Watermarking algorithms analysis on radiological images

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Abstract - **This article presents the results of the implementation and evaluation of the most common algorithms on medical images watermarking. The algorithms were modified to bring them to its maximum insertion capacity, and also modified to work with images of more than 8 bits, due to radiological images work with 8, 12 and 16 depth bits in gray scale depending on the study type. The algorithms were tested with a set of DICOM images which have been left available online. The DICOM watermarked images were tested with common attacks to evaluate the behavior of the algorithms. Conclusions were drawn based on the algorithms performance applied to medical images.**

Keywords — **Watermarking algorithms, algorithm performance, medical images.**

I. INTRODUCTION

With the improvement of new radiological modalities and the emergence of new modalities, every day a higher amount of radiological images are generated which impacts in the storage capacity of radiological systems. Also, the growing interest in internet technologies and the communications enhancements to transmit radiological studies through the internet makes security one of the main requirements, as much for images and data as for processes such that transmission and storage. The more required aspects of security are confidentiality and integrity of the data [1] for these applications. Lately, watermarking on medical images has been an option to provide security on medical images.

Watermarking algorithms, either robust or fragile, degrade in different measure the medical images [2]. This is what motivates this work, to evaluate several watermarking algorithms that have been focused on medical images to get a set of images that serves like a corpus with their performance of several algorithms.

In this work, 88 DICOM format medical images from several kinds of studies (Magnetic Resonance (MR) Tomography (CT) and Ultrasound (US)) have been taken as a vehicle [3] for testing the algorithms:

- 29 MR 512x512x16bits
- 10 CT 340x340x12 bits
- 19 CT 512x512x12 bits
- 20 CT 512x512x16 bits
- 10 US 640x480x8 bits

Several algorithms focused on medical images [2, 4-9], except [9], were modified to work with higher bit depth (as DICOM format demands) and bringing them to its maximum insertion capacity. Also reversible algorithms were taken into account, but we already use the simple form like [10] that in the last step uses the least significant bit. These algorithms were implemented in Matlab as well as the programmed attacks, and they are also available in [3].

The images were divided into 9 groups, according to the modality and study type. Based on the Mean Squared Error (MSE) and in the Peak Signal to Noise Ratio (PSNR) measurements of the watermarked images against the average of each group, 9 images were selected as a light corpus, one of each type. As the results for the algorithms were different, the mode was taken to select an image by each type of study.

On each image every algorithm was applied and the resulting watermarked image was tested against various attacks including rotation and cropping, brightness and contrast. All the results can be observed in [3]. The result analysis is presented at the end of this work. There exists standard benchmarks as Stirmark or Chechmark but they are not suitable for medical images because they work with images of eight bits of deep and medical images have more bits.

II. Algorithms

Special interest was granted on 12 algorithms as most of them work with medical images [2, 4-8], they are:

1. Less significant bit (LSB), using the first less significant bit of each pixel [2, 4].
2. LSB using the second less significant bit of each pixel [4].

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3. LSB using the third less significant bit of each pixel [4].
4. LSB using the fourth less significant bit of each pixel [2].
5. LSB using the first and the second less significant bit of each pixel [5].
6. LSB at the center of the image and wavelet in the border [6].
7. Wavelet on three levels using the second and the third levels on the HL LH frequencies [7].
8. Wavelet on four levels of the same author of the number listed before and using the same high frequencies [8].
9. Wavelet on three levels using blocks of 8x8, using the HL, LH and the HH coefficients. [5].
10. Using the discrete cosine transform in 8x8 pixel blocks on the less significant bits of the coefficients [5].
11. Using discrete cosine transform, needs the original image to recover the watermark [9].
12. Using coefficients of the fast Fourier transform, using the high frequencies only to get less degradation on images [5].

More details about the algorithms can be found in [3]. There are other more recent algorithms like [11] but they are not focused on medical images.

These algorithms work either in the domain space (LSB) or in the transform domain (wavelets, Cosine Domain Transform (DCT) and Fourier). The ones that use the LSB do it on each pixel of the entire image, like in Figure 1 that shows an ultrasound of 8 bits for each pixel.

