Reversible medical image watermarking based on wavelet histogram shifting

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Abstract: This paper introduces a reversible and scalable blind watermarking method for medical images based on histogram shifting in wavelet domain. The histogram shifting-based watermarking especially in spatial domain suffers from the overhead of positions information that has to be embedded. This not only has negative impact on the capacity of the embedded data, but also reduces the quality of the watermarked image. To overcome this problem, a new histogram shifting approach in wavelet domain is introduced which adaptively manages the parts of the required histogram to be shifted. For inserting watermark data, two thresholds, T_1 and T_2, are determined in the high-frequency sub-bands of the histogram based on the size of watermark data. Two zero-points, Z_1 and Z_2, are created in the histogram shifting. In the histogram shifting procedure, only small parts of the histogram have been shifted and therefore, introduced distortion has been considerably decreased and the quality of the watermarked image has been increased. Applications of the method were examined for the multiple medical image watermarking. Two sets of data, one as copyright watermark and the other as caption watermark which contains patients' information, are first encrypted and then inserted in the high-frequency sub-bands in the integer wavelet domain. Inserting the data in different sub-bands besides encryption of it by a private key provides high security for the embedded data. Experimental results obtained for several watermarked medical images indicate imperceptibility of the approach even for high payloads. The proposed approach overcomes other related works introduced in the recent literatures.

Keywords: histogram shifting, multiple watermarking, medical images, reversible, zero-points, integer wavelet, scalable

1 INTRODUCTION

Recent advances in digital information technology facilitate fast transfer of digital data via internet. Therefore, distinguishing of original content from copied versions has become a challenge. Digital watermarking techniques are required in the transfer procedure to ensure copyright protection. Digital watermarking refers to the process of embedding an imperceptible and detectable mark in a digital content such as image to ensure copyright protection and to prevent unauthorised access.[1–3] Watermark usually provides ancillary information about the host image. There are several ways such as header files and bar codes to ensure copyright protection. Taking into account the advantages of watermarking (e.g. imperceptibility and inseparability of watermark and

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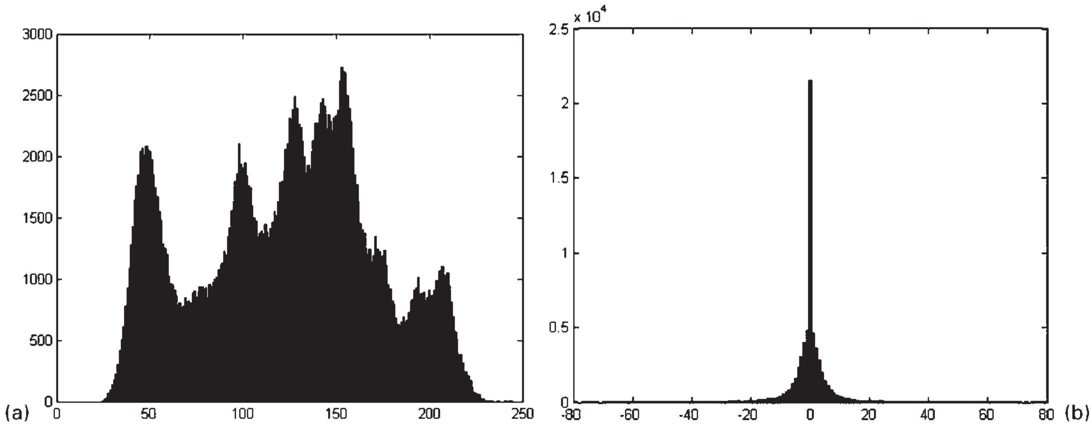


1 Histogram of a typical image: (a) spatial domain; (b) transformed domain

capability of undergoing transformation) make it attractive for realistic applications.

Although digital watermarking solves the problems associated with header files and bar codes, it introduces a new aspect of challenge. Embedding a watermark into a host image introduces distortions in the quality of the host. In medical application, the host image is required to be reconstructed from the watermarked image without any loss. Reversible watermarking algorithms are recognised as a solution.[1,4–10] Reversible watermarking could also be employed to restrict access to the original host image. Watermarked image is accessible for all, but only authorised person can access the original image.[4]

