A REVERSIBLE DATA HIDING METHOD BY HISTOGRAM SHIFTING IN HIGH QUALITY MEDICAL IMAGES

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Abstract:

Enormous demands for recognizing complicated anatomical structures in medical images have been demanded on high quality of medical image such as each pixel expressed by 16-bit depth. Now, most of data hiding algorithms are still applied in 8-bit depth medical images. We proposed a histogram shifting method for image reversible data hiding testing on high bit depth medical images. Among image local block pixels, we exploit the high correlation for smooth surface of anatomical structure in medical images. Thus, we apply a different value for each block of pixels to produce a difference histogram to embed secret bits. During data embedding stage, the image blocks are divided into two categories due to two corresponding embedding strategies. Via an inverse histogram shifting mechanism, the original image will be accurately recovered after the hidden data extraction. Due to requirements of medical images for data hiding, we proposed six criteria: (1) Well-suited for high quality medical images (2) Without salt-and-pepper (3) Applicable to medical image with smooth surface (4) Well-suited sparse
histogram of intensity levels (5) Free location map (6) Ability of adjusting data embedding capacity, PSNR and Inter-Slice PSNR. We proposed a data hiding methods satisfying above 6 criteria.

Keywords:
reversible data embedding, histogram, difference expansion, medical image, criteria.

1. Introduction

Recently, most hospitals have already established the electronic medical information to make healthcare better, safer, and more efficient. Over the Internet, digitized medical information is very convenient to transmit among patients, medical professionals, health care providers, and institutes of medicine. However, many risks are more and more increasing such as illegal accessing and unauthorized tampering. Therefore, data hiding plays an important role in information security such as authentication, fingerprinting, copy control, security, and covert communication. Depending on the relationship between the embedded message and the cover image, data hiding techniques are divided into two categories: steganographic applications and digital watermarking. Applications of steganographic are no relationship to the cover image used for communication. The cover image means nothing to the sender except masking the secret message. Digital watermarking has a close relationship to the cover image such as adding the cover image caption, author signature, and authentication code in it.

According to permanent distortion of the cover image, digital watermarking are divided into irreversible data hiding and reversible data hiding [23][24]. Because of permanent distortion of the cover image, the original images cannot restore from stego-images Thus, irreversible data hiding techniques are hard to satisfy many circumstances such as in the field of law enforcement, medical imaging systems, military imaging systems, remote sensing, and high precision systems in
scientific research.

Nowadays, reversible data hiding, which is also called lossless data hiding, has drawn much attention among researchers [12][23][33]. Reversible data hiding has complete blind restoration of the original data from stego-images after the hidden data retrieved. In general, reversible data hiding techniques can be classified into three groups by Feng et al. [5]: data compression [3], pixel-value difference expansion (DE) [21][23][35] scheme and histogram-based scheme [12].

DE is one kind of integer wavelet transform proposed by Tian [30]. In order to realize a high-capacity and low-distortion reversible watermarking, Tian examined the redundancy in digital images by expanding the difference between the two neighboring pixel pairs to achieve a high-capacity and low-distortion reversible watermarking. By the generalized DE method, Alatter [1] applied Tian’s scheme to hide several bits in the DE of vectors of adjacent pixels. Later on, Kim et al. [17] improved DE method to reduce the size of the location map. Further, Lin et al. proposed a DE scheme to remove the location map completely. In order to improve overflow map, Hu et al. [13] proposed a new DE algorithm.

Histogram shifting is another technique applied in reversible watermarking schemes. Vleeschouwer et al. [32] attempted to achieve reversibility by Circular interpretation of bijective transformations. Ni et al. [23] utilized a zero and a peak point of image histogram to embed messages. Luo et al. [19] exploits the high correlation among image block pixels to produce a difference histogram and embedded secret data by a multi-level histogram shifting mechanism.

In 2003, De Vleeschouwer et al. [32] proposed a robust lossless data hiding technique against a high-quality JPEG compression based on the modulo-256 addition. Unfortunately, applying the modulo-256 addition method will produce salt-and-pepper noise. Therefore, many papers [24] proposed a robust (or semi-fragile) lossless data hiding technique to overcome this drawback.
With the development of electronic medical information and the network technique, data hiding plays an important role for medical images. Until now, many algorithms [12][15][20] have been proposed. Most of them were applied in 8-bit depth medical image expressing intensity 0~255. Now, high quality medical devices are applied for improving the detection rate of diseases and treating at the early stage. A vast amount of demands for recognizing complicated anatomical structures in images have been required on high quality of medical image with 16-bit depth. Because of 16-bit depth with intensity 65,536 discrete levels and the smooth surface of anatomical structures required, it is becoming more and more difficult to find duplicate intensities embedding secret bits in embedding algorithms.

We develop a novel reversible data embedding scheme testing on 16-bit depth with dicom medical image. This scheme proposes 6 criteria well-suitable for requirements of medical images. The detail will be described in the following. This paper is organized as follows: Section 2 describes the criteria of reversible data hiding. Section 3, we present our method. Section 4 presents the experimental results. And finally in section 5 is conclusion and discussion.

2. The criteria of reversible data hiding

In general, the quality of a reversible data hiding is measured by payload capacity limit, visual quality, and complexity. However, high resolution medical images are different from low resolution medical images ex. 8-bit depth image. We divide the criteria of reversible data hiding into traditional criteria of reversible data hiding and the criteria of reversible data hiding in medical image described as follows.

