Reversible Data Hiding in Binary Images by Symmetrical Flipping Degree Histogram Modification

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Abstract

The visual qualities are limited in marked images by using the existing reversible data hiding (RDH) methods. In this paper, we propose a novel RDH method based on symmetrical flipping degree (SFD) histogram modification. First, the SFD which are a score to measure the distance between the pixels in the block is obtained. The better the visual quality a block has which is with a small SFD. Then the symmetrical flipping groups (SFGs) are generated from the SFD histogram. For its pre-processing, the SFGs with larger SFDs are utilized by flipping the blocks with smallest appearance times. The selected blocks with a large SFD in an SFG and least appearance times are selected to be flipped so that the new blocks are with the symmetrical SFD and in other SFG. Finally, in the blocks with a larger SFD, the appropriate corresponding pixels are selected adaptively to flip for information embedding. Experimental results demonstrate the feasibility of our proposed method and under the same embedding capacity, the visual quality is satisfactory.

Keywords: Reversible data hiding, Binary image, Symmetrical flipping group (SFG), Symmetrical flipping degree (SFD), Visual quality

1 Introduction

With the development of the Internet and digital multimedia, digital images spread through the Internet fast and easily. The applications of multimedia data are becoming more and more widespread [1]. For the purpose of information protection, integrity authentication, and copyright protection, authentication information could be hidden in digital media. Data hiding [1-3], a practice of digital authentication [4], is a technique for embedding secret messages into cover media. A considerable number of data hiding techniques [5-12] used in images, audios, and videos have been proposed. Compared with 8 bits per gray pixel in gray-scale images or 24 bits per color pixel in color images, binary images have different visual representations with only 1 bit per pixel. Binary images have less redundancy to embed secret messages. Therefore, data hiding techniques for gray-scale images or color images are not suitable for binary images.

Data hiding in the binary images is of great significance as binary images are used in a wide range of applications, such as electronic documents, scanned texts, and digital signature. Many data hiding methods [13-15] have been proposed in recent years for binary images. In [13], Yang et al. proposed a blind data hiding method with maintaining the connectivity of pixels in a local region. They imposed three transition criteria to determine the "flippability" of a pixel and embedded the secret messages in "embeddable" blocks which achieved good performance in visual quality and the embedding capacity. Cao et al. [14] proposed an edge-adaptive data hiding method by establishing a dense edge-adaptive grid (EAG) along the object contours. Feng et al. [15] defined a distortion function to evaluate the impact of flipping considering the pixels cluster and boundary connectivity. With the distortion function, the marked image had good visual quality without degrading the embedding capacity.

Reversible data hiding (RDH) [16-17], also known as lossless data hiding, is a technique that not only extracts the hidden messages but also recovers completely the original image. The unrecoverable distortion in cover images is not allowed in some sensitive scenarios such as medical imagery [18] law enforcement, and military imagery. So the messages extraction and original image recovering are necessary for these applications.

In recent years, some RDH method for binary images [19-23] have been proposed. In [19], an RDH mechanism based on pair-wise logical computation (PWLC) is proposed by Tsai et al. which recovers the host image without utilizing any additional information. However, the embedding capacity is limited and the visual quality of the marked image is not good. In [20], Xuan et al. proposed a scheme using run-length (RL) histogram modification. They scanned the host image from a specific order to generate a sequence of RL couples, then embedded data into black RL histogram.

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Ho et al. [21] gathered and quantified statistical data of the occurrence frequencies of various patterns and designed a high-capacity reversible data hiding scheme based on pattern substitution after establishing some pattern exchange relationships. This method can achieve high capacity but the visual quality of the marked image is still not satisfactory. In [22], Kim et al. proposed an n-pairs pattern method which can achieve great embedding capacity by histogram modification. In [23], Zhang et al. proposed a binary image magnification strategy for magnifying the original image to achieve reversibility which using the cross-shape pattern as the reference block pattern.

In view of the above RDH methods that can achieve a great payload but the visual quality is limited. In this paper, we propose a novel RDH scheme based on symmetrical flipping degree (SFD) histogram modification. SFDs are to measure the distance between the pixels in the block. The smaller the SFD it is, the better the visual quality a block has. Then the symmetrical flipping groups (SFGs) are generated from the SFD histogram. For the pre-processing, the SFGs with larger SFDs are utilized by flipping the blocks with smallest appearance times. While embedding messages, the appropriate corresponding pixels are selected adaptively to be flipped. As the SFDs between different SFGs are symmetrical, the reversibility of the message embedding and extraction are achieved.

