Robust Watermarking Scheme for Medical Image Using Optimization Method

Baiying Lei[1], Tianfu Wang[1], Siping Chen[1], Dong Ni[1]*,and Haijun Lei[2]

[1]Department of Biomedical Engineering, School of Medicine, Shenzhen University,
National-Regional Key Technology Engineering Laboratory for Medical Ultrasound,
Guangdong Key Laboratory for Biomedical Measurements and Ultrasound Imaging, Shenzhen, China, 518060
[2]College of Computer Science and Software Engineering, Shenzhen University, Shenzhen, China,518060
(Email:{leiby, tfwang, chensiping, *nidong, lhj}@szu.edu.cn)

Abstract- Currently, most medical images are stored and exchanged without any consideration of security, and hence it is highly desirable to provide content protection for medical images that are used in a secured environment. In this paper, a new and robust watermarking method is proposed to address this security issue. Specifically, signature information and textual data are inserted into the original medical images. The integer wavelet transform (IWT) are combined with singular value decomposition (SVD) to provide robustness in the proposed method. Meanwhile, differential evolution (DE) is used to optimally design the quantization steps (QSs) for controlling the watermarking strength. With hybrid techniques such as IWT, SVD, and DE, the proposed watermarking algorithm not only achieves good imperceptibility, but also high robustness. Experimental results demonstrate that the proposed method outperforms existing methods.

***Keywords*—Robust Watermarking; Differential Evolution; Medical Image**

I. INTRODUCTION

With the development of the telediagnosis, telesurgery, and hospital information system, medical images have become one of the most important tools for physicians to determine healthcare diagnostic procedures for patients [1-3]. Watermarking [4] is found to be an effective and promising mechanism. The reversible watermarking technique or lossless method [5] is especially useful for medical images because the original image can be completely restored and retrieved at the receiver side.

It is known that larger quantization steps (QSs) provides more robustness but cause higher distortion of host image quality. On the other hand, smaller QSs often result in higher transparency but leads to lower robustness [6]. Different medical images have different spectral components, and thus lead to different tolerance to distortion. As a result, a single QS is usually not applicable to the host medical images. To solve this problem, one popular way is to insert multiple watermarks. Another way is to find the optimized solutions by trial and error. However, without considering of any properties of the host signals, the QS used is usually far from optimal. Consequently, a lot of intelligent techniques such as genetic algorithm (GA) [7], constrained clonal selection algorithm (CSA) [8], particle swarm optimization (PSO) [9], and differential evolution (DE) [10] have been proposed and are shown to effectively resolve these issues. Furthermore, these utilized intelligent techniques are often applied in the transform domain such as discrete cosine transform (DCT) [8], discrete wavelet transform (DWT) [10], integer wavelet transform (IWT) [8], lifting wavelet transform (LWT) [25], singular value decomposition (SVD) [8, 10, 11], and spatial domain [11] to optimize the conflicting watermarking requirements. However, the reported performance of existing methods is still not optimal and needs further improvement.

It is reported that DE [12] is able to obtain optimal solutions over a specified range simultaneously, and hence the best solution can be achieved. In view of this, the learning abilities of DE are exploited for selection of QS and provide two-fold benefits. Firstly, the selection of proper QSs as adaptive watermark controlling parameter can achieve better imperceptibility performance. Secondly, DE is able to determine QSs for embedding the watermark which offer improved detection performance (in the presence of various attacks) even without attack estimation and knowledge of watermark.

The key objective of this paper is to design a robust watermarking system aiming to effectively prevent the illegal use of the medical images without affecting the perceptual quality. The proposed heuristic watermarking scheme incorporates wavelet transform, SVD, DE, and scrambling technique. Singular values (SVs) of the low frequency wavelet transform coefficient of medical images are adopted to embed watermark in the host image by employing optimized QSs determined using the DE heuristic algorithm. This paper is organized as follows. Section II discusses the proposed methodology in detail. The experimental analysis is provided in Section III and the validation of the performance of the proposed method. This is followed by the conclusion in Section IV.

II. PROPOSED METHOD

A. Watermarking Embedding

Figure 1 shows the flowchart of the proposed watermark embedding process, which are described as below:

Step 1: The host image (*I*) is divided into sub-blocks B^k, where $k = 1, 2..., W_w \times W_h$, W_w and W_h are the width and height of the watermark respectively.

Step 2: In order to improve the security of the whole digital watermarking system, scrambling algorithm is applied to both meaningful signature and clinical text data first. In our watermark embedding scheme, the pixel space relationship of the watermark image sequence (*W*) is first dispelled and scrambled to generate the shuffled sequence (*E*) by a secret key (*K*), whose length is $W_w \times W_h$.

Step 3: Two-level wavelet transform is applied to each sub-block. Coefficients in the low frequency part are selected to design robust watermarking algorithm against additive noise, filtering, and JPEG compression.

