LOSSLESS DATA HIDING BASED ON IMPROVED VQ INDEX JOINT NEIGHBORING CODING

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ABSTRACT. Data hiding is a form of steganography to embed secret data into digital media for the purpose of content authentication, annotation and copyright protection. Lossless data hiding is a special kind of data hiding technique that guarantees the digital media can be losslessly restored after the secret data are correctly extracted. In the past several years, several reversible data hiding schemes for Vector Quantization (VQ) compressed images have been proposed. Some embed data during the VQ encoding process such as Side-Match VQ (SMVQ)-based and Modified Fast Correlation VQ (MFCVQ)-based methods; others embed data during the VQ index streaming process such as the Joint Neighboring Coding (JNC)-based scheme. This paper presents an improved JNC (IJNC) process for both lossless data hiding and lossless index compression. The JNC process performs data hiding on each index outside the seed area, while the proposed IJNC process performs data hiding on each 2×2 index block without any seed area. Experimental results show that our scheme outperforms three recently proposed schemes, namely JNC-based, SMVQ-based and MFCVQ-based data hiding methods, in terms of the hiding capacity and the stego image quality.

Keywords: Data hiding, Lossless data hiding, Vector quantization, Joint neighboring coding, Index compression

1. Introduction. The concealment of information within computer files is a common way used in modern steganography [1-3]. Media files are ideal ones for steganographic transmission because of their large size. In this paper, we focus on techniques for hiding information in images. Data hiding schemes can be broadly classified into two categories, i.e., irreversible data hiding and reversible data hiding. For some special applications in military, medical and forensic areas, it is crucial to recover the original host image without any distortion after the extraction of the secret data. Reversible data hiding in images can be performed in the spatial or compressed domain. Barton presented the first spatial-domain reversible data hiding scheme [4] that compresses several bits of the original host image and then hides the compressed data and the secret data in the host image. Celik et al. proposed a novel reversible data hiding algorithm [5] based on a generalization of the well-known LSB (Least Significant Bit) modification. Tian proposed a famous reversible data hiding technique [6] based on a so-called difference expansion operation. Thodi and Rodriguez proposed a prediction-error based reversible watermarking scheme [7]. Alattar proposed a reversible watermarking algorithm [8] with very high data hiding capacity for color images. Zhao et al. proposed a high capacity novel hiding scheme [9] based on reversible secret sharing.

Since most images are stored in compressed formats such as JPEG and JPEG2000, reversible data hiding techniques in the compressed domain are useful and necessary.

Besides JPEG and JPEG2000 compression methods, Vector Quantization (VQ) is another famous block-based image compression technique that has been widely studied and used due to its characteristics of easy implementation and high efficiency. Yang et al. proposed a reversible watermarking scheme [13] based on modified fast correlation VQ (MFCVQ). However, the hiding capacity of the MFCVQ method is unstable and low. To improve the hiding capacity, Chang et al. proposed several reversible data hiding algorithms [14-17] based on the side-match VQ (SMVQ) and modified SMVQ. Recently, several reversible data hiding schemes based on VQ index coding have been proposed. Chang et al. proposed a reversible data embedding scheme [18] based on the VQ image compression technique which emphasizes that the original VQ compressed codes can be recovered after data extraction. Chang et al. presented a reversible information hiding method [19] for VQ-compressed grayscale images by using the so-called joint neighboring coding (JNC) technique. Similarly, Lu et al. [20] proposed a reversible data hiding algorithm based on the VQ-index residual value coding. This algorithm can achieve a higher PSNR and a higher data hiding capacity than the algorithms proposed in [13,17]. The main problems of the above algorithms lie in that they require seed areas and either their bit rates are higher than the original VQ method or their PSNR values are lower than the original VQ method.

In this paper, we propose an improved joint neighboring coding (IJNC) algorithm for lossless data hiding with index compression ability. Our contribution lies in the elimination of the restriction of seed areas and the proposal of performing the data hiding and index compression simultaneously based on $2 \times 2$ index blocks. Thus, the capacity, one of the most important properties of data hiding schemes, is increased in the proposed scheme. At the same time, the bit rate, one of the most important properties of image compression, is reduced in the proposed scheme. Furthermore, the proposed scheme can preserve the same image quality as the original VQ compressed image.

