Medical Technologies Journal, Volume: 5, Issue: 1, January-Mars 2023, Pages:594-603. Doi : https://doi.org/10.26415/2572-004X-vol5iss1p594-603

An Optimized Medical Image Watermarking Approach for E-Health Applications

Type of article: Original

ABDI Hadjer, BOUKLI HACENE Ismail
Biomedical Engineering Laboratory, Tlemcen University, Algeria,

Abstract

Background: In recent years, information and communication technologies have been widely used in the healthcare sector. This development enables E-Health applications to transmit medical data, as well as their sharing and remote access by healthcare professionals. However, due to their sensitivity, medical data in general, and medical images in particular, are vulnerable to a variety of illegitimate attacks. Therefore, suitable security and effective protection are necessary during transmission.

Method: In consideration of these challenges, we put forth a security system relying on digital watermarking with the aim of ensuring the integrity and authenticity of medical images. The proposed approach is based on Integer Wavelet Transform as an embedding algorithm; furthermore, Particles Swarm Optimization was employed to select the optimal scaling factor, which allows the system to be compatible with different medical imaging modalities.

Results: The experimental results demonstrate that the method provides a high imperceptibility and robustness for both secret watermark and watermarked images. In addition, the proposed scheme performs better for medical images compared with similar watermarking algorithms.

Conclusion: As it is suitable for a lossless-data application, IWT is the best choice for medical images integrity. Furthermore, using the PSO algorithm enables the algorithm to be compatible with different medical imaging modalities.

Key words: medical images, digital watermarking, medical data security, IWT, PSO.

Corresponding author: ABDI Hadjer, Biomedical Engineering Laboratory, Tlemcen University, Algeria.
Email: hadjer.abdi@univ-tlemcen.dz
Received: December 25 2022. Reviewed: February 27 2023. Accepted: 03 May 2023. Published: 15 October 2023.
Medical Technologies Journal subscribes to the principles of the Committee on Publication Ethics (COPE).

1. Introduction

The e-Health application refers to the use of digital technologies and communication to facilitate the improvement of healthcare services. This discipline took the advantage of internet for the transmission of medical data and the remote communication with healthcare professionals. However, transmitting medical data on the internet makes the integrity of this data vulnerable to illegal attacks and unlawful manipulation which endangers the patient's life.

Due to these circumstances, finding the best medical data security solution is constantly a challenge, with the integrity and confidentiality of patient information being the core objectives.

Meanwhile, digital watermarking is a security technique that enables the incorporation of a signal (data) into various forms of information, including audio, video, and images. In the medical field, the mark (logo or patient information) is added to the medical image. This security method is the most applied to guarantee authenticity and ownership protection [1]. Digital watermarking algorithms are assessed according to the following requirements[2]:

- Robustness means the resistance of the watermark against illegal manipulation.
- Imperceptibility refers to the ability of a watermarking technique to maintain the transparency of the watermark while preserving the quality of the watermarked image.

- Capacity refers to the maximum size of the watermark that can be embedded into the host signal (such as an image or audio signal) without degrading the quality or perceptibility of the original signal.

However, these elements are difficult to achieve at the same time [3], [4].
This research paper introduces a refined technique for watermarking medical images, aiming to maintain their integrity and authenticity. The proposed approach combines the Integer Wavelet Transform and Practical Swarm Optimization. The paper is structured as follows: Section 2 examines previous studies in the field and introduces the proposed method. Section 3 outlines the algorithm in detail and provides an overview of the integer wavelet transform domain and PSO algorithm. Section 4 presents the findings and facilitates discussion. Lastly, Section 5 concludes the paper.

