Enhancing Medical Image Security : An Adaptable and robust watermarking Scheme

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Abstract

In recent years, digital image watermarking has attracted much attention from researchers because of its great ability to ensure the security and protection of information against unauthorized access or illegal modification. In this paper, a robust watermarking scheme for medical images based on the discrete wavelet transform (DWT), the singular value decomposition (SVD), and the Arnold transform (AT) has been proposed. Several image modalities including ultrasound, CT scan, PET scan, X-ray, and MRI were used to test our proposed method. On the other hand, two metrics PSNR and SSIM were used to assess the imperceptibility while the NC metric was used to evaluate the robustness. Experimental results without attacks showed that our method offers good imperceptibility with a PSNR above 45dB and SSIM close to 1. After applying the attacks, the results showed that the method presents good robustness with NC close to 1. In conclusion, our proposed method offers a good compromise between imperceptibility and robustness which allows it to be a valuable method in the field of e-health.

Keywords

Medical image watermarking, DWT, SVD, Arnold transform

1 Introduction

The development of information and communication systems and the high use of electronic management of medical records have enabled the sharing or exchange of digital medical images around the world for several services such as telemedicine, teleradiology, telediagnosis, and teleconsultation. For that, a system for effectively sharing the medical files of patients between several hospitals or centers must ensure good protection and security of these data. To solve this problem, the Watermarking system appears as one of the most effective methods for ensuring the integrity and authenticity of these data. It aims to secure storage and transmission and could ensure the authentication of information and only legal duplication in the exchange of health information.s [1].

The digital watermarking technique consists of inserting information called the watermark into the original image. In general, this watermark can be a logo, text, or image [2]. Watermarking techniques can be classified based on two domains. Firstly, a spatial domain where the watermark is inserted directly by modifying the values of the pixels of the original image. Secondly, the frequential domain, where the watermark is inserted in the coefficients of transformation of the original [3] [4]. The requirements of a good watermarking system are [5] :

— robustness, which is the effectiveness of a watermarking system against the usual image processing operations such as filtering, compression, geometric transformation, ... commonly called attacks [5] ;

— imperceptibility, which means that after the insertion of the watermark, the watermarked image's quality must remain faithful to the original and the watermarked image must ensure the same diagnostic reliability [5] [3] ;

— capacity, refers to the amount of information to be embedded in the original image [2] [6]

In the context of medical images, these properties are particularly important, because, in addition to the sensitivity of the information they contain, they are designed to perform a diagnostic task.

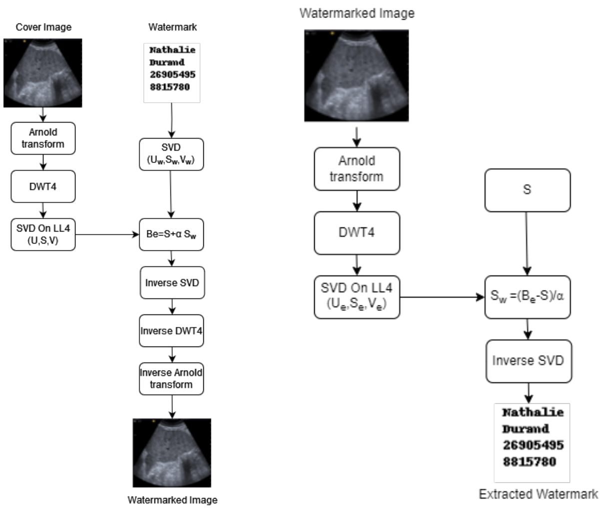
Several studies have been developed in the field of medical image watermarking. Movahed et al. [4] proposed a watermarking method dedicated to Computerized Tomography (CT) medical images. et al. [7] proposed a watermarking method based on “multiple watermarking systems", where they used a Discrete Wavelet Transform (DWT) and Discrete Cosine Transform (DCT), with a quantization step of the frequency coefficients. Mahyudin *et al.* [1] introduced the Arnold Transform in their algorithm to improve the robustness of the watermarking process. Recently, Vaidya *et al.* [8] proposed the embedding of a patient's fingerprint in different modalities using hybrid transform. Some studies have proposed deep-learning methods for watermarking purposes in medical images. Singh *et al.*[9] provides a comprehensive review of watermarking techniques in deep learning environments, emphasizing their accuracy and learning ability. However, the explainability of deep learning methods in medical applications is an ongoing challenge and has not been addressed in medical watermarking, which is a major concern in the medical community.

In this paper, we propose a versatile watermarking of medical images based on the DWT SVD and the Arnold transform. DWT is used for its compatibility with compression and its robustness against several attacks. The Arnold transform is applied for its encryption effect to increase the security of the watermark. The rest of this paper is organized as follows : Section 2 presents the proposed watermarking scheme. Section 3 presents further experiments, results, and discussion on the method. The paper is concluded in section 4.