2. Related Works. Vector Quantization (VQ) is an attractive block-based encoding method for image compression with a high compression ratio in recent years. VQ can be defined as a mapping from the $k$-dimensional Euclidean space $\mathbb{R}^k$ into a finite codebook $C = \{c_i | i = 0, 1, \ldots, N - 1\}$, where $c_i$ is a codeword and $N$ is the codebook size. VQ first generates a representative codebook offline based on a number of training vectors using, typically, the well-known LBG algorithm [21]. During the encoding process, each $k$-dimensional input image block $\mathbf{x} = (x_0, x_1, \ldots, x_{k-1})$ is compared with the codewords in the codebook $C = \{c_0, c_1, \ldots, c_{N-1}\}$ to find the best matching codeword $c_i = (c_{i,0}, c_{i,1}, \ldots, c_{i,k-1})$. And then the index $i$ of the best matching codeword is assigned to $\mathbf{x}$. After all the input image blocks are encoded, an index table can be obtained. The indices in the index table are transmitted over the channel to the decoder. The decoder has the same codebook as the encoder. For each index $i$, the decoder merely performs a simple table look-up operation to obtain $c_i$ and then utilizes $c_i$ to reconstruct each input image block $\mathbf{x}$.

2.1. MFCVQ-based reversible data hiding algorithm. The MFCVQ-based reversible data hiding scheme [13] performs the data hiding process during the VQ encoding. In MFCVQ, for the current image block $\mathbf{x}$ outside the seed area, it is encoded by using
its four neighboring encoded image blocks \(c_u, c_l, c_s\) and \(c_r\). For each input image block \(x\), MFCVQ first checks the embeddability of \(x\), and then performs the hiding & coding process for the embeddable block while performs the pure coding process for the non-embeddable block. To check the embeddability, the distances between the encoded adjacent blocks and the current block \(x\) are computed respectively as \(d_u = d(x, c_u)\), \(d_l = d(x, c_l)\) and \(d_r = d(x, c_r)\), and the smallest distance \(d_{\text{min}}\) is found out of \(\{d_u, d_l, d_l, d_r\}\). Then, \(d_{\text{min}}\) is compared with the pre-defined distance threshold \(TH\). If \(d_{\text{min}} \leq TH\), the current block \(x\) is embeddable and the flag bit ‘0’ is sent to the codestream. Otherwise, the current block \(x\) is non-embeddable and the flag bit ‘1’ is sent to the codestream. For the embeddable block, the mean vector \(c_{\text{mean}} = (c_u + c_l + c_s + c_r)/4\) is first calculated, and then the hiding & coding process is performed according to the secret bit. If the secret bit to be embedded is ‘0’, the best-matched codeword \(c_{\text{best}}\) of \(c_{\text{mean}}\) is found out of \(\{c_u, c_r, c_s, c_l\}\), and the two location bits of \(c_{\text{best}}\) are sent to the codestream (the two location bits of \(c_s, c_u, c_l, c_r\) are ‘00’, ‘01’, ‘10’ and ‘11’ respectively). If the secret bit to be embedded is ‘1’, the best-matched codeword \(c_x\) of \(x\) is found out of \(\{c_u, c_r, c_s, c_l\}\), and the two location bits of \(c_x\) are sent to the codestream. Note that if \(c_x = c_{\text{best}}\), the next best-matched code vector \(c'_x \neq c_{\text{best}}\) should be selected. For the non-embeddable block, the normal coding process is performed, i.e., the best-matched codeword \(c_{x,\text{best}}\) is found from the whole codebook \(C\) for the current block \(x\), and the index of \(c_{x,\text{best}}\) is sent to the codestream.

The main drawback of MFCVQ-based hiding method is that the hiding capacity of the MFCVQ method is unstable and low, since the embeddable locations are determined by a pre-defined distance threshold. Furthermore, the PSNR value of the stego image is much less than the original VQ-compressed image.

