

Medical image watermarking using bit threshold map based on just noticeable distortion in discrete cosine transform

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Abstract.

BACKGROUND: Medical images stored in a hospital system are generally confidential and integrated and require strict security. However, medical information stored on digital medical imaging systems, as well as picture archiving and communication systems (PACS), are vulnerable to attack when the data are transferred over wireless or wired communication networks.

OBJECTIVE: To solve this problem, a watermarking algorithm for medical images is proposed using a bit threshold map based on just noticeable distortion (JND) in the discrete cosine transform (DCT) method.

METHODS: The low-frequency component comprises a considerable amount of the signal energy for most images. As a result, it has a crucial effect on the image quality. Therefore, in this paper, the proposed algorithm embeds watermarks based on the low-frequency components of the image, such as the DC coefficient of the DCT.

RESULTS: When watermarks are embedded in a low frequency area, the subjective image quality is often degraded. To compensate for the degradation of the imperceptibility of the watermarking system, which results from embedding watermarks in the low-frequency component, this research considers the human visual system. In addition, the embedding strength of the JND value is used to improve the watermarking imperceptibility.

CONCLUSIONS: We applied the proposed watermarking algorithm to a variety of medical images using a computer simulation. The algorithm's performance was verified using a variety of attacks for eliminating watermarks. The simulation results show that the proposed algorithm robustly provides protection against a variety of possible attacks.

Keywords: Medical image, digital image watermarking, non-destructive testing, human visual system, just noticeable distortion, discrete cosine transform, bit threshold map

1. Introduction

Digital image watermarking is an effective method in copyright protection. In watermarking technology, the robustness of the technology against attacks is key. A digital image watermarking system is generally similar to a communication system composed of three main elements: a watermark embedder, communication channel, and watermark detector. The embedder and detector are typically more

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attractive to researchers [1]. Researchers additionally consider the design properties of the digital watermarking system, as shown in Eq. (1), which is used to embed the watermark in frequency domain images [2].

$$v'_i = v_i + \alpha x_i, \quad (1)$$

where v'_i denotes the discrete cosine transform (DCT) coefficients after conducting the watermarking process, v_i denotes the DCT coefficients before the watermarking process is conducted, α is the control parameter, and x_i denotes the binary values of the watermark.

Today, medical images containing information relating to the health of patients are widely used in patient diagnosis. However, owing to the large data size of medical images, high-quality telemetry communication technology is required for their transfer. Network safety is also significant when transferring medical images. To prevent security problems from occurring, the host medical image can be watermarked with patient information. The cover images used a watermark of encoded patient data that is not detectable before being transferred over the network. The doctor can then check whether the watermark is inserted before proceeding with the diagnosis; moreover, the watermark should not interfere with the image. This application is essential for telemedicine [3,4].

The significant demand for these technologies has prompted the advancement of watermarking techniques that can be applied to various medical imaging media. Numerous medical image watermarking schemes in the frequency domain have been proposed [5]. More robust methods have been developed for frequency-domain-based watermarking scheme filtering and geometry attacks than for spatial-domain-based watermarking techniques. The fusion-based watermarking technique has also been studied [6,7]. This technique prevents the distortion of the information contained in the noise added to the original image. Moreover, in 2014, Bose et al. proposed a method for biomedical applications of watermarking algorithms [8] in medical video watermarking systems. In 2014, Eswaraiyah et al. presented a fragile region of interest (ROI)-based medical image watermarking technique using tampering detection and recovery [9]. The algorithm stored in the ROI of the fragile watermark information of the least significant bit (LSB) and enhanced ROI is part of the recovery without loss. Furthermore, the run-length coding scheme is used to improve filling capacity.

The most important aspect of the watermarking technique is determining the strength of the watermark insertion. To resist normal signal processing and related attacks, the embedding strength should be as high as possible. However, because the watermark directly affects the host image, the higher the embedding strength, the lower is the quality of the watermarked image. In other words, the robustness and imperceptibility of the watermark are inversely proportional. In addition, when improving invisibility of the embedded watermark, the human visual system (HVS) model must be considered. In this way, the strength of the watermark can be adapted to the features of the host image to guarantee the maximum-possible imperceptibility of the watermark [10,11]. These technologies are utilized in information security technologies and testing techniques using images in industry, not just in the medical field. In particular, the use of the non-destructive testing technique of C-SCAN using an ultrasound image, and increase in industrial automation, as image processing techniques applied has been applied to security and inspection.