2. Related work

Digital watermarking algorithms could be classified according to embedding domain[5]. Where either the spatial or transform domain, are used to perform the embedding. On the other hand, frequency domain algorithms offer greater robustness against various types of attacks, while maintaining a high level of imperceptibility and computational complexity. The process of embedding data involves modulating the coefficients of a frequency transform in this domain. [1], [6]. Digital watermarking often utilizes common frequency transforms such as Fourier, Wavelet, Walsh-Hadamard, and discrete cosine transform. [7].
Khare et al [8], presented a security approach for telemedicine applications that utilized Homomorphic transform (HT), redundant discrete wavelet transforms (RDWT), and singular value decomposition (SVD). To further strengthen the security of the proposed approach, they integrated a 2D chaotic Arnold transform (AT). Experimental results showed that their algorithm outperformed other existing works in terms of robustness.
In their research, Thakur et al [9] introduced a hybrid watermarking algorithm for medical images that utilizes multiple techniques. The proposed method combines the non-subsampled contour-let transform (NSCT), multiple levels of discrete wavelet transform (DWT), and singular value decomposition (SVD) to ensure high imperceptibility and robustness. To enhance security, the researchers applied a 2D-logistic map-based chaotic encryption to the watermarked medical image.
Tamal et al [10] proposed a medical image watermarking algorithm based on IWT that utilizes a hash function and logistic mapping. The proposed algorithm segments the medical image into two regions, namely the region of interest (ROI) and the region of non-interest (RONI). The secret data is then embedded into the RONI.
Digital watermarking is a technique that involves embedding secret data into a cover image using a constant number known as the "scaling factor." The quality of the watermarking algorithm is often determined by the value of this scaling factor. However, selecting the optimal scaling factor is not always an easy task and usually involves conducting a series of experiments to find the most suitable one for the cover image. This can be a time-consuming and impractical process for researchers. Therefore, developing an optimized watermarking algorithm that can automatically determine the appropriate scaling factor for each cover image is an essential requirement for improving the efficiency and practicality of watermarking techniques.
To solve this problem, optimization algorithms are used to select an optimal factor according to the characteristics of the cover image.
Kulkarni et al [11] presented an optimal digital watermarking algorithm based on SVD and DWT. In this work three optimization algorithm were compared in term of componential time: Genetic algorithm (GA), Particle Swarm Optimization (PSO) and Artificial Bee Colony (ABC), where GA results were the most promising. , Ting Zhu et al [12] proposed an improved Genetic Algorithm. And the outcomes demonstrated the scheme's effectiveness against various attacks.

3. Proposed Method

In this paper, an optimized image watermarking technique based on frequency domain is proposed where we used IWT in the embedding and the extraction process. In addition, an optimal scaling factor was selected based on PSO algorithm to make the proposed algorithm compatible with different medical imaging modalities.

3.1 Technical Information

3.1.1 Integer Wavelet Transform

The IWT is an integer-to-integer wavelet analysis algorithm, which has the ability to decompose an image into four sub-band which are approximation image (LL), and three details, horizontal (HL), vertical (LH) and diagonal (HH). The process can be repeated several times on approximation sub-band to get 1-n DWT level. This technique can embed more watermarks keeping the quality of the image [13]. The wavelets give a more significant shape of the treated image, and they present multi-resolution characteristics, as well as, IWT provide both temporal and frequency information; also, this transform computationally faster and suitable in lossless-data application compared with the traditional wavelet transform [14].

IWT is based generally on lifting wavelet transform, it can be computed by three steps: split, predict and update.

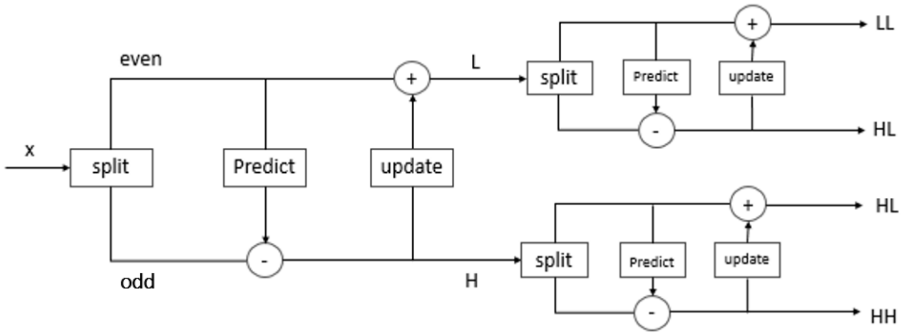


Fig 1. Integer Wavelet Transform Decomposition

3.1.2 Particle Swarm Optimization

PSO [15] is a meta-heuristic algorithm that takes inspiration from the collective behavior of swarming animals, such as birds, to solve problems. The algorithm is designed around the principle of social interaction, where a swarm is formed by a group of particles or agents, with each particle responsible for searching the best possible solution and saving the positional coordinates of this solution as their "personal best".

The ultimate solution to the optimization problem is found by selecting the best value achieved by any particle in the neighborhood of the current particle, which is known as the "global best" solution.