2 PROPOSED WATERMARKING SCHEME

2.1 Insertion process

To insert the watermark, we first applied image processing techniques on both the original and the watermark. Then Arnold transform, DWT, and SVD are applied, and the entire algorithm is represented in Figure1(a).



(a) Watermark embedding process

(b) Watermark extracting process

FIGURE 1 – *Watermarking process*

The watermarked image is generated. At the end of the process, the result is evaluated using the performance metrics : PSNR and SSIM.

2.2 Extraction process

The watermark extraction process is the reverse of the insertion one as presented in Figure1(b). At the end of this process, the NC is used to assess the robustness of the system.

2.3 Performance metrics

In this study, we used two categories of metrics to assess the performance of the system. The first category aims to evaluate the imperceptibility and image quality of the watermarked image. This is typically measured using metrics such as the peak-signal-to-noise ratio (PSNR) and the structural similarity index measure (SSIM). The second one aims to assess the robustness of the watermarking system against various attacks. This is typically measured using the normalized correlation (NC) coefficient that evaluates the similarity between the original and the attacked watermark.

TABLEAU 1 – *Results without an attack on US Image*

Gain factor(α)	PSNR(dB)	SSIM	NC
0.01	47.7279	0.9930	0.9903
0.02	47.7778	0.9931	0.9976
0.03	47.7778	0.9931	0.9987
0.04	47.3529	0.9918	0.9986
0.05	47.3529	0.9918	0.9984
0.06	46.5723	0.9891	0.9999
0.07	46.5723	0.9891	0.9999
0.08	45.5992	0.9852	0.9996
0.09	45.5992	0.9852	1.0

3 RESULTS AND DISCUSSION

In this part, we present the evaluation results and a comparison with the results proposed in the literature. The size of the original image used is 1024×1024 and 64×64 for the watermark. Images from several medical imaging modalities such as US [10], CT, PET-scan, X-ray [11], and MRI [12] are used.
The numerical results without attack for the different gain factor values are presented in Table 1 where the maximum value of $PSNR = 47.7778dB$ and $SSIM = 0.9931$ is given at $\alpha = 0.02$ and $\alpha = 0.03$. The results for several image modalities without attack, the comparison of the results without attack with the existent results, and the comparison of the results with the attack of our system with the literature's results are presented in table 2, 3 and 4. These tests are carried out for $\alpha = 0.07$ this later value was determined empirically in this context of medical imaging it is valuable at this stage and before an automation process in ongoing work.
Table 1 presents the evaluation of PSNR, SSIM, and NC according to the gain factor. It shows that the PSNR and SSIM values decrease when the gain factor increases. This explains that the greater the gain factor, the more important the watermark is in the watermarked image, which will reduce the value of NC.
It is worth mentioning that our proposed method has a lower PSNR and high SSIM than the method proposed in [1]. This can be explained by the fact that the watermark used in our method contains more characters than the one used by Mahyudin *et al.* [1]. This indicates that the proposed scheme has a greater capacity to embed information. Furthermore, the SSIM is more correlated to the human visual

TABLEAU 2 – *Comparison of the proposed method with the existing watermarking scheme without attack*

Image modality	Watermarking scheme in [1]			Watermarking scheme in [8]			Watermarking scheme in [13]			Prpposed method		
	PSNR	SSIM	NC	PSNR	SSIM	NC	PSNR	SSIM	NC	PSNR	SSIM	NC
Pet-Scan	-	-	-	36.56	0.9821	1.0	24.5103	-	0.9327	46.6764	0.9975	1.0
X-Ray	50.7885	0.9957	1.0	35.43	0.9857	1.0	28.0304	-	0.9488	46.4854	0.9948	1.0
MRI	50.6744	0.9586	1.0	37.07	0.9815	1.0	38.0842	-	0.9869	46.0375	0.9828	0.9784
CT	50.7628	0.9983	1.0	33.85	0.9844	1.0	36.9234	-	0.9154	46.7419	0.9830	0.9868
US	50.7897	0.9539	1.0	36.47	0.9878	1.0	21.4548		0.8865	46.5723	0.9891	0.9999

TABLEAU 3 – *Robustness (NC values) of the proposed VS existing ones under attacks applied on US images*