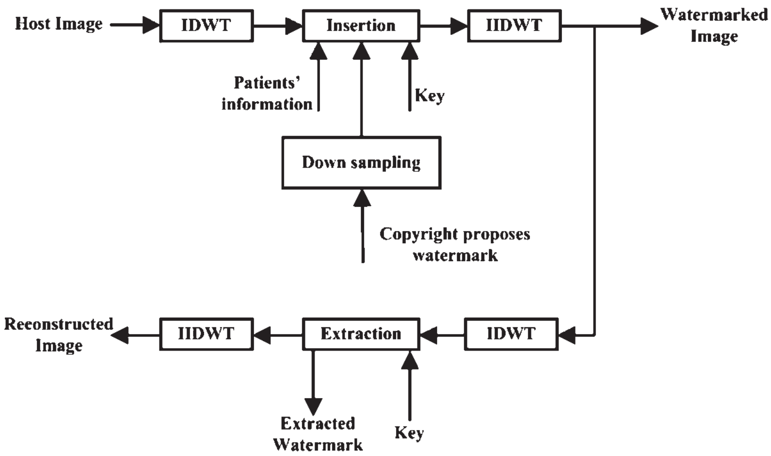
Modern digital healthcare systems facilitate easy access to medical images and provide an easy way to distribute and manipulate them. Exchange of medical images could efficiently provide easy and fast access to medical experts and decrease healthcare costs. To increase the reliability of the experts' decision, large amounts of patients' vital information including patients' information and examination is usually transmitted with medical images from one healthcare centre to others. For the secure transmissions of these data and to prevent unauthorised access to the patients' information, they must be suitably inserted in medical images. Data hiding algorithms and especially watermarking algorithms are employed in inserting procedure. On the other hand, to ensure the copyright protection of the content, a mark such as the hospital logo or the doctor signature must be inserted in the host image. Thus, at least two separate sets of data with different aims must be inserted into the host image called multiple watermarking. Moreover, because of life-and-death inherent of medical images, no distortion is acceptable after watermark extraction. Therefore, reversible property must be met in watermarking procedure.[1,11–17]

In medical image watermarking application, scalability is used to effectively achieve the multiple image watermarking. This objective can be achieved by inserting a lower version of the watermark in the host image. In this case, some provided capacity remains to insert patients' examination, while the copyright protection proposes are achieved.[13–15]

Medical image watermarking is often implemented in two different ways. In the first way, the whole image is used to embed the watermark data. In the second one, the image is divided to the region of interest (ROI) and region of non-interest (RONI), and then the watermark data is inserted in the RONI.[15–17] For the implementation of each one, various watermarking algorithms such as histogram shifting, histogram compression and compressed binary bit-plane are employed. Significant higher capacity of the first category makes it more favourable than the second one. On the other hand, using the histogram compression or compressed binary bit-plane needs some overhead data, for which one could reconstruct the host image and watermark without any distortion. Therefore, it seems that histogram shifting applied to the whole image can be an appropriate choice for medical image multiple watermarking.

Histogram shifting can be implemented in spatial and transformed domain. Figure 1 shows the histogram of a typical image in both domains. In spatial domain, some pixels of the host image are selected and modified, so a gap named zero-point appears in the image histogram. Location of this zero-point is used to insert watermark bits in the host image. The mentioned gap is created in the histogram to prevent the interference of the host image and watermark data. The modified pixels could get their preliminary value after watermark extraction.[1,9,10] To achieve lossless watermarking algorithm in transformed domain, an integer wavelet transform is often used. The required gap for inserting the watermark bits is created in this domain by modifying some of the wavelet coefficients. Integer wavelet transform maps integer image components (pixels) to integer coefficients in wavelet domain and therefore prevents overflow when the coefficients are coded into specified number of bits.[1,5,6,11,18–20]

Owing to the increased exchange of medical data between healthcares, reversible image watermarking algorithms has recently become an emerged research area.[2,5–10,18–20] The introduced algorithm for reversible watermarking in Ref. 2 uses pairs of minimum and maximum points to insert watermark in the host image. A partial of the histogram in spatial domain located between the maximum and minimum points are shifted to right or left to create a zero-point. For lossless extraction of the host image and watermark, the minimum points' information must be embedded in the host image as the overhead data. Inserting of the overhead data instead of the watermark data causes reduction of the algorithm efficiency. In Ref. 6, a reversible watermarking algorithm based on histogram compression in spatial domain had been introduced. It uses simple shifting of the bits to create the required zero-point in the histogram. Lossless extraction of the host image is provided by expansion of the compressed histogram. The intact histogram of the host image could not be obtained by expansion of the compressed histogram. So, the error between these two histograms must be inserted in the host image as the overhead data. The philosophy of introduced methods in Refs 10 and 11 relies on the similarity of the neighbouring pixels to achieve higher capacity compared with Ref. 2. In general, the pixels value for neighbouring ones is close to each other. Therefore, the peak point for the residual histogram is greater than that for the pure spatial histogram. However, the problem associated with Ref. 2 is not solved in these researches. Implementation of the algorithms introduced in spatial domain is limited to the low payloads and thus is not appropriate for high payload application such as the medical one.[1,18] To significantly increase the capacity of the watermarking algorithms, the process of watermarking is better to be done in wavelet domain. The routine histogram shape of high-frequency sub-bands, besides low impact of disturbances in these sub-bands on human visual system (HVS), makes wavelet coefficients which are located in these sub-bands, as good candidates for watermark embedding. Xuan *et al.*[18] introduced a reversible watermarking algorithm in wavelet domain by using histogram shifting. A threshold close to the peak point (zero) of the histogram is selectd and then the coefficients greater than this threshold shift to the right by one unit. Locations of the threshold and created zero-point are used to insert the watermark data. If the data to-be-embedded remain, a new zero-point is created and this process continues until all the watermark bits be inserted. In Ref. 18, the thresholds are selected completely arbitrarily in the middle region of the histogram where a large number of coefficients exist. Thus, creating the zero-points requires a wide region of the histogram to be shifted and consequently has a negative impact on the imperceptibility of the watermarked image. The introduced method in Ref. 19 is really another version of the method introduced in Ref. 18. The host image is first divided into the non-overlapping blocks and then the data to-be-embedded insert in the high-frequency wavelet coefficients of each block. The insertion process is done via LSB-substitution or bit shifting. Reversibility of the algorithm could be achieved by embedding the side information in the host image which has negative impact on imperceptibility of the watermarked image. Furthermore, perceptible distortions appear in the border of the neighbouring blocks. In addition to the above challenges associated with each algorithm, the mentioned algorithms only embed one type of data such as hospital logo or vital information of patients in the host image. Therefore, only one aspect of data hiding advantages such as copyright proposes can be achieved which is not so favourable in the medical image application. Embedding of watermark in RONI introduced in Refs. 15–17. Reversibility of the watermarking algorithm as the most important feature in medical application has been often neglected at this category. Theses papers focused on the authentication and robustness of the algorithm which are not very important issues in medical images watermarking. In other words, they often embed multiple watermarks to ensure the copyright protection, to help authentication, and to prevent unauthorised access. However, the correct diagnosis of disease can be practical when vital and personal information and