In our method, we applied the PSO algorithm to select the best scaling factor for the embedding. Both of Pick Signal to Noise Ration and Normalized Correlation value was used in the fitness function (Fi) Eq.1. In addition, the watermarked image was exposed to different attacks in order to obtain the best performance in term of imperceptibility and robustness.

$$F_i = PSNR(I, I_w) + \sum NC(W, W_e)_i \qquad (1)$$

The Peak Signal-to-Noise Ratio (PSNR) is a metric used to assess distortion when comparing images, commonly employed in watermarking. Its purpose is to evaluate the degree of imperceptibility between the cover image (I) and the watermarked image (Iw). PSNR is typically expressed in decibels (dB) and is calculated according to Eq. 2.

$$PSNR(I, I_w) = 10 * \log 10 \frac{MAX_1^2}{MSE} \qquad (2)$$

Where: MAX_1 denote the highest fluctuation of the input image and MSE to represent the mean square error between two images (Eq. 3).

$$MSE(I, I_w) = \frac{1}{MN} \sum_{i=0}^{N-1} \sum_{j=0}^{M-1} (I(i,j) - I_w(i,j))^2 \qquad (3)$$

The statistical measure NC (W, We) is employed to assess the correlation between the original watermark and the extracted image. It determines the degree of similarity between them, and it is defined as shown in Eq. 4.

$$NC = \frac{\sum_{x=1}^{M} \sum_{y=1}^{N} w(x,y).w'(x,y)}{\sum_{x=1}^{M} \sum_{y=1}^{N} w^2(x,y)} \qquad (4)$$

w(x,y) represents the original watermark, while w'(x,y) represents the extracted watermark.

3.2 Embedding and Extraction Process

During the embedding phase of a watermarking scheme, two processes are typically carried out, namely embedding and extraction. In this particular study, the embedding phase involved applying two levels of Integer Wavelet Transform (IWT) to the medical cover image, which resulted in four sub-bands (LL2, HL2, LH2, and HH2). The binary image was then embedded into the LH2 sub-band, where two coefficients were modified using a scaling factor α that was determined through PSO optimization. The cover image was also decomposed using the 'Haar' wavelet in this study.

Finally, an inverse LWT was applied to reconstruct the watermarked image. To enhance security and privacy, the same steps were applied during the extraction phase to the watermarked image to extract the secret watermark.

- **Embedding steps**

1. **Let (I) be the cover image, (W) be the watermark image**
2. **Apply two levels of IWT to (I) and divide the sub-bands LH_2 into (4x4) blocks**
3. **From each block, select 2 coefficients (C_1 and C_2) and embed W into the selected sub-band using the following rules:**

   if W == 1:

   $C_1' = C_1 + \propto;$

   $C_2' = C_2 - \propto;$

   if W== 0

   $C_1' = C_1 - \propto;$

   $C_2' = C_2 + \propto;$
4. **Restore the watermarked image (I') by applying an inverse IWT.**

- **Extraction steps:**

1. **Apply two levels of IWT to the watermarked image and divide the LH_2 sub-band into (4x4) blocks**
2. **From each block, select 2 coefficients (C_1 and C_2) and extract the watermark using the following rules:**

   if $C_1 > C_2$:
   W = 1;
   if $C_1 < C_2$:
   W= 0;
3. **Restore the secret watermark image.**

