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A Robust Hybrid Watermarking Technique for Securing Medical Image

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Abstract: In the aim to contribute to the security of medical image, we present a robust watermarking method which combines discrete wavelet transform (DWT), discrete cosine transform (DCT) and singular value decomposition (SVD). This approach is intended to insert an invisible image watermark in a medical image. The cover medical image is divided up into the third level of DWT coefficients and then is transformed by DCT and SVD. The same procedure is applied to the watermark image. The singular value of watermark is inserted into the singular value of the high-frequency sub bands of the third level DWT of the cover image. However, the insertion of the watermark in these areas makes it possible to reinforce the robustness of the system of watermarking without hindering the quality of the watermarked image. The performance of the proposed method was evaluated in term of invisibility by calculating the Peak Signal to Noise Ratio (PSNR) between the original and the watermarked image and in term of robustness by measuring the normalized correlation coefficient (NC) between the original watermark and the extracted watermark after applying attacks. The experimental results approve that our proposed hybrid algorithm gives an excellent compromise imperceptibility and robustness against several attacks such as Gaussian noise, Salt-and-Pepper, Speckle noise, Average filter, Median filter, and Wiener filter compared with existing methods.

Keywords: Image processing, Securing, Medical application, Digital watermarking, DWT, DCT, SVD.

1. Introduction

Telemedicine is the use of information and communication technologies to supply clinical health care at a distance, it is a well-known application that facilitates the transfer of an enormous amount of medical data. In order to contribute to the security of sharing and transferring of medical images, the digital watermarking has emerged as an alternative and complementary solution to ensure authorized access and content authentication [1].

The system of watermarking should be imperceptible (not affect the visual quality of the cover medical image) and robust (the detection of watermark should be possible even if the image undergoes several attacks). The insertion of the watermark is generally performed in the spatial domain or the frequency domain.

In the spatial domain the insertion is done directly in the values of the pixels of the original image [2, 3], it's easy to implement but is fragile against attacks. For example, adding noise or lossy compression can easily degrade the quality of an image or remove the watermark.

Compared to the spatial domain, the insertion in transform domain enhances the performance of watermarking by choosing the pixels that will be more resistant and robust against various attacks such as filtering, noise, and compression. The watermark is inserted by modulating the coefficients of a transform. Among the transforms used in the algorithms of digital images watermarking, we can cite discrete Fourier transform (DFT), discrete cosine transform (DCT), discrete wavelet transform (DWT) and singular value decomposition (SVD). Moreover, the combination of these transformations can increase the efficiency of the watermarking scheme. There are some contributions which propose hybrid methods in the literature like:

Kumar et al [4] proposed a hybrid method of watermarking based on DWT and SVD.

In this paper, the cover image is divided into the third level of DWT. Afterward, the watermark is inserted into the singular values of HL3 and LH3 sub bands.

In [5], the authors present a robust hybrid technique of watermarking based on DWT, DCT, and SVD. After the decomposition of the cover image into first level DWT, the low-frequency subband of the host image and watermark image are transformed by using DCT and SVD. Then the singular value of the watermark image is integrated into the singular value of the cover image. The watermarked image is obtained by inverse SVD, DCT, and DWT respectively.

In [6], the authors present a new technique of watermarking based on DWT-DCT to insert the watermark into the medical images. The first step consists of decomposing the medical image into four sub-bands, low frequency (LL) and high-frequency image's details (HL, LH, HH). The second step is to apply DCT on HH sub-band and then embeds the watermark. The watermarked image is constructed by inverse DCT and DWT.

In this paper, a robust watermarking technique for medical images based on DWT, DCT, and SVD has been proposed. The strong points of this approach, it is that the insertion of watermark is made into high frequency sub bands HH, what offers a better invisibility, as well as the decomposition DWT up to third level makes it possible to increase the robustness of the system of watermarking against various attacks.

The article is classified as follows: section 2 presents the techniques of watermarking used in our method and describes their advantages. In section 3, the proposed hybrid technique DWT-DCT-SVD has been presented with a description of the steps of watermark embedding and extracting algorithms. Section 4 presents the experimental results obtained using Matlab R2013b and finally the conclusion of work is drawn in Section 5.