2 Block diagram of the proposed watermarking system

examination of patients are available to an expert which is completely missing in these researches.

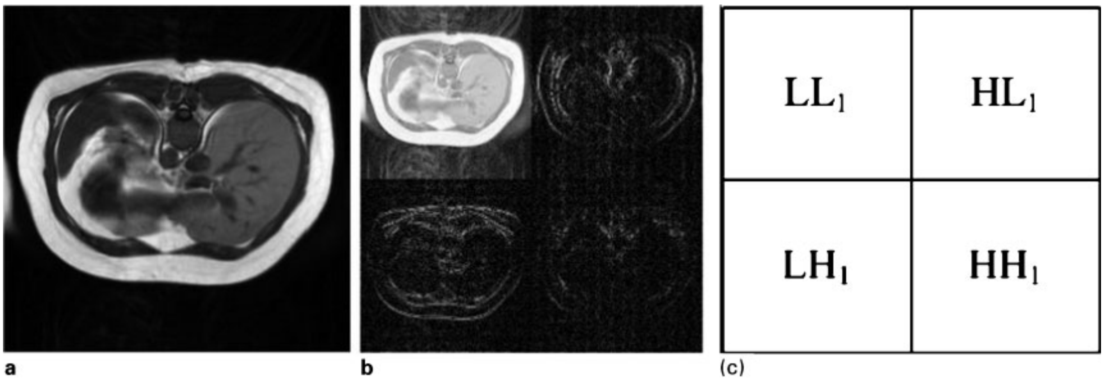
In general, all of the above mentioned researches based on histogram shifting have two major difficulties. First, for the low payloads, the thresholds are selected in the middle part of the histogram where a large number of coefficients exist. Therefore, a large number of coefficients are modified in the shifting process as it is not required. It causes quality reduction of the watermarked image. Second, high payloads are achievable only when the histogram shifting procedure has been done several times. These studies do not introduce an algorithm for finding the thresholds and they often select thresholds arbitrarily and close to the peak point (sometimes the peak point), which significantly decrease the watermarked image quality. However, higher quality of watermarked image can be achieved by selecting the threshold far from the peak point (zero) for low payloads and by decreasing the number of times that the shifting procedure occurs for high payloads.

This paper proposes an algorithm which fulfils the above mentioned requirements for histogram shifting of the high-frequency wavelet sub-bands. Based on the required capacity, two thresholds, one in the beginning part (left part) and the other in the end part (right part) of the histogram, are selected. Each threshold provides a part of the required capacity for the watermark data. A significant number of coefficients located in the middle part of the histogram are kept unchanged and thus, a high quality for the watermarked image is obtained. These thresholds and zero-points guarantee the smallest area shift in the histogram according to the capacity required for the watermark and therefore, it is expected to provide a high imperceptibility for the watermarked image. Moreover, the shifted parts are located in the beginning and end parts of the histogram which contain higher frequency values which are less sensitive to HVS.

The rest of this paper is organised as follows. In Section 2, the block diagram for the proposed watermarking system is introduced. Section 3 discusses the insertion and extraction algorithms. In Section 4, simulation details and simulation results are explained and finally, Section 5 concludes the paper.

2 THE PROPOSED WATERMARKING SYSTEM

The block diagram of the proposed watermarking system is shown in Fig. 2. The used watermark data consist of the patients' examination and a lower version of the copyright proposes mark. This watermark is encrypted by a private key and then inserted in the decomposed image obtained by applying a two-dimensional (2D) integer discrete wavelet transform (IDWT). Finally, inverse IDWT (IIDWT) is applied to the watermarked coefficients to obtain the watermarked image in the spatial domain. In the end, host image and watermark are obtained by doing the mentioned stages in the embedder but in reverse direction. Details of the insertion and extraction algorithms will be given in the next section. Note that the watermark extraction is completely blind and the host image data are not required in the detector to achieve reversible property.



