A Reversible Data Hiding Scheme Based on IWT and the Sudoku Method

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Abstract

A reversible data hiding scheme based on integer-to-integer wavelet transform is proposed in this paper. The scheme uses a Sudoku-based method to embed data by modifying the wavelet coefficients. First, the algorithm performs the one-level integer wavelet transform of the host image and obtains four sub-bands, i.e., LL1, HL1, LH1, and HH1. Then, the HL1 sub-band is used as the base matrix, and the LH1 sub-band is used as the variable matrix to embed the secret digits according to a Sudoku table. A location map is created to record the embeddable coefficients, and the map is embedded into the sub-band of HH1. The experimental results showed that our proposed scheme produced a higher-quality stego image than those existing hiding schemes.

Keywords: Integer-to-integer wavelet transform, location map, reversible data hiding, Sudoku-based method

1 Introduction

Steganography refers to embedding secret information in a host image and transmitting the image without the secret information being discovered. The two focuses of the process are the embedding capacity and the invisibility of the embedded message. Generally, as the embedding capacity increases, the quality of the stego image decreases. Thus, there is always a trade-off between embedding capacity and the quality of the image, and different choices are made depending on the specific applications in which the process is used.

In recent years, with the rapid development of multimedia technology, steganography has been used extensively [5, 6, 14]. The aims of the reversible data hiding technique are to extract the embedded secret information and to restore the host image losslessly. In many fields (e.g., law enforcement, medical, and military), the recovery of the host image, as well as the secret information, is required [9]. Reversible data hiding can be implemented in the spatial domain [7, 8, 11, 12, 15, 18, 19, 20, 21, 22] and in the transformed domain [4, 13, 23, 24, 25]. In the spatial domain, Honsinger et al. used a modulo 256 addition algorithm to embed data in the spatial domain [7]. Tian proposed a reversible, data-embedding method using difference expansion between adjacent pixels [20]. Ni et al. proposed a reversible data hiding approach that involved the modification of the histogram of the host image [18]; in their approach, multiple pairs of maximum points and minimum points of the histogram are used to embed the secret data, and they achieved a high peak signal-to - noise ratio (PSNR) value, i.e., above 48 dB. Tai et al. proposed a reversible data hiding scheme based on modifying the histogram of pixel differences [19]. A reversible, image-hiding technique that uses predictive coding and histogram shifting is presented in [21]. Hu et al. performed difference expansion (DE)-based, reversible data hiding with an improved overflow location map [8]. Luo et al. proposed a reversible data hiding method based on preservation of the block median [15]. Tseng et al. presented a reversible data hiding scheme based on the expansion of the prediction error [22].

In the transformed domain, Xuan et al. presented a novel, high-capacity, lossless data hiding approach based on the integer wavelet transform (IWT); they used the modification of the histogram to prevent overflow/underflow caused by the modification of the wavelets coefficients [24]. A reversible hiding in discrete cosine transform (DCT)-based, compressed images was proposed in [4]. Wu et al. proposed a reversible data hiding algorithm based on histogram shifting using difference integer wavelet coefficients [23]. In each sub-band, the difference of two neighboring integer wavelet coefficients is obtained, and the peak point of the differences in the histogram is searched for data hiding in the wavelet coefficients. Although schemes in the transformed domain have been used for some time, the existing methods still have many problems, such as poor quality images even when the embedding capacity is small and difficulty in extending the embedding capacity.

In addition, some research on reversible data hiding has been done in encrypted images [16, 26]. Zhang presented a separable reversible data hiding method in encrypted images, in which an encryption key was used to encrypt the original, uncompressed image and a data-hiding key was used to create a sparse space to accommodate the secret. The receiver can extract the secret and recover the host image without any error only when he or she has both the encryption key and the data-hiding key [26].

The reference-table-based hiding schemes embed a secret digit into a pair of host pixels according to a predetermined table [2, 3, 27]. Zhang et al. proposed a data hiding technique that exploited the modification of directions (EMD), and a higher embedding efficiency was obtained [27]. Chang et al. presented an information hiding scheme using Sudoku, and the embedding capacity was improved notably [2].

Based on the Sudoku method proposed by Chang et al., we present a novel, reversible, data hiding approach in wavelet domain in this paper. The main contributions of our scheme include 1) high payload and 2) high image quality due to embedding in the wavelet domain.

The rest of the paper is organized as follows. Section 2 introduces related work, including the integer wavelet transform approach and the Sudoku hiding scheme. The proposed scheme is presented in Section 3. The experimental results and our analysis of them are presented in Section 4. Our conclusions are presented in Section 5.