2. Background and theory

The proposed technique of watermarking medical image was based on DWT-DCT-SVD. One of the advantages of the wavelet transform DWT is that it is based on the characteristics of the human visual system. This allows us to use the watermark in the regions where the HVS is less sensitive like high-resolution detail bands. The insertion of the watermark in these regions makes it possible to increase the robustness without affecting the quality of the image.

The DCT reduces the spatial correlation between the pixels of an image and it offers a good robustness to attacks such as the adjustment of contrast, filtering, and compression. And finally, The SVD stores the maximum energy of the image in a minimum of singular values. The main advantage of this method is that the singular values (SV) are very stable.

2.1 Discrete wavelet transform (DWT)

DWT is a new technique which is used to represent an image in a new time and frequency scale in recent years [1]. The transform is based on small waves called wavelet of varying frequency.

Applying wavelet transform [7] on two-dimensional images divides the image into four sub-bands: a lower resolution approximation image (LL), horizontal (HL), vertical (LH) and diagonal (HH) detail components. The maximum energy of an image is concentrated in low-frequency sub-band (LL) whereas high-frequency components sub-band (HL, LH, and HH) correspond to edges and textures.

2.2 Discrete cosine transform (DCT)

Discrete Cosine Transform (DCT) [8] is the most popular transform function used in signal processing. It transforms a signal from spatial domain to frequency domain. The insertion of the watermark is done in the middle frequency.

The discrete cosine transform of an image x of dimensions $N \times N$ is computed according to Eq. (1):

$$DCT\,(m,n) = \tag{1}$$

$$\frac{1}{\sqrt{2N}} c(m).c(n) \sum_{k=0}^{N-1} \sum_{l=0}^{N-1} x(k,l) cos(\frac{(2k+1)m\pi}{2N}) cos(\frac{(2l+1)n\pi}{2N})$$

$$C(m), C(n) =$$

$$\left\{ \frac{1}{\sqrt{N}}, m,n = 0 \;;\quad \sqrt{\frac{2}{N}}\,, m,n = 1\ up\ to\ N-1 \right\}$$

2.3 Singular value decomposition (SVD)

The singular value decomposition [9] of a matrix I is the factorization of the form:

$$I = USV^T \tag{2}$$

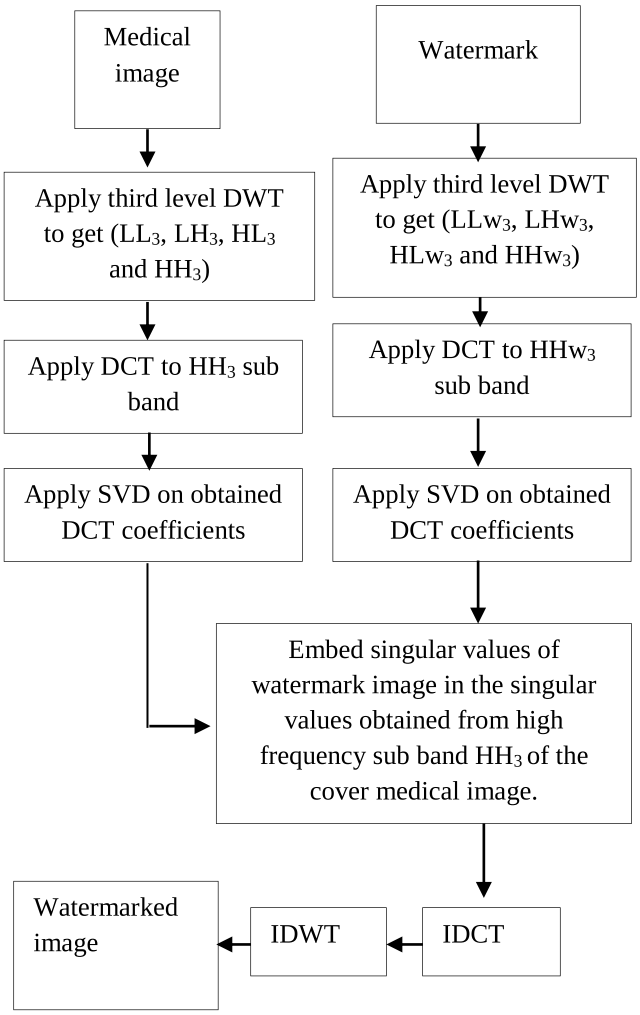


Figure.1 Watermark embedding process using DWT-DCT-SVD

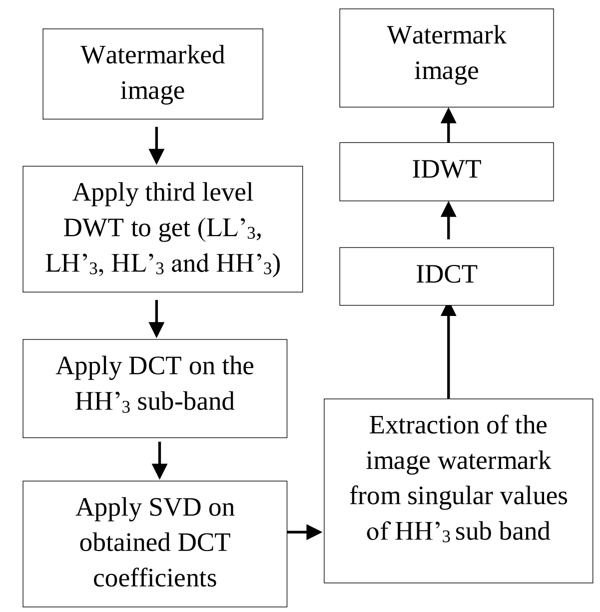


Figure.2 Watermark extraction process using DWT-DCT-SVD

Where U and V are orthogonal matrices of size *N*x*N* and *S* is a diagonal matrix which comprises the singular values *(s1, s2, ...,sN)* of the matrix I.

3. Proposed hybrid technique

The aim of this article is to present and analyze a robust method of watermarking based on a combination of three techniques: DWT, DCT, and SVD.

The ultimate goal of this proposed method is to increase the robustness of the system in terms of quality and confidentiality. Fig. 1 and Fig. 2 illustrates the watermark embedding and extracting process respectively.

3.1 Watermark embedding algorithm

1. Apply the third level DWT transform using Haar wavelet on cover medical image and watermark image to get (LL_3, HL_3, LH_3, HH_3) and (LLw_3,HLw_3, LHw_3, HHw_3) sub-bands respectively.
2. Apply DCT to the selected sub-bands (HH_3,HH_{W3}) and then apply SVD to obtain Eq. (3) and Eq. (4):

$$I = U_{HH3} \times S_{HH3} \times V_{HH3^T} \quad (3)$$

$$W = U_W \times S_W \times V_{W^T} \quad (4)$$

3. Modify the singular values of *HH3* sub-band of the cover image with the singular values of HH_{W3} sub-band of the watermark image:

$$S_{IW} = S_{HH3} + (\alpha \times S_W) \quad (5)$$

Such as (α: scaling factor)

4. Apply inverse DCT and inverse DWT to produce the watermarked medical image.

3.2 Watermark extracting algorithm

1. Apply the third level DWT transform on the watermarked image to get LL'3, HL'3, LH'3 and HH'3 sub-bands.
2. Apply DCT and then SVD to the selected sub-band HH'_3:

$$I_{wat} = U_{HH'3} \times S_{HH'3} \times V_{HH'3} \quad (6)$$

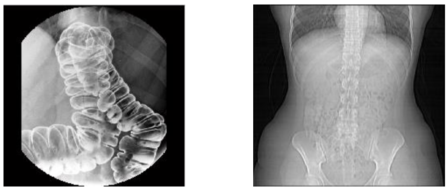
3. Obtain singular values of the watermark from singular values of high-frequency sub-bands (HH'_3, HH_3) of watermarked image and cover image respectively by Eq. (7):