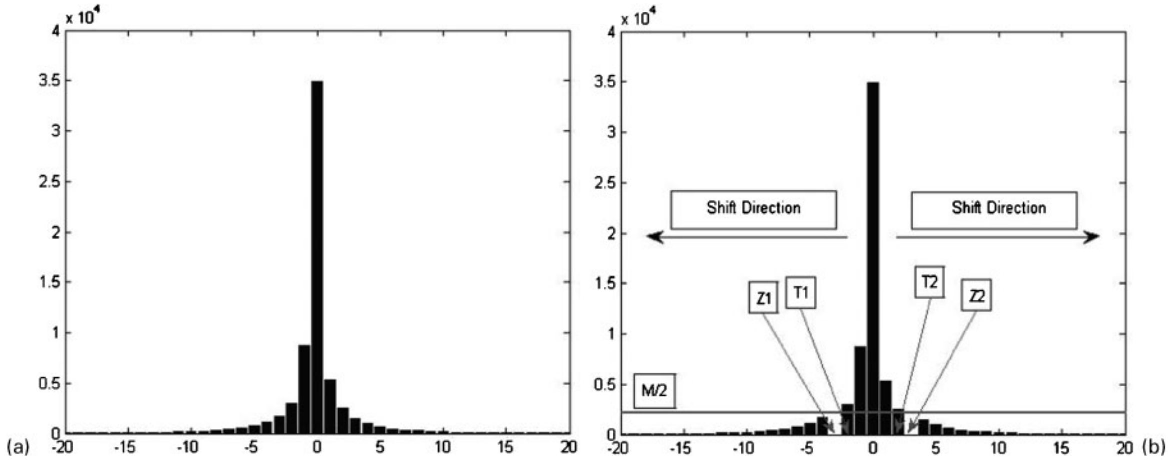
3 (a) A medical host image; (b) decomposed image by applying one level of IDWT; (c) frequency sub-bands of (b)

3 INSERTION AND EXTRACTION ALGORITHM

Applying L level of a 2D integer wavelet transform to an image decomposes the image to $3\times L+1$ sub-bands, one low frequency sub-band called LL_L and $3\times L$ high-frequency sub-bands referred to as LH_i, HL_i and HH_i ($i=1, 2, \ldots, L$). A typical decomposed medical image for $L=1$ and its sub-bands are shown in Fig. 3. Histogram of the high-frequency sub-bands of Fig. 3a after decomposition by one-level IDWT is shown in Fig. 4a. The figure shows a Laplacian-like distribution around a peak point (zero). According to the capacity required for the watermark insertion, two coefficients, called thresholds, are selected. Assume an M-bit watermark pattern, a horizontal line at $M/2$ are drawn to find the proper thresholds, one in the left side (beginning part) of the histogram, called T_1, and the other in the right side (end part), called T_2, as shown in Fig. 4b. Then the left side of T_1 is shifted to left by one unit and the right side of T_2 is shifted to right by one unit. Because of a narrow band histogram of high-frequency sub-bands for medical images, there is no concern about the overflow of coefficients after histogram shifting. This shifting causes to appear two gaps, one at the left of T_1 and the other at the right of T_2 which are called zero-points and referred to as Z_1 and Z_2, respectively. The thresholds and zero-point locations are used during watermarking insertion and extraction algorithms. Note that several pairs of coefficients in the range of $[T_1, T_2]$ can be selected as thresholds. However, T_1 and T_2 are selected in such a way that the shifted regions are small as much as possible, while the required capacities for inserting data are provided. If one of the thresholds becomes zero, the other one is also fixed at zero. In this case, first, the right hand of zero is shifted to right side by one unit and then the watermark data is inserted in the histogram. Then, if the data to-be-embedded are remained, the left hand side is shifted and inserting is continued. Unauthorised access to the embedded data in the host image could be completely eliminated by using a private key in the embedder. By this key, the watermark data are encrypted and then inserted in the host image. Only the authorised user can extract the intact watermark and host image by knowing the extraction algorithm and by having the same private key. Details of insertion and extraction algorithms are as follows.

3.1 The watermark insertion algorithm

1. Apply L levels of a 2D IDWT to the host image to obtain the decomposed one.
2. Find T_1 and T_2 (as mentioned above) on the histogram of the high-frequency sub-bands (i.e. LH_i, HL_i, HH_i, $i=1, 2, \ldots L$).
3. Create the zero-points (Z_1 and Z_2):
   - Shift the left side of T_1 to left by one unit to create zero-point Z_1 (Fig. 4b)
   - Shift the right side of T_2 to right by one unit to create zero-point Z_2 (Fig. 4b).
4. Create lower resolutions of the copyright protection binary logo watermark to some by down sampling the watermark as shown in Fig. 5 (separating odd and even rows and columns).
5. Encryption of the watermark, using a private key (total size of the watermark is $M+N$, including M bits copyright watermark and N bits patient personal and examination data).
6. Insert the watermark (W):
   - Divide the watermark into two parts ($W1$ and W_2). The first half of the watermark as W_1 (size: $M+N/2$) and the second half as W_2 [size: $(M+N)/2$]