2.1 Traditional criteria of reversible data hiding

The basic requirement of data hiding is low quality degradation on the image after data embedding. In order to measure the quality of a reversible data embedding, Tian [30] provided 3 criteria: (1)
payload capacity limit (2) visual quality (3) complexity. We describe detail as follows:

(1) Payload capacity limit

The maximum amount of secret bits can be embedded to cover images with acceptable visual quality.

(2) Visual quality

The difference between the cover image and the stego-image is low degree of distortion. The PSNR is most commonly adapted to measure the quality of reconstruction of lossless data hiding.

(3) Complexity

The complexity is a method to measure efficiency of a data hiding algorithm. In general, complexity is analyzed by quantifying the amount of resources needed such as time and storage.

2.2. The criteria of reversible data hiding in medical image

Many medical images are a volume structure constructed by a series of images slices. Modern medical devices produce high quality medical images for detecting diseases. Therefore, more criteria are needed to measure high quality medical images for identifying complicated anatomical structures. We proposed 6 criteria to measure data hiding algorithms such as well-suited for high quality medical images, applicable to medical images with smooth surface, without salt-and-pepper, ability of
adjusting data embedding capacity, PSNR and Inter-Slice PSNR, sparse histogram of intensity levels, and free location map. The detail demonstrated as follows:

1. Well-suited for high quality medical images

In digitalized images, a certain number of bits is assigned to each pixel to represent its intensity. The number of bits, the bit depth, will determine the number of gray levels between the minimum and maximum intensities that the imaging devices are able to capture. High quality images have high resolution and high bit-depth up to 12 bits or more per pixel. If the bit depth is not sufficient, the images will be a loss of gray-scale resolution [10][26]. In High-Resolution Computed Tomography (HRCT), CT images with a higher resolution and bit-depth can demonstrate subtle anatomical structures such as tissue characterization to detect diseases [34][38]. In other words, HRCT can get higher contrast CT data. Nowadays, enormous demands for recognizing complicated anatomical structures in medical images have been required on high quality of medical images [26] such as each pixels expressed by 16-bit depth as shown in Figure 1. A 16-bit depth image can handle 65,536 discrete levels of information instead of the 256 levels achieved by 8-bit image. In Figure 2, 8-bit images express intensity 255 as most of light anatomical structures in medical images. However, 16-bit depth image demonstrates the light part of anatomical structures as different intensity. In general, medical image have background of the images (or called None ROI) [6] which does not contribute to the diagnosis. Because high bit-depth medical images are detail-rich images, ROI area utilizes more intensity to presented anatomical structures for disease diagnosis. Some schemes are hard to embed secrets to ROI area. For instance, the schemes search for continuous duplicate values to hide secrets. Thus, most of secret bits will be embedded in None ROI area. Unfortunately, there is a copy attack [6] in these kinds of schemes. If a data hiding scheme is well-suited for high quality medical images, the embedded secret bits will distribute to whole images with copy attack avoidance.
(2) Without salt-and-pepper

Salt and pepper noise is one kind of noise typically seen on images presented by white and black pixels. In other words, the histogram for the salt-and-pepper has an extra peak at the white end of the spectrum since the noise components were pure black and white [11] as shown in Figure 3.

From the position of salt-and-pepper, the illegal attackers can easily get the information to revise the stego-image.

(3) Applicable to medical image with smooth surface

In medical images, volume structure is an important feature to record the complexity and variability of anatomical shape. A volume structure is assembled by a series of medical image slices from image scanner. For instance, a complete scan of an average patient’s lung cavity produces approximately 500 isotropic CT images [22][36]. Furthermore, each slice of images can
also be reconstructed 3D model to detect anatomical structures such as nodule, fissure, and trachea [2]. By geometric algorithm, surfaces of anatomical structures will be detected by smooth implicit functions [37]. Therefore, it is important for data hiding scheme to preserve smooth surface in medical images.

In order to measure smooth surface in volume of medical images, we define a formula to compare original slices with stego slices by the average difference intensity described as follows.

\[
P(i, j) = \text{avg} \left( |p - p_L| + |p - p_R| + |p - p_U| + |p - p_D| + |p - p_{next}| \right)
\]

Where \( i = 1, \ldots, W, \ j = 1, \ldots, H \). \( p_L, p_R, p_U, \text{and } p_D \) are left, right, up, down pixel of \( p \) respectively. \( p_{next} \) is the position \( p \) located on the next slice. We compute the average difference intensity of each pixel \( p_{cover}(i, j) \) and \( p_{stego}(i, j) \) for cover image and stego image respectively. Then we construct \( p_{cover}(i, j) \) as a new image name as \( C_{\text{difference}} \). And construct \( p_{stego}(i, j) \) as a new image called \( S_{\text{difference}} \). The PSNR of \( C_{\text{difference}} \) and \( S_{\text{difference}} \) image defines as follows.

\[
\text{Inter-Slice PSNR} = 10 \log_{10} \left( \frac{\text{Image Bit depth}^2}{MSE_{\text{Inter-Slice}}} \right)
\]

\[
\text{MSE}_{\text{Inter-Slice}} = \frac{1}{m \times n} \sum_{i=1}^{m} \sum_{j=1}^{n} (C_{\text{difference}}(i, j) - S_{\text{difference}}(i, j))^2
\]
Where \( m \) and \( n \) are the width and height of the \( C_{\text{difference}} \) and \( S_{\text{difference}} \). All Inter-Slice PSNR of volume medical images can present the quality of smooth surface.