2 Related Work

2.1 Integer Wavelet Transform

Digital images use integers to represent the pixels gray values. The integer wavelet transform (IWT) can map the gray values into integer wavelet coefficients losslessly. We can write the Haar transform as pairwise averages and differences:

$$s_{1,k} = \frac{s_{0,2k} + s_{0,2k+1}}{2}, \quad d_{1,k} = s_{0,2k+1} - s_{0,2k}. \quad (1)$$

where $d_{i,k}$ is the k^{th} high frequency wavelet coefficient at the i^{th} level, $s_{i,k}$ is the k^{th} low frequency wavelet coefficient at the i^{th} level ($i>0$), and $s_{0,k}$ represents the k^{th} pixel itself [1].

Based on Equation (1), the forward transform and the inverse transform can be calculated according to Table 1.

The decomposition of the image at level 1 is shown in Figure 1, where LL1 denotes the low-frequency wavelet sub-band, and HL1, LH1, and HH1 represent detail wavelet sub-bands.

Table 1: Integer wavelet transform

Forward transform	Inverse transform
$d_{1,k} = s_{0,2k+1} - s_{0,2k}$	$s_{0,2k} = s_{1,k} - \lfloor d_{1,k}/2 \rfloor$
$s_{1,k} = s_{0,2k} + \lfloor d_{1,k}/2 \rfloor$	$s_{0,2k+1} = d_{1,k} + s_{0,2k}$

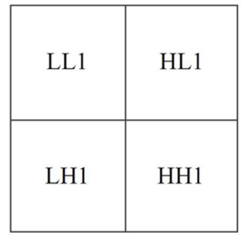


Figure 1: The decomposition of the image at level 1

2.2 Sudoku-Table-Based Hiding Scheme

Chang and Chou proposed a novel information hiding scheme using a Sudoku table. Assuming that the range of the gray values of the pixels in the host image is [0,255], the size of the reference table N should be 256×256, and it is constructed by duplicating a Sudoku table. An example of reference table N is shown in Figure 2. After that, the secret message is transformed to digits in the 9-ary notational system, i.e., $S=\{s_1,s_2,s_3,\ldots,s_k\}$ ($s_i \in [0,8]$, $i=1,2,\ldots,K$), where K is the length of the 9-ary secret sequence. Assume that a pair of embeddable pixels in the host image is (p_i,p_{i+1}), where p is the pixels gray value, p_i and p_{i+1} are used as indices of the reference table, and a number can be found in the table, i.e., $N(p_i,p_{i+1})$. The steps to find the pixels gray values of the stego image, (p_i^s,p_{i+1}^s), is described as follows:

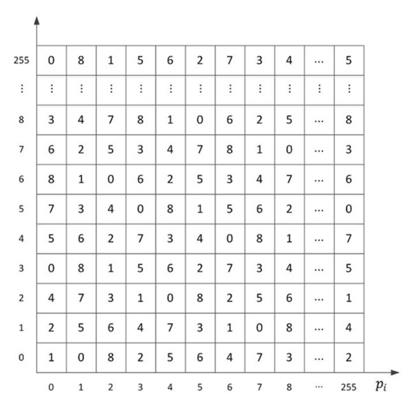


Figure 2: An example of the reference matrix N

S1: Keep p_i unchanged, search (p_i^V,p_{i+1}^V) in the vertical direction as follows:

$$p_i^V = p_i,$$

$$p_{i+1}^V = \begin{cases} p_{i+1} \pm a, \text{ where } N\left(p_i^V, p_{i+1}^V\right) = s_i, \text{ if } 3 < p_{i+1} < 25 \\ b, \quad \text{where } N\left(p_i^V, p_{i+1}^V\right) = s_i, \quad \text{if } p_{i+1} \le 3 \\ c, \quad \text{where } N\left(p_i^V, p_{i+1}^V\right) = s_i, \quad \text{else} \end{cases}$$

$$\text{for } a = 0,1,2,3,4;\ b = 0,1,\cdots,7,8;\ \text{ and } c = 247, 248, \cdots, 255. \tag{2}$$