### 2.2. The SMVQ-based reversible data hiding algorithm

The original side-match VQ based image coding scheme was proposed by Kim [22]. The SMVQ encoder first uses the master codebook to encode the blocks in the first column and the blocks in the first row. Then all other image blocks are encoded from left to right row by row using the correlation of neighboring encoded blocks. Let \(x\) denote the current processing vector, and \(u\) and \(l\) be the codewords of the upper and left neighboring blocks, respectively. The side-match distortion of a codeword \(c\) in \(C\) is defined as \(smd(c) = vd(c) + hd(c)\), where the vertical and horizontal distortions of \(c\) are defined as \(vd(c) = \sum_{i=0}^{3} (u(i,3) - c_{(0,i)})^2\) and \(hd(c) = \sum_{i=0}^{3} (l(i,3) - c(i,0))^2\), where \(x_{(i,j)}\) denotes the value of the \(j^{th}\) pixel of the \(i^{th}\) row in an image block \(x\). Then SMVQ encoder sorts the master codebook \(C\) according to the side-match distortion of all codewords, and selects the first \(N_s\) \((N_s < N)\) codewords to form the state codebook \(C_s\) of \(x\), whose side-match distortions are the smallest. SMVQ encoder next picks the closest codeword of \(x\) from the state codebook \(C_s\) and transmits the index of this closest codeword to the receiver.

Chang et al. [17] first employed the SMVQ technique in reversible data hiding field. They also view the blocks in the uppermost row and the leftmost column that are encoded by the standard VQ as the seed area. For each block \(x\) outside the seed area, a state codebook is generated based on its upper and left encoded blocks. The best matching codeword \(c_{\text{min}}\) of the current block \(x\) is found from the state codebook. Then an approximate codeword is obtained by

\[
c_b = \left\lfloor \frac{2c_{\text{min}} + c_a}{3} \right\rfloor
\]
where $c_i$ is the closest codeword to $c_{\text{min}}$ in the state codebook. $|v|$ stands for the operation of obtaining a different but closest vector with integer components to $v$. To hide a secret bit ‘0’, the codeword $c_{\text{min}}$ is used to encode the current block. To hide a secret bit ‘1’, the approximate codeword $c_i$ is used to encode the current block. In the extraction phase, the receiver compares each received block with the corresponding codeword from the state codebook. If the Euclidean distance is equal to 0, the secret bit is 0, and the codeword remains unchanged; otherwise, the secret bit 1 is extracted and the codeword $c_i$ is replaced with $c_{\text{min}}$.

The main drawback of SMVQ-based hiding method is that the PSNR value of the stego image is much less than the original VQ-compressed image.

2.3. JNC-based reversible data hiding algorithm. Recently, Chang et al. [19] presented a new reversible data hiding algorithm based on the joint neighboring coding (JNC) technique to hide data in the VQ index table. This method embeds secret data by using the difference values between the current VQ-compressed index and left or upper neighboring indices. Given a $P \times Q$-sized host gray-level image $I$ and the codebook $C$ containing $N$ 16-dimensional codewords $c_i$, $i = 0, 1, \ldots, N - 1$. Before the JNC coding process, several preprocessing steps should be performed. First, compute the sum of each codeword $c_i$ by $s_i = \sum_{j=0}^{15} c_{ij}$. Second, sort the codebook $C$ according to $s_i$ in the ascending order: $s_0 \leq s_1 \leq \cdots \leq s_{N-1}$ in order to make neighboring codewords close to each other. Finally, based on the sorted codebook, encode the $P \times Q$-sized image into a $(P/4) \times (Q/4)$-sized index matrix $P = \{p_{i,j}|i = 0, 1, \ldots, P/4 - 1; j = 0, 1, \ldots, Q/4 - 1\}$ that is often called index table.

With the index table $P$ in hand, the secret data are then embedded by encoding the VQ indices outside the seed area, i.e., $p_{ij}, i \neq 0$ and $j \neq 0$. This process is performed by encoding the difference values $d$’s between the left neighboring index $p_{i,j-1}$ or the upper neighboring index $p_{i-1,j}$ and the index $p_{ij}$. The embedding strategy is based on the secret bit. If the secret bit is ‘1’, then the difference value $d = p_{i,j-1} - p_{ij}$ is computed. If the secret bit is ‘0’, then the difference value $d = p_{i-1,j} - p_{ij}$ is computed. Based on the dynamic range of $d$, Chang et al. considered four cases as follows [19]:

Case 1: $0 < d < 2^m - 1$. The index $p_{ij}$ is encoded into the binary form $11 || d_2$ or $01 || d_2$ to represent embedding the secret bit 1 or 0, respectively. Here, $||$ denotes the concatenation operation, and $m$ should be properly selected based on the distribution of index differences.

Case 2: $-(2^m - 1) < d < 0$. The index $p_{ij}$ is encoded into the binary form $10 || d_2$ or $00 || d_2$ to represent embedding the secret bit ‘1’ or ‘0’, respectively.