(4) Well-suited sparse histogram of intensity levels

In high bit-depth (up to 12 bits per pixel or more) of medical images modalities such as CR, CT, MR, and US, the images have sparse histogram of intensity levels [27][28][29]. In other words, the image intensities are quantized to a number of levels on the wider range to make viewing images easier. Thus, the brightest actual level gets closer to the brightest nominally possible. The numeric values of originally consecutive quantization levels result in consecutive integers, i.e. less continuous duplicate value. There are many data hiding proposed by recording continuous duplicate value to embed data. Due to medical images with 16-bit depth, more intensity demonstrates different anatomical structures producing duplicate values rarely.

(5) Free location map

In order to reversible data hiding, some reversible data hiding methods must embed partial image data [12] or hiding an image-dependent location map for image restoration [31]. Some methods
[16][17][19] need to produce location map or coefficient map to remember the embedding to solve overflow and underflow problems. However, those methods not only consume location map storage but also require computation costs highly for hidden data extraction. For huge image database or video database, location map also prevent real time data extraction for video sequences [14]. Therefore, it is important to develop location map-free methods [7][8] for data hiding.

(6) Ability of adjusting data embedding capacity, PSNR, and Inter-Slice PSNR

We can adjust block size, partition level, number of embedding bits to handle capacity, PSNR, and Inter-Slice PSNR. Large block size will improve PSNR and decrease capacities. Conversely, small block size can increase capacities and reduce PSNR. By experiment shown in Session 4, capacity and PSNR is higher than those of partition level 3. When the embedding bits are increased, PSNR will reduce and capacity is going to increase. Inter-Slice PSNR will decrease when block size is small. In order to meet the requirements of medical images, we can apply the proper block size, partition level, number of embedding bits to process data hiding.
3. A Reversible Image Data Hiding Algorithm

Due to the smooth surface of anatomical structures in medical images, difference values of local block pixels have a high correlation, and expected to be very close to zero. We proposed histogram shifting model utilizing the statistics of difference value to decide the optimal threshold k for embedding secret bits. Depending on difference value of each block, data embedding strategy is divided into two categories: negative and positive values. There are 8 steps at data embedding stage. The details are demonstrated in Figure 7, which shows the flowcharts of the embedding process.

3.1. Data Embedding

Data embedding strategy applies optimal threshold k to embed secret bits by a shift quantity nk (n≥0). The main idea for bit embedding is that the difference value α is kept within a specified range of thresholds nk and -nk to embed bits “1” or “0”. Based on the difference value α, data embedding strategy is separated into two categories: positive difference values (α≥0) and negative
difference value ($\alpha < 0$). For all non-overlaying blocks, the statistics of difference value of each block is divided into zone 0 and zone 1, which embed “0” and “1” respectively. The strategy of data embedding is demonstrated in Figure 5. The embedding process is described as follows:

Step 1: Image by Non-overlaying Blocks Partition

In the technique suggested in the Ni method [23], the image $I$ with size $W \times H$ is divided into a set of $u \times v$ blocks where $u$ and $v$ are even.
Step2: Computation of difference value for each of blocks

In general, pixels of a block are highly correlated and exhibit strong spatial redundancy in local blocks of the image. Therefore, it is possible to create a free space for embedding extra information by transforming the image. Suppose each block of difference pair pattern \( M(i, j) \) is a \( W_b \times H_b \) binary image and divided into A and B zone. The definition describes as follows.

\[
\begin{align*}
    Zone A &= \begin{cases} 
    M(2i-1, 2j-1) = 1 \\
    M(2i, 2j) = 1 
    \end{cases} \\
    Zone B &= \begin{cases} 
    M(2i-1, 2j) = -1 \\
    M(2i, 2j-1) = -1 
    \end{cases}
\end{align*}
\]

(4)

(5)

Where \( i = 1, ..., \frac{W_b}{2}, j = 1, ..., \frac{H_b}{2} \). Both \( W_b \) and \( H_b \) are even.

In Figure 4, the histogram of difference values will be close to zero. Considering image block size 8 \( \times \) 8, the block is equally divided into two sets of pixels, i.e. zones A and B. Zone A are marked by “+” and Zone B marked by “-“ as shown in Figure 6. Let \( a_i \) is all pixels of marked by “+” and \( b_i \) is all pixels of marked by “-“.

The difference value \( \alpha \) is defined as the arithmetic average by pixel pairs grayscale values within the block. Therefore, two neighboring pixels are selected and further marked by “+” and “-” to calculate difference value \( \alpha \). The formula of difference value \( \alpha \) is describes as below.

\[
\alpha = \frac{1}{n} \sum_{i=1}^{n} (a_i - b_i)
\]

(6)

Where \( n \) is the number of pixel pairs. For instance, a given 8 \( \times \) 8 image block will produce 32 pixel pairs. The difference value \( \alpha \) will be obtained -0.0625 by the formula (6). The histogram of difference values will be concentrated on zeros and distributed between -2.33 to 2.38.
Step 3: Construction of difference image

When difference values in each block are produced, the total number of difference values will be used to construct a difference image. For a \((u \times v)\) image, the size of the difference image can be computed as:

\[
\text{Size of difference image} = \left\lfloor \frac{W}{u} \right\rfloor \times \left\lfloor \frac{H}{v} \right\rfloor \tag{7}
\]

where \(W \times H\) is the size of Image and \(u \times v\) is the size of block. Both \(u\) and \(v\) are also even.

