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Hybrid multiple watermarking technique for securing medical images of modalities MRI, CT scan, and X-ray

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ABSTRACT

In order to contribute to the security of sharing and transferring medical images, we had presented a multiple watermarking technique for multiple protections; it was based on the combination of three transformations: the discrete wavelet transform (DWT), the fast Walsh-Hadamard transform (FWHT) and, the singular value decomposition (SVD). In this paper, three watermark images of sizes 512x 512 were inserted into a single medical image of various modalities such as magnetic resonance imaging (MRI), computed tomography (CT), and X-Radiation (X-ray). After applying DWT up to the third level on the original image, the high-resolution sub-bands were being selected subsequently to apply FWHT and then SVD. The singular values of the three watermark images were inserted into the singular values of the cover medical image. The experimental results showed the effectiveness of the proposed method in terms of quality and robustness compared to other reported techniques cited in the literature.

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1. INTRODUCTION

The evolution of information and communication technologies (ICTs) and the development of telecommunication applications in healthcare networks play an important role in the patient diagnosis. This evolution may raise concerns about the preservation and confidentiality of data transferred between hospitals [1]. In this context, the digital watermarking has emerged as a solution to fight against all types of fraud. The digital watermarking [2, 3] is a recent discipline which consists of inserting an invisible watermark into a cover medical image. Currently, the insertion in the frequency domain can ensure a high degree of security of medical data by preserving their integrity and confidentiality.

Among transforms well known in the literature we can cite: Discrete Wavelet Transform (DWT), Fast Walsh-Hadamard Transform (FWHT), Discrete Cosine Transform (DCT), Singular Value Decomposition (SVD), Stationary Wavelet Transform (SWT), and Discrete Fourier Transform (DFT). The multiple watermarking [4-14] is a recent discipline which aims to increase the robustness of the watermarking system to have a multiple protection of medical images. In our algorithm, we have proposed a robust multiple watermarking for medical images of diverse modalities such as Magnetic Resonance Imaging (MRI), Computed Tomography (CT), and X-rays.

This contribution is a follow up of our work done in [9], it's able to insert three watermarks of sizes 512x512 without altering the quality of the watermarked image and its robustness against noise, filtering, and compression attacks. This paper resumes the following sections: section 2 presents the techniques of watermarking used in our method. In section 3, DWT-FWHT-SVD based watermarking algorithm has been proposed. In section 4, the experimental results were being presented and finally, a conclusion was drawn. The strong points of our proposed algorithm compared to other reported techniques [4-8] is that the insertion of the three watermarks was made in the high-frequency sub bands (HH) up the third level DWT of the original image. Also, it combines the advantages of DWT, FWHT and SVD cited in section 2 (Background).

2. BACKGROUND

The proposed method combines the advantages of the three selected transforms DWT, FWHT and SVD. The Discrete Wavelet Transform (DWT) provides better data identification appropriate to human perception (HVS) which allows that the watermark is integrated effectively [15]. It has the advantage of making the system of watermarking more robust without degrading the quality of the image. The Fast Walsh-Hadamard Transform (FWHT) [16] offers advantages such as fast computation of Walsh-Hadamard coefficients and less required storage space. And finally, the Singular Value Decomposition (SVD) [17] has two important properties, the first is that even if we apply a variation in the singular values, it does not affect the quality of the image and the second is that the singular values have a great stability and therefore they change slightly after application of different attacks.

2.1. Discrete wavelet transform (DWT)

The discrete wavelet transform (DWT) [18, 19] is a mathematical analysis tool which provides both the frequency and the spatial description of an image. The image goes through low pass filters known as "scale function" and high pass filters known as "wavelet function". These two filters are successively applied over the whole image and at the output, we obtain four frequency sub-bands: a frequency sub band (LL) called approximation sub band, and three high-frequency sub-bands characterized by their spatial orientations HL (horizontal), LH (vertical), and HH (diagonal). The approximation image (LL) is a reduced version of the initial image, while the details (HH, HL and LH) contain only the texture and contour information of the image [20].

2.2. Fast walsh-hadamard transform (FWHT)

The FWHT [21] is an orthogonal transformation that decomposes a signal into a set of orthogonal, rectangular waveforms called Walsh functions. The Hadamard transform [22] HN is defined by (1):

$$\mathrm{H_N} = \frac{1}{\sqrt{2}}\begin{pmatrix} \mathrm{H_{N-1}} & \mathrm{H_{N-1}} \\ \mathrm{H_{N-1}} & -\mathrm{H_{N-1}} \end{pmatrix} \tag{1}$$

where H_N is a 2^Nx2^N matrix and N>0.