The main contributions of our proposed method are: (1) Proposing an embedding method based on the visual quality using SFDs; (2) Presenting a reversible scheme based on symmetrical flipping groups generated by SFDs.

The remainder of this paper is organized as follows. In Section 2, we describe the SFGs construction and modification for RDH. The proposed embedding and extraction procedures are presented in details in Section 3. Section 4 discusses our experimental results and proves our proposed method achieves better visual quality. Finally, we present the conclusion in Section 5.

2 The Proposed Method

In this section, the proposed RDH method are presented in details. To achieve data hiding, the best-flipped pixels need to be selected to minimize the visual distortion. For reversibility, these best precise flipped pixels need to be extracted in case of their unknown locations. First, the symmetrical flipping degrees (SFDs) of the blocks are defined, and we explain why the smaller the SFD is, the better the visual quality the image has. Then the appearance times' histogram is constructed from the SFDs. The symmetrical flipping groups (SFGs) are generated by SFDs. The selected blocks with a large SFD in an SFG and least appearance times are selected to be flipped so that the new blocks are with the symmetrical SFD and in other SFG. Finally, in the blocks with a larger SFD, the appropriate corresponding pixels are selected adaptively to flip for information embedding.

2.1 Symmetrical Flipping Degree Histogram Definition

Some RDH methods based on histogram modification are proposed [24-25]. We propose the SFD histogram and explain the symmetrical property of SFD which provides the guarantee for RDH in binary images.

Since data hiding of binary images can only be done by pixel flipped, and the visual quality is easily affected even if there is only one pixel flipped, the proposed reversible data hiding method should ensure that visual imperceptibility is satisfied. In a binary image, the distance between two pixels is important for mutual interference perceived by the human eye. For a center pixel, the visual distortion caused by flipping the diagonal neighbor is smaller than flipping the horizontal or vertical neighbor. Furthermore, when the center pixel is substantially the same as the neighbor pixel, flipping the center pixel will result in large visual distortion.

Let the binary image divide into non-overlapped 3×3 blocks, as shown in Figure 1. In [26], ranking each pixel's flipping priority, the concept of "flippability" is proposed based on the smoothness and connectivity in 3×3 image blocks.

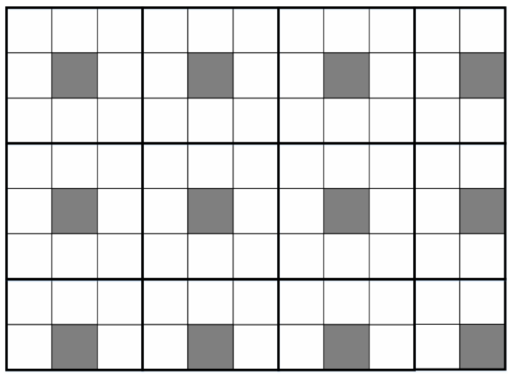


Figure 1. Example of an 8×11 binary image divided into non-overlapped 3×3 blocks

In the 3×3 block B shown in Figure 2, the center pixel is denoted as Ct. The nine pixels in B are b_1, b_2, b_3, b_4, Ct, b_6, b_7, b_8, b_9. The SFD Dg of the block B is defined as:

$$Dg = \sum_{i=1}^{4} w(i) f(Ct, b_i) + \sum_{i=6}^{9} w(i) f(Ct, b_i) \quad \textbf{(1)}$$

where $w(i)$ is the weight denoted as:

$$w(i) = \frac{1}{\sqrt{1 + (i-5) \, mod \, 2}}, \; i = 1,2,3,4,5,6,7,8,9 \quad \textbf{(2)}$$

and $f(a,b)$ is denoted as:

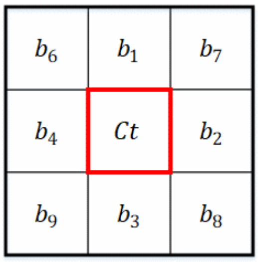
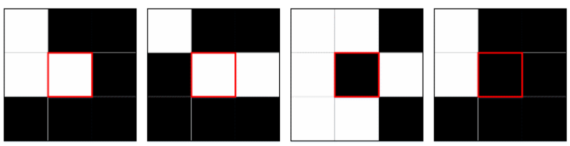