Step 4: Building histogram from difference image

When the difference value \(\alpha\) is produced in each block, the total number of differences \(N_d\) are applied to generate histogram statistics as

\[
N_d = \left\lfloor \frac{W}{u} \right\rfloor \times \left\lfloor \frac{H}{v} \right\rfloor \tag{8}
\]

Where \(W \times H\) is the total number of image, \(u \times v\) is the total number of blocks. Both of \(u\) and \(v\) are even. Obviously, a smaller block size partition corresponds to a larger \(N_d\).

Step 5: Selecting threshold

We compute a positive optimal threshold from positive blocks of difference images. In the same way, a negative optimal threshold will be computed from negative blocks of difference images. The formula is described as follows:

(1) Difference \(\alpha \geq 0\)

\[
k_{P-h} = \left\lfloor (\alpha_{\text{max}_P} - \alpha_{\text{zero}} + 1)/\text{PartitionLevel}\right\rfloor \tag{9}
\]

\[
k = k_{P-h} + \lfloor \text{mod}(k_{P-h}, 2) \rfloor \tag{10}
\]

Where \(\alpha_{\text{max}_P}\) is maximum difference values from the whole positive part and \(\alpha_{\text{zero}}\) is 0.
for the center of the coordinate. Partition Level is the parameter of partition number. For instance, the image of difference values are -2.33, -2, -2.3, 1.2, 2.38, and partition level is set to 3. \( \alpha_{\text{max}_P} \) is 2.38 and \( \alpha_{\text{zero}_P} \) is 0. Thus, the optimal threshold \( k \) will be obtained as shown as follow.

\[
k_{P,h} = \left\lceil (2.38 - 0 + 1) / 3 \right\rceil = 2
\]
\[
k = 2 + \left\lceil \text{mod}(2, 2) \right\rceil = 2
\]

(2) Difference \( \alpha < 0 \)

\[
k_{N,h} = \left\lceil (\alpha_{\text{zero}} - \alpha_{\text{min}_N} + 1) / \text{PartitionLevel} \right\rceil
\]
\[
- k = ( k_{N,h} + \left\lceil \text{mod}(k_{N,h}, 2) \right\rceil ) \times -1
\]  \hspace{1cm} (11)

Where \( \alpha_{\text{max}_N} \) is maximum of difference values from the whole negative part. For example, the image of difference values are -2.33, -2, -2.3, 1.2, 2.38, and partition level is set to 3. \( \alpha_{\text{zero}} \) is 0 and \( \alpha_{\text{min}_N} \) is -2.33. Thus, the optimal threshold \( k \) will be obtained as demonstrated as follow.

\[
k_{N,h} = \left\lceil (0 - (-2.33) + 1) / 3 \right\rceil = 2
\]
\[
- k = (2 + \left\lceil \text{mod}(2, 2) \right\rceil ) = -2
\]
Step 6: Embedding secret bits for each of blocks by histogram shifting

This step is the important operation of data embedding, and different values $\alpha$ for each block are tackled with different shifting strategies. For simplicity, we take the example of PL (Partition Level) = 3 and $8 \times 8$ block partition as shown in Figure 5. These embedding strategies are based on the difference value $\alpha$ and divided into two categories: positive and negative values as shown in Figure 5 and Figure 8.

Category 1: The difference value $\alpha$ is positive value, $\alpha \geq 0$.

In this category, the difference value $\alpha$ is always positive. For simplicity, the partition level (PL) is set to 3. Therefore, three cases are considered in the following.

Case 1: $0 \leq \alpha \leq k$

In this case, the difference value $\alpha$ is located between threshold 0 and $k$. If embedding bit is “1”, the histogram of the block is shifted to right with distance $k$. If embedding bit is “0”, the block keeps intact.

Case 2: $k \leq \alpha \leq 2k$

In this case, the difference value $\alpha$ is located between threshold $k$ and $2k$. If

Figure 9 Adjust histogram of original image for each blocks
embedding bit is “1”, the histogram of the block is shifted right to 2k. If the embedding bit is “0”, the histogram of the block is shifted right to k.

Case 3: $2k \leq \alpha \leq 3k$

In this case, the difference value $\alpha$ is located between threshold $2k$ and $3k$. If embedding bit is “1”, the histogram of the block is shifted right to $3k$. If the embedding bit is “0”, the histogram of the block is shifted right to $2k$.

Category 2: The difference value $\alpha$ is negative value, $\alpha < 0$.

In this category, we consider the difference value $\alpha$ is always negative. There are three cases demonstrated as the following.

Case 1: $-k \leq \alpha \leq 0$

In this case, the difference value $\alpha$ is located between threshold $-k$ and 0. If embedding bits is “1”, the histogram of the block is shifted left to $k$. if embedding bit is “0”, the block keeps intact.

Case 2: $-2k \leq \alpha \leq -k$

In this case, the difference value $\alpha$ is located between threshold $-2k$ and $-k$. If embedding bit is “1”, the histogram of the block is shifted left to $2k$. If the embedding bit is “0”, the histogram of the block is shifted left to $k$.