$$S_{ew} = \frac{(S_{HH'3} - S_{HH3})}{\alpha} \quad (7)$$

4. Obtain extracted watermark by applying inverse singular value decomposition by using following Eq. (8):

$$W' = U_W \times S_{ew} \times V_W \quad (8)$$

5. Apply inverse DCT and inverse DWT to obtain final extracted watermark.



(a) (b)
Figure. 3 Cover medical images: (a) megacolon and (b) abdominal

(a) (b)
Figure.4 Watermark images: (a) girl face and (b) fingerprint

4. Experimental results and analysis

The proposed DWT-DCT-SVD based scheme was implemented in Matlab R2013b.

Various experiments are performed on two cover medical images 'Megacolon' and 'Abdominal' of size "512x512" and 'girl face', 'fingerprint' of size "512x512" taken as watermark images shown in Fig. 3 and 4.The performance of the proposed watermarking approach is evaluated in terms of imperceptibility and robustness against various attacks.

The Peak Signal to Noise Ratio (PSNR The Peak Signal to Noise Ratio (PSNR): measures the similarity between the original image and the watermarked image [10]:

$$PSNR = 10 \log [((255)^2)/MSE] \quad (9)$$

Where MSE [10] represents the mean square error to measure the perceptual distance between watermarked and original image.

MSE can be defined as [11]:

$$MSE = \frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} [I(i,j) - I'(i,j)]^2 \quad (10)$$

Where I and I' are the original image and the watermarked image of size M x N respectively.

However, robustness is measured by the normalized correlation coefficient (NC) [12]:

$$NC = \frac{\sum_i \sum_j (W(i,j) * W'(i,j))}{\sqrt{(\sum_i \sum_j (W_{(i,j)})^2)(\sum_i \sum_j (W'_{(i,j)})^2)}} \quad (11)$$

Where W (i, j) and W' (i, j) are the pixel intensity values at coordinates (i, j) of original and extracted watermark respectively.

The imperceptibility of a watermark is measured by calculating the PSNR between the original image and the watermarked image. Fig.5 shows the application of our method DWT-DCT-SVD, there is no visual difference between the cover medical images and watermarked images.

In Table 1 and Table 2, the performance of the proposed method for two cover medical images 'Megacolon' and 'Abdominal' against watermark images 'Girl face' and 'Fingerprint' had been evaluated without any noise attacks.

In the case where the original image is 'Megacolon', the maximum PSNR values obtained are 58.03 dB and 51.78 dB and minimum PSNR values are 39.46 dB and 33.09 dB against inserted watermarks 'Girl face' and 'Fingerprint' at scaling factor (α) = 0.1 and 0.9 respectively.

In the other case where the original image is 'Abdominal', the maximum PSNR values obtained are 57.80 dB and 51.26 dB and minimum PSNR values are 39.02 dB and 32.56 dB against inserted watermarks 'Girl face' and 'Fingerprint' at scaling factor (α) = 0.1 and 0.9 respectively.
However, the NC values in all scaling factor are 1 in the both cases.

According to the interpretation of the results shown in tables 1 and 2, we conclude that the insertion of the watermark by the proposed technique gives good invisibility.