Figure 2. The 9 pixels in the 3×3 block B, whose center pixel is denoted as Ct

$$f(a,b)=\begin{cases}1, & \text{if } a\neq b\\ 0, & \text{if } a=b\end{cases} \quad \textbf{(3)}$$

In fact, the SFD Dg describes the number of neighbor pixels that are different from the central pixel. At Eq. (2) larger weights are assigned to horizontal or vertical neighbors b_1, b_2, b_3 and b_4, as they are closer to the center pixel, and the effect of flipping diagonal neighbor is less than the effect on flipping horizontal or vertical neighbors based on the center pixel. Obviously, if the 3×3 block B is a uniform block which means all pixels of the block are black or white, the SFD $Dg=0$. The larger the SFD of the block, the greater the distance between the center pixel Ct to its neighbor pixels, which means that the similarity of the center pixel to the neighbor pixels is smaller, and it is considered to be the edge or noise point of the image.

For the center pixel, it has four diagonal neighbors, two vertical neighbors, and two horizontal neighbors. At Eq. (2), it seems that the $w(i)$ of the four vertical or horizontal neighbors are the same, and they are greater than the $w(i)$ of the four diagonal neighbors. We define that if two blocks have the same SFD, the blocks are called the same pattern. Otherwise, they are different patterns because of different SFD. An example of blocks with SFDs is shown in Figure 3. In Figure 3 (a) and (b), two blocks with the same SFD but with different shape, which called the same pattern. In Figure 3 (a) and (c), two blocks with different SFDs, and the center pixel in Figure 3 (c) seems to be the edge or noise point.



(a) block 1. (b) block 2. (c) block 3. (c) block 4.

Figure 3. Example of blocks with the same and different SFDs. (a) The block 1 has SFD $Dg=5.1213$. (b) The block 2 has the same SFD $Dg=5.1213$ with block 1 in (a). (c) The block 3 has different SFD $Dg=5.4142$ with block 1 in (a). (d) The block 4 obtaining by flipped the center pixel of block 1 in (a) has different SFD $Dg=1.7071$

The number D of the diagonal neighbors different from Ct in a block is defined as:

$$D=\sum_{i=1}^{4} f(Ct,b_i) \quad \textbf{(4)}$$

and the number N of the vertical and horizontal neighbors different from Ct are defined as:

$$N=\sum_{i=6}^{9} f(Ct,b_i) \quad \textbf{(5)}$$

Since the values of D and N can be 0, 1, 2, 3, and 4 respectively, there are 25 patterns can be generated. When $D=4$ and $N=4$, the block has the greatest SFD denoted as Dg_{max}, which means that its center pixel Ct is completely distinct from the neighbor eight points. When $D=0$ and $N=0$, the block has the smallest $Dg_{min}=0$, which means that its center pixel Ct is completely the same as the neighbor eight points.

For a given $M\times N$ binary image, there are $\dfrac{M\times N}{3\times3}$ blocks. While generating the SFD histogram $H(x)$, $x\in\{1,2,\ldots,24,25\}$, we scan the blocks in the image and calculate the SFD $Dg(k)$ of the k-th block according to Eq. (1). the SFD histogram $H(x)$ is defined as:

$$H(x)=\sum_{k=1}^{\frac{M\times N}{3\times3}} f(Dg(k),Dg(x)) \quad \textbf{(6)}$$

where $x\in\{1,2,\ldots,24,25\}$ is the index of all the 25 patterns.

After generating the SFD histogram $H(x)$, the symmetrical property of SFD should be considered. After flipping the center pixel Ct in a block, the new SFD of new the block can be confirmed. For example, in Figure 3 (a) a block with $D=3$ and $N=3$, flipping the center pixel and the new block in Figure 3 (d) with $D=1$ and $N=1$ will be confirmed. Since the new D and N taking the value of 0, 1, 2, 3 and 4, the new block still belongs to the 25 patterns. And the SFD is still in the SFD histogram $H(x)$. In conclusion, the SFDs in the $H(x)$ with 25 patterns have a symmetrical relationship, which provides the guarantee for RDH in binary images.