Step 4: Perform SVD on the low frequency wavelet transform of each block to generate SVs (S^k).

Step 5: Watermark bits are embedded by the coefficient quantization, where the first SVs are quantized. The first SVs of wavelet approximate coefficients are selected to be more robust to geometric distortion.

We start the embedding of the watermark embedding with the normalization:

$$S_N^k = \left\| S^k \right\|, \tag{4}$$

where $\|\bullet\|$ is L_1, L_2 or L_∞ normalization operation according to the properties of images. Let $S_a^k = floor(S_N^k / \Delta^k)$, where $floor(\bullet)$ is rounding operation towards the negative infinity, Δ^k is quantization step. The first SVs are modified by the value of the shuffled message:

$$S_w^k = \begin{cases} S_a^k + 1 - \mathrm{mod}(S_a^k, 2), & E(i,j) = 1, \\ S_a^k + 1 - \mathrm{mod}((S_a^k + 1), 2), & E(i,j) = 0, \end{cases} \tag{5}$$

where $\mathrm{mod}(\bullet)$ is modulation operation. SVs are further updated to get back the signal as below:

$$S_w^k = \Delta^k \times S_w^k + \Delta^k / 2, \tag{6}$$

and

$$S_w^{k*} = S^k \times S_w^k / S_N^k. \tag{7}$$

Step 6: Apply SVD calculations to obtain the updated SVs for the host signals.

Step 7: The inverse wavelet transform is performed to obtain the watermarked host medical images (I^*).

B. Watermark Extraction

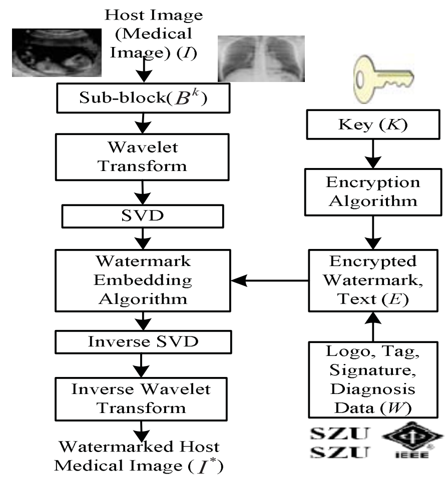

Figure 1. Diagram of watermark embedding.

Generally, the watermark extraction is the inverse of the watermark insertion and described as below:

Step 1: The watermarked host medical image (I^*) is divided into sub-blocks B^{*k}, where $k = 1, 2..., W_w \times W_h$.

Step 2: Two-level wavelet transform is applied to each sub-block B^{**k}. The approximate coefficients are selected for SVD calculation.

Step 3: Perform SVD on the low frequency of each block to generate SVs (S^{**k}).

Step 4: The SVs (S^{**k}) is then normalized by:

$$S_N^{**k} = \left\| S^{**k} \right\|, \tag{8}$$

Let $S_a^{**k} = floor(S_N^{**k} / \Delta^k)$, the shuffled message is then extracted with the following rule:

$$E^*(i,j) = \begin{cases} 0, & \mathrm{mod}(S_w^{k*}, 2) = 0, \\ 1, & \mathrm{mod}(S_w^{k*}, 2) = 1. \end{cases} \tag{9}$$

Step 5: The final watermark is obtained by the reshuffling of the shuffled message.

C. Design of fitness function

To optimize the watermarking performance, it is important to design the objective function which represents the system performance. To achieve this goal, we need to tradeoff between the robustness and imperceptibility. Normalized cross correlation coefficient (*NC*) is regarded as an effective way to measure the robustness in the literature [9]. Meanwhile, the mean structural similarity index measure (*MSSIM*) is considered as a very good metric for the evalutaion of the perceptual simimlarity [3]. Therefore, both NC and MSSIM are adopted in the fitness function.

Figure 2 shows the DE algorithm applied in the proposed watermarking approach. Since the watemarking is usually under a lot of attacks, the common singal manipulation attcks such as JPEG compression (JG), rescaling (RS), cropping (CP), adding Gaussian noise (GN), low pass filtering (LF), median filtering (MF), rotation (RT), and adding salt&pepper noise (SN) are considered in the DE optimization process. Finally, the fitness function is finally designed as:

$$\text{fitness}=\max(\alpha \times MSSIM + \beta \times \frac{1}{R}\sum_{i=1}^{R} w_i \times NC_i), \quad (10)$$

where R is the total number of attacks. Weighting factors α and β are introduced as significant difference might take place between the metrics of the watermarked medical host image and the extracted watermark. The metrics selected here can successfully converge to a value using DE.

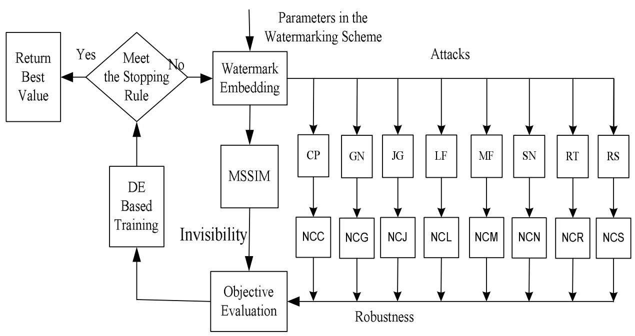

Figure 2. DE algorithm applied in the watermarking algorithm.

III. EXPERIMENTAL RESULTS

Simulations are carried out to demonstrate the effectiveness of the proposed watermarking scheme. As shown in Figure 3. Noted that the images shown here are resized), three 512×512 medical images including Xray, MRI, ultrasound (US) image, two 64×64 watermarks (one is text data, another one is logo or signature) are employed in our experiments. The maximum generation is 80. The DE optimization parameters are empirically obtained and are $CR = 0.4, F = 0.2, P = 30$. The weighting factors are also obtained based on numerous experimental results and validated empirically. The weighting factors are closely related to the tradeoff between robustness and imperceptibility, and are set as: $\alpha = \beta = 0.5$.

Figure 3. Host medical images and watermarks

Table I summarizes the finess value (Fit), PSNR value, and average NC value of all attacks (NCA) value of three host medical images. It can be noted that XRAY, US, and MRI images have very similar performance. It can be also observed that the wavelet transform method generally outperform the pure SVD method. The high PSNR, MSSIM and NC results show that the proposed method achieve good balance of robustness and fidelity.

TABLE I. OPTIMIZATION RESULTS.

	Transform	Fit	PSNR	MSSIM	NCA
XRAY	IWT	0.9791	48.39	0.9934	0.9738
	LWT	0.9708	48.06	0.9924	0.9623
	DWT	0.9703	48.03	0.9924	0.9615
	SVD	0.9694	48.03	0.9621	0.9604
US	IWT	0.9749	48.35	0.993	0.9679
	LWT	0.9704	48.47	0.9934	0.9612
	DWT	0.9701	48.43	0.9934	0.9608
	SVD	0.9688	48.42	0.9935	0.9588
MRI	IWT	0.9746	48.31	0.992	0.968
	LWT	0.9657	47.94	0.992	0.9549
	DWT	0.9636	48.08	0.9917	0.9513
	SVD	0.9615	47.99	0.9915	0.9499

The following attacks are applied to test the robustnes of the watermarking performance: a) CP (5% signal is cropped randomly); b) GN (1% Gaussian noise is added); c) JG (JPEG compression with quality factor 80); d) LF (3×3 Gaussian low pass filtering is applied); e) MF (3×3 median filtering is added); f) SN (1% salt&pepper noise is fedded); g) RS (image size is enlarged to 2 and then reduced to the original size); h) RT (rotate 5°). Figure 4 shows the NC results after these attacks. It can be seen that methods with IWT, DWT and LWT have a better performance than the pure SVD algorithm due to the multiresolution and properties of the wavelet transforms. Moreover, it can be seen that IWT achieves the best performance compared to DWT and LWT, while DWT and LWT have very similar performance in terms of the NC results.

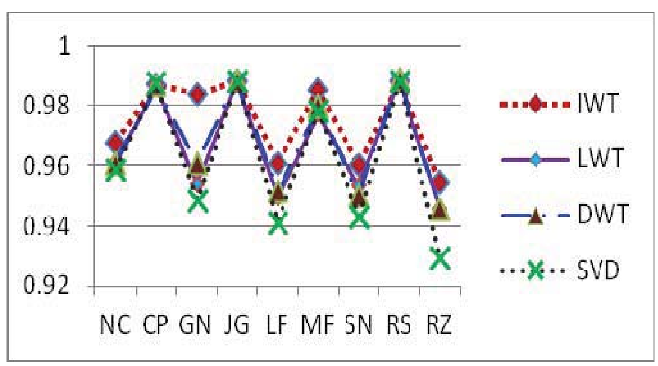

Figure 4. Performance comparision of IWT, DWT, LWT and SVD.

To further validate the proposed method, our algorithm is compared with algorithm in [7] which uses genetic algorithm optimization in the multi-wavelet transform. Table 2 shows that our proposed method outperform algorithm in [7] in terms of PSNR and MSSIM results.

TABLE II. COMPARISON RESULTS.

	PSNR				MSSIM			
	[7]	DWT	LWT	IWT	[7]	DWT	LWT	IWT
XRAY	42.25	48.02	48.06	48.39	0.9687	0.9924	0.9924	0.9934
US	42.12	48.35	48.47	48.43	0.9815	0.9934	0.9934	0.993
MRI	41.32	48.31	47.94	48.08	0.9724	0.9917	0.992	0.992

Figure 5 shows the fitness (objective) value, quantization step, MSSIM, and NC results converge after certain geneartion and achieve the best values. We can see that the balance of the robustness and imperceptbility is obtained from the convergence results. The saturated values are achieved by the best value for the inputed medical images and parameters. It is obvious that the DE optimization can be successfully applied in the medical image watermarking for paramater optimization.

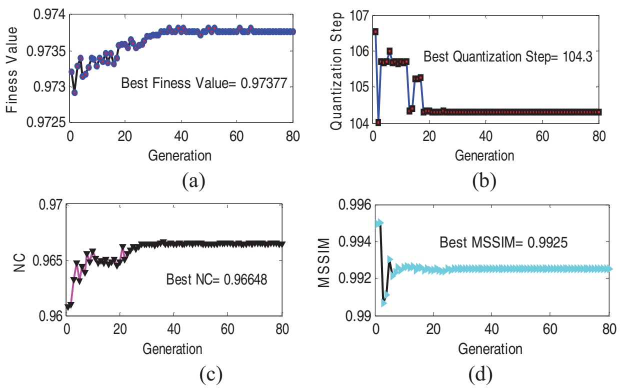

Figure 5. DE optimization results; (a)Fitness value results; (b)QSs results; (c)MSSIM results; (d) NC results.

IV. CONCLUSIONS

In this article, a robust and reversible watermarking approach that effectively embeds and extracts watermarks for medical images with DE optimization is proposed. The proposed method inserts double watermarks into the original host images by modifying the SVs of different blocks. Furthermore, DE was capitalized to optimize the QSs for controlling watermark strength with the specially designed fitness function. This method not only provides good watermark transparency, but also achieves high robustness against various attacks. Experimental results show the superiority of the wavelet algorithm over pure SVD in terms of PSNR and MSSIM. It is also demonstrated that the proposed method obtains better results with DE method compared with the related GA optimization algorithm. The proposed method is proven to suitable for general content protection of medical images.

ACKNOWLEDGEMENT

The work was supported partly by National Natural Science Foundation of China (Project No. 61101026, 61372006, 60871060 and 61031003), and partly by Shenzhen Research Project (Project No. JCYJ20130329105033277 and JSE201109150013A).

REFERENCES

[1] X. Kong and R. Feng, "Watermarking medical signals for telemedicine," IEEE Transactions on Information Technology in Biomedicine, vol. 5, pp. 195-201, 2001.

[2] A. Giakoumaki, S. Pavlopoulos, and D. Koutsouris, "Multiple image watermarking applied to health information management," IEEE Transactions on Information Technology in Biomedicine, vol. 10, pp. 722-732, 2006.

[3] S. Das and M. K. Kundu, "Effective management of medical information through a novel blind watermarking technique," Journal of medical systems, vol. 36, pp. 3339-3351, 2012.

[4] C. I. Podilchuk and E. J. Delp, "Digital watermarking: Algorithm and application," IEEE Signal Processing Magazine, vol. 18, pp. 33-46, 2001.

[5] M. U. Celik, G. Sharma, and A. M. Tekalp, "Lossless watermarking for image authentication: A new framework and an implementation," IEEE Transactions on Image Processing, vol. 15, pp. 1042-1049, 2006.

[6] B. Chen and G. W. Wornell, "Quantization index modulation: A class of provably good methods for digital watermarking and information embedding," IEEE Transactions on Information Theory, vol. 47, pp. 1423-1443, 2001.

[7] P. Kumsawat, K. Attakitmongcol, and A. Srikaew, "A new approach for optimization in image watermarking by using genetic algorithms," IEEE Transactions on Signal Processing, vol. 53, pp. 4707-4719, 2005.

[8] V. Aslantas, S. Ozer, and S. Ozturk, "Improving the performance of DCT-based fragile watermarking using intelligent optimization algorithms," Optics Communications, vol. 282, pp. 2806-2817, 2009.

[9] R. S. Run, S. J. Horng, J. L. Lai, T. W. Kao, and R. J. Chen, "An improved SVD-based watermarking technique for copyright protection," Expert Systems with Applications, vol. 39, pp. 673-689, 2012.

[10] V. Aslantas, "An optimal robust digital image watermarking based on SVD using differential evolution algorithm," Optics Communications, vol. 282, pp. 769-777, 2009.

[11] R. Liu and T. Tan, "An SVD-based watermarking scheme for protecting rightful ownership," IEEE Transactions on Multimedia, vol. 4, pp. 121-128, 2002.

[12] R. Storn and K. Price, "Differential Evolution - A Simple and Efficient Heuristic for Global Optimization over Continuous Spaces," Journal of Global Optimization, vol. 11, pp. 341-359, 1997.