2.3. Singular value decomposition (SVD)

Any image, represented by a matrix, can be factored into a product of an orthogonal matrix by a diagonal matrix by another orthogonal matrix. This transformation is called the Singular Value Decomposition (SVD) of a matrix. The aim of SVD decomposition is to create an approximation of the image using only some terms of the diagonal matrix of the decomposition. The SVD [23] of a matrix I is of the form (2):

$$I = U \times S \times V^T \tag{2}$$

U and V are orthogonal matrices of size NxN and S is a diagonal matrix of image I.

3. PROPOSED TECHNIQUE

Our proposed method is based on DWT-FWHT-SVD combination, it respects the compromise between invisibility, robustness and capacity. In this algorithm, we have inserted three watermarks into a single medical image on which the main goal is to enhance the security and the confidentiality of the watermarking system.

3.1. Embedding process

1. The cover medical image is divided by DWT transform using Daubechies wavelet until the third level and then the high-frequency sub-bands of the first, the second and the third level (HH_1, HH_2, and HH_3) are selected respectively.

2. The step1 is applied on the first watermark image and then the high frequency sub-band HH_{3w1} is selected.
3. Apply the second and the first level of DWT to the second and the third watermark images respectively and then select HH_{2w2} and HH_{1w3}.
4. Apply FWHT on the selected sub-bands HH_1, HH_2, HH_3 and HH_{3w1} of the original medical image and the first watermark image respectively and then apply SVD on FWHT coefficients of the selected sub-bands (HH_1, HH_2, HH_3 and HH_{3w1}) and on HH_{2w2} and HH_{1w3} of the second and the third watermark images to get:

$$I_i = U_i S_i V_i^T \text{ , i=HH}_1\text{, HH}_2 \text{ and HH}_3 \quad (3)$$

$$wat_i = U_j S_j V_j^T \text{ , j=HH}_{3w1}\text{, HH}_{2w2} \text{ and HH}_{1w3} \quad (4)$$

5. Modify the singular values of HH_3 of the cover medical image with the singular values of HH_{3w1} of watermark 1, the singular values of HH_2 of the cover medical image with the singular values of HH_{2w2} of watermark 2 and finally the singular values of HH_1 of the cover medical image with the singular values of HH_{1w3} by (5):

$$I_{wati} = S_i + \alpha * S_j \quad (5)$$

which α: scaling factor.

6. Apply inverse FWHT and inverse DWT to get the watermarked medical image.

3.2. Extracting process

1. Decomposing the cover medical image into the third level DWT transform using Daubechies wavelet and then select HH_1, HH_2, and HH_3.
2. Apply step1 to the first watermark image and select HH_{3w1}.
3. Apply the second and the first level of DWT to the second and the third watermark images respectively and then select HH_{2w2} and HH_{1w3}.
4. Apply FWHT on the selected sub bands HH_1, HH_2, HH_3 and HH_{3w1} of the original medical image and watermark image1 respectively and then apply SVD on FWHT coefficients of (HH_1, HH_2, HH_3 and HH_{3w1}) and on HH_{2w2} and HH_{1w3} of the second and the third watermark images to get (3) and (4).
5. Apply step 1 and 4 to watermarked medical image to obtain:

$$I_{wati} = U_{wati} S_{wati} V_{wati}^T \text{ , i=HH}_1\text{, HH}_2 \text{ and HH}_3 \quad (6)$$

6. The singular values of the high frequency sub-bands of the three watermarks are obtained by the singular values of HH_3 HH_2, and HH_1 of the watermarked medical image and the cover medical image respectively by (7):

$$S'_j = (S_{wati} - S_i)/\alpha \quad (7)$$

7. We obtain the extracted watermark image 1 by applying ISVD using (7) and then we apply inverse FWHT and inverse DWT.
8. And finally, we obtain the extracted watermark image 2 and the extracted watermark image 3 by applying ISVD using (7) and then apply inverse DWT.