4 (a) Typical histogram of high frequency sub-bands of a medical grey scale image; (b) histogram shifting (T_1 and T_2 are thresholds and Z_1 and Z_2 are zero-points)

- Insert bit 0 and bit 1 of W_1 at T_1 and Z_1 respectively: find the coefficients in the high-frequency sub-bands of the decomposed image where their value is equal to T_1. For each found coefficient (C_i), embed one bit of W_1 (W_{1i}):

$$C_i = C_i - W_{1i} \tag{1}$$

where i=1, 2, …, $(M+N)/2$
- Insert bit 0 and bit 1 of W_2 at T_2 and Z_2, respectively: find the coefficients in the high-frequency sub-bands of the decomposed image where their value is equal to T_2. For each found coefficient (C_j), embed one bit of W_2 (W_{2j}):

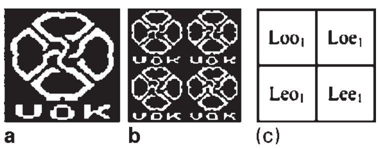
$$C_j = C_j + W_{2j} \tag{2}$$

where j=1, 2, …, $(M+N)/2$.

7. Apply L levels of 2D IIDWT to obtain the watermarked image in spatial domain.

3.2 The watermark extraction algorithm

1. Apply L levels of a 2D IDWT to the watermarked image to obtain the decomposed watermarked image.
2. Extract the watermark (W):



5 (a) watermark; (b) downsampled watermark; (c) sub-bands of (b)

- Scan the high-frequency sub-bands of the decomposed image to find the coefficients the value of which is equal to T_1 or Z_1. For each found coefficient, extract one bit of W_1 by considering T_1 as 0 and Z_1 as 1
- Scan the high-frequency sub-bands of the decomposed image to find the coefficients the value of which is equal to T_2 or Z_2. For each found coefficient, extract one bit of W_2 by considering T_2 as 0 and Z_2 as 1
- Reconstruct of W by using W_1 and W_2 as the first and second half parts of W, respectively

$$W = [W_1, W_2]$$

3. Shift the high-frequency sub-bands histogram in reverses direction:

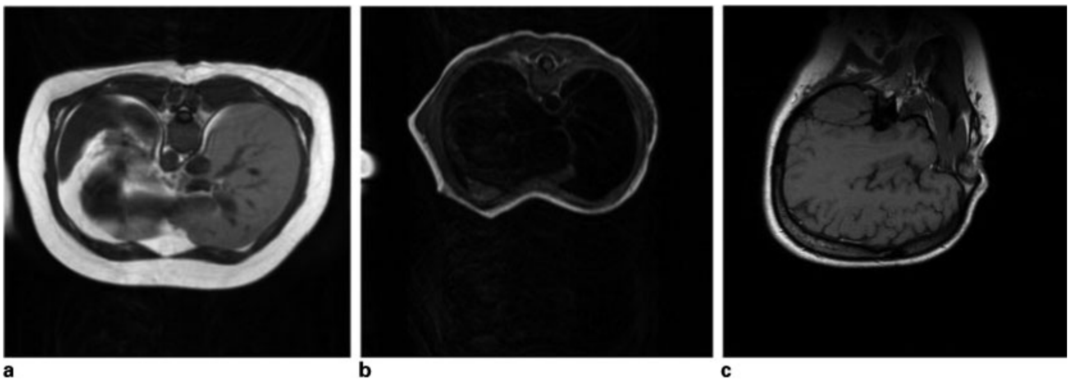
- Shift the left side of T_1 to right by one unit
- Shift the right side of T_2 to left by one unit.

4. Decrypt the extracted watermark by using the private key.
5. Apply L levels of 2D IIDWT to reconstruct the original host image.

There is no need to have the host image during watermark extraction process; therefore, the process is completely blind.

4 EXPERIMENTAL RESULTS

The proposed watermarking system has been software-implemented in Matlab. Three sets of MRI data, MR_liver_t1 (57 slices), MR_ped_chest (76



6 A slice of the medical images used for test: (a) MR_liver_t1; (b) MR_ped_chest; (c) MR_sag_head

slices) and MR_sag_head (58 slices), have been used as host medical images for test. Figure 6 shows one slice of each set. Host images are grey scale with spatial resolution of 256×256 pixels. A binary logo image with resolution of 64×64 pixels has been used as watermark for the copyright proposes (Fig. 5a). For each MRI data set, watermarking has been done for all slices. peak signal-to-noise ratio (PSNR), mean structural similarity index measure (MSSIM) and just-noticeable distortion (JND) reported in this section for each MRI data set are the mean values obtained for all watermarked slices.

Superiority of the proposed method compared with other methods is demonstrated by considering two scenarios. The first scenario is dedicated to demonstrate the superiority of the method for the low payloads. The second scenario demonstrates the superiority of the method for high payloads, which is appropriate for multiple watermarking proposes.