All these algorithms were modified to reach the maximum insertion capacity by removing the control bits, used as a flag for the message recovery (like the size of the message or where the message is hidden), and redundancy used by error correction algorithms. The 12 modified algorithms were tested on Lena gray scale image of 512x512x8 bits in order to get a perspective of the watermarking capacity of them, the results are shown in Table 1.

Table 1 shows the algorithms used, their total insertion capacity expressed also in bits per pixel (bpp) and the correlation. The last two metrics were obtained using the formulas (1) and (2) respectively.

$$bpp = {}^{Nbits}\!/_{512*512} \quad (1)$$

$$corr = \frac{\sum_m \sum_n (A_{mn} - \overline{A})(B_{mn} - \overline{B})}{\sqrt{\left(\sum_m \sum_n (A_{mn} - \overline{A})^2\right)\left(\sum_m \sum_n (B_{mn} - \overline{B})^2\right)}} \quad (2)$$

Where A and B are the original image and the watermarked image respectively, $\overline{A}$ is the average value of pixels intensity values of A, the same applies for $\overline{B}$; m and n are the dimensions of the images.

From Table 1 it can be seen that the FFT algorithm, 12, fails to retrieve the message due to the high frequencies it uses, while in others the correlation value in comparison to the original message is very good.

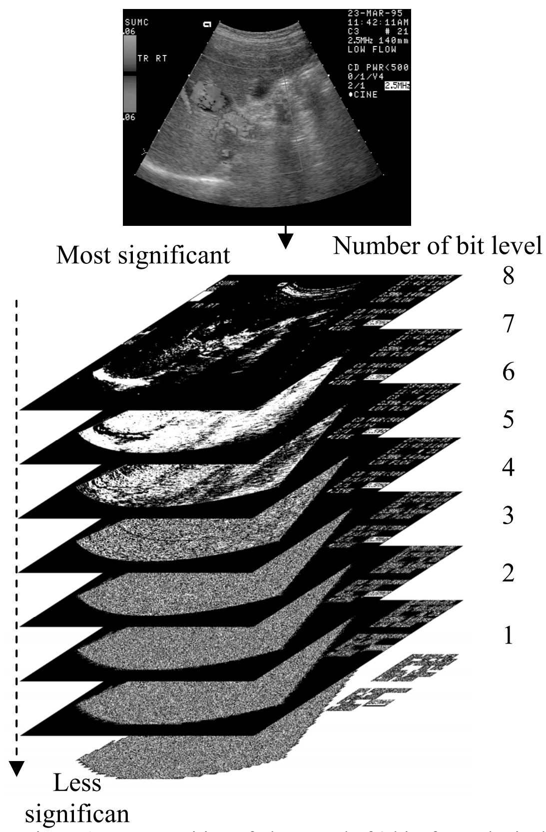

Figure 1 Decomposition of ultrasound of 8 bits for each pixel

TABLE 1
QUANTITY OF BITS INSERTED ON LENA IMAGE 512X512

	Algorithm	Inserted bits	Bits per pixel	Correlation
1	LSB 1st bit	262,144	1	1
2	LSB 2nd bit	262,144	1	1
3	LSB 3rd bit	262,144	1	1
4	LSB 4th bit	262,144	1	1
5	LSB 1st and 2nd	524,288	2	1
6	LSB and wavelet	261,136	0.9961	0.9945
7	Wavelet 3 levels	106,497	0.4062	0.9308
8	Wavelet 4 levels	108,545	0.4140	0.9338
9	Wavelet blocks 8x8	245,760	0.9375	0.879
10	DCT blocks 8x8	147,456	0.5625	0.9554
11	DCT all image	262144	1	0.9606
12	FFT coefficients	260144	0.9923	0.3949

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III. Selected images

After selecting the algorithms and evaluating them using Lena, a medical light corpus was obtained by applying the 12 different watermarking algorithms to the 88 different DICOM medical images. MSE (3) and PSNR (4) averages were computed for each watermarked image in the group with respect to the original. From each group, the image that was closest to the average metrics was selected as a representative of that group for that algorithm.

$$MSE = \frac{1}{M\,N}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}\left(f(x,y) - f'(x,y)\right)^2 \quad (3)$$

$$PSNR = 10 \times \log_{10}\frac{MaxBits^2}{MSE}\,dB \quad (4)$$

For each algorithm the image that was closest to the average value was different within the same group; so the mode of the image that was closest to average was selected. The 9 selected DICOM images are shown in Figure 2.