S2: Keep p_{i+1}unchanged, searching (p_i^H,p_{i+1}^H) the horizontal direction as follows:

$$p_{i+1}^H = p_{i+1},$$

$$p_i^H = \begin{cases} p_i \pm a, \text{ where } N\left(p_i^H, p_{i+1}^H\right) = s_i\ , \text{ if } 3 < p_i < 252 \\ b, \quad \text{where } N\left(p_i^H, p_{i+1}^H\right) = s_i, \quad \text{if } p_i \le 3 \\ c, \quad \text{where } N\left(p_i^H, p_{i+1}^H\right) = s_i, \quad \text{else} \end{cases}$$

$$\text{for} a = 0,1,2,3,4;\ b = 0,1,\cdots,8;\ \text{ and } c = 247, 248, \cdots, 255. \tag{3}$$

S3: When $p_i < 252$ and $p_{i+1} < 255$, record $x_n = \lfloor \frac{p_i}{3} \rfloor \times 3$, $y_n = \lfloor \frac{p_{i+1}}{3} \rfloor \times 3$, search (p_i^N, p_{i+1}^N) in the neighbors as follows:

$$\begin{cases} p_i^N = x_n + k \\ p_{i+1}^N = y_n + l \end{cases} \quad \text{if } p_i < 252, \text{and } p_{i+1} < 255,$$

$$\text{where } N\left(p_i^N, p_{i+1}^N\right) = s_i, \text{and } k{=}0,1,2; l = 0,1,2\ . \tag{4}$$

where $\lfloor x \rfloor$ denotes the largest integer smaller than x.

After the above searching operations, three corresponding candidates'positions, i.e., (p_i^V, p_{i+1}^V), (p_i^H, p_{i+1}^H), and (p_i^N, p_{i+1}^N), in the reference table can be obtained. Then, the distances from the locating point (p_i, p_{i+1}) to the candidates'position can be calculated, respectively. The candidate with the smallest distance is chosen, i.e., the corresponding candidate's position is recorded as (p_i^s, p_{i+1}^s). Then, the pixel pair in the host image, (p_i, p_{i+1}) is modified to (p_i^s, p_{i+1}^s) as the gray values in the stego image.

3 The Proposed Scheme

3.1 Framework of the Proposed Data Hiding Scheme

The main idea of the proposed scheme is to use a Sudoku-based scheme to embed data by modifying the integer wavelet coefficients in the wavelet domain. The proposed scheme includes two procedures, i.e., data embedding and data extraction with recovery of the host image. The flowcharts of the two procedures are shown in Figure 3 and Figure 4, respectively.

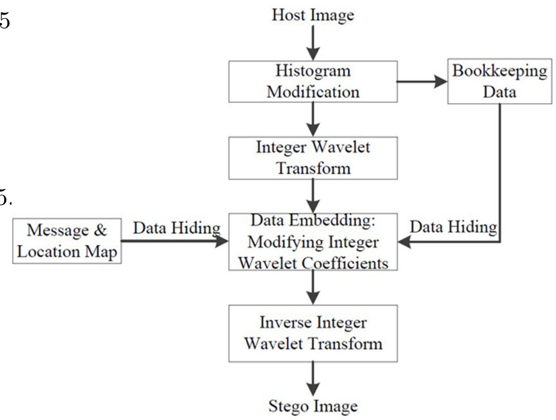


Figure 3: Flowchart of data embedding

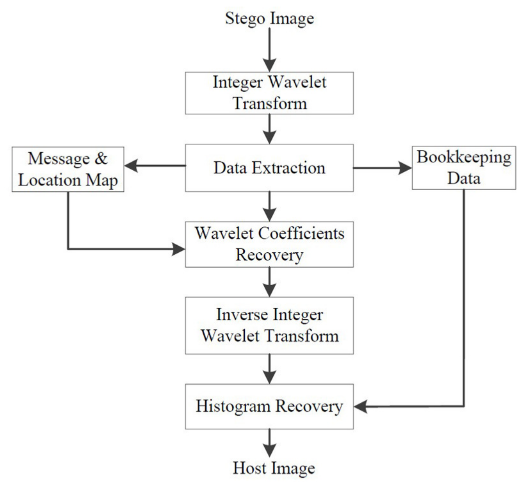


Figure 4: Flowchart of data extraction and host image recovery

For the data embedding part, histogram shifting is applied first to the host image to prevent overflow/underflow during the frequency transformation. In this process, overhead bookkeeping information is generated and recorded. After that, the modified host image is decomposed by IWT. The embedding algorithm is used in the selected wavelet coefficients. To extract the secret message and restore the host image, a location map that indicates the embedding positions is needed, and the map will be embedded in the IWT coefficients.