In this paper, we present a medical image watermarking algorithm using DCT and the just noticeable distortion (JND) method based on HVS. To improve the imperceptibility of the watermarking system, a JND mask based on the HVS model is used. In DCT, the domain of the discrete decomposed image has the highest energy in the host image; therefore, it has a crucial effect on the image quality. Conventional DCT watermarking algorithms do not utilize the baseband to retain invisibility. That is, they do not utilize

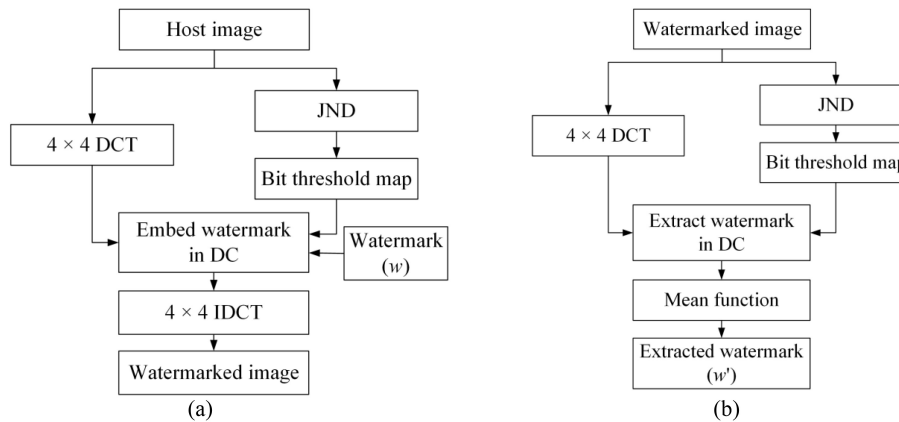


Fig. 1. Block diagram of the proposed medical image watermarking process: (a) embedding process, (b) detecting process.

the characteristics of the DC coefficients that participate in the watermark embedding. Therefore, their robustness deteriorates when facing various attacks. Thus, to reduce the limitations of the conventional algorithms, the proposed algorithm uses the DC coefficients in the watermark-embedding step. In addition, because embedding the watermark in the DC coefficients degrades the invisibility, this algorithm includes the JND mask as the embedding strength to compensate for the invisibility degradation.

2. Proposed watermarking methods

2.1. Overview of proposed method

To embed watermarks in the low-frequency components of the original image, the proposed algorithm uses a 4×4 block DCT. Numerous DC coefficients are generated using a 4×4 block DCT in the original image. As a result, a large amount of the embedded watermark is robust to attack. However, the correct approach does not unconditionally increase the number of DC coefficients to reduce the amount of sub-sampling of the DCT block. Using a computer simulation, we confirmed that the 4×4 block DCT optimizes the trade-off between capacity and performance in resisting watermark attacks.

The proposed method changes the lower bits of a DC coefficient to embed a watermark, and one watermark bit is embedded in the DC coefficient of each block. To determine the number of lower bits needed for a DC coefficient to embed a watermark, a JND from a self-reference image is used as the embedding strength of the watermark. In the watermark extraction process, this method can extract watermarks using the lower bits of a DC coefficient for each block in the watermarked image. A block diagram of the proposed method is shown in Fig. 1.

2.2. Discrete cosine transformation

DCT is a widely used transformation technique for image processing of various types. Through DCT, spatial domain data can be transformed into the frequency domain, while frequency domain data can be transformed back to the spatial domain using the inverse DCT (IDCT). The DCT formulas [12] are as follows:

$$D(i, j) = \frac{1}{\sqrt{2N}} C(i) C(j) \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} f(x, y) \times \cos \left[\frac{(2x+1)i\pi}{2N} \right] \cos \left[\frac{(2y+1)j\pi}{2N} \right] \quad (2)$$

$$y(x, y) = \frac{1}{\sqrt{2N}} \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} C(i)C(j)D(i, j) \times \cos \left[\frac{(2x+1)i\pi}{2N} \right] \cos \left[\frac{(2y+1)j\pi}{2N} \right] \quad (3)$$

where $C(k) = \begin{cases} \frac{1}{\sqrt{2}} & \text{if } k = 0, \\ 1 & \text{if } k = 1, 2, \dots, N-1. \end{cases}$