This light medical corpus will serve from now on to test the 12 selected algorithms in order to show their performance in terms of insertion capacity and robustness to certain attacks commonly found in the medical environment such us rotating and cropping, brightness and contrast.

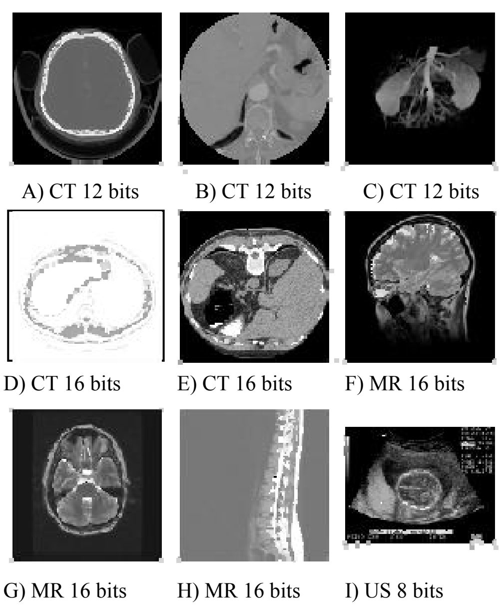

Figure 2 Selected medical images, representing of each group, all of them of 512 x 512, except for A and I that are 340 x 340 and 640 x 480 respectively

Steps for the selection of the light corpus:

1. Apply the 12 different watermarking algorithms to the big corpus.
2. Get the results of the MSE and PSNR calculated for all the images.
3. Divide in groups the images according to the modality and get the MSE and PSNR average of each group.
4. Select the image nearest to the average for each group.
5. Compute the mode because the image selected in the last step was different on each algorithm.

IV. Attacks

Using the light corpus, some attacks were performed over the watermarked images. These attacks were:

-Rotating and cropping

For the angles of 15°, 30°, 45°, 60°, 75° and 90°. The cropped corners after rotation were lost in the process.

-Brightness

The brightness was varied in six steps, from the original images until it was white. This process is explained below.

-Contrast

Using the Matlab automatic contrast function and gamma correction, getting clear and dark images, as explained below.

To perform the brightness attack, formula (5) that modifies each pixel of the image was used.

$$f(x,y) = g(x,y) + \beta \quad (5)$$

TABLE 2
PLACES FOR ALL THE ALGORITHMS USING MSE AND PSNR MEASURE

List	Algorithm	Average MSE	Average PSNR	Average Order	Mode Order
1	LSB 1st bit	0.21	89.74	1	1
2	LSB 2nd bit	0.86	83.68	4	4
3	LSB 3rd bit	3.42	77.69	10	10
4	LSB 4th bit	15.45	71.24	12	12
5	LSB 1st and 2nd	1.24	82.08	7	8
6	LSB y wavelet	0.26	88.97	2	2
7	Wavelet 3 levels	1.03	82.91	5	5
8	Wavelet 4 levels	1.44	81.43	9	9
9	Wavelet blocks 8x8	1.24	82.09	6	7
10	DCT blocks 8x8	7.56	74.24	11	11
11	DCT all image	0.52	85.89	3	3
12	FFT coefficients	1.31	81.96	8	6

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Where β is the value of brightness added to each pixel, this value was different for each step. The value grows for each step and is different because of the bit depth. The value of β grows proportionally to the bits depth of each image.