For data extraction and recovery of the host image, the location map and overhead bookkeeping information are extracted first. The location map is used to extract the secret information and to restore the wavelet coefficients. After that, the inverse integer wavelet transform is implemented, and the gray values in the spatial domain are obtained. Finally, the original host image is obtained by inverse histogram shifting according to the overhead bookkeeping information.

3.2 Histogram Modification

As stated in Section 2.2, the Sudoku-table-based algorithm itself will not generate the problem of overflow/underflow. However, when it is used in the wavelet domain, after the wavelet coefficients are modified, it may influence their reconstruction, i.e., overflow/underflow may occur after the inverse IWT, and some gray values in the stego image may be out of the range of [0,255]. To prevent overflow/underflow, histogram modification was used in the paper. And overhead bookkeeping data were generated and recorded to recover the host image.

Here is an example that shows how to narrow down the histogram. Assuming that the size of the host image is 6×6 with 8 gray scales, Figure 5 and Figure 6 show that the histogram is narrowed down 1 gray scale for both sides.

Figure 7 shows the pattern of the overhead bookkeeping information [22].

As shown in Figure 7, V is the length of the overhead bookkeeping information, and n is the shifted number of the gray scale for both sides. $left$ and $right$ are vectors, which are composed of 0 and 1. Scan the host image, $left$ is used to record information for the left-side shifted gray values. And, in a similar way, $right$ is used to record information for the right-side shifted gray values. The size of the $left$ is determined by the numbers of the shifted gray values in the left side, while the size of the $right$ is determined by the numbers of the shifted gray values in the right side. As shown in Figure 5, for the $left$, when we encounter gray value "0", we record a bit "1" in the $left$, whereas, when we encounter gray value "1" ; we record a bit "0" in the $left$. Finally, we obtain the $left$ information as "10100" and the $right$ information as "0100100".

3.3 Data Embedding

Assume that the size of the host image is $M\times$N, the length of the secret is K, and the secret sequence is $S=\{s_1,s_2,s_3,\ldots,s_k\}$ ($s_i \in [0,8]$, $i=1,2,\ldots,K$). Modify the histogram of the host image and apply the one-level

0	6	5	2	3	4
2	1	7	4	5	6
0	3	2	3	3	4
6	5	4	3	2	2
5	3	7	6	4	1
4	2	1	4	6	5

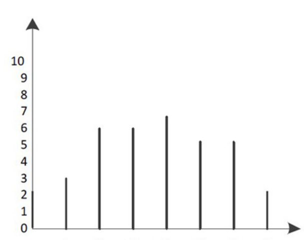


Figure 5: Original image data and histogram

1	5	5	2	3	4
2	1	6	4	5	5
1	3	2	3	3	4
5	5	4	3	2	2
5	3	6	5	4	2
4	2	2	4	5	5

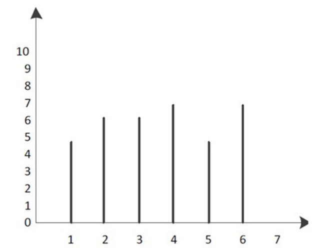


Figure 6: Modified image data and histogram

V	*n*	*left*	*right*

Figure 7: Overhead bookkeeping information

integer wavelet transform to the modified host image; then, four sub-bands (LL1, HL1, LH1, and HH1) are obtained after the decomposition. Note that the sizes of the sub-bands are all $(M/2) \times (N/2)$. After the integer wavelet transform, the wavelet coefficients in the four sub-bands may be beyond of the range of [0,255], for instance, the range of the transformed wavelet coefficients is $[c_{min}, c_{max}]$, where c_{min} may be less than 0, and c_{max} may be more than 255. We must adjust the wavelet coefficients to be above 0 to hide the secret message, so add $c_{min}+1$ to all the coefficients of IWT if $c_{min} < 0$, and the range of the modified wavelet coefficients is changed into$[1, c^*_{min}]$, where $c^*_{min} = c_{max} + c_{min} + 1$.