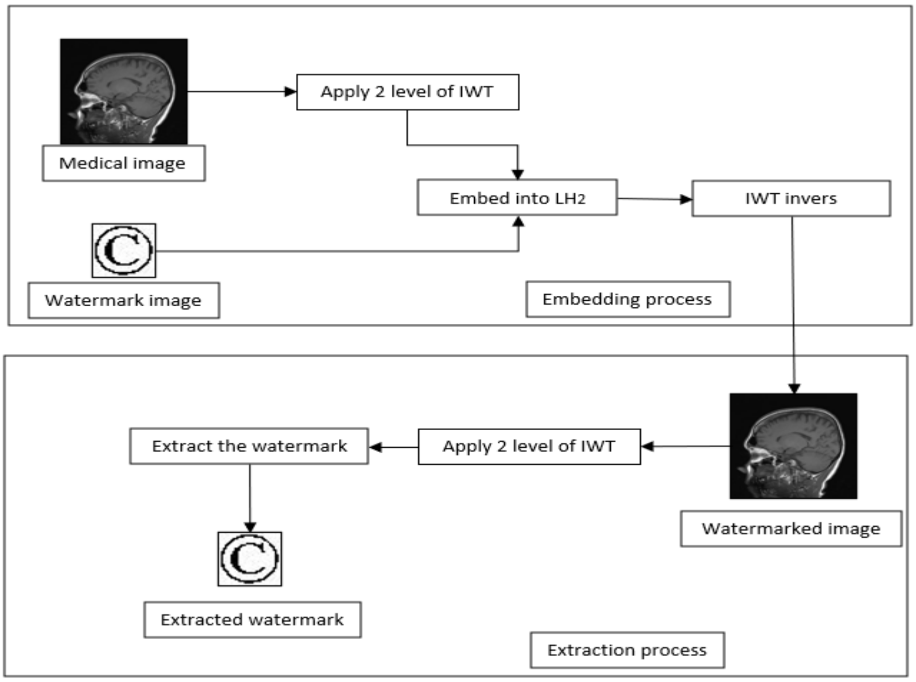


Fig 2. Embedding and extraction process

3.3 Optimization Process

The PSO algorithm was used in this phase to determine the best scaling factor for the cover image. To generate the watermarked image and extract the secret watermark, both the embedding and extraction processes were used. The watermarked image was subjected to various attacks, including filtering, noise addition, and RST attacks, to assess the algorithm's performance. The algorithm's imperceptibility and robustness were then assessed using the Peak Signal to Noise Ratio (PSNR) and Normalized Correlation (NC), respectively. Based on the two parameters, the fitness function was used to calculate the fitness value, and the best performance was used to select the optimal scaling factor.

Medical Technologies Journal, Volume: 5, Issue: 1, January-Mars 2023, Pages:594-603. Doi :
https://doi.org/10.26415/2572-004X-vol5iss1p594-603

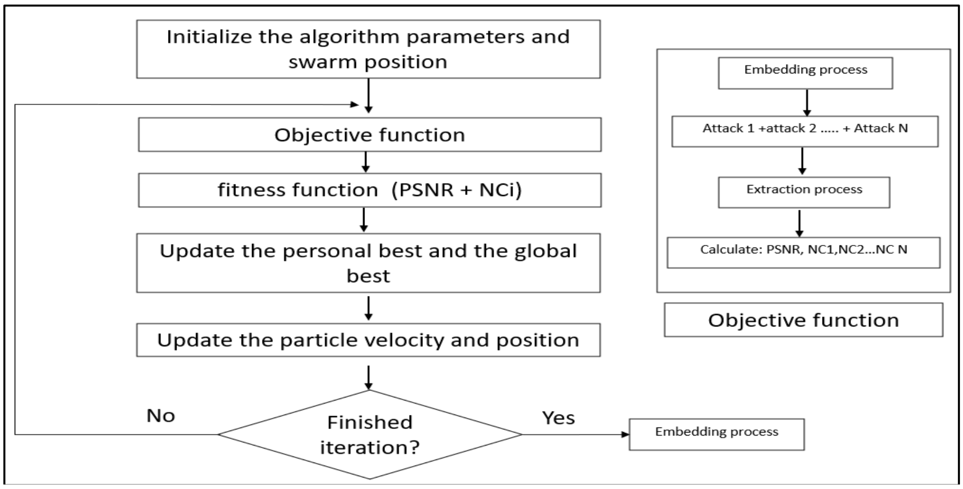


Fig 3. PSO based watermarking algorithm.