Gamma correction is obtained using the formula (6). The γ value is between 0 and 1 to get a dark image, and over 1 to get a clear image.

$$f(x, y) = g(x, y)^{\gamma} \qquad (6)$$

V. Results

In order to observe which algorithms degrade less the watermarked images, the MSE and PSNR metrics were obtained after watermarking the entire corpus (88 images). Results for the light medical corpus are shown in Table 2, which coincide with the entire corpus.

The order for them is located on the Table 2 numbered from 1 to 12 from the algorithm that degraded least the image to the most degrading. The 5 algorithms that produce less degradation on the images are shown for both, average and mode order.

From Table 2, the insertion capacity for the different image sizes can be obtained by multiplying the total of pixels in the image by the number of bits per pixel. Results marked with black are the algorithms that do not coincide in all studies; the algorithms that produce less degradation are:
1) LSB on the first bit, 2) LSB y wavelet, 3) DCT all image, 4) LSB en the 2nd bit, 5) Wavelet 3 levels.

TABLE 3
AVERAGE MSE IN THE DIFFERENT GROUPS FOR THE LIGHT CORPUS

	MSE								
	CT 1-10	**CT 11-19**	**CT 20-29**	**CT 30-39**	**CT 40-49**	**MR 60-68**	**MR 69-78**	**MR 79-80**	**US 89-98**
1	0.20	0.22	0.15	0.22	0.21	0.28	0.21	0.28	0.15
2	0.80	0.88	0.61	0.88	0.85	1.10	0.86	1.12	0.66
3	3.23	3.55	2.42	3.43	3.42	4.46	3.35	4.48	2.47
4	12.76	14.14	26.39	13.73	13.62	18.40	13.32	17.51	9.15
5	1.17	1.27	0.87	1.26	1.24	1.59	1.23	1.62	0.94
6	0.22	0.23	0.24	0.31	0.23	0.34	0.23	0.35	0.16
7	0.89	0.98	1.16	1.19	0.96	1.22	0.93	1.23	0.67
8	1.26	1.38	1.65	1.69	1.34	1.69	1.31	1.69	0.95
9	1.07	1.18	1.44	1.48	1.15	1.47	1.10	1.48	0.81
10	6.53	7.25	8.96	8.93	6.84	8.80	6.82	9.08	4.86
11	0.44	0.49	0.62	0.62	0.47	0.61	0.47	0.62	0.33
12	2.19	1.16	1.30	1.48	1.15	1.37	1.05	1.46	0.67

TABLE 4
AVERAGE PSNR IN THE DIFFERENT GROUPS FOR THE LIGHT CORPUS

	PSNR								
	CT 1-10	**CT 11-19**	**CT 20-29**	**CT 30-39**	**CT 40-49**	**MR 60-68**	**MR 69-78**	**MR 79-80**	**US 89-98**
1	79.2	78.8	80.4	102.9	103.0	101.9	103.0	101.8	56.3
2	73.2	72.7	74.4	96.90	97.02	95.90	97.01	95.83	49.9
3	67.1	66.7	68.4	90.97	90.99	89.84	91.08	89.81	44.2
4	61.1	60.7	58.0	84.95	84.98	83.68	85.08	83.90	38.5
5	71.5	71.1	72.8	95.32	95.40	94.30	95.43	94.24	48.44
6	78.8	78.5	78.5	101.4	102.7	100.9	102.6	100.8	56.1
7	72.7	72.38	71.59	95.56	96.51	95.46	96.63	95.45	49.93
8	71.2	70.8	70.0	94.05	95.06	94.04	95.15	94.04	48.3
9	71.9	71.5	70.6	94.63	95.71	94.66	95.90	94.62	49.1
10	64.0	63.6	62.7	86.81	87.97	86.88	87.99	86.75	41.3
11	75.8	75.3	74.3	98.42	99.58	98.47	99.65	98.41	52.9
12	68.8	71.6	71.1	94.63	95.71	94.95	96.12	94.70	49.9

Table 3 and Table 4 show MSE and PSNR respectively, which indicate the degradation caused to the images of each different group applied to the light corpus tagged on the top of each column. PSNR values above 30 are acceptable, however, the higher the value, the lower the degradation [12].