2.2 Symmetrical Flipping Groups Construction

After generating the SFD histogram $H(x)$, we focusing on the embedding process in RDH. The symmetrical relationship in 25 SFDs indicates that once the SFD in the marked image is known, the original block can be known. In particular, when $x=13$, $D=2$ and $N=1$, regardless of the state of the original center pixel Ct is "0" or "1", the SFD of the block remains unchanged after the rollover. So $x=13$ is the center of symmetry in the histogram.

For a central pixel, the visual effect of flipping diagonal neighbors is less than flipping horizontal or vertical neighbors, so the SFD histogram $H(x)$ is constructed in an ascending order by *N*. The 25 patterns are classified into 5 groups. We defined the symmetrical flipping groups (SFGs) as:

$$SFG(n) = \begin{Bmatrix} H(5n), \\ H(5n-1), \\ H(5n-2), \\ H(5n-3), \\ H(5n-4) \end{Bmatrix} \qquad \textbf{(7)}$$

where $n = 1, 2, 3, 4, 5$. It means that two points in the same groups have the same number *N* of the vertical and horizontal neighbors different from *Ct*. Due to the definition of SFD, only blocks with larger SFDs can be flipped and changed into the new blocks with small SFDs. So we defined that the blocks with SFDs in groups *SFG*(4) and *SFG*(5) are considered to embed messages.

2.3 Flippable Pixel Selection

An example of the pre-processing and flippable pixel selection for the embedding process is shown in Figure 4. In Figure 4(a), for the pre-processing before the embedding process, we need to find the embeddable blocks in the original image. In the SFD histogram *H*(*x*), minimum zero point $H(\alpha)$ is considered as the best point to embed message, where $H(\alpha) \in SFG(4)$ or $H(\alpha) \in SFG(5)$. The original image is without the block with $Dg(\alpha)$ as the zero appearance times. If there is no minimum zero point $H(\alpha)$, we set $H(\alpha) = 0$ by flipping the center pixel, where $H(\beta)$ is the Symmetrical point of $H(\alpha)$ where $H(\beta) \in SFG(2)$ or $H(\beta) \in SFG(1)$ and $\beta = 26 - \alpha$. The pre-processed SFD histogram is constructed with the empty point $H(\alpha)$ before embedding the secret message.