4. EXPERIMENTAL RESULTS

We have implemented our proposed multiple watermarking technique DWT-FWHT-SVD in MATLAB R2013b. Several experimental tests were performed on the original medical images of various modalities of size 512x512 shown in Figure 1. 'Elaine', 'Hill', and 'Fingerprint' are considered as watermarks of the same size of the cover image shown in Figure 2. To evaluate the performance of our proposed algorithm in terms of invisibility and robustness, various evaluation tools are taken into consideration such as: the Mean Square Error (MSE), Peak Signal to Noise Ratio (PSNR), Structural Similarity Index Measure (SSIM) and Normalized Correlation Coefficient (NC). The PSNR is described as follows [15]:

$$PSNR = 10\ log \left[\frac{(255)^2}{MSE}\right] \quad (8)$$

MSE [18] represents the mean square error which measures the perceptual distance between original and watermarked image:

$$MSE = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}[A(i,j) - A'(i,j)]^2 \tag{9}$$

A and A' represent the original and the watermarked medical image of size MxN respectively.

The second metric used for evaluating the quality of the image is Structural Similar Index Measure (SSIM) [24, 25] measures the similarity between two images: the original image and the watermarked image. It varies between two values 1 and -1. The 1 value indicates that the two images are identical.

$$SSIM = l(I, I_W).c(I, I_W).s(I, I_W) \tag{10}$$

I and Iw are the original image and watermarked image respectively. $l(I, I_W)$ is luminance comparison function, $c(I, I_W)$ is contrast comparison and $s(I, I_W)$ is structural comparison.

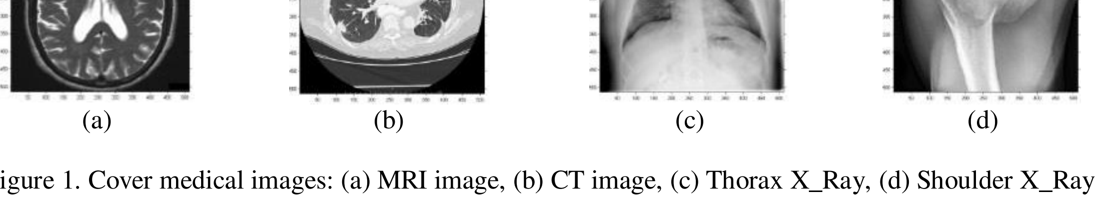
The robustness is measured by normalized correlation coefficient (NC) [13]:

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

W (i, j) and W' (i, j) are the original and extracted watermark respectively. The optimal NC value must be superior to 0.97. The invisibility of inserting three watermarks into a single cover medical image is evaluated by calculating PSNR and SSIM. Figure 3 shows the cover medical images 'MRI', 'CT scan', and 'X_ray', the watermarks 'Elaine', 'Hill' and 'Fingerprint' and, the watermarked images. This figure shows that our proposed algorithm gives a perfect invisibility.

In Tables 1 and 2 the performance of our approach has been evaluated without any noise attacks. In Table 1, we have calculated the PSNR and the SSIM values of the cover medical images 'MRI image', 'CT image', 'Thorax X_Ray' and 'Shoulder X_Ray' at different gain factors. The maximum PSNR and SSIM values obtained against the three inserted watermark images 'Elaine', 'Hill' and 'Fingerprint' are respectively INF and 0.9995 at gain factor 0.01. And the minimum PSNR and SSIM values are respectively 58.2494 dB and 0.8956 at gain factor 0.08. To say that a PSNR is good, it must be greater than 30 dB and also for SSIM it must tend to 1. So from Table 1, we can say that the results are satisfying. In order to highlight our approach in term of invisibility, a comparison has been made with other reported techniques [4, 6, 7, 8] shown in Table 1. Also at gain factor 0.9 and 0.003 the PSNR values obtained respectively are 45.1898 dB and INF against 22.6116 dB of [5] and 41.3448 dB of [22]. From the results obtained, we can conclude that our algorithm gives a good invisibility. Moreover, the NC values of the cover medical images without applying any noise attack are 1 in all gain factors as shown in Table 2.