Case 3: $d = 0$. The index $p_{ij}$ is encoded into the binary form $11 || d_2$ or $01 || d_2$ to represent embedding the secret bit ‘1’ or ‘0’, respectively. Here, $d_2$ is represented with $m$ digits ‘0’.

Case 4: $|d| > 2^m - 1$. The index $p_{ij}$ is encoded into the binary form $10 || 00...0 (m \text{ digits } ‘0’) || (p_{ij})_2$, or $00 || 00...0 (m \text{ digits } ‘0’) || (p_{ij})_2$ to represent embedding the secret bit ‘1’ or ‘0’, respectively. Here, $(p_{ij})_2$ is the binary representation of $p_{ij}$ with $\log_2 N$ bits.

The main drawback of JNC-based hiding method is that the bit rate of the stego image is a bit larger than the original VQ-compressed image.

3. Proposed Algorithm. From Section 2, we can see that MFCVQ, SMVQ and JNC-based data hiding methods do not embed secret bits in the seed area. Second, they perform the data hiding process in embeddable blocks one by one. In order to embed more secret bits, the first strategy that we bethink of is to cancel the seed area and make all blocks embeddable. In order to reduce the coding bit rate, the second strategy that we adopt
is to perform the index coding process on each 2×2 index block rather than one by one. Based on these two strategies, we propose a novel data hiding scheme based on improved joint neighboring coding. The main idea of our scheme is to first vector quantize the cover image, obtaining an index table, and then divide the index table into non-overlapping 2×2 index blocks. Finally, we encode the indices in each 2×2 index block according to four input secret bits and the dynamic range evaluated by the difference between the maximal index value and the minimal index value in the index block. The proposed algorithm consists of three stages, i.e., the VQ encoding stage, the data hiding & index coding stage and the data extraction and decoding stage, which can be illustrated as follows:

3.1. The VQ encoding stage. This stage is a preprocessing stage before data hiding and index coding. The aim of this stage is to obtain the index table for later use. Given a \( P \times Q \)-sized 256 grayscale host image \( I \) and the codebook \( C \) with \( N \) 16-dimensional codewords \( c_i, i = 0, 1, \ldots, 511 \) (we adopt \( k = 4 \times 4 \) and \( N = 512 \) in this paper), this stage can be expressed as follows:

Step 1: For each codeword \( c_i \), compute its sum value by \( s_i = \sum_{j=0}^{15} c_{ij}, i = 0, 1, \ldots, 511 \).
Step 2: Sort the codebook \( C \) according to \( s_i \) in the ascending order, \( s_0 \leq s_1 \leq \cdots \leq s_{511} \), obtaining the sorted codebook \( C_s \).
Step 3: The original cover image \( I \) is divided into non-overlapping 4×4-sized blocks \( b_{i,j}, i = 0, 1, \ldots, P/4 - 1; j = 0, 1, \ldots, Q/4 - 1 \).
Step 4: Encode each image block \( b_{i,j} \) with the sorted codebook \( C_s \) based on the fast nearest neighbor search algorithm [23] or [24], obtaining the index of its best matched codeword, \( p_{i,j} \). All these indices compose the index table \( P = \{p_{i,j}| i = 0, 1, \ldots, P/4 - 1; j = 0, 1, \ldots, Q/4 - 1 \} \).

3.2. The data hiding and index coding stage. With the index table \( P \) in hand, now we can introduce our reversible data hiding and index coding algorithm. Before embedding, we perform the permutation operation on the secret bit sequence in order to enhance the security. Our embedding method is performed not index by index but on each 2×2 index block in order to make full use of the correlation between neighboring indices, and thus the encoding bit rate can be reduced. Assume the index table \( P \) is segmented into non-overlapping 2×2 index blocks, \( q_{h,l}, h = 0, 1, \ldots, P/8 - 1; l = 0, 1, \ldots, Q/8 - 1 \). Here, \( q_{h,l} = \{P_{2h:2l+1}, P_{2h+1:2l+1}, P_{2h+2:2l+1}, P_{2h+3:2l+1}\} \), and we adopt \{‘00’, ‘01’, ‘10’, ‘11’\} to denote their locations accordingly. For each 2×2 index block \( q_{h,l} \), assume the corresponding 4 secret bits to be embedded are \{\(w_1, w_2, w_3, w_4\)\}, the data hiding and index coding process can be illustrated detailedly as follows:

Step 1: Find the maximal and minimal indices \( p_{\text{max}} \) and \( p_{\text{min}} \) in \( q_{h,l} \), and record their location bits \( w_{\text{max}} \in \{‘00’, ‘01’, ‘10’, ‘11’\} \) and \( w_{\text{min}} \in \{‘00’, ‘01’, ‘10’, ‘11’\} \) respectively.
Step 2: Calculate the dynamic range \( r = p_{\text{max}} - p_{\text{min}} \). For \( N = 512 \), based on the dynamic range \( r \), consider eight cases as shown in Table 1. Obviously, it requires 3 bits to denote each case. Append these 3 bits (they are called range bits \( w_{\text{ran}} \) in this paper) to the codestream. (If \( N = 256 \), we may consider four cases, and thus each case requires 2 bits).
Step 3: Viewing the first two secret bits \( w_1 \) and \( w_2 \) as the location bits, find the reference index \( p_{\text{ref}} \) in \( q_{m,n} \) (e.g., if the first two secret bits is ‘01’, then \( p_{\text{ref}} = p_{2h,2l+1} \)). Append the 2 secret bits \( w_{\text{ref}} = w_1||w_2 \) (they are called reference location bits) followed by the 9 bits \( (p_{\text{ref}})_{2} \) (since the codebook size \( N = 512 \)) to the codestream. Here, \(|\rangle\) denotes the concatenation operation, and \( ( )_2 \) denotes the operation to get the binary description of a number.
Step 4: According to the third secret bit \( w_3 \), select the comparison index \( p_{\text{com}} \) out of \( \{p_{\text{max}}, p_{\text{min}}\} \). If \( w_3 = 1 \), then set \( p_{\text{com}} = p_{\text{max}} \) and \( w_{\text{com}} = w_{\text{max}} \); Otherwise, if \( w_3 = 0 \),
Our data hiding scheme is reversible because we can recover the original index table after data extraction, and thus the original VQ compressed image can be losslessly recovered. The input is the IJNC codestream, our purpose is to extract the secret bit sequence and recover the original VQ compressed image. In the decoding and extracting stage, this can be done by following the steps below.}

### Table 1. Eight cases considered for coding the index differences ($N = 512$)

<table>
<thead>
<tr>
<th>Case</th>
<th>Dynamic Range</th>
<th>Range Bits</th>
<th>$m$ (number of bits required to code each difference)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>$0 \leq r &lt; 2$</td>
<td>’000’</td>
<td>1</td>
</tr>
<tr>
<td>Case 2</td>
<td>$2 \leq r &lt; 4$</td>
<td>’001’</td>
<td>2</td>
</tr>
<tr>
<td>Case 3</td>
<td>$4 \leq r &lt; 8$</td>
<td>’010’</td>
<td>3</td>
</tr>
<tr>
<td>Case 4</td>
<td>$8 \leq r &lt; 16$</td>
<td>’011’</td>
<td>4</td>
</tr>
<tr>
<td>Case 5</td>
<td>$16 \leq r &lt; 32$</td>
<td>’100’</td>
<td>5</td>
</tr>
<tr>
<td>Case 6</td>
<td>$32 \leq r &lt; 64$</td>
<td>’101’</td>
<td>6</td>
</tr>
<tr>
<td>Case 7</td>
<td>$64 \leq r &lt; 128$</td>
<td>’110’</td>
<td>7</td>
</tr>
<tr>
<td>Case 8</td>
<td>$r \geq 128$</td>
<td>’111’</td>
<td>9</td>
</tr>
</tbody>
</table>

### Figure 1. The bit string structure for encoding each index block ($N = 512$)

then set $p_{com} = p_{min}$ and $w_{com} = w_{min}$. Here we should consider two cases. In Case 1, the reference index and the comparison index are located at the same position, i.e., $p_{ref} = p_{com}$ and $w_{ref} = w_{com}$. Denote the remainder 3 indices in $q_{h,l}$ as $p_A$, $p_B$ and $p_C$ respectively (in the raster-scan order). In Case 2, the reference index and the comparison index are located at different positions, i.e., $w_{ref} \neq w_{com}$. Except for $p_{com}$, define $p_A = p_{ref}$ and denote the remainder 2 indices in $q_{h,l}$ as $p_B$ and $p_C$ respectively (in the raster-scan order). Append the third secret bit $w_3$ followed by the 2 comparison location bits $w_{com}$ to the codestream.