4.1 Scenario A

In this scenario, one level of integer wavelet transform is applied to the host image and the decomposed image is obtained. First, the watermark is encrypted by a private key and then inserted in the host image based on embedding algorithm. Table 1 shows the PSNR results obtained for scenario A.

As previously stated, the philosophy of selecting thresholds which have the capacity equal to $M/2$ instead of M is to meet the required capacity by using thresholds which are far from the peak point. Therefore, a large number of wavelet coefficients located in the middle region of histogram (around zero) are kept unchanged. Table 2 shows the selected thresholds for the proposed method and the method proposed in Ref. 18. The percentage of distorted coefficients in the both methods is also shown in this table. It is obvious that the proposed method significantly reduces the shifted coefficients and thus improves watermarked image quality.

Table 1 PSNR results for scenario A

Host images	Host image size (pixels)	Watermark size (bits)	PSNR (dB)
MR_liver_t1(57 slices)	256×256	32×32	57.13
MR_ped_chest(76 slices)			58.09
MR_sag_head(58 slices)			57.21
MR_liver_t1(57 slices)		64×64	53.60
MR_ped_chest(76 slices)			54.03
MR_sag_head(58 slices)			53.07

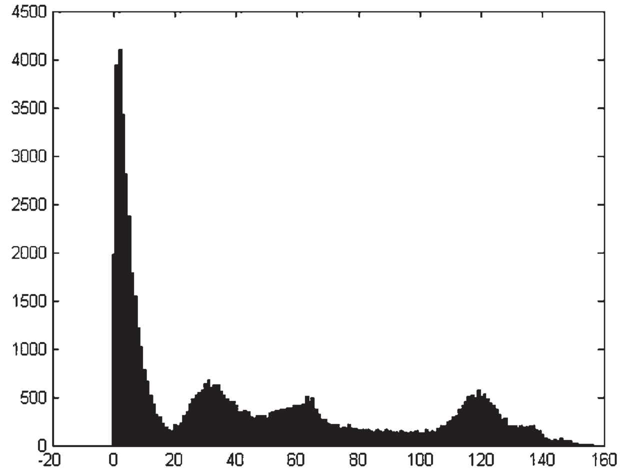
Table 2 Selected threshold in Ref. 18, the proposed algorithm and comparison between them

Host image	Slice no.	Payload (bits)	T (Ref. 18)	Distorted bits (%)[18]	T_1, T_2 (proposed method)	Distorted bits (%) (proposed method)
MR_ped_chest	48	9000	0	58	−3, 2	41
MR_sag_head	48	6000	0	28	−2, 2	18
MR_liver_t1	35	12 000	0	27	−2, 1	19

PSNR is a meaningful criterion to show the advantages of the algorithm for high payloads. However, it is not an appropriate criterion to compare the various watermarking algorithms for low payloads (pure watermarking proposes). Therefore, JND and MSSIM are introduced as the better choice for low payloads comparison. JND is the smallest detectable difference by HVS between the host image and the watermarked image.[22] Lower JND indicates the better quality for watermarked image. MSSIM is also recognised as another meaningful criterion for evaluation of similarity between two images.

The algorithms introduced in[2,18] are also software-implemented and the results are compared with the proposed algorithm in Table 3 by PSNR, JND and MSSIM criteria. It is demonstrated from Table 3 that the proposed algorithm provides better quality for the watermarked image compared with methods in Refs. 2 and 18. The results show the lower JND for Ref. 2, i.e. higher watermarked image quality, compared with Ref. 18. Peak point for medical images is located in the beginning of the histogram (Fig. 7). Thus, by shifting the histogram between the minimum and maximum points, almost all of the pixels value increased by one unit and therefore, a perceptible frequency distortion for HVS is not introduced. However, in Ref. 18, a substantial region of the wavelet coefficients is changed and the other kept intact and thus, JND increases. Taking into account the very low numbers of shifted coefficients in the proposed method besides location of these coefficients (shifted parts contain higher frequency values that are less sensitive to HVS) causes a better JND for the proposed method compared with Ref. 2. A comparison between the algorithms introduced in Refs. 2 and 18 and the proposed method in this paper are carried out for a wider range of payloads in Fig. 8.

In the implementation of the proposed algorithm, usually the selected T_1 and T_2 (based on the proposed algorithm in Section 3) have coefficients more than $M/2$. In this case, all of the capacity provided by T_1 can be used to insert watermark data and for the remained watermark data, a new T_2 which satisfy the required remained capacity is selected. By this technique, T_2 which is selected based on the algorithm introduced in Section 3 is increased by one/two unit for some of the slices. Experimental results show improvement in JND results by using this technique.