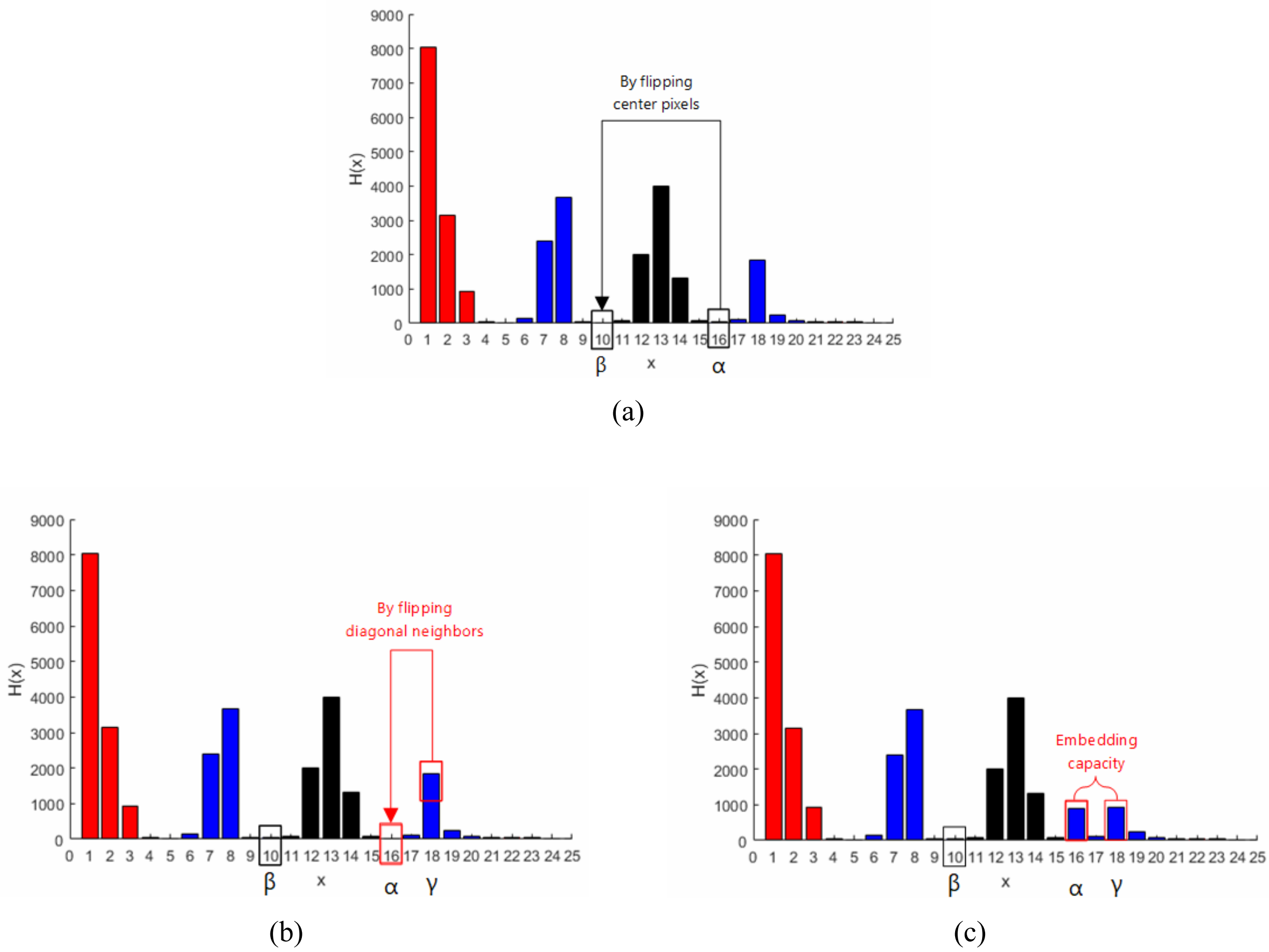


Figure 4. Example of the pre-processing and flippable pixel selection for the embedding process. Per 5 bins with the same color are in the same group. (a) The pre-processing by setting $H(\alpha) = 0$ to $H(\beta)$ by flipping the center pixel. (b) Embedding process by flipping the diagonal neighbors. (c) The final SFD histogram *H*(*x*) for marked image with the embedding capacity

In Figure 4(b), when $H(\alpha)$ is equal to 0, the related point $H(\gamma)$ which is in the same SFG as $H(\alpha)$ is selected to embed the message by flipping the diagonal neighbors of the block.

This related point $H(\gamma)$ must meet the following three conditions:

(1) $H(\gamma)$ is in the same SFG as $H(\alpha)$;

(2) $\gamma > \alpha$;

(3) $H(\gamma)$ is the greatest point in the SFG it belongs.

The first condition is to ensure that least neighbors will be flipped as the points $H(\gamma)$ and $H(\alpha)$ in the same SFG have the same N and only diagonal neighbors can be flipped. The second condition is to ensure that the SFD is smaller after flipping the diagonal neighbors, so that the effect of the visual quality can decrease. The last condition gives the maximum embedding capacity as embedding the messages by changing the blocks in $H(\gamma)$ into the new blocks in $H(\alpha)$.

To ensure related point $H(\gamma)$, for all blocks with $Dg(\gamma)$, we calculate the difference number between diagonal neighbors b_6, b_7, b_8 and b_9 and Ct, respectively. The diagonal neighbors with top $(\gamma - \alpha)$ the difference number are selected as the embeddable pixels. And mark the index of diagonal neighbors. According to the index, the original block in the point $H(\gamma)$ can be restored from $H(\alpha)$.

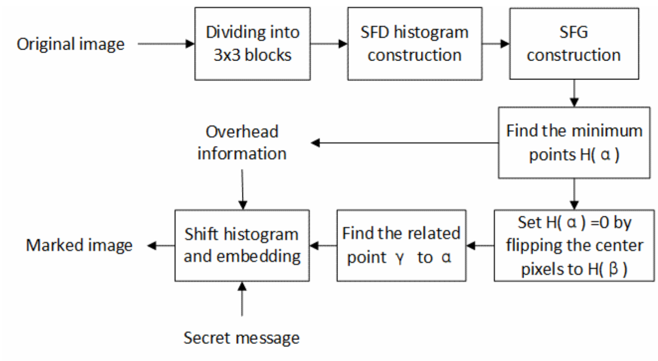


Figure 5. The framework of the embedding process for our proposed RDH method

3 The Framework of Embedding and Extraction

In this section, the proposed reversible data hiding method is constructed, and the data embedding and extraction processes are shown by the block diagrams in Figure 5 and Figure 6, respectively.