After modifying the wavelet coefficients, assume that the range of HL1 is $[1,H]$ and that the range of LH1 is $[1,W]$. Therefore, the size of the reference table in our proposed scheme is $H \times W$. Figure 8 shows part of the coefficients in HL1 and LH1. To embed the secret digits, a reference table N is constructed by duplicating a Sudoku table with the size of $H \times W$ in both horizontal and vertical directions. After that, we subtract LH1 from HL1 to obtain a differential matrix,D, as below:

$$D(i,j) = HL1(i,j) - LH1(i,j) = 0, (i \in [1, M/2], j \in [i, N/2]). \tag{5}$$

The differential matrix D of the example shown in Figure 8 is represented in Figure 9(a). When embedding, we choose the coefficients in the same position, i.e.,(i,j), in LH1 and HL1, respectively, which are named as a *coefficient pair* in this paper, and we judge whether the coefficient pair is embeddable by the following requirement:

$$D\,(i,j) = k, \tag{6}$$

where $k = k_{min}, \ldots, -1, 0, 1, \ldots, k_{max}$, $1 \le i \le M/2$ and $1 \le j \le N/2$. Simultaneously, a location map that indicates the secret-carry-coefficient is generated, as shown in Figure 9(b).

151	151	149	148	149	149	150	148
149	148	149	151	150	148	148	150
149	150	150	149	151	151	150	148
152	151	150	150	147	151	154	152
149	150	149	149	152	150	146	148
150	148	151	150	147	149	151	151
150	150	150	148	152	151	148	148
150	149	150	150	147	149	148	150

(a)*HL1*

150	150	153	151	146	152	150	148
150	149	150	151	147	152	148	149
150	151	152	151	146	151	151	150
149	150	152	149	149	149	147	151
150	150	151	149	150	150	149	148
150	150	149	149	149	149	151	150
150	150	145	149	149	148	152	151
151	152	148	150	147	150	148	150

(b) *LH1*

Figure 8: Part of the coefficients in HL1 and LH1

1	1	-4	-3	3	-3	0	0
-1	-1	-1	0	3	-4	0	1
-1	-1	-2	-2	5	0	-1	-2
3	1	-2	1	-2	2	7	1
-1	0	-2	0	2	0	-3	0
0	-2	2	1	-2	0	0	1
0	0	5	-1	3	3	-4	-3
-1	-3	2	0	0	-1	0	0

(a)

0	0	0	0	0	0	1	1
0	0	0	1	0	0	1	0
0	0	0	0	0	1	0	0
0	0	0	0	0	0	0	0
0	1	0	1	0	1	0	1
1	0	0	0	0	1	1	0
1	1	0	0	0	0	0	0
0	0	0	1	1	0	1	1

(b)

Figure 9: Differential matrix and Location map (a) Differential matrix D between and ; (b) Location map L

When embedding, we use HL1 as the base matrix and LH1 as the variable matrix. That is to say, for an embeddable coefficient pair, we keep the coefficient HL1(i,j) unchanged and modify the coefficient LH1(i,j), according to the reference table, to embed a secret digit.

For example, consider the wavelet coefficients subject to $D(i,j) = HL1(i,j) - LH1(i,j), (i \in [1, M/2], j \in [1, N/2])$; the embedding procedures follow:

S1: Determine the wavelet coefficients subject to $D(i,j) = HL1(i,j) - LH1(i,j), (i \in [1, M/2], j \in [1, N/2])$ and the coefficient pair of which is (p_i, p_{i+1}), where $p_i = HL1(i,j)$ and $p_{i+1} = LH1(i,j)$.

S2: The size of reference table N is $H \times W$, and the next-to-be-embedded secret digit is s_i, so the stego coefficient pair,(p_i^s, p_{i+1}^s), as in Equation (7):

$$p_i^s = p_i,$$

$$p_{i+1}^s = \begin{cases} a, & \text{where } N\left(p_i^s, p_{i+1}^s\right) = s_i \\ & \quad \text{and } a = 0, 1, \cdots, 8, \text{ if } p_{i+1} \leq 3 \\ W - a, & \text{where } N\left(p_i^s, p_{i+1}^s\right) = s_i \\ & \quad \text{and } a = 0, 1, \cdots, 8, \text{ if } p_{i+1} \geq W - 3 \\ p_{i+1} \pm a, & \text{where } N\left(p_i^s, p_{i+1}^s\right) = s_i \text{ and} \\ & \quad a = 0, 1, \cdots, 4, \text{ if } 3 < p_{i+1} < W - 3. \end{cases} \quad (7)$$

S3: Record the stego coefficient pair as $HL1(i,j) = p_i^s$,$LH1(i,j) = p_{i+1}^s$.

Assuming that the sizes of HL1 and LH1 are 3×3, that the size of reference table N is $H \times W$, and that the next-to-be-embedded secret digit is $s_i = 6$, Fig. 10 shows the embedding procedure when the wavelet coefficients are subject to $D(i,j) = HL1(i,j) - LH1(i,j) = 0$, where $i \in [1, M/2]$ and $j \in [1, N/2]$.