According to the obtained results (Table 3 and 4) it seems that the best performer algorithm for all the images is the number one followed by the number 6 and 11 in that order. The algorithms that work on the transform domain are resistant to some attacks. It seems that the best option to work with the medical images is the DCT because of the lower degradation and robustness.

After that, we analyzed the algorithms in relation to the correlation results obtained from both, the watermarked image and the attacked watermarked image. These results are mentioned next per every attack.

[3] shows also the MSE and PSNR for the attacked watermarked images against the only watermarked images. The averages and standard deviation of the PSNRs of all attacks indicate almost equal degradation, except for some cases with a minimum variance of the average. The results obtained per attack are shown next.

Rotation and cropping

Rotation was performed to the watermarked images of 15, 30, 45, 60, 75 and 90 degrees. The percentages represent the correlation between the attacked watermarked images against the original message inserted. As mentioned, the algorithms that work in the domain transform use an error correction algorithm in order to improve their performance.

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TABLE 5
ROTATION AND CROPPING RESULTS

Attack		*Rotation and Cropping*		
		15°	*30°*	*45°*
Correlation values	*LSB*	*81-85%*	*72-76%*	*70-74%*
	Transform	*13-63%*	*4-40%*	*4-43%*

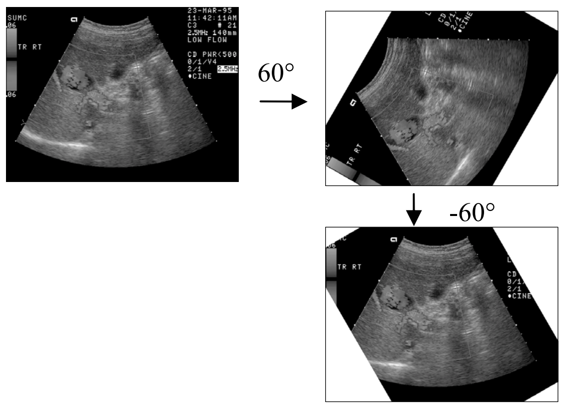

Figure 3 Rotation and cropping attack for 60 degrees

However, here these error correction algorithms have not been included for a more just comparison against the LSB methods. Table 5 shows the results for the different rotation degrees expressed in percentage of the correlation with the minimum and maximum values. Although 60, 75 and 90 degrees were also tested, results for 60 are similar to 30 degrees, 75 are similar to 15 degrees and 90 get 100% of correlation.

From the 5 algorithms that degrade less the images, it was seen from the attacks results that wavelet algorithm number 7 performed better than DCT algorithm number 11.

Figure 3 shows this type of attacks for 60 degrees rotation and cropping.

For 30 degrees rotation, wavelet algorithm number 7 performed better than DCT algorithm number 11 by 20%. For 90 degrees rotation, the ultrasound that is not squared lost in general a 20% of the information.

Brightness

As mentioned above, for the brightness attacks β was different according to the pixel depth. For 8 bits images β=35, for 12 bits β= 600 and for 16 bits β=10,000.

There were good results in general, except for the image of the group CT 512x512 16 30-39 that is already a white image. For this image, the algorithms cannot recover a large percentage due to the saturation caused by an increase of brightness; the correlation is between 16% and 20% of the message. The performance of Wavelets based algorithms was the poorest.

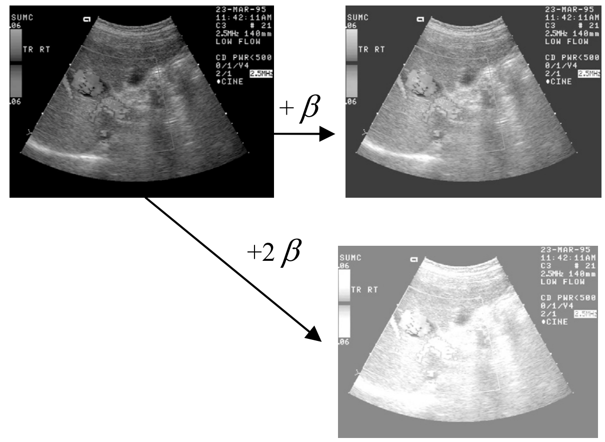

Figure 4 Brightness attack with β equal to 35 for 8 bits

For brightness 1, a correlation between 98% and 100% was obtained.