In the above formulas, $f(x, y)$ stands for the pixel value at position (x, y) , $D(i, j)$ represents the coefficient value in frequency domain position (i, j) , and N denotes the length or width of the image. The coefficient at the top left corner of the frequency domain matrix represents the DC value of the image's frequency domain. The remaining parts are the AC values, with the absolute value of the AC in each position representing the magnitude of the energy.

2.3. Just noticeable distortion

HVS is an important aspect of subjective image quality. Therefore, the subjective image quality can be improved by reflecting human visual characteristics. This capability is increasingly being studied [13, 14]. Human visual characteristics can be divided into human visual sensitivity and visual interest. HVS includes various characteristics of luminance adaptive motion and contrast sensitivity. Regarding these characteristics, Chou's JND model [13] is mathematically constructed as a subjective quality correlation, which is characterized by the highest luminance adjustment.

For this reason, Chou's JND model was selected for this study to embed the watermarks. JND refers to the maximum distortion that the HVS cannot perceive. It plays an important role in perceptual image processing. Chou's JND model is employed to quantify the perceptual redundancy and provide each signal being coded with a visibility distortion threshold. Below this threshold, reconstruction errors are rendered imperceptible [15–17]. This model analyzes the local properties of image signals to incorporate threshold sensitivities due to background luminance and texture-masking effects. The model is estimated by analyzing local properties of image signals.

2.4. Bit threshold map

This study uses the JND value and bit threshold map (BTM) for the watermark embedding strength and position. By referencing the bit threshold value of each block, a watermark is embedded or extracted from the lower bits of the DC coefficient. A block diagram of the bit threshold map is shown in Fig. 2. As shown in the block diagram, a BTM is generated by executing Step 4.

- Step 1. Generate a self-reference image with parts of the low-frequency component in the original image.
- Step 2. Apply Chou's luminance mask to generate the JND matrix for the self-reference image.
- Step 3. Decompose the JND matrix into a 4×4 block without overlap and apply DCT to each block.
- Step 4. Use the DC coefficient to generate a BTM. Calculate the bit-threshold value in the DC coefficient using Eq. (4).

$$2^m < DC(i, j) \leq 2^{m+1}, \text{ where } 0 \leq i \leq H/4 \text{ and } 0 \leq j \leq W/4 \quad (4)$$

where $DC(i, j)$ is the DC coefficient of the JND matrix, H and W represent the height and width of the matrix, respectively, and m represents the bit threshold for dividing each block.

In the proposed method, a one-bit threshold is generated per block; the bit threshold map is $H/4 \times W/4$ of the matrix. Figure 3 shows an example of calculating the bit threshold in each block.

3. Simulation

3.1. Proposed watermarking algorithm

3.1.1. Watermark embedding algorithm

To embed watermarks in the low-frequency components of the original image, the proposed algorithm uses a 4×4 block DCT. This algorithm changes the lower bits of the DC coefficient to embed the watermark. A watermark bit is embedded in the DC coefficient of each block. To determine the number of lower bits needed for the DC coefficient to embed a watermark, a JND from a self-reference image is used as the embedding strength of the watermarks. If the determined number of lower bits of a DC coefficient is n , the corresponding $n - 1$ lower bits are changed to 0, and the n th lower bit is replaced with a watermark bit.

3.1.2. Watermark detecting algorithm

In the watermark extraction process, the algorithm can extract watermarks using the lower bits of the DC coefficient of each block in the watermarked image. Medical image watermark extraction is similar to reversing the watermark-embedding process. First, the image is decomposed into non-overlapping 4×4 blocks. The DCT is calculated to estimate where the watermark should be inserted. Extracting the watermark from the DC coefficient of the block results in a bit threshold value for each block. Second, in referencing the bit threshold value of each block, the watermark is extracted from the lower bits of the DC coefficient. If the bit threshold value of the block is m , the formula for extracting the watermark inserted in the DC coefficient is

$$\begin{aligned} DC(i, j) &= a_L 2^L + \dots + a_m \times 2^m + a_{m-1} \times 2^{m-1} + \dots + a_0 \times 2^0 \\ watermark &= a_m \otimes a_{m-1} \\ \text{where } 0 \leq i \leq H/4 \text{ and } 0 \leq j \leq W/4 \end{aligned} \quad (5)$$

Finally, the extended watermark in the watermark bits is obtained for the entire block. A mean function is used in the expanded watermark to extract the final watermark.