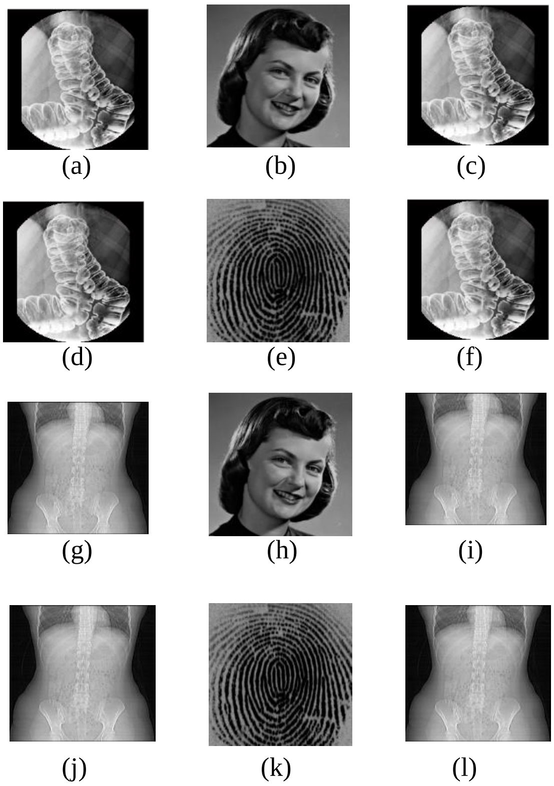


Figure.5 (a, d, g, j) Cover medical images, (b, e, h, k) Watermark images, and (c, f, i, l) Watermarked images

Table1. PSNR, NC performance of the proposed method at different gain factor for cover medical image 'megacolon'

Gain factor (α)	Watermark (Girl face)		Watermark (Fingerprint)	
	PSNR	NC	PSNR	NC
0.1	58.03	1	51.78	1
0.2	52.24	1	45.90	1
0.3	48.82	1	42.40	1
0.4	46.34	1	39.93	1
0.5	44.42	1	38.06	1
0.6	42.88	1	36.51	1
0.7	41.62	1	35.20	1
0.8	40.47	1	34.07	1
0.9	39.46	1	33.09	1

Table2. PSNR, NC performance of the proposed method at different gain factor for cover medical image 'abdominal'.

Gain factor (α)	Watermark (Girl face)		Watermark (Fingerprint)	
	PSNR	NC	PSNR	NC
0.1	57.80	1	51.26	1
0.2	51.76	1	45.42	1
0.3	48.40	1	41.98	1
0.4	45.86	1	39.52	1
0.5	44.03	1	37.62	1
0.6	42.50	1	36.03	1
0.7	41.13	1	34.71	1
0.8	40.02	1	33.57	1
0.9	39.02	1	32.56	1

To test and check the robustness of our watermarking algorithm, there must be a strong correlation between the watermark and the extracted watermark after various attacks. In general, an NC value is acceptable if it is 0.75 or higher [13].

The robustness of the proposed watermarking scheme has been demonstrated by applying various noise attacks on the watermarked image such as Gaussian noise, Salt & pepper, Speckle noise and filtering attacks such as Average filter, Median filter and Wiener filter shown in Table 3, 4, 5 and 6.

In Table 3 and 4, the NC values of extracted watermarks 'Girl face' and 'Finger print' of test medical images have been evaluated for HH band at scaling factor (α) = 0.8 respectively, the results show that the proposed scheme has high degree of robustness than results reported by [5].

At high density (0.08) of Gaussian noise, Salt & pepper and Speckle noise, the efficiency of the proposed method gives maximum NC of 0.9997, 0.9998, 0.9999 compared to 0.9523, 0.9468, 0.9458 obtained by [5]. And the efficiency of the proposed method against Average filter [5, 5] gives maximum NC of 0.9976 compared to 0.9909 obtained by [5].

The drawbacks of [5] compared to our contribution is that the insertion of the watermark was made in the low frequency bands (LL) of the first level DWT of the original image. However, in our approach, the watermark was inserted in the high frequency sub-bands of the third level of DWT which offers a better robustness.

The robustness of the proposed method against Gaussian noise (0.1), Salt and pepper (1.0), Speckle noise (0.1) and Average filter [13, 13] has been compared with [13], shown in Table 5.

In Table 6, the maximum NC values at scaling factor (α) = 0.8 with proposed method has been obtained as 1 for Gaussian noise (0.01) against 0.9830, 0.9582, 0.8152 obtained by [14], [15] and [16] respectively, 1 for Salt and pepper noise 0.01 against 0.9972, 0.9888 and 0.8863 obtained by [14], [15] and [16] respectively, and finally 1 for speckle noise 0.01 against 0.9868 and 0.7382 obtained by [15] and [16] respectively.

The performance of the proposed watermarking scheme which based on the advantages of combination DWT-DCT-SVD and the insertion in the high frequency sub bands gives very good results compared with other reported techniques.