4. Result And Discussion

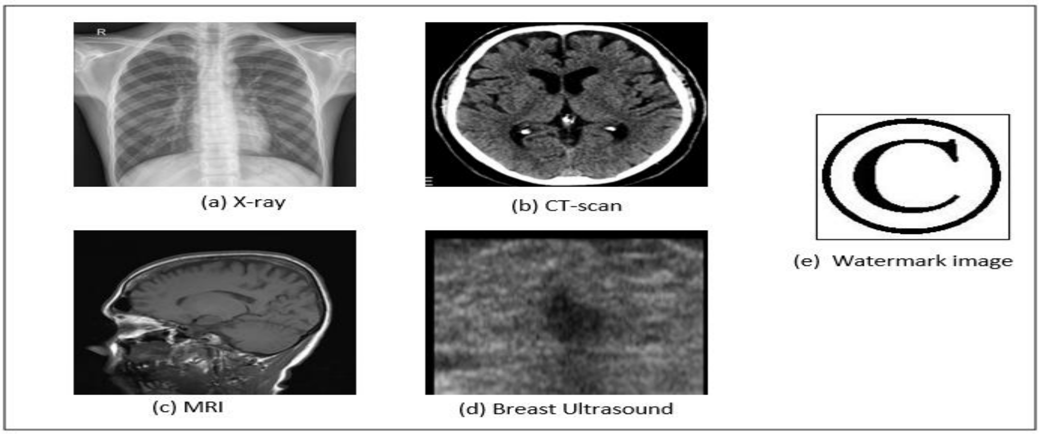


Fig 4. (a-d) Medical images used for the test, (e) Watermark image

The study used a collection of 512x512 medical images from various modalities, such as X-ray, MRI, breast ultrasound, and CT-scan, as cover images (as illustrated in Figure 4), along with a 32x32 binary image as a secret watermark. The proposed algorithm was implemented in MATLAB R2017b and evaluated based on the PSNR, NC, and SSIM. To determine the scheme's robustness, the watermarked image was subjected to several attacks and compared to the state-of-the-art method.

The results of the imperceptibility test for different medical modalities are presented in Figures 5 and 6, showing excellent performance with a PSNR>40 and SSIM>0.9. Particularly, CT-scan images had a PSNR of 47.3118 and SSIM of 0.9884. Tables 1, 2, and 3 demonstrate the robustness of the approach under attacks, indicating that the extracted watermark successfully resisted most attacks, especially geometric attacks, which are among the most challenging attacks in watermarking schemes.

Table 4 displays a visual representation of the watermarked image and the extracted watermark, highlighting the algorithm's good perceptual quality. However, the study suggests that enhancing the robustness level is necessary to make the watermark more resilient to the strongest attacks.

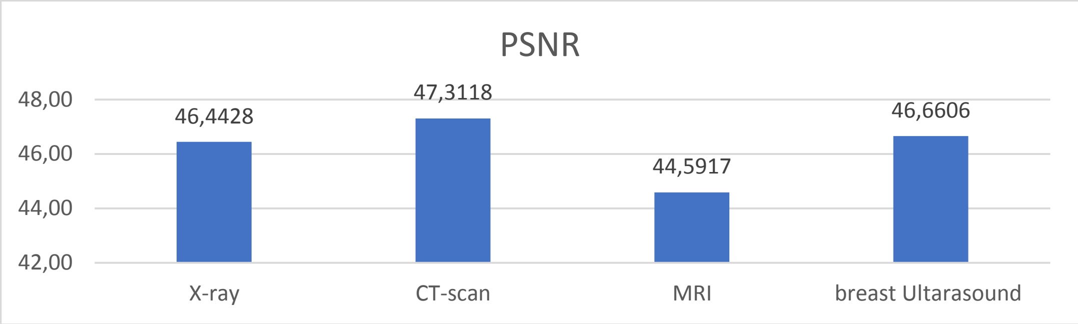


Fig 5. PSNR performance for different medical imaging modalities.

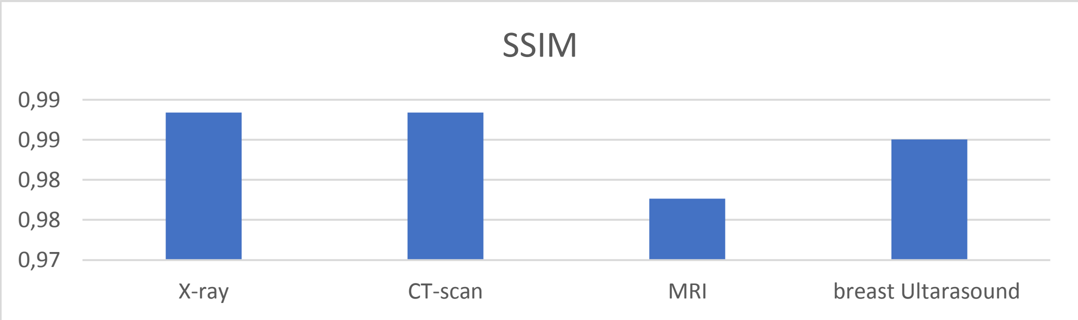


Fig 6. SSIM performance for different medical imaging modalities.

Table 1. Robustness performance under filtering attacks.