Table 2: Different hiding levels L with their corresponding k

L	1	2	3	4	...	L_{max}
k	0	-1,0	-1,0,1	-2,-1,0,1,2	...	$k_{min} \cdots k_{max}$

To increase the payload, more values of k can be chosen. Table 2 shows different hiding levels L with various k.

To record the embedding positions, a location map is created and is compressed by run length encoding (RLE). After that, the compressed location map is embedded into the high-frequency sub-band HH1 using LSB replacement. If the location map is too large to be embedded into the LSB of HH1, then the second LSB and the third LSB of HH1 will be used to embed the location map.

Input: A host image I of size $M \times N$ and the secret message S;

Output: A stego image $I^{'}$;

Steps:

1) Modify the histogram of the host image to prevent overflow/underflow and record the bookkeeping data for the recovery of the host image.

2) Apply the one-level integer wavelet transform to the modified host image and obtain four sub-bands (LL1, HL1, LH1, and HH1) after the decomposition.

3) A reference table N that depends on the IWT coefficients is constructed by duplicating the Sudoku table in this step. That is, when $c_{min} < 0$, add $c_{min} + 1$ to the wavelet coefficients to ensure all the wavelet coefficients is greater than 0, and then find the maximum modified wavelet coefficients $c_{max}^{'}$ from HL1 and LH1 and duplicate the Sudoku table to achieve a reference table N in the range of $[0, c_{max}^{'}]$.

4) Subtract LH1 from HL1 to obtain the differential matrix D. Go through D to find the elements subject to $D(i,j) = k$, where $k = k_{min}, \ldots, -1, 0, 1, \ldots, k_{max}$, $1 \leq i \leq M/2$ and $1 \leq j \leq N/2$, of which positions are recorded as $L1, L2, \ldots, Lk$, respectively. The matrices of $L1, L2, \ldots, Lk$ serve as the location map, which will be embedded into the high frequency sub-band HH1 using the LSB replacement.

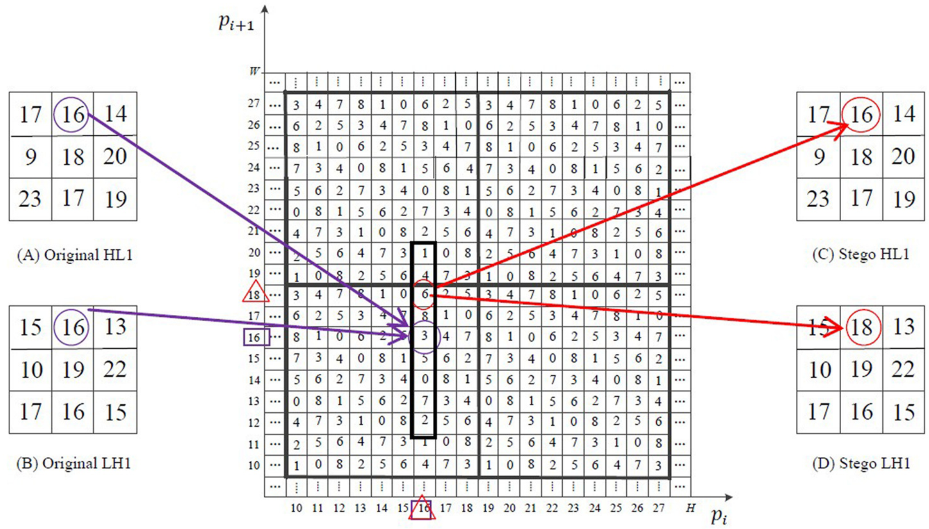


Figure 10: Example of embedding procedure

5) Use HL1 as the base matrix and LH1 as the variable matrix and apply the proposed embedding algorithm to the wavelet coefficients to embed the secret message.

6) Subtract $c_{min}+1$ to the wavelet coefficients if $c_{min} < 0$ in Step 3).

7) Perform the inverse integer wavelet transform to generate the stego image.

3.4 Data Extraction

In data extraction procedure, we extract overhead bookkeeping data and the location map from the stego image to obtain the secret message and restore the host image. As shown in the flowchart of data extraction in Figure 4, the process is described as follows:

Input: Stego image I';

Output: A host image I of size $M \times N$ and the secret message S;

Steps:

1) Apply the one-level integer wavelet transform to the stego image and get four sub-bands, LL1, HL1, LH1, and HH1, after the decomposition.