Case 3: $-3k \leq \alpha \leq -2k$
In this case, the difference value $\alpha$ is located between threshold $-3k$ and $-2k$. If embedding bit is “1”, the histogram of the block is shifted left to $3k$. If the embedding bit is “0”, the histogram of the block is shifted left to $2k$.

The previous conditions of two categories cover all situations that a block may encounter. Because the pixel grayscale values in a local block are often highly correlated, the optimal threshold $k$ will not be changed dramatically on sign 16-bit depth in medical image. Apparently, the detailed description of the bit-embedding procedure demonstrates that the modified pixel grayscale value is still on range of image, and hence no overflow/underflow will take place. The detail is described in Step 8. For improving PSNR in small block size, we also can set a threshold of histogram to embed secrets described in section 2.2(6).

Step 7: Adjusting histogram of original image for each blocks

The optimal threshold $k$ divided by 2 is known as half optimal threshold. Add half optimal threshold to “+” part. At the same time, subtract half optimal threshold from “-” part. If the optimal threshold is 6, the element of 38 will be a member of “+”. Thus 38 plus half optimal threshold is equal to 41. Applying the same process, the element of 24 is a member of “-”.

Therefore, 24 minus half optimal threshold is equal to 21, demonstrated as Figure 9.

Step 8: Overflow/Underflow process

In general, the store format of medical image slices can be divided two categories: sing bit and unsing bit. Therefore, both of them have the different ways to process overflow/underflow problem. At first, we compute the utilization rate as follows.

$$\text{intensity rate} = \frac{\text{the range of intensity}}{2^{\text{bit_depth}}}$$

$$\text{underflow/overflow rate} = \frac{\text{value of underflow/overflow}}{2^{\text{bit_depth}}}$$

The Utilization Rate = abs( intensity rate) + abs(underflow/overflow rate)
Next step is adjust image histogram to prevent overflow/underflow problem. Because of underflow/overflow rate is generally very low in high bit-depth medical images, using bit images have underflow problem and sign bit images have no overflow/underflow problem. Therefore, we adjust the histogram of stego image to right shift with underflow distance in unsign bit image when concentrate rate is less than 1 without location map. For instance unsign 16-bit depth in TABLE VI, the slice No.00000.dcm has the intensity rate 0.0141 (max intensity 923 min intensity 0) and underflow/overflow rate -0.000061(-4/2^16). Thus, the Utilization Rate is 0.0140. The 16-bit depth images have enough intensity to solve underflow problem apparently. Therefore, we shift histogram leftward 4 for underflow.

3.2. Data Extraction

Data extraction process will extract secret message correctly and can reverse the marked image back to the original without any distortions. There are some parameters for data extraction such as block size, partition level, number of embedding bits, and the shift histogram value for underflow/overflow. At the first step, the image shift back histogram for overflow/underflow. Similar to data embedding process, the second step is image

<table>
<thead>
<tr>
<th>Block Size</th>
<th>1.3.6.1.4.1.9328.50.14.219.dcm</th>
<th>1.3.6.1.4.1.9328.50.14.320.dcm</th>
<th>1.3.6.1.4.1.9328.50.14.160.dcm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min Difference</td>
<td>Max Difference</td>
<td>PSNR</td>
</tr>
<tr>
<td>16×16</td>
<td>2.33</td>
<td>2.38</td>
<td>99.34</td>
</tr>
<tr>
<td>8 × 8</td>
<td>7.25</td>
<td>5.84</td>
<td>97.51</td>
</tr>
<tr>
<td>8 × 4</td>
<td>-13.38</td>
<td>14.5</td>
<td>92.58</td>
</tr>
<tr>
<td>4 × 8</td>
<td>-12.44</td>
<td>13.94</td>
<td>92.51</td>
</tr>
<tr>
<td>4 × 4</td>
<td>-22.38</td>
<td>18.63</td>
<td>89.07</td>
</tr>
<tr>
<td>2 × 2</td>
<td>-79</td>
<td>94.5</td>
<td>78.49</td>
</tr>
</tbody>
</table>
non-overlaying blocks partition with block size 8 × 8, 4 × 4, 2 × 2 and so on. Then, compute the difference value \( \alpha \) from each block by the formula (6). According to all of difference value \( \alpha \), we construct difference image and build histogram for extraction. Next step, the optimal threshold is computed by the following formula:

\[
k_{p-h} = \left\lfloor \frac{(\alpha_{\max_p} - \alpha_{\text{zero}} + 1)}{\text{PartitionLevel}*2} \right\rfloor
\]

\[
k = k_{p-h} + \left\lfloor \mod(k_{p-h}, 2) \right\rfloor
\]

Since both minimum and maximum control bits are embedded, the optimal threshold \( k \) will be recovered correctly. According to all of difference value and optimal threshold \( k \), each of block difference values is tackled with different shifting strategies as shown in Figure 10. If difference value \( \alpha \) fall on the zone “0”, the extract bit “0” will be extracted and the difference value \( \alpha \) is shifted toward left. If difference value \( \alpha \) fall on the zone “1”, the extract bit “1” will be extracted and the difference value \( \alpha \) is shifted toward left. For instance, if a block difference value is located in 5k~6k belonging to zone “1”, the secret bit “1” will be extracted and the difference value will