Attacks	*X-ray*		*CT- scan*		*MRI*		*Breast ultrasound*	
	NC	SSIM	NC	SSIM	NC	SSIM	NC	SSIM
no attack	0,9689	0,9998	0,7822	0,9981	0,8928	0,9992	1,0000	1,0000
Median filtering (2x2)	0,9744	0,9998	0,6359	0,9964	0,9059	0,9992	1,0000	1,0000
Weiner (3x3)	0,8877	0,9991	0,5905	0,9954	0,8437	0,9987	0,9971	1,0000
Weiner (2x2)	0,9217	0,9993	0,6574	0,9967	0,8770	0,9990	1,0000	1,0000

Table 2. Robustness performance under noise addition, JPEG compression and histogram attacks

Attacks	*X-ray*		*CT- scan*		*MRI*		*Breast ultrasound*	
	NC	SSIM	NC	SSIM	NC	SSIM	NC	SSIM
Gaussian Noise (0.5%)	0,8784	0,9990	0,5717	0,9946	0,8489	0,9987	0,9885	0,9999
Gaussian Noise (0.1%)	0,9629	0,9997	0,7525	0,9978	0,8896	0,9990	0,9222	0,9992
Salt & Pepper Noise (1%)	0,9104	0,9993	0,7064	0,9973	0,8527	0,9985	0,9885	0,9999
Salt & Pepper Noise (0.1%)	0,9716	0,9998	0,7691	0,9979	0,8935	0,9991	1,0000	1,0000
Speckle Noise (0.1%)	0,9742	0,9998	0,7778	0,9981	0,8647	0,9989	1,0000	1,0000
JPEG Q= 50	0,9551	0,9997	0,6787	0,9970	0,8798	0,9989	1,0000	1,0000
JPEG Q= 80	0,9742	0,9998	0,7811	0,9981	0,9059	0,9992	0,9942	1,0000
histogram Equalization	0,9659	0,9997	0,8159	0,9985	0,8902	0,9989	1,0000	1,0000

Table 3. robustness performance under geometric attacks

Attacks	*X-ray*		*CT- scan*		*MRI*		*Breast ultrasound*	
	NC	SSIM	NC	SSIM	NC	SSIM	NC	SSIM
Rotation 5°	0,9604	0,9997	0,7180	0,9974	0,8791	0,9989	1,0000	1,0000
Rotation 35°	0,9353	0,9994	0,7316	0,9975	0,8767	0,9989	1,0000	1,0000
Rotation 15°	0,9659	0,9997	0,7420	0,9977	0,8791	0,9989	1,0000	1,0000
Rotation 45°	0,9130	0,9992	0,7337	0,9976	0,8847	0,9989	1,0000	1,0000
Scaling 0.5	0,8518	0,9981	0,7440	0,9978	0,8840	0,9990	1,0000	1,0000
Scaling 1,25	0,9659	0,9998	0,7513	0,9949	0,8164	0,9984	1,0000	1,0000
Scaling 1,5	0,9742	0,9998	0,7605	0,9978	0,8953	0,9991	1,0000	1,0000
Scaling 0,75	0,8910	0,9983	0,7712	0,9980	0,8953	0,9991	1,0000	1,0000
Scaling 1,75	0,9124	0,9993	0,6841	0,9969	0,8471	0,9986	1,0000	1,0000
Shift[3V,3H]	0,9744	0,9998	0,7681	0,9979	0,9034	0,9992	1,0000	1,0000
Shift[30V,03H]	0,8084	0,9945	0,7701	0,9980	0,9002	0,9991	0,8288	0,9948

In table 4 we compared the proposed method with similar watermarking approaches. In the first scheme a hybrid scheme based on LWT and SVD was used in the embedding algorithm. The second algorithm was proposed by Ting Zhu et al[12] where they use IWT along with SVD for the embedding, in addition the algorithm was optimized using GA. From this table we can presume that our method performs better in term of imperceptibility where the result was the best comparing with the others. However, the robustness results were less but very close from other technique which encourage us to increase the robustness algorithm in the future work.