Table 3. Normalized correlation coefficient of extracted watermark ‘Girl face’ from test medical images at scaling factor = 0.8

Attacks	NC values (Proposed method using medical image ‘Megacolon’)	NC values (Proposed method using medical image ‘Abdominal’)	NC values of [5] method
Gaussian noise with mean=0, Var-0.01	0.9999	0.9999	0.9872
Gaussian noise with mean=0, Var-0.02	0.9998	0.9996	0.9841
Gaussian noise with mean=0, Var-0.03	0.9998	0.9992	0.9803
Gaussian noise with mean=0, Var-0.04	0.9996	0.9989	0.9760
Gaussian noise with mean=0, Var-0.05	0.9995	0.9983	0.9709
Gaussian noise with mean=0, Var-0.06	0.9994	0.9975	0.9649
Gaussian noise with mean=0, Var-0.07	0.9991	0.9973	0.9587
Gaussian noise with mean=0, Var-0.08	0.9988	0.9966	0.9523
Salt & Pepper with (Density=0.01)	1	0.9999	0.9962
Salt & Pepper with (Density=0.02)	0.9999	0.9998	0.9917
Salt & Pepper with (Density=0.03)	0.9998	0.9997	0.9869
Salt & Pepper with (Density=0.04)	0.9998	0.9995	0.9799
Salt & Pepper with (Density=0.05)	0.9997	0.9992	0.9729
Salt & Pepper with (Density=0.06)	0.9996	0.9989	0.9641
Salt & Pepper with (Density=0.07)	0.9995	0.9987	0.9551
Salt & Pepper with (Density=0.08)	0.9994	0.9983	0.9468
Speckle noise with (Density=0.01)	1	1	0.9981
Speckle noise with (Density=0.02)	1	1	0.9906
Speckle noise with (Density=0.03)	0.9999	1	0.9849
Speckle noise with (Density=0.04)	0.9999	0.9999	0.9786
Speckle noise with (Density=0.05)	0.9999	0.9998	0.9718
Speckle noise with (Density=0.06)	0.9999	0.9998	0.9631
Speckle noise with (Density=0.07)	0.9999	0.9998	0.9540
Speckle noise with (Density=0.08)	0.9999	0.9996	0.9458
AverageFilter[5, 5]	0.9960	0.9976	0.9909

Table 4.Normalized correlation coefficient of extracted watermark ‘Fingerprint’ from test medical images at scaling factor = 0.8

Attacks	NC values (Proposed method using medical image ‘Megacolon’)	NC values (Proposed method using medical image ‘Abdominal’)	NC values of [5] method
Gaussian noise with mean=0, Var-0.01	0.9998	1	0.9872
Gaussian noise with mean=0, Var-0.02	0.9998	0.9999	0.9841
Gaussian noise with mean=0, Var-0.03	0.9998	0.9999	0.9803
Gaussian noise with mean=0, Var-0.04	0.9998	0.9997	0.9760
Gaussian noise with mean=0, Var-0.05	0.9998	0.9997	0.9709
Gaussian noise with mean=0, Var-0.06	0.9998	0.9995	0.9649
Gaussian noise with mean=0, Var-0.07	0.9997	0.9995	0.9587
Gaussian noise with mean=0, Var-0.08	0.9997	0.9992	0.9523
Salt & Pepper with (Density=0.01)	0.9998	1	0.9962
Salt & Pepper with (Density=0.02)	0.9998	1	0.9917
Salt & Pepper with (Density=0.03)	0.9998	0.9999	0.9869
Salt & Pepper with (Density=0.04)	0.9998	0.9999	0.9799
Salt & Pepper with (Density=0.05)	0.9998	0.9998	0.9729
Salt & Pepper with (Density=0.06)	0.9998	0.9997	0.9641
Salt & Pepper with (Density=0.07)	0.9998	0.9996	0.9551
Salt & Pepper with (Density=0.08)	0.9998	0.9995	0.9468
Speckle noise with (Density=0.01)	0.9998	1	0.9981
Speckle noise with (Density=0.02)	0.9998	1	0.9906
Speckle noise with (Density=0.03)	0.9998	1	0.9849
Speckle noise with (Density=0.04)	0.9998	0.9999	0.9786
Speckle noise with (Density=0.05)	0.9998	0.9999	0.9718
Speckle noise with (Density=0.06)	0.9998	0.9999	0.9631
Speckle noise with (Density=0.07)	0.9998	0.9999	0.9540
Speckle noise with (Density=0.08)	0.9998	0.9999	0.9458
AverageFilter[5, 5]	0.9919	0.9940	0.9909