Step 5: According to the secret bits $w_3$ and $w_4$, calculate the differences among $p_{com}$, $p_A$, $p_B$ and $p_C$. If $w_4 = 0$ and $w_3 = 0$, then $d_A = p_{com} - p_A$, $d_B = p_B - p_{com}$ and $d_C = p_{com} - p_C$. If $w_4 = 0$ and $w_3 = 1$, then $d_A = p_{com} - p_A$, $d_B = p_{com} - p_B$ and $d_C = p_{com} - p_C$. If $w_4 = 1$ and $w_3 = 0$, then $d_A = p_{com} - p_A$, $d_B = p_B - p_{com}$ and $d_C = p_{com} - p_B$. If $w_4 = 1$ and $w_3 = 1$, then $d_A = p_A - p_{com}$, $d_B = p_B - p_{com}$, $d_C = p_{com} - p_{com}$. We easily find that $w_A$ can indicate the sign of the differences, i.e., if $w_4 = 0$, the sign is positive; otherwise, the sign is negative.

Step 6: According to the dynamic range $r$ given in Table 1, look up the number of bits (it is denoted by $m$) required to encode each difference. If $w_4 = 0$, 3$m$ bits are used to denote $(d_A)_2$, $(d_B)_2$ and $(d_C)_2$. Otherwise, if $w_4 = 1$, 3$m$ bits are used to denote $(-d_A)_2$, $(-d_B)_2$ and $(-d_C)_2$. Append the fourth secret bit $w_4$ followed by the 3$m$ bits of $d_A$, $d_B$ and $d_C$ to the codestream.

Perform Step 1 to Step 6 for each 2×2 index block $q_{h,l}$, we can hide four bits in each index block and output a bit string whose length is $18 + 3m$ as given in Figure 1. Here, $m$ is different from block to block. If most of the index blocks are with $m < 6$, then the bit rate can be reduced compared to the original index table that requires 36 bits to denote four indices in each index block ($N = 512$). An index coding and data hiding example for a typical 2×2 index block is shown in Figure 2.

### 3.3. The decoding and extracting stage.

Our data hiding scheme is reversible because we can recover the original index table after data extraction, and thus the original VQ compressed image can be losslessly recovered. The input is the IJNC codestream, our purpose is to extract the secret bit sequence and recover the original VQ compressed image.
image. Assume \( N = 512 \), the detailed decoding and extracting process can be described as follows.

Step 1: Read the next 3 bits into \( w_{ran} \) from the codestream, find the corresponding case in Table 1, and look up the value \( m \) in Table 1.

Step 2: Read the next 11 bits from the codestream. Get the first 2 bits \( w_1 \) and \( w_2 \) as the reference location bits \( w_{ref} \), append them to the output secret bit sequence. Transform the last 9 bits into the reference index \( p_{ref} \), and put this index in the current index block according to the location bits \( w_{ref} \).

Step 3: Read the next 3 bits from the codestream. Get the first bit \( w_3 \), append it to the output secret bit sequence. Get the last two bits as the comparison location bits \( w_{com} \).

Step 4: Read the next 1+3m bits from the codestream. Get the first bit \( w_4 \), append it to the output secret bit sequence. Transform the following three \( m \) bits into three positive difference values \( d_{A+}, d_B+, \) and \( d_{C+} \). If \( w_4 = 0, d_A = d_{A+}, d_B = d_B+ \) and \( d_C = d_{C+} \); Otherwise, \( d_A = -d_{A+}, d_B = -d_B+ \) and \( d_C = -d_{C+} \).

Step 5: Except for the reference index, recover the other three indices in the current 2x2 index block. Here, we should consider two cases:

Case 1: \( w_{ref} = w_{com} \). In this case, the reference index is just the comparison index, and thus \( p_{com} = p_{ref} \). If \( w_4 = 0 \) and \( w_3 = 0 \), then \( p_A = d_A + p_{com}, p_B = d_B + p_{com} \) and \( p_C = d_C + p_{com} \). If \( w_4 = 0 \) and \( w_3 = 1 \), then \( p_A = p_{com} - d_A, p_B = p_{com} - d_B \) and \( p_C = p_{com} - d_C \). If \( w_4 = 1 \) and \( w_3 = 0 \), then \( p_A = p_{com} - d_A, p_B = p_{com} - d_B \) and \( p_C = p_{com} - d_C \). If \( w_4 = 1 \) and \( w_3 = 1 \), then \( p_A = d_A + p_{com}, p_B = d_B + p_{com} \) and \( p_C = d_C + p_{com} \). Put \( p_A, p_B \) and \( p_C \) at the remainder 3 locations in the raster-scan order.