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**TABLE II.** Test results for a 395×512×16 Grayscale Medical Image with partition as 3, 4

<table>
<thead>
<tr>
<th>Image</th>
<th>Block size</th>
<th>Capacity</th>
<th>Partition Level = 3</th>
<th>Partition Level = 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dcm 395x512 (16bits)</td>
<td>16x16</td>
<td>768</td>
<td>99.21</td>
<td>99.34</td>
</tr>
<tr>
<td></td>
<td>8x8</td>
<td>3,136</td>
<td>93</td>
<td>97.51</td>
</tr>
<tr>
<td></td>
<td>8x4</td>
<td>6,272</td>
<td>89.51</td>
<td>92.58</td>
</tr>
<tr>
<td></td>
<td>4x8</td>
<td>6,272</td>
<td>89.49</td>
<td>92.51</td>
</tr>
<tr>
<td></td>
<td>4x4</td>
<td>12,544</td>
<td>86.78</td>
<td>89.07</td>
</tr>
<tr>
<td></td>
<td>2x2</td>
<td>50,432</td>
<td>75.69</td>
<td>78.49</td>
</tr>
<tr>
<td></td>
<td>2x1</td>
<td>100,864</td>
<td>70.32</td>
<td>73.13</td>
</tr>
<tr>
<td></td>
<td>1x2</td>
<td>101,120</td>
<td>65.1</td>
<td>67.68</td>
</tr>
</tbody>
</table>

**TABLE III.** Test results for a 395×512×16 Grayscale Medical Image with secret 1-bit and 2-bit

<table>
<thead>
<tr>
<th>Image</th>
<th>Block size</th>
<th>Capacity</th>
<th>PSNR</th>
<th>Secret 1-bit</th>
<th>PSNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dcm 395x512 (16bits)</td>
<td>16x16</td>
<td>766</td>
<td>99.3</td>
<td>1,532</td>
<td>0.008</td>
</tr>
<tr>
<td></td>
<td>8x8</td>
<td>3,134</td>
<td>97.5</td>
<td>6,268</td>
<td>0.031</td>
</tr>
<tr>
<td></td>
<td>8x4</td>
<td>6,270</td>
<td>92.6</td>
<td>12,540</td>
<td>0.062</td>
</tr>
<tr>
<td></td>
<td>4x8</td>
<td>6,270</td>
<td>92.5</td>
<td>12,540</td>
<td>0.062</td>
</tr>
<tr>
<td></td>
<td>4x4</td>
<td>12,542</td>
<td>89.1</td>
<td>25,084</td>
<td>0.124</td>
</tr>
<tr>
<td></td>
<td>2x2</td>
<td>50,430</td>
<td>78.5</td>
<td>100,858</td>
<td>0.499</td>
</tr>
<tr>
<td></td>
<td>2x1</td>
<td>100,862</td>
<td>73.1</td>
<td>201,724</td>
<td>0.997</td>
</tr>
<tr>
<td></td>
<td>1x2</td>
<td>101,118</td>
<td>67.7</td>
<td>202,236</td>
<td>1.000</td>
</tr>
</tbody>
</table>

20
be shifted back toward 2k~3k with distance 3k. The difference $\alpha$ of each block is not parameter for embedding phase and extraction phase. In other words, difference $\alpha$ will produce different value in cover image and stego-image. According to the strategy of data extraction in Figure 10, we can extract the original image and secret bits correctly.

