DWT, DCT, HFT and IMD-WC-T*

Table 1 presents a numerical summary of the overall rendering evaluation based on the three-performance metrics: imperceptibility, execution time and robustness for the four methods.

Table 1: Performance evaluation based on imperceptibility, execution time and robustness for the four methods under review: IM-DWT, DCT, HFT and IMD-WC-T methods

Performance indecatore		Technique			
		IM-DWT	DCT	HFT	IMD-WC-T
Imperceptibility (PSNR in dB)		49.6	29.8	37.0149	41.28
Execution Time (ms)		7.625	2.41	10.3	9.6
Robustness	Gama Correction (At gama value = 0.5)	99.9	100	99.6	99.9
	Histogram Equalization (At hgram value = 6)	98.3	98.7	96.2	96.6

4. Conclusions

The main objective is to obtain improved performance in terms of imperceptibility, robustness to Gama Correction and Histogram Equalization. Furthermore, the quality of recovered watermark image has been improved than that obtainable using the methods based on the DWT or DCT techniques, separately. As stated in this paper, the novelty of this study arises from successively using the improved DWT with expanding the watermark with a PN sequence with a certain button in the coefficient to finalize the produced watermark image after decomposing the host picture with DWT at level 2.

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Main Works:

- **Ahmed S. Salama,** Mohammed A. Al-Qodah Abdullah M. Iliyasu, Awad Kh. Al-Asmari and Fei Yan "A Hybrid Fusion Technique for Watermarking Digital Images", Advances in Intelligent Systems and Computing Volume 240, 2014, pp 207-217.
- **Ahmed S. Salama**, Mohamed Amr Mokhtar, and Mazhar B. Tayel, "A Triple-Layer Encryption-Based Watermarking Technique for Improving Security of Medical Images", Journal of Medical Imaging and Health Informatics Vol. 9, Number 3, March 2019, pp. 610-619(10).
- **Ahmed S. Salama** and Mohamed Amr Mokhtar, 2016. "Combined Technique for Improving Digital Image Watermarking", 2nd IEEE International Conference on Computer and a Communications

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