Case 2: \( w_{ref} \neq w_{com} \). In this case, \( p_A \) is the difference between \( p_{com} \) and \( p_{ref} \). If \( w_4 = 0 \) and \( w_3 = 0 \), then \( p_{com} = d_A - p_{ref} \). If \( w_4 = 0 \) and \( w_3 = 1 \), then \( p_{com} = p_{ref} + d_A \). If \( w_4 = 1 \) and \( w_3 = 0 \), then \( p_{com} = -p_{ref} + d_A \). If \( w_4 = 1 \) and \( w_3 = 1 \), then \( p_{com} = d_A - p_{ref} \). Put \( p_{com} \) in the current 2x2 index block according to the location bits \( w_{com} \). Now turn to recover left two indices. If \( w_4 = 0 \) and \( w_3 = 0 \), then \( p_B = d_B + p_{com} \) and \( p_C = d_C + p_{com} \). If \( w_4 = 0 \) and \( w_3 = 1 \), then \( p_B = p_{com} - d_B \) and \( p_C = p_{com} - d_C \). If \( w_4 = 1 \) and \( w_3 = 0 \),

\[
\begin{align*}
412 & \rightarrow 407 \\
407 & \rightarrow 405 \\
\end{align*}
\]

**Figure 2. A detailed example to hide 4 bits and encode an index block**

\[
\begin{align*}
\text{Input bits} = & \text{10100101011} \rightarrow w_4 = 0, w_3 = 0, w_2 = 1 \\
\text{Index block} & \rightarrow 412, 407, 405 \\
\text{Secret bits} & \rightarrow 0110
\end{align*}
\]

\[
\begin{align*}
w_{ran} = & 010^3, m = 3 \\
w_{ref} = & w_4 \rightarrow 407, p_{ref} = 407 \\
A & \rightarrow 407(5) \\
B & 7 \\
\end{align*}
\]

**Figure 3. A detailed example to extract secret data and decode an index block**

\[
\begin{align*}
\text{Input bits} = & \text{101001010111100101011101111111} \rightarrow w_4 \rightarrow 0110, p_{ref} = 407, \text{Index block} \\
\text{Index block} & \rightarrow 412, 407, 405 \\
\text{Secret bits} & \rightarrow 0110
\end{align*}
\]
then $p_B = p_{\text{com}} - d_B$ and $p_C = p_{\text{com}} - d_C$. If $w_4 = 1$ and $w_3 = 1$, then $p_B = d_B + p_{\text{com}}$ and $p_C = d_C + p_{\text{com}}$. Put $p_B$ and $p_C$ at the remainder 2 locations in the raster-scan order.

Repeatedly perform Step 1 to Step 5 for all $2 \times 2$ index blocks, we can recover the original VQ index table and output the whole secret bit sequence. Figure 3 gives an example to show the decoding and data extraction process for an index block. According to the restored VQ indices and the sorted codebook, we can reconstruct the original VQ-compressed image. In this way, the whole reversible process is realized.

### 4. Experimental Results

To evaluate the proposed scheme, we use six test images, Lena, Peppers, Mandrill, Boat, Goldhill and Jet F16, of the same size $512 \times 512$ with 256 gray scales. The $512$-sized master codebook $C$ is generated by the LBG algorithm based on two training images, Lena and Peppers, where the dimension of each codeword is $4 \times 4$. Comparisons among our algorithm, the MFCVQ-based algorithm [13], the SMVQ-based algorithm [17] and the JNC-based algorithm [19] are performed.

In order to show the distribution of $2 \times 2$ index blocks for different images, Table 2 lists the number of index blocks belong to each case of Table 1. Because the total number of bits required to encode an index block based on our algorithm is $18 + 3m$ while the number of bits required to encode four indices based on the basic VQ ($N = 512$) is 36, in order to reduce the bit rate, we expect to have $18 + 3m \leq 36$, i.e., $m \leq 6$, for most index blocks. From Table 2, we can see that, for all images except for the Mandrill image, most index blocks belong to the first 6 cases, thus our scheme can reduce the bit rate as shown in Table 3. The Mandrill image is very complex with high detail and it is outside of the training set, which make the variation of indices in most index blocks be large, and thus most index blocks belong to Case 7 and the bit rate is somewhat larger than that of the normal VQ.