To check and improve the robustness of our watermarking system, we have applied a various attacks such as JPEG compression, Gaussian noise, Salt & pepper, median filtering, and histogram attacks at scaling factor 0.07. The NC performance of our approach against various attacks compared to existing methods [4, 5, 6, 8, 22] is shown in Table 3. The maximum NC value obtained at scaling factor 0.07 is 1 against JPEG compression (QF-100) compared to 0.9939 of [6] and 0.9886 of [8], 1 against Salt & pepper (density=0.001), compared to 0.8227 of [4], 0.9908 of [6], 0.9658 of [8], and 0.8227 of [22], and 1 against median filtering compared to 0.9993 of [4], 0.9939 of [5], 0.9861 of [6], and 0.0123 of [8]. Moreover, the NC values obtained against all attacks are superior to other reported techniques [4, 5, 6, 8, 22]. The results obtained in terms of imperceptibility, robustness, and capacity of insertion approve that our contribution is effective.



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

Figure 1. Cover medical images: (a) MRI image, (b) CT image, (c) Thorax X_Ray, (d) Shoulder X_Ray

Figure 2. Watermark images: (a) Elaine, (b) Hill, (c) Fingerprint

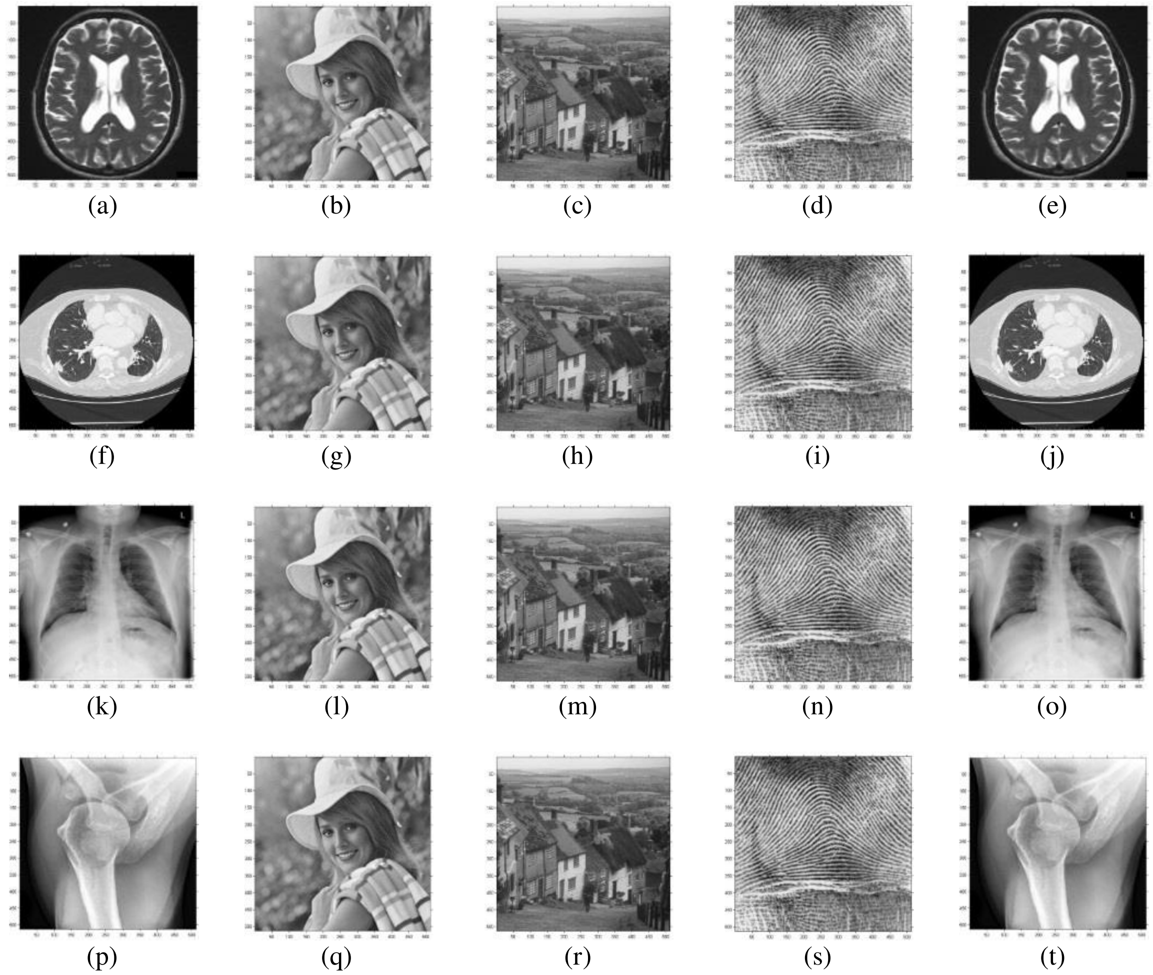


Figure 3. (a, f, k, p) Cover medical images, (b, g, l, q) Watermark image 1 ‘Elaine’, (c, h, m, r) Watermark image 2 ‘hill’, (d, i, n, s) Watermark image 3 ‘fingerprint’, (e, j, o, t) Watermarked images