Table 4. Visual representation for the watermarked image and the extracted watermark

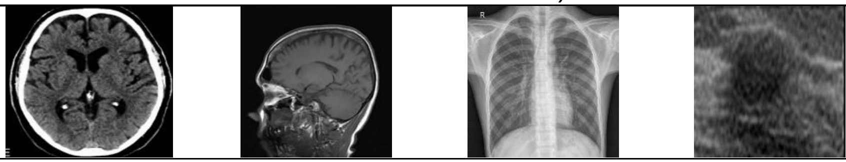
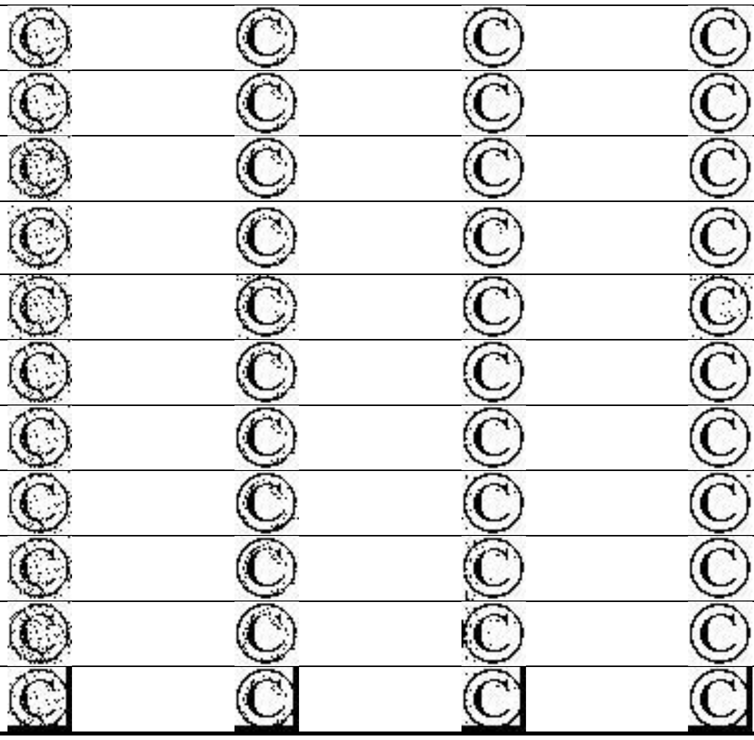
	CT-scan	*MRI*	*X-ray*	*Ultrasound*
Watermarked image				
	Extracted watermark			
no attack				
Median				
Weiner filtering				
Gaussian Noise				
Salt & Pepper Noise				
Speckle Noise				
JPEG Q= 80				
histogram Equalization				
Rotation 45°				
Scaling 0.75				
Shift [H50, V50]				

Table 5. Comparison of the proposed technique with similar scheme in term of NC using 'lena' image

	Ours	*LWT-SVD*	*Ting Zhu et al[12]*
PSNR	46,4451	38,2698	36.2500
no attack	0,9839	1.0000	1.0000
Median filtering	0,9133	0.8990	0.9875
Weiner filtering	0,8439	0.7940	-
Gaussian Noise	0,8903	0.8790	0.9990
Salt & Pepper Noise	0,9197	0.870	-
Speckle Noise	0,9186	0.9900	-
JPEG compression	0,9263	1.0000	0.9989
Histogram Equalization	0,9263	0.9998	-
Rotation	0,8878	0.794	-
Scaling	0,9024	0.8960	0.9954

5. Conclusion

This paper introduces an optimized digital watermarking technique for medical images that utilizes Integer Wavelet Transform (IWT) in both the embedding and extraction processes. IWT is a suitable choice for lossless-data applications, making it ideal for ensuring medical image integrity. Furthermore, Particle Swarm Optimization (PSO) is employed to select the optimal scaling factor, allowing our scheme to handle images from various modalities. The experimental results demonstrate that the proposed scheme outperforms similar schemes in terms of both imperceptibility and robustness.
In our future work we attend to enhance the algorithm by testing other optimization algorithm and using hybrid algorithm in the embedding process.

6. Acknowledgement

The authors would like to thank the Directorate-General of Scientific Research and Technological Development (Direction Générale de la Recherche Scientifique et du Développement Technologique, DGRSDT, URL: www.dgrsdt.dz, Algeria) for the financial assistance towards this research.

7. Conflict of interest statement

We certify that there is no conflict of interest with any financial organization in the subject matter or materials discussed in this manuscript.

8. Authors' biography

ABDI Hadjer: obtained a Master's graduate in biomedical engineering, specialising in Telemedicine, and currently, she is a Ph.D. student in biomedical engineering, specialising in Telemedicine and Biomedical Informatics from Tlemcen University. Her research focuses on medical data security, exploring ways to enhance the confidentiality, integrity, and availability of medical data.
Boukli-Hacene Ismail: obtained B.Sc. in Electronics, M.Sc. in Electronic Biomedical, and Ph.D. degree in Electronic Biomedical from University of Tlemcen, Algeria, His research interests are image processing, medical image compression, wavelets transform, wireless communication systems and optimal encoder. He has more than 20 publications in specialized journals with impact factors.