To show the superiority of our proposed algorithm, we compare it with the MFCVQ-based algorithm [13], the SMVQ-based algorithm [17] and the JNC-based algorithm [19]. Four aspects of performance are adopted in the experiments to evaluate a data hiding scheme, i.e., the capacity representing the maximum number of secret bits that can be hidden, the peak signal to noise ratio (PSNR) representing the quality of the stego-image, the bit rate representing the performance of the compression efficiency whose unit is bits per pixel (bpp), and the embedding efficiency indicating the number of embedded secret data when a bit of the binary code stream has been transmitted. Obviously, the embedding efficiency can be calculated as: $\text{Capacity} / (\text{Bit rate} \times P \times Q)$. Because the VQ codebook is generated from the Lena and Peppers images, so their PSNRs based on any schemes are much higher than those of other test images outside the training set. Because the Mandrill

<table>
<thead>
<tr>
<th>Image</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
<th>Case 4</th>
<th>Case 5</th>
<th>Case 6</th>
<th>Case 7</th>
<th>Case 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lena</td>
<td>162</td>
<td>51</td>
<td>362</td>
<td>782</td>
<td>890</td>
<td>738</td>
<td>622</td>
<td>489</td>
</tr>
<tr>
<td>Peppers</td>
<td>211</td>
<td>147</td>
<td>376</td>
<td>756</td>
<td>928</td>
<td>599</td>
<td>505</td>
<td>574</td>
</tr>
<tr>
<td>Mandrill</td>
<td>2</td>
<td>2</td>
<td>55</td>
<td>216</td>
<td>597</td>
<td>1216</td>
<td>1502</td>
<td>506</td>
</tr>
<tr>
<td>Boat</td>
<td>283</td>
<td>70</td>
<td>217</td>
<td>698</td>
<td>887</td>
<td>843</td>
<td>638</td>
<td>460</td>
</tr>
<tr>
<td>Goldhill</td>
<td>227</td>
<td>42</td>
<td>140</td>
<td>474</td>
<td>1010</td>
<td>1189</td>
<td>812</td>
<td>202</td>
</tr>
<tr>
<td>Jet_F16</td>
<td>678</td>
<td>286</td>
<td>638</td>
<td>512</td>
<td>402</td>
<td>438</td>
<td>591</td>
<td>551</td>
</tr>
</tbody>
</table>
image is a high-detail image outside the training set, its encoding quality is far worse than any other image. As shown in Table 3, the PSNRs of stego images in our scheme and the JNC-based method are exactly equal to those of the original VQ compressed images, the reason is that the proposed IJNC-based scheme and the JNC-based scheme reversibly hide data during the coding of the VQ index table and no distortions are introduced in the index coding and data hiding process. The MFCVQ-based and SMVQ-based methods reversibly hide data during the VQ encoding and no operations are performed on the consequent VQ index coding process, and their reversibility means that they can recover the original MFCVQ-encoded image and the SMVQ-encoded image respectively. However, the MFCVQ and SMVQ based encoding methods obtain worse image quality by around 2dB, although they obtain relatively lower bit rates.

With respect to the embedding capacity, the proposed scheme achieves the highest embedding capacity. Compared with the SMVQ-based scheme and the JNC-based scheme, our scheme embeds information in all indices without the seed area, so we can embed 255 more bits in the index table. Our proposed scheme achieves significantly better embedding capacity in comparison with the MFCVQ-based method. The embedding capacity of the MFCVQ-based method is quite low because this method just embeds the secret data into smooth image blocks outside the seed area.

In regard to the bit rate, from Table 3, we can see that the MFCVQ and SMVQ based methods obtain relatively lower bit rates while our scheme and the JNC-based scheme achieve relatively higher bit rates. This is because the MFCVQ scheme only uses 3 bits to encode one embeddable VQ-compressed index, while the SMVQ only uses 7 bits \((N_s = 128)\) to denote each index outside the seed area. Anyhow, compared with the ordinary VQ, our scheme can not only hide information but also compress indices, because our scheme can get lower bit rates by around 0.02bpp for most images except the Mandrill image. Compared with the JNC-based scheme, our scheme can achieve lower bit rates for all test images by around 0.04bpp.

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Performance Lena</th>
<th>Peppers</th>
<th>Mandrill</th>
<th>Boat</th>
<th>Goldhill</th>
<th>Jet_F16</th>
</tr>
</thead>
<tbody>
<tr>
<td>VQ ((N = 512))</td