3.2. Evaluation methods

The performance of the proposed algorithm was tested on various image types. The test images included medical resonance imaging (MRI), computed tomography (CT), ultrasonic and X-ray images. The images were 512×512 pixels [18]. In the simulation, a 4×4 block was used for the DCT. The watermarks were 32×32 binary logos extended to 128×128 . The peak-to-peak signal-to-noise ratio (PSNR) was used to analyze the quality of the watermarked image. The PSNR is defined as

$$PSNR = 10 \log_{10} \frac{255^2}{MSE}, \quad MSE = \frac{1}{MN} \sum_{i=1}^M \sum_{j=1}^N ((I_{i,j} - I'_{i,j})^2), \quad (6)$$

where I and I' represent the host image and watermarked image, respectively, and M and N represent the image height and width, respectively.

The amount of mismatched data between the embedded watermark and extracted watermark is used to quantify the similarity of the watermarks. The normalized correlation (NC) of the embedded watermark and extracted watermark is defined as follows:

$$NC = \frac{\sum_{i,j} w_{i,j} w'_{i,j}}{\sum_{i,j} w_{i,j}^2}, \quad (7)$$

where w and w' respectively represent the embedded watermark and extracted watermark.

Table 1
PSNR values of the watermarked images processed by the proposed method and conventional method

Image	MRI		CT		X-ray	
	Proposed method	Liu's method	Proposed method	Liu's method	Proposed method	Liu's method
PSNR(dB)	44.40	39.23	44.53	38.56	44.99	37.36