9. References

[1] A. Anand et A. K. Singh, « Watermarking techniques for medical data authentication: a survey », *Multimed. Tools Appl.*, p. 1-33, 2020.
[2] N. Agarwal, A. K. Singh, et P. K. Singh, « Survey of robust and imperceptible watermarking », *Multimed. Tools Appl.*, vol. 78, n° 7, p. 8603-8633, 2019.
[3] A. Pourhadi et H. Mahdavi-Nasab, « A robust digital image watermarking scheme based on bat algorithm optimization and SURF detector in SWT domain », *Multimed. Tools Appl.*, vol. 79, n° 29, p. 21653-21677, août 2020, doi: 10.1007/s11042-020-08960-0.
[4] A. Anand et A. K. Singh, « Watermarking techniques for medical data authentication: a survey », *Multimed. Tools Appl.*, vol. 80, n° 20, p. 30165-30197, août 2021, doi: 10.1007/s11042-020-08801-0.
[5] A. F. Qasim, F. Meziane, et R. Aspin, « Digital watermarking: Applicability for developing trust in medical imaging workflows state of the art review », *Comput. Sci. Rev.*, vol. 27, p. 45-60, 2018.

[6] A. K. Singh, M. Dave, et A. Mohan, « Hybrid technique for robust and imperceptible multiple watermarking using medical images », *Multimed. Tools Appl.*, vol. 75, nº 14, p. 8381-8401, 2016.
[7] D. G. Savakar et S. Pujar, « Digital image watermarking using DWT and FWHT », *Int. J. Image Graph. Signal Process.*, vol. 11, nº 6, p. 50, 2018.
[8] P. Khare et V. K. Srivastava, « A secured and robust medical image watermarking approach for protecting integrity of medical images », *Trans. Emerg. Telecommun. Technol.*, 2020.
[9] S. Thakur, A. K. Singh, S. P. Ghrera, et A. Mohan, « Chaotic based secure watermarking approach for medical images », *Multimed. Tools Appl.*, vol. 79, nº 7, p. 4263-4276, 2020.
[10] T. A. Tamal, C. Saha, Md. F. Hossain, et S. Rahman, « Integer Wavelet Transform Based Medical Image Watermarking for Tamper Detection », in *2019 International Conference on Electrical, Computer and Communication Engineering (ECCE)*, févr. 2019, p. 1-6. doi: 10.1109/ECACE.2019.8679152.
[11] B. P. Kulkarni, S. Sai Krishna, K. Meenakshi, P. Kora, et K. Swaraja, « Performance Analysis of Optimization Algorithms GA, PSO, and ABC based on DWT-SVD watermarking in OpenCV Python Environment », in *2020 International Conference for Emerging Technology (INCET)*, juin 2020, p. 1-5. doi: 10.1109/INCET49848.2020.9154134.
[12] T. Zhu, W. Qu, et W. Cao, « An optimized image watermarking algorithm based on SVD and IWT », *J. Supercomput.*, vol. 78, nº 1, p. 222-237, janv. 2022, doi: 10.1007/s11227-021-03886-2.
[13] S. M. Mousavi, A. Naghsh, et S. Abu-Bakar, « Watermarking techniques used in medical images: a survey », *J. Digit. Imaging*, vol. 27, nº 6, p. 714-729, 2014.
[14] SONI, Neetika, SAINI, Indu, et SINGH, Butta. An integer wavelet transform and pixel value differencing based feature specific hybrid technique for 2D ECG steganography with high payload capacity. Multimedia Tools and Applications, 2021, vol. 80, p. 8505-8540. https://doi.org/10.1007/s11042-020-09856-9
[15] M. Bansal, A. Mishra, et A. Sharma, « SVD–DWT Hybrid Frequency Domain Watermarking for Gray Scale Images Using Particle Swarm Optimization », in *Soft Computing for Problem Solving*, A. Tiwari, K. Ahuja, A. Yadav, J. C. Bansal, K. Deep, et A. K. Nagar, Éd., in Advances in Intelligent Systems and Computing. Singapore: Springer, 2021, p. 125-136. doi: 10.1007/978-981-16-2709-5_11.