2) Extract the overhead bookkeeping data and location map from the LSB of the sub-band of HH1. According to the location map, the secret message can be obtained, and the modified wavelet coefficients can be restored.

3) Perform inverse integer wavelet transform to generate the image, the histogram of which has been shifted in the embedding phase. Using the extracted bookkeeping data, the host image can be recovered.

4 Theoretical Analysis and Experimental Results

The peak signal-to-noise ratio (PSNR) is used extensively to evaluate image quality, and PSNR is defined as:

$$PSNR = 10\log_{10}\frac{255^2}{MSE}(dB), \quad (2)$$

$$MSE = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}[I(i,j) - I'(i,j)]^2, \quad (3)$$

where MSE is the mean square error, indicating the differences between the host image I and the stego image I', and $I(i,j)$ and $I'(i,j)$ represent the gray values in the host image and stego image at location (i,j), respectively.

In the following experiments, seven 512×512 grayscale images were selected to test the performance of our proposed scheme; the images are shown in Figure 11. The PSNRs of the stego images with different hiding levels, L, are shown in Table 3. The experimental results indicated that the embedding rate increased and the PSNR decreased as the L value increased.

We compared our algorithm with that proposed by Wu et al. [23] and Ni et al. [18]. Table 4 summarizes the experimental results of Wu et al.'s method and the proposed scheme in terms of the embedding rate and the quality of the stego image. The results show that, for similar embedding rates, the proposed method provided higher PSNR than Wu's scheme. Table 5 shows the experimental results of Ni et al.'s method and the proposed scheme in terms of the embedding rate and the quality of the stego image. For most embedding scenarios, the results showed that the performance of the proposed scheme was better than that of Ni's scheme.

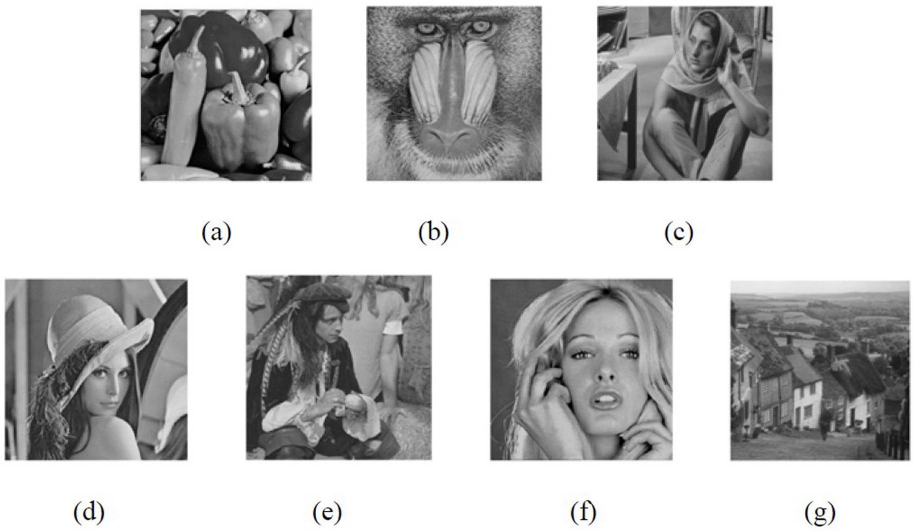


Figure 11: Host images (a) Peppers (b) Baboon, (c) Barbara, (d) Lena, (e) Man (f) Tiffany and (g) Goldhill

Table 3: Embedding rate, R, and its corresponding PSNR of the stego image with different hiding levels L

Image	$L = 1$		$L = 2$		$L = 3$	
(512 × 512)	R/bpp	PSNR	R/bpp	PSNR	R/bpp	PSNR
lena	0.063	52.99	0.123	49.71	0.183	45.55
Tiffany	0.054	51.46	0.101	49.29	0.147	46.64
Baboon	0.019	57.33	0.037	54.50	0.059	52.80
Barbara	0.048	54.34	0.094	50.99	0.141	49.29
Peppers	0.058	51.05	0.114	48.85	0.170	46.05
Goldhill	0.042	54.87	0.083	51.64	0.122	49.92
Man	0.059	45.29	0.103	44.72	0.147	44.27