7 Typical histogram of a medical grey-scale image in spatial domain

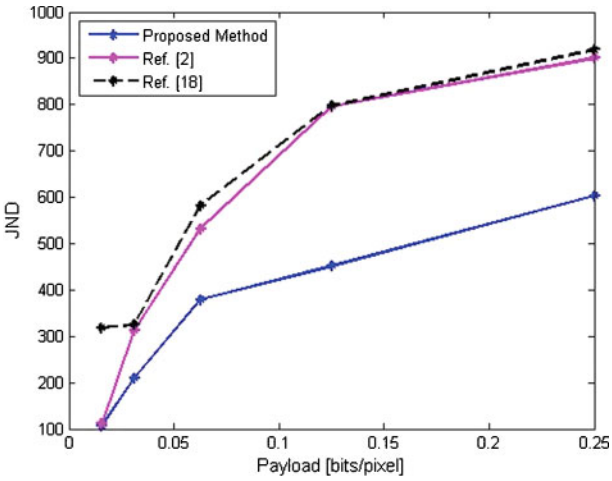
4.2 Scenario B

In this scenario, superiority of the proposed method for embedding high amount of data in the host image is demonstrated. Two sets of high-frequency sub-bands are provided for embedding the watermark data (two separate sets) by applying two levels of IDWT (Fig. 9).

In the insertion procedure, the copyright proposes watermark is decomposed into its odd and even rows and columns to have four lower resolutions (Fig. 5b) and the patients' personal examination data are also included for insertion. After encryption of the copyright proposes watermark and patients' examination

Table 3 Comparison of PSNR, JND and MSSIM between proposed method and methods in Refs. 2 and 18

		MR_liver_t1			MR_ped_chest			MR_sag_head		
Algorithm	Logo Size (bits)	PSNR	JND	MSSIM	PSNR	JND	MSSIM	PSNR	JND	MSSIM
Ref. 2	32×32	48.70	237.06	0.9959	49.10	606.99	0.9942	47.12	111.37	0.9984
Ref. 18		51.17	730.98	0.9956	51.57	1192	0.9904	51.86	318.68	0.9953
Proposed method		57.13	129.12	0.9992	58.09	433.43	0.9989	57.21	105.90	0.9990
Ref. 2	64×64	48.64	567	0.9958	49.02	787.96	0.9942	46.09	312.32	0.9981
Ref. 18		50.94	746	0.9950	51.31	1250	0.9897	51.94	325.57	0.9953
Proposed method		53.60	503.37	0.9971	54.03	737.57	0.9964	53.07	209.48	0.9958



8 JND values for different payloads for MR_ped_chest set

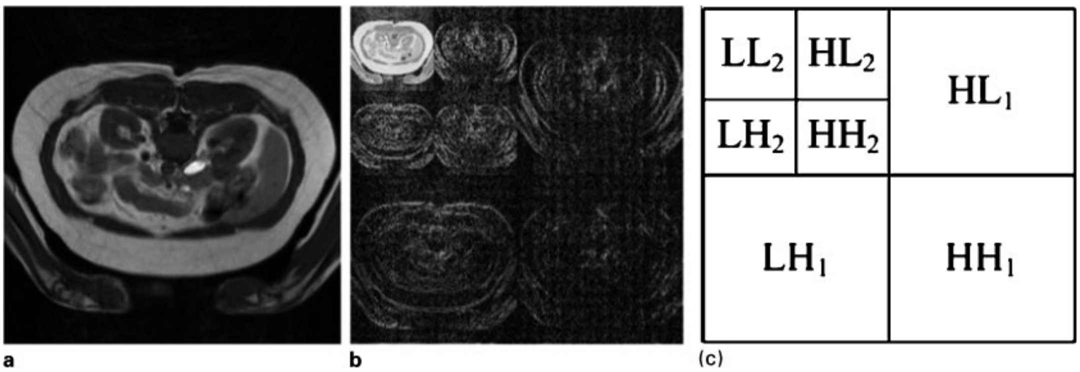
data by using a private key, they are inserted in the first and second levels of high-frequency sub-bands of the decomposed image, respectively.

Impact of increasing IDWT levels on the quality of the watermarked image is demonstrated by comparing scenario B and A for low payloads. After that, the method extends to the higher payloads.

For embedding watermark data, the first sub-band of the decomposed watermark (Loo_1) is inserted in the three middle high-frequency sub-bands (LH_2, HL_2 and HH_2) and the remained part of the decomposed watermark (Loe_1, Leo_1 and Lee_1) are inserted in the three high-frequency sub-bands (LH_1, HL_1 and HH_1). The PSNR, MSSIM and JND are shown in Table 4. According to the results presented in Tables 3 and 4, PSNR and MSSIM values for the proposed algorithm with one level of integer wavelet transform ($L=1$) are greater than with two levels ($L=2$) and the JND values are lower. It is due to the part of the watermark bits that is inserted into the three middle high-frequency sub-bands (LH_2, HL_2 and HH_2) for $L=2$. These sub-bands contain some lower-frequency components compared to LH_1, HL_1 and HH_1 which have a negative impact on imperceptibility of the watermarked image.

The results for higher payloads are reported in Table 5. For high payloads, Loo_1 sub-band of copyright watermark which has a smaller size is inserted into the three middle high-frequency sub-bands (LH_2, HL_2 and HH_2), and the patients' information and examination are inserted in the LH_1, HL_1 and HH_1. For inserting the watermark in the two sets of high-frequency sub-bands, a procedure similar to scenario A must be followed.