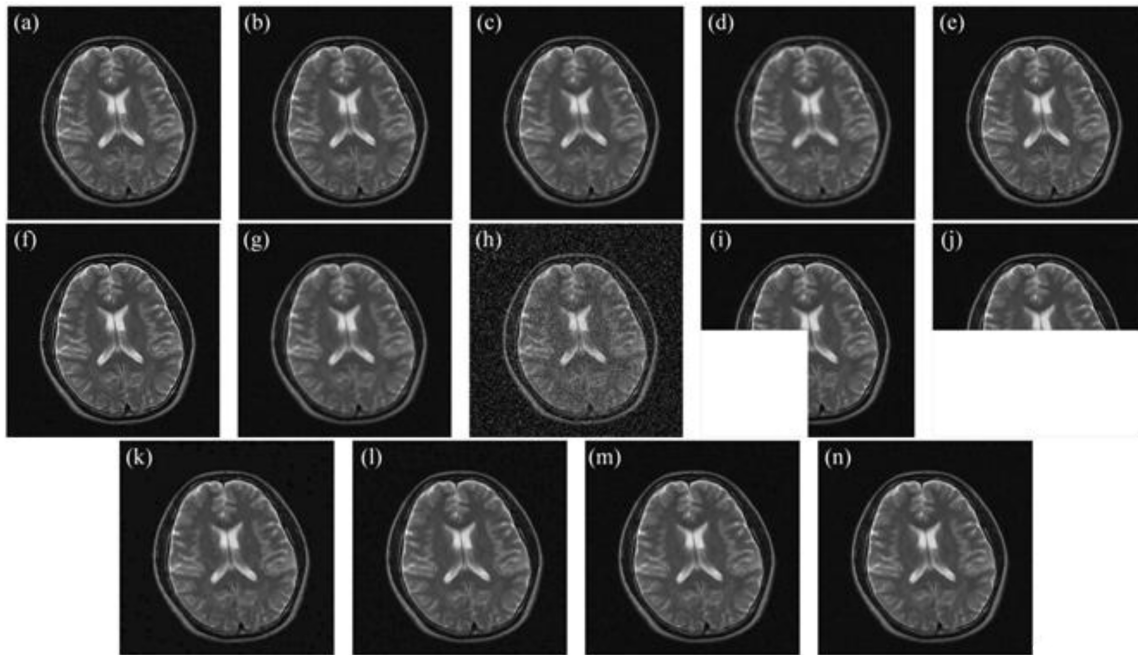


Fig. 6. Attacked watermarked MRI images: (a) Gaussian noise, (b) median filter, (c) Wiener filter, (d) midpoint filter, (e) resampling, (f) sharpening, (g) trimmed mean filtering, (h) salt and pepper noise, (i) crop 25%, (j) crop 50%, (k) JPEG compression 10%, (l) JPEG compression 30%, (m) JPEG compression 50%, and (n) JPEG compression 70%.

4. Results and discussion

A checkmark attack tool was used to evaluate the robustness of the proposed watermarking algorithm. We invoked three types of attacks: JPEG compression, various filters, and a crop method. The simulation results of a comparison of the PSNR value of the proposed method with conventional methods for invisibility evaluation are shown in Table 1. The sample images processed by the proposed method have higher invisibility than those processed by the conventional method. The higher invisibility is assumed to be on account of the HVS based on DC coefficients being changed to prevent quality degradation.

Visual analysis of the attacked watermarked image is shown in Fig. 6. Fourteen types of attack filtering, such as Gaussian noise, median filter, and Wiener filter, were used to evaluate the robustness of the proposed method compared to that of the conventional method. The results show that lower robustness against filters involves an emphasis in high frequency filtering, such as sharpening. However, the NC value is higher in the proposed method than in the conventional method, which indicates that the proposed algorithm has high robustness in protecting against the majority of attack filters.

The extracted watermark images and NC values of the proposed method and conventional method were obtained from the attacked watermarked medical images. These are shown in Table 2.

Table 2

Extracted watermark images and NC values according to various attacks for test embedded watermark images using the proposed and conventional methods

Images Method	MRI				CT				X-ray			
	Proposed method		Liu's method		Proposed method		Liu's method		Proposed method		Liu's method	
Attack	NC	w'	NC	w'	NC	w'	NC	w'	NC	w'	NC	w'
Gaussian noise	0.99		0.80		0.98		0.71		0.80		0.69	
Median (3×3)	0.98		0.07		0.97		0.12		0.99		0.12	
Wiener (3×3)	0.98		0.17		0.94		0.22		0.94		0.20	
Midpoint	0.95		0.15		0.96		0.20		0.85		0.29	
Resampling	0.98		0.33		0.97		0.24		0.94		0.23	
Sharpening	0.16		0.35		0.16		0.29		0.53		0.55	
Trimmed mean	0.92		0.78		0.99		0.75		0.83		0.70	
Salt & pepper noise	0.99		0.56		0.95		0.50		0.90		0.47	
JPEG compression 70%	1.00		0.89		1.00		0.95		1.00		0.83	
JPEG compression 50%	1.00		0.50		0.99		0.60		0.92		0.55	
JPEG compression 30%	0.69		0.25		0.88		0.30		0.55		0.38	
JPEG compression 10%	0.01		0.11		0.30		0.15		0.41		0.18	
Crop 25%	1.00		0.65		1.00		0.74		1.00		0.78	
Crop 50%	0.53		0.49		0.58		0.47		0.58		0.51	

5. Conclusion

In this paper, we proposed a medical image watermarking algorithm that employs a bit threshold map based on JND in DCT methods. This technique for embedding and extracting a watermark based on the DC coefficients in the low frequency region of the DCT have been described. Because the low frequency comprises most energy of the original image, it crucially affects the image quality. The proposed algorithm depends on the bit threshold map based on the JND of the image. The watermark is automatically embedded in the DC coefficient. This has a considerable effect on robustness and image quality. Moreover, it provides excellent invisibility because it considers the HVS when embedding the watermark. We performed a simulation evaluation to verify the robustness of the proposed method. The robustness was confirmed by embedding the watermark in the low-frequency component of the DC coefficient. The results show that the proposed approach is robust against a variety of attacks.

In our future work, we intend to develop an ultrasonic scanning non-destructive testing (NDT) technique [19] to enhance the processing performance and reliability.

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Conflict of interest

None to report.

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