Table 5. Performance of proposed method against Gaussian noise (0.1), Salt & pepper (1), Speckle noise (0.1) and Average Filter [13, 13]

Attacks	**NC values (Proposed method using medical image 'Megacolon')**		**NC values (Proposed method using medical image 'Abdominal')**		**NC values of [13] method**
	Extracted watermark 'Girl face'	**Extractedwatermark 'Fingerprint'**	**Extracted watermark 'Girl face'**	**Extractedwatermark 'Fingerprint'**	
Gaussian noise with mean=0, Var-0.1	0.9981	0.9996	0.9957	0.9989	0.9636
Salt & Pepper with (Density=1)	0.9808	0.9916	0.9651	0.9824	0.9244
Speckle noise with (Density=0.1)	0.9998	0.9998	0.9995	0.9999	0.8943
AverageFilter[13, 13]	0.9862	0.9755	0.9941	0.9860	0.8736

Table 6. Comparison of NC values with existing methods at gain = 0.8

Attacks	**Existing Schemes**			**Proposed scheme**
	[14]	**[15]**	**[16]**	
Gaussian noisemean=0, Var-0.01	0 .9830	0.9582	0.8152	**1**
Gaussian noisemean=0, Var-0.02	Not shown	0.9457	Not shown	0.9999
Gaussian noisemean=0, Var-0.05	0.9743	Not shown	Not shown	0.9998
Gaussian noisemean=0, Var-0.005	Not shown	Not shown	0.8531	**1**
Salt & Pepper noise (Density=0.01)	0.9972	0.9888	0.8863	**1**
Salt & Pepper noise (Density=0.05)	0.9955	Not shown	Not shown	0.9998
Salt & Pepper noise (Density=0.003)	Not shown	Not shown	0.9576	**1**
Speckle noise (Density=0.01)	Not shown	0.9868	0.7382	**1**
Speckle noise (Density=0.05)	0.9955	Not shown	Not shown	0.9999
Averagefilter	0.9975	Not shown	0.9736	0.9996
Medianfilter [3,3]	0.9988	Not shown	0.7774	0.9995
Wienerfilter [3,3]	0.9989	Not shown	0.7890	0.9997

5. Conclusion

In this paper, a hybrid watermarking technique DWT-DCT-SVD has been presented to ensure the copyright protection and security of medical image.

The proposed watermarking algorithm combines the advantages of DWT, DCT, and SVD. The DWT provides better identification of appropriate data based on the characteristics of the human visual system HVS. The DCT gives good perceptual invisibility and robustness. And finally, the main advantage of SVD is that the singular values are very stable, when small information (perturbations) is added into an image, their singular values do not change significantly.

Many tests have allowed highlighting our proposed technique, it has the advantage to insert a large amount of data (watermark of size 512x512) without impacting the quality of the image, as well as its robustness against various attacks.

The simulation results in term of invisibility gives a maximum PSNR value = 58.03 dB at scaling factor 0.1 and in term of robustness gives a maximum NC value = 1 against noise attacks such as Gaussian noise, Salt & pepper and Speckle noise, also an excellent NC values against filtering attacks like Average filter, Median filter and Wiener filter compared to other reported techniques. These results approve that our contribution is able to give a very good compromise imperceptibility and robustness.

In the future research, we will try to enhance the performance of our algorithm in terms of robustness, capacity and imperceptibility and to further research on techniques of watermarking for medical applications.

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