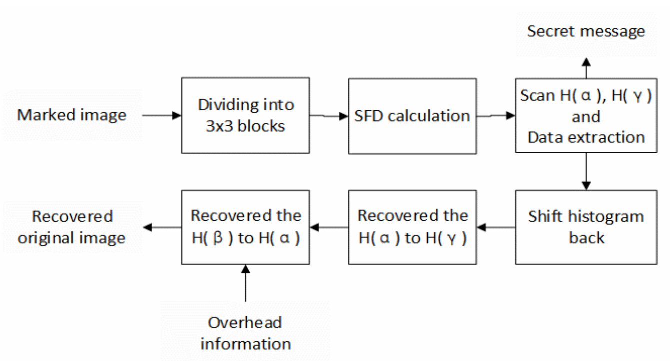


Figure 6. The framework of the extraction process for our proposed RDH method

3.1 Embedding Process

For a given binary original image I_o of size $M \times N$, we embed the secret messages sequence S with the length of l_s. The embedding procedure includes the following steps:

(1) Divide I_o into non-overlapped 3×3 blocks and calculate the SFD $Dg(k)$ of each block. Generate the SFD histogram $H(x)$ of I_o, where $x \in \{1, 2, ..., 24, 25\}$;

(2) In the histogram $H(x)$, find the minimum point $H(\alpha)$ and the symmetrical point $H(\beta)$;

(3) If the minimum point $H(\alpha) > 0$, all the blocks with $Dg(\alpha)$ in I_o need to be recorded as overhead bookkeeping information. Then set $H(\alpha) = 0$, and obtain image I_0';

(4) Find the related point $H(\gamma)$ in the same group SFG as $H(\alpha)$ is;

(5) In the block with $Dg(\gamma)$, count and select the top $(\gamma - \alpha)$ amount of b_6, b_7, b_8 and b_9 different from Ct. Assume that $(\gamma - \alpha) = 2$), if the amount of b_6 and b_7 who are different from Ct is greater then b_8 and b_9, b_6 and b_7 is denoted as the message-embedded pixels;

(6) Scan the blocks in the image I_0', once meet the block with $Dg(\gamma)$ and its message-embedded pixels are different from the center pixel. If the to-be-embedded bit of S is "1", the message-embedded pixels need to be flipped. Otherwise, if the to-be-embedded bit of S is "0", the pixels of this block will be remained. Finally the marked image I_M is obtained.

3.2 Extraction Process

For a given marked image I_M with the secret message embedded of size $M \times N$, the extracting procedure includes the following steps:

(1) Divide I_M into non-overlapped 3×3 blocks and calculate the SFD of each block;

(2) Scan the blocks, once meet the block with $Dg(\gamma)$, a bit "0" is extracted. If a block with $Dg(\alpha)$ is encountered, a bit "1", is extracted. And then flip the message-embedded pixels of this block;

(3) According to the overhead bookkeeping information, recover the blocks with $Dg(\alpha)$ from the blocks with $Dg(\beta)$. Finally the recovered original image I_R is obtained.

4 Experimental Results

In this section, we first introduce the experimental conditions. And then propose a set of experiments to demonstrate the high performance and effectiveness of the proposed method.

4.1 Experiment Conditions

This paper uses the different types of binary images including CAD graph, painting, pattern and document, which are some common binary image, to compare the performance of n-pair patterns [22].

To further evaluate the visual quality, two methods are used to measure the objective visual quality of the marker image. Peak Signal-to-Noise Ratio (PSNR) [27] presents distortion by measuring the amount of flipped pixels in the marker image. DRD [28] is used to measure the reciprocal distance on adjacent pixels to present distortion caused by flipped pixels.

Some experiments are carried out to demonstrate the high performance and effectiveness of the proposed method. In [22], Kim et al. proposed n-pair pattern method by dividing the binary image into pairs of n-length pixels. It takes these pairs as n-bit binaries and converts them to decimal to generate a histogram.