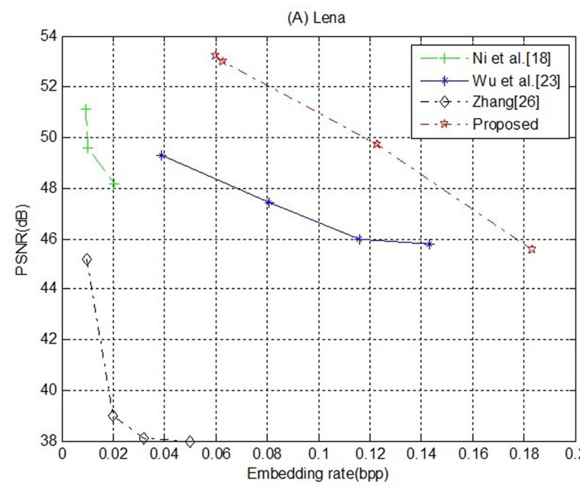
Table 4: Results of embedding rate and image quality comparisons with Wu et al.'s scheme [23]

Image	R/bpp		PSNR	
(512 × 512)	Wu et al.	Proposed	Wu et al.	Proposed
lena	0.143	0.183	45.81	45.55
Tiffany	0.103	0.147	45.25	46.64
Baboon	0.047	0.059	45.12	52.80
Barbara	0.130	0.141	45.74	49.29
Peppers	0.092	0.170	45.23	46.05
Goldhill	0.121	0.122	45.57	49.92
Man	0.108	0.147	41.37	44.27

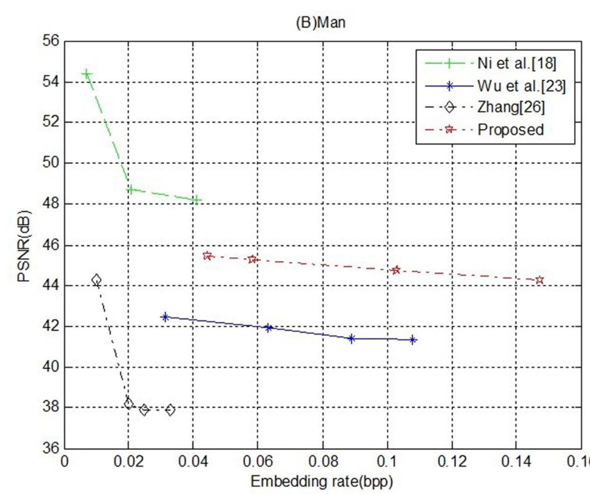
Table 5: Results of embedding rate and image quality comparisons with Ni et al.'s scheme [18]

Image	R/bpp		PSNR	
(512 × 512)	Ni et al.	Proposed	Ni et al.	Proposed
lena	0.021	0.063	48.18	52.99
Tiffany	0.029	0.054	48.26	51.46
Baboon	0.021	0.037	48.18	54.50
Barbara	0.018	0.048	50.18	54.34
Peppers	0.022	0.058	48.23	51.05
Goldhill	0.020	0.042	48.39	54.87
Man	0.041	0.059	48.22	45.29

Figure 12 shows the performance of our proposed scheme with respect to PSNR vs. embedding rate. The comparisons of our scheme with Wu et al.'s method [23], Ni et al.'s scheme [18], and Zhang's technique [26] also are shown. The experimental results indicated that Ni's scheme provided good image quality when the embedding rate was low. But, being restrained by the number of the peak points in the histogram of the host image, its embedding rate depended on the host image, and it was consistently low. When the embedding rate was high, the image quality of our proposed scheme was better than those of all of the existing schemes. This was because our scheme makes full use of the characteristics of the wavelet coefficients when we embed the secret message. We chose wavelet coefficients that had little impact on image quality in which to embed secret information, and the eventual result was good performance.



(a)



(b)

Figure 12: Comparisons of embedding performances: (a) Lena; (b) Man

5 Conclusions

In this paper, a reversible data hiding scheme is proposed based on integer-to-integer wavelet transform and a Sudoku-based hiding scheme. Our Sudoku-based data hiding algorithm scheme is reversible, which implies that the hidden data can be extracted and that the host image can be restored successfully. In addition, our proposed scheme takes advantage of the characteristics of the wavelet coefficients, which have different influences on image quality, to embed secret information, and it achieved good quality images and high embedding capacity. In addition, we can increase the capacity of the proposed scheme by adjusting the embedding positions. According to the simulation results, the proposed scheme provided a suitable capacity with high quality images. A comparison of the results achieved with the proposed technique to those achieved by Wu et al.'s method [23], Ni et al.'s method [18], and Zhang's method [26] demonstrated and confirmed the good performance of the proposed scheme.

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