For brightness 2-6, there was just a little correlation reduction against brightness 1 attack because of the saturation, reducing an average of 1% at each step.

Only algorithm 10 that uses DCT on blocks reduced the correlation from 100% with brightness 1 to 7% with brightness 6. In Figure 4 this type of attack is exemplified with an ultrasound image.

Contrast

As mentioned above, there were 3 contrast attacks: 1) automatic, using Matlab function, 2) dark, using gamma correction with γ=0.4 in equation (6), and 3) clear, using gamma correction with γ=1.1 also in equation (6).

For the 'white' image, the best results were obtained with the transform domain algorithms, due to it is an extremely white image with some black pixels, and contrast does not affect the watermark. In fact this has the lowest average MSE.

For dark contrast, the best correlation achieved was 45% with the darkest images: CT 512x512 12 20-29 and US 640x480 8 89-98 for transform domain and LSB on the first bit algorithms respectively.

For clear contrast, the best correlation results were obtained for the two images mentioned above. For the ultrasound, the correlation was 48% with LSB algorithm on the 4th bit and for CT 512x512 12 20-29 image, the correlation reached 83% with DCT algorithm 11.

The third image that shows better performance was CT 512x512 16 30-39, but only on the DCT reaching a 55% of correlation on both cases of the DCT.

Figure 5 exemplifies the clear and dark contrast attacks on an ultrasound image.

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VI. Discussion

According to the results, the algorithms that performed better to the rotation and cropping attack were LSB, while the ones that work on the transform domain had values that were very low with respect to the LSB. This is because the cropping causes synchronization reference is lost thus making difficult the recovery of the watermark.

In general, the algorithms that show better performance to the brightness attack are those that work on the transform domain; they have a similar correlation percentage in various algorithms, in the different attacks and for all types of images. The only image that does not show a good performance to this attack was the representative of the group CT 512x512 16 30-39, this is because the image is already saturated and with the brightness attack lost the inserted information.

For the contrast attack good results were obtained for specific images and specific algorithms; that is why some algorithms perform better than others, except for those algorithms that work on the DCT.

VII. Conclusions

This paper presents some comparisons among some different algorithms results with different images are a proof that not all the algorithms perform equally for the different images and for the different attacks. As expected the LSB algorithms have less degradation but poor robustness and the best to work on the transform domain is the DCT because it degrades less. We present a corpus and find a light corpus to work with digital watermarks over medical images.

It is known that fragile algorithms like LSB degrade less the images and may be the most indicated to work in medical imaging. However, robust algorithms based on the transform domain may be preferred due to their resistance to attacks. This is contrary to our results for different image types, while LSB based algorithms are better for some types of images, domain based are better for other ones. So, it is recommended that depending on the image type, the algorithm to insert information is chosen. Also, insertion capacity must be taken into account, LSB based algorithms offer higher capacity while transform domain lower one.

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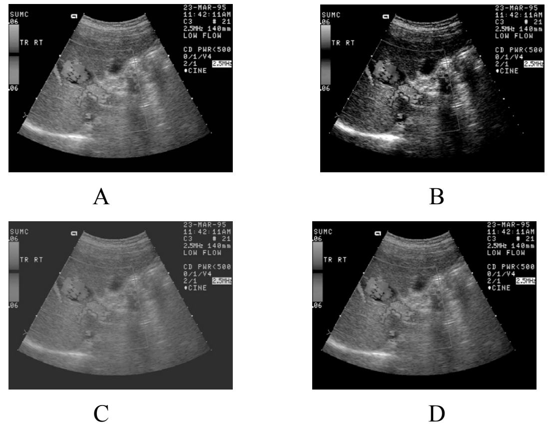

Figure 5 Contrast attack (A) automatic, (B) dark and (C) clear on the original ultrasound (D)

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