Attacks/Noise	Noise density	Scheme [13]	Scheme in [1]	Proposed
		NC	NC	NC
Gaussian	0.0001	0.9785	—	0.9996
	0.0005	0.8311	—	0.9996
Rotation	5°	0.8908	—	0.9990
	10°	0.8913	—	0.9596
Salt and pepper	0.0001	0.9975	—	0.9997
	0.001	0.8761	0.9981	0.9999
	0.05	—	0.9290	0.9988
Speckle Noise	0.01	0.8277	0.8814	0.9589
	0.05	—	0.9765	0.9986

system than the PSNR in terms of perceptual and diagnostic quality [14] considering the simplest metric to implement. We can conclude that the proposed method offers good imperceptibility, which makes it a valuable method usable in medical applications. To evaluate the robustness of our method, we applied and simulated different types of attacks : a rotation and 3 types of noise, including Gaussian noise, speckle noise, and salt and pepper noise. The results are summarised in Table 2. The values of NC are very close to the value of NC without attacks, indicating that the proposed watermarking scheme has good resistance to these attacks. Table 3 presents a comparison with the method proposed in [1] and [13]. The results indicate that the proposed method has mostly a higher NC for all noise and rotation than that presented by the scheme in [1] and [13]. This can be explained by the presence of the Arnold transform in our algorithm, which increases the security and survivability of the watermark against attacks. Also, one could see that the proposed method has high results in terms of robustness in watermark recovery under noises thanks to the multiplying factor α that allows to management of the reinforcement of the watermark.

Table 4 shows the comparison with the method proposed by VAIDYA *et al.* [8]. It turns out that the proposed method presents an NC higher against all the attacks used and for all image modalities except MRI. The main difference is that authors in [8] used a larger watermark size, which reduces the quality of the watermarked image as shown in table 2. However, the extracted watermark is very similar

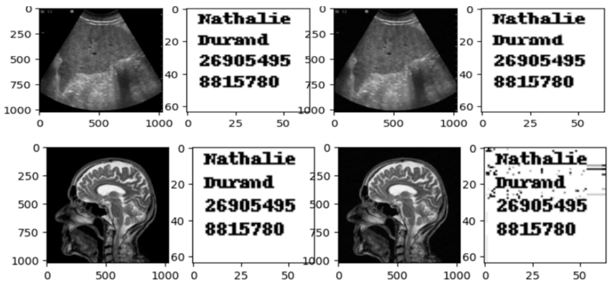


FIGURE 2 – *Watermarked US and MRI images with embedded watermark .From left to right : cover image, watermark, watermarked image, and extracted watermark*

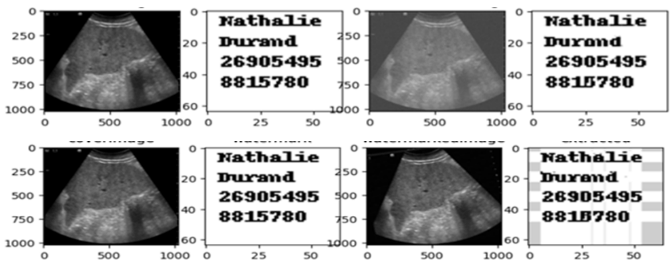


FIGURE 3 – *Visual inspection of US watermarked image with embedded watermark under attack. From left to right : cover image, watermark, watermarked image under attack and extracted watermark*

to the original watermark compared to the state-of-the-art methods. We can therefore conclude that the proposed method offers good robustness against several types of attacks, including adding noise, filtering, and rotation.

For a preview of the rendering quality, Figure 3 shows the resulting images after the embedding of the watermark and the recovered watermark, and Figure 3 offers a visual inspection of images with embedded watermark under attack and the recovered watermark.

4 Conclusion

In this paper, we proposed a robust and adaptive medical image watermarking algorithm based on DWT-SVD and the Arnold transform. DWT is used for its compatibility with compression and its robustness against several attacks. The Arnold transform is applied to increase the security of

TABLEAU 4 – *Performance Comparison on different modalities under attacks*

Attacks	Watermarking Scheme in [8]					Proposed method				
	US	MRI	CT-Scan	Pet-Scan	X-ray	US	MRI	CT-Scan	Pet-Scan	X-ray
Gaussian noise (0,0.002)	0.9745	0.9613	0.9361	0.9708	0.9673	0.9994	0.9737	0.9998	1.0	1.0
Salt and Pepper (0.001)	0.9941	0.9914	0.9792	0.9950	0.9935	0.9999	0.9905	0.9999	1.0	1.0
Median filter (3x3)	0.9890	0.9882	0.9314	0.9833	0.9797	0.9996	0.9792	0.9998	1.0	1.0

the watermark. Several modalities are used for the realization of the tests namely, CT, US, PET-Scan, X-ray, and MRI. The result without attack shows that our method offers good imperceptibility where all the PSNR values are greater than 45dB, those of SSIM are close to 1 and the NC values are very close to 1. Imperceptibility is a key factor in medical imaging. It enables reliable diagnosis and ensures that the quality of the diagnosis is not compromised. Several attacks have been applied, and the experimental results showed that our method has a high robustness. Therefore, the proposed scheme is valuable in enhancing the security of data used in e-health applications. As ongoing work, we are trying to insert the watermark in the region of non-interest of the image in a retrospective dataset with a real attack and to complete the security scheme for the transmission chain far beyond the watermarking process.

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