4. Experimental Results

Our scheme has successfully applied to high quality medical images of the patient slice with standard dicom format medical image DICOM (Digital Imaging and Communications in Medicine) from the
<table>
<thead>
<tr>
<th>Image Name from the National Cancer Imaging Archive</th>
<th>Image Size</th>
<th>2 × 2</th>
<th>4 × 4</th>
<th>PSNR</th>
<th>Capacity</th>
<th>bpp</th>
<th>Overflow</th>
<th>PSNR</th>
<th>Capacity</th>
<th>bpp</th>
<th>Overflow</th>
</tr>
</thead>
<tbody>
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<td>1.3.6.1.4.1.9328.50.14.159.dcm</td>
<td>395 × 512</td>
<td>0.49871</td>
<td>No</td>
<td>66.21</td>
<td>25,084</td>
<td>0.12403</td>
<td>73.63</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.3.6.1.4.1.9328.50.14.1207.dcm</td>
<td>429 × 512</td>
<td>0.49882</td>
<td>No</td>
<td>68.23</td>
<td>27,388</td>
<td>0.12469</td>
<td>75.06</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
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<td>1.3.6.1.4.1.9328.50.14.1210.dcm</td>
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<td>0.49882</td>
<td>No</td>
<td>71.72</td>
<td>27,388</td>
<td>0.12469</td>
<td>81.59</td>
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<td></td>
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<tr>
<td>1.3.6.1.4.1.9328.50.14.1278.dcm</td>
<td>444 × 512</td>
<td>0.49998</td>
<td>No</td>
<td>70.51</td>
<td>28,412</td>
<td>0.12498</td>
<td>80.64</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.3.6.1.4.1.9328.50.14.1280.dcm</td>
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<td>0.49998</td>
<td>No</td>
<td>63.17</td>
<td>28,412</td>
<td>0.12498</td>
<td>71.18</td>
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<tr>
<td>1.3.6.1.4.1.9328.50.14.157.dcm</td>
<td>395 × 512</td>
<td>0.49871</td>
<td>No</td>
<td>69.06</td>
<td>25,084</td>
<td>0.12403</td>
<td>79.09</td>
<td>No</td>
<td></td>
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<td></td>
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<tr>
<td>1.3.6.1.4.1.9328.50.14.1411.dcm</td>
<td>458 × 512</td>
<td>0.49998</td>
<td>No</td>
<td>72.77</td>
<td>29,180</td>
<td>0.12444</td>
<td>80.88</td>
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<td>1.3.6.1.4.1.9328.50.14.160.dcm</td>
<td>444 × 512</td>
<td>0.49998</td>
<td>No</td>
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<td>28,412</td>
<td>0.12498</td>
<td>79.16</td>
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<td>1.3.6.1.4.1.9328.50.14.1908.dcm</td>
<td>547 × 512</td>
<td>0.49907</td>
<td>No</td>
<td>60.06</td>
<td>34,812</td>
<td>0.12430</td>
<td>69.77</td>
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<td>0.49907</td>
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<td>34,812</td>
<td>0.12430</td>
<td>76.79</td>
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<td>350 × 512</td>
<td>0.49998</td>
<td>No</td>
<td>62.67</td>
<td>22,268</td>
<td>0.12426</td>
<td>71.52</td>
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<td>0.49998</td>
<td>No</td>
<td>69.06</td>
<td>27,132</td>
<td>0.12498</td>
<td>80.06</td>
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<td>27,132</td>
<td>0.12498</td>
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<td>No</td>
<td>66.05</td>
<td>28,924</td>
<td>0.12443</td>
<td>73.07</td>
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<td>0.12403</td>
<td>76.38</td>
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<td>No</td>
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<td>33,276</td>
<td>0.12427</td>
<td>73.35</td>
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<td>0.49870</td>
<td>No</td>
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<td>0.12403</td>
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<td>1.3.6.1.4.1.9328.50.14.2363.dcm</td>
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<td>0.49903</td>
<td>No</td>
<td>65.92</td>
<td>33,276</td>
<td>0.12427</td>
<td>78.33</td>
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<tr>
<td>1.3.6.1.4.1.9328.50.14.2366.dcm</td>
<td>523 × 512</td>
<td>0.49903</td>
<td>No</td>
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<td>523 × 512</td>
<td>0.49903</td>
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<td>69.52</td>
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<td>523 × 512</td>
<td>0.49903</td>
<td>No</td>
<td>58.52</td>
<td>33,276</td>
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<td>33,276</td>
<td>0.12427</td>
<td>76.57</td>
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<td>0.49871</td>
<td>No</td>
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<td>0.12403</td>
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<td>0.12427</td>
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<td>No</td>
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</tbody>
</table>
National Cancer Imaging Archive [25]. We adopt MATLAB to implement our method and the program was run on a Notebook with 2.67 GHz processor and 4.0 GB RAM. On average, 8.75 seconds were required to embed secret bits on a 444×512 CT slice. For measure experiments, the stego-images was measured by PSNR (peak signal to noise ratio) and MSE (mean square error) defined as the following:

\[
\text{PSNR} = 10 \log_{10} \left( \frac{M \times N \times \max |I|^2}{\text{MSE}} \right)
\]

\[
\text{MSE} = \frac{1}{M \times N} \sum_{i=1}^{M} \sum_{j=1}^{N} (I(i,j) - I'(i,j))^2
\]

<table>
<thead>
<tr>
<th>Image Name</th>
<th>Image Size</th>
<th>Block Size</th>
<th>Capacity</th>
<th>bpp</th>
<th>PSNR</th>
<th>Overflow/Underflow</th>
<th>Underflow (minimum value)</th>
</tr>
</thead>
<tbody>
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<td>970</td>
<td>0.01480</td>
<td>94.06471</td>
<td>Yes</td>
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<td>93.61658</td>
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<table>
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<th>Image Name from the National Cancer Imaging Archive</th>
<th>Image Size</th>
<th>Capacity</th>
<th>bpp</th>
<th>PSNR</th>
<th>Overflow/Underflow</th>
<th>Underflow (minimum value)</th>
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<td>77.75624</td>
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<td>000008.dcm</td>
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<td>0.06067</td>
<td>74.44366</td>
<td>Yes</td>
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<td>50.63647</td>
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</table>
\[
PSNR = 10 \log_{10} \left( \frac{(\text{Image Bit depth})^2}{MSE} \right), \quad \text{and} \\
MSE = \frac{1}{m \times n} \sum_{i=1}^{m} \sum_{j=1}^{n} (c_{ij} - \bar{c}_{ij})^2
\]

Where image bit depth is 16. \(m\) and \(n\) are the width and height of the cover image and the stego-image. \(c_{ij}\) and \(\bar{c}_{ij}\) are the intensities of the pixels located between cover and stego images. With different block size, PSNR will be decreased because the maximum and minimum of difference value have a larger distance shown in TABLE I. A collection of various block size experiments affects the capacity and PSNR shown in TABLE II. Large block size resulted in the embedding capacities of decreasing. However, small block size with more capacities will make PSNR reduce. For each block size and capacity, values of PSNR in partition level 4 is higher than those of partition level 3. In TABLE III, we embed the secret n-bit (n=1 or 2) message \(m\) in each pixel. At the same block size and partition level, secret 2-bit has more embedding capacity than secret 1-bit. Unfortunately, PSNR of secret 2-bit will be reduced due to increasing amount of capacity. Therefore, PSNR and capacity are usually in conflict. If the embedding capacity is improved, the PSNR will drop and vice versa. Thus, a tradeoff between the data embedding capacity and PSNR of the marked image is an important issue for a target application.

According to experiments in TABLE I, TABLE II, and TABLE III, we can adjust the block size, partition level, and n-bits in secret message to meet the requirements of PSNR and capacity for specific applications. From Figure 11(a), secret 2-bit message \(m\) in each pixel has better quality than secret 1-bit because PSNR-Capacity curve of secret 2-bit is smooth. When the amount of capacity is 100,858 in secret 2-bit, which is almost two times compared with 1-bit, PSNR value is still acceptable in 69.65. Apparently, the more capacity, the less PSNR. At the block size 5, the amounts of capacity of secret 2-bit will be increased dramatically than those of secret 1-bit as shown in Figure 11(b). In general, the smaller block size, the higher amount of capacity. As the same block size, secret 2-bit obtains lower values of PSNR than those of secret 1-bit as shown in Figure 11(c). In Figure 11(d) the
higher block size, the lower optimal threshold $k$. The following (TABLE IV) are some test examples. We applied the data embedding to 32 slices from the National Cancer Imaging Archive with sign 16-bit depth image. All PSNR are above 61 dB. On the sing 16-bit depth, the optimal block size is $2 \times 2$ because the capacity is the largest and also have higher PSNR shown in TABLE IV. On the unsign 16-bit depth, the optimal block size is $2 \times 2$ for the values of PSNR are acceptable about 74.

Considering underflow/overflow problem, we test on sign 16-bit-depth (TABLE I~TABLE IV) and unsigned 16-bit depth medical images (TABLE V~TABLE VI). Because of high bit-depth, small range of intensity, and small value of underflow/overflow, the utilization rate is very low. Therefore, there is no underflow/overflow problem in sign 16-bit depth (TABLE I~TABLE IV) medical images. For unsigned 16-bit depth, underflow problem will be processed shown in TABLE V and TABLE VI. In the block size $2 \times 2$, the maximum of underflow is -11 shown in TABLE V. After shifting image histogram to rightward for underflow process, the PSNR will be above 74. In order to preserve smooth surface structure in volume of medical images, we use the Inter-Slice PSNR to measure the neighbor pixels of difference intensity between two slices shown in TABLE VI. In general, the best quality of smooth surface will have higher Inter-Slice PSNR.

5. Conclusions and Discussion

We have proposed a novel reversible image data hiding scheme by applying difference bit-embedding strategies in high bit-depth of volume structure on medical images. Until now, most of reversible data hiding schemes are still designed to apply on a single medical image. However, many of medical images have volume structures produced by medical scanners. In this paper, we propose six criteria for reversible data hiding scheme in medical images. Sign and unsigned 16-bit depth high quality medical images with dicom format are tested on our algorithm. Because adopting block based with shift histogram, our embedding method can distribute secret bits to whole images with copy
attack avoidance. Thus, our method is well-suited for high quality medical images and without salt-and-pepper. We apply the utilization rate and histogram shift to solve underflow/overflow problem. Our scheme satisfies the criterion of free location map because shift distance is the only parameter to be recorded. Our algorithm is applied in volume structure medical images. For preserving smooth surface of anatomical structure to reassemble image slices as a volume of 3D medical images, we define the Inter-Slice PSNR to measure the distance between neighbor pixels and adjust block size, threshold $k$, and number of embedding bits to improve smooth surface quality. Because pixels of a block are highly correlated and exhibit strong spatial redundancy, our scheme applied blocks of difference pair pattern to create a free space for embedding secret bits. Thus, our scheme performs on sparse histogram of intensity very well.

We compare several other histogram shifting based methods with our method in TABLE VII described as follows. Our algorithm has satisfied all criteria in TABLE VII. Ni et al. [24] scheme applied difference pair patterns to hide data. Because embed bit is “0” or “1” by shifting the same histogram in

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<tbody>
<tr>
<td>1. Well-suited for high quality medical images</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
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<tr>
<td>2. Without salt-and-pepper</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<td>3. Applicable to medical image with smooth surface</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
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<td>4. Well-suited for sparse histogram of intensity levels</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
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<td>5. Free location map</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
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<td>6. Ability of adjusting data embedding capacity, PSNR, Inter-Slice PSNR</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
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<td>7. Without error correction</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
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</table>

TABLE VII. The comparison of data hiding schemes
bit-embedding process, some mistakes have to be corrected by error correction coding such as BCH(63,7,15) at extraction stage. Adopting difference pairs pattern with partition level, our scheme has no errors because embed bits “0” or “1” are shifted to different histogram bins. In the reversible data hiding aspect, our scheme is the first paper to propose smooth surface preserving on volumes of medical images for 3D model reconstruction. The others of schemes only test on single image. Luo et al. has location map to record the underflow/overflow position. Chang et al. utilize the continuous duplicate values to embed secrets. Therefore, this scheme does not match the criteria 1, 3, 4, 6. Applying the modulo-256 addition method to process underflow/overflow problem, Vleeschouwer’s scheme will produce salt-and-pepper.

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References