4.2 Visual Qualities Comparison

The original and marked images using our proposed method are shown in Figure 7. The objective visual quality comparison of marked images is shown in Table 1. The results show that under the same embedding capacity, our proposed method has better visual quality than n-pair patterns [22] employed the PSNR measurement in all experimental images. And the CAD, painting and document marked images present the satisfactory visual quality as the DRDs are also better than n-pair patterns [22].

In [22], the embedding of secret message relies on the modification of the decimal histogram. The image content does not be taken into account when flipping the pixels, resulting in a large impact on the visual quality of the image.

4.3 Location Map Comparison

In some cases, both methods need to record some overhead information to help restore the image. The overhead information of the marked image called location map (LM) is presented in Table 1. The results show that the two methods have close value in visual quality under the same embedding capacity, but our location map is much smaller than n-pair patterns [22]. In summary, our approach achieves reversible data hiding with less storage space.

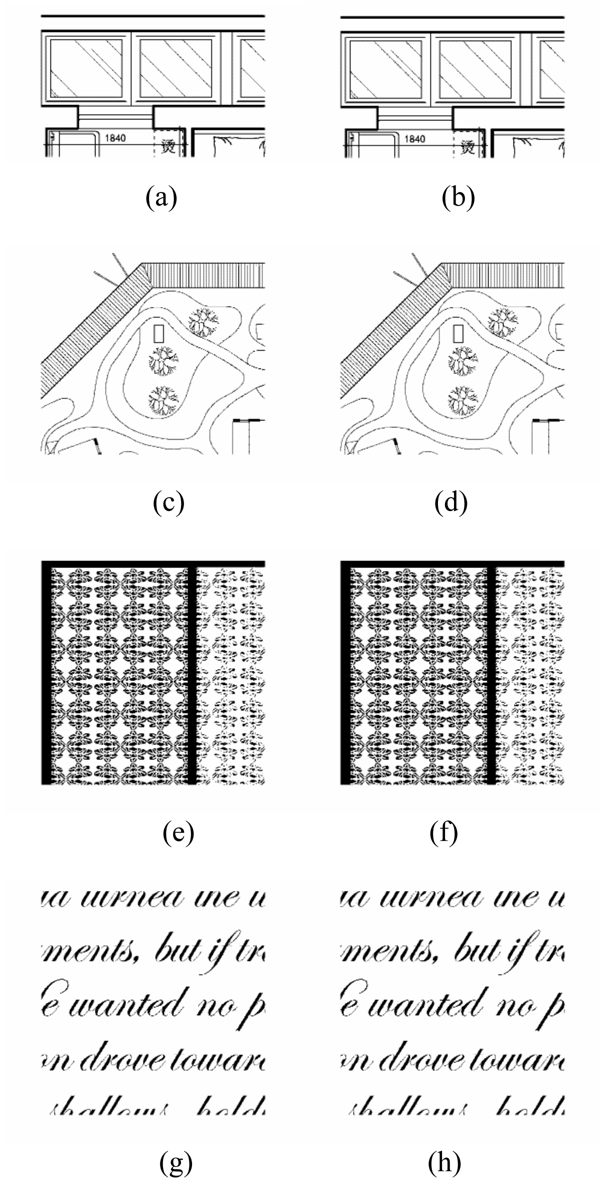


Figure 7. The original and marked images using our proposed method. (a) The original CAD image. (b) The marked CAD image. (c) The original painting image. (d) The marked painting image. (e) The original pattern image. (f) The marked pattern image. (g) The original document image. (h) The marked document image

Table 1. The objective visual quality and location map comparison of a marked image

Images (Payload)	n-pair patterns [22]			Proposed		
	LM	PSNR	DRD	LM	PSNR	DRD
CAD (101)	0	32.17	0.08	0	**35.73**	**0.05**
Painting (171)	15	29.78	0.11	**1**	**31.73**	**0.10**
Patten (66)	25	33.36	0.02	**3**	**35.10**	0.02
Document (78)	2	33.65	0.05	**0**	**36.70**	**0.03**

5 Conclusions

In this paper, we proposed a novel reversible data hiding scheme in binary images using symmetrical flipping degree (SFD) histogram modification. The SFD is defined to measure the visual quality of an image, and the histogram modification is reversible with the symmetry of SFD. Our scheme is achieved with low distortion of visual quality. And it does not require the original image for the extraction process, which achieves the reversible method. In the future, we will push forward the RDH construction for binary images standing on the better visual quality and higher embedding payload, which is still a challenging work.

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