Table 1. Performance PSNR values at different gain factor

Gain Factor		Proposed Algorithm				[4]	[6]	[7]	[8]
		MRI Image	CT Image	Thorax X_Ray	Shoulder X_Ray				
0.01	PSNR	INF	83.5656	80.6136	102.3162	29.65	41.36	-	43.88
	SSIM	0.9994	0.9995	0.9975	0.9983	-	-	-	-
0.05	PSNR	69.7974	63.9039	68.7027	82.5390	31.11	36.94	40.040889	36.53
	SSIM	0.9862	0.9884	0.9516	0.9687	-	-	-	-
0.07	PSNR	64.6313	59.7649	65.5777	78.4423	-	-	-	-
	SSIM	0.9747	0.9784	0.9160	0.9438	-	-	-	-
0.08	PSNR	61.2895	58.2494	64.3345	77.6180	-	34.46	-	33.59
	SSIM	0.9679	0.9589	0.8956	0.9297	-	-	-	-

Table 2. Performance NC values for cover medical images against three watermarks: ‘Elaine’, ‘hill’, and ‘fingerprint’at different gain factors

Gain Factor	NC Values											
	MRI Image			CT Image			Thorax X_Ray			Shoulder X_Ray		
	Elaine	Hill	Finger-print	Elaine	Hill	Finger-print	Elaine	Hill	Finger-print	Elaine	Hill	Finger-print
0.01	1	1	1	1	1	1	1	1	1	1	1	1
0.05	1	1	1	1	1	1	1	1	1	1	1	1
0.07	1	1	1	1	1	1	1	1	1	1	1	1
0.08	1	1	1	1	1	1	1	1	1	1	1	1

Table 3. Performance NC values against attacks compared to [4, 5, 6, 8, 22] at scaling factor 0.07

Attacks	Proposed Method			[4]	[5]	[6]	[8]	[22]
	NC Elaine	NC Hill	NC Finger print					
JPEG compression (QF-10)	0.9992	0.9996	0.9983	0.9913	-	0.9907	0.3120	-
JPEG compression (QF-30)	0.9997	0.9998	0.9990	-	-	0.9913	0.9803	-
JPEG compression (QF-50)	0.9997	0.9999	0.9992	0.9708	0.9935	-	-	-
JPEG compression (QF-60)	0.9997	0.9999	0.9994	-	-	0.9934	0.9703	-
JPEG compression (QF-70)	0.9998	0.9999	0.9995	-	-	0.9936	-	-
JPEG compression (QF-100)	0.9999	1	1	-	-	0.9939	0.9886	-
Gaussian noise (M=0,V=0.001)	0.9987	0.9999	0.9996	0.9591	-	0.9908	0.9466	0.7426
Salt & pepper (density =0.01)	0.9912	0.9994	0.9972	-	0.9867	0.9684	0.7747	-
Salt & pepper (density =0.001)	0.9995	1	0.9999	0.8227	-	0.9908	0.9658	0.8227
Median Filtering	0.9999	1	1	0.9993	0.9939	0.9861	0.0123	-
Histogram	0.9999	0.9982	0.9969	0.8157	0.9942	-	-	-

5. CONCLUSION

In this article, we have presented a robust multiple watermarking methods based on the combination of three techniques DWT, FWT, and SVD. Three watermark images ‘Elaine’, ‘Hill’ and ‘Fingerprint’ are embedded into a single cover medical image of modalities: magnetic resonance imaging (MRI), computed tomography (CT), and X_Ray. The insertion of these three watermarks was made in the high-frequency sub bands HH1, HH2 and HH3 of the cover medical image. However, the insertion into theses sub bands can augment the robustness of watermarking scheme and can give a good quality of resulting image. The obtained results approve that the quality of our proposed scheme is perfect compared to other methods in terms of invisibility, robustness, and capacity. In the future works, we will optimize the performance of our contribution against geometric attacks.

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