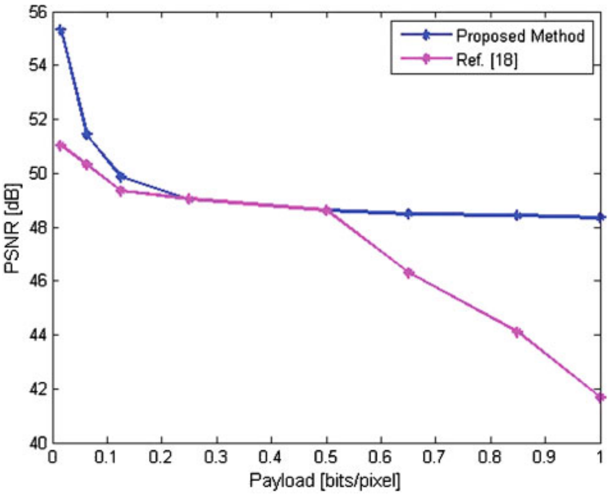
In Ref. 18, high-payload watermark insertion is achievable by selecting the $[-T, T]$ range and continuously shifting of the histogram in the mentioned



9 (a) A medical host image; (b) decomposed image by applying two levels of IDWT; (c) frequency sub-bands of (b)

Table 4 Results of PSNR for scenario B

Image set	Logo size (bits)	PSNR (dB)	JND	MSSIM
MR_liver_t1	32 × 32	54.13	180.63	0.9990
MR_ped_chest		55.32	457.46	0.9978
MR_sag_head		55.00	127.08	0.9988
MR_liver_t1	64 × 64	50.80	570.71	0.9961
MR_ped_chest		51.43	782.37	0.9947
MR_sag_head		51.52	277.15	0.9949



10 PSNR values for different payloads for MR_ped_chest set

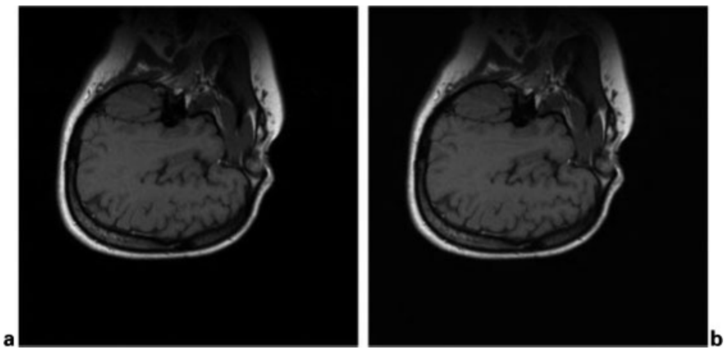
range. Assuming that the watermark size is 65 536 (i.e. payloads=1 bit/pixel), T must be selected as 5 (T=5). Therefore, the histogram is shifted six times to right and five times to left. However, the proposed algorithm shifts the histogram only one time to right and one time to left. Experimental results show 6-dB difference in PSNR between the algorithm in Ref. 18 and the proposed algorithm for 1 bit/pixel payload. Figure 10 shows the comparison of PSNR between the proposed method in this paper and the method in Ref. 18 for a wide range of payloads. In this figure, for the payloads 0.27–0.53 bit/pixel, both methods have the same PSNR. In this range, the threshold is selected equal to zero and both methods shift the right hand of the histogram to right by one unit. Implementation of the introduced method in Ref. 2 is limited only to the low payloads, where watermark data could be inserted in the host image only by one time shifting of the histogram. Therefore, it could not be an appropriate algorithm for multiple watermarking which is usually required for medical images watermarking.

As a visual result, Fig. 11 shows the host and watermarked images for slice 14 of MR_sag_head data set (payload=1 bit/pixel). It is obvious that the HVS cannot identify any disturbance in the watermarked image.

Note that applying attacks to the watermarked image to show the robustness of the method causes image quality loss which is in conflict of the reversibility idea that requires extraction of the host image and the inserted watermark without any loss.

5 CONCLUSIONS

A reversible blind medical image watermarking approach in wavelet domain is proposed. According to the requirement of medical images, two sets of watermark data are inserted in the host image. The



11 (a) Host image; (b) watermarked image for 1 bit/pixel (PSNR=49.54 dB)

Table 5 Results of PSNR for greater payloads

Host image	Payload (bit/pixel)	No. of bits	PSNR (dB)
MR_ped_chest (76 slices)	0.0156	1024	55.32
	0.0625	4096	51.43
	0.1250	8192	49.87
	0.2500	16 384	49.03
	0.5000	32 768	48.62
	1.0000	65 536	48.35

first set ensures the copyright protection and the second one provides ancillary information about the host image owner situation for the true diagnosis of disease in the end. Scalability is employed in the insertion procedure to effectively achieve multiple medical image watermarking. The watermark data are encrypted by a private key to improve the security of the method and prevent unauthorised access.

The method uses two thresholds located in the beginning and end part of the wavelet histogram to insert the watermark data. The selection of thresholds far from the middle of the histogram for low payloads along with only one shifting procedure per region, even for high payloads, guarantees significant improvement in watermarked image quality compared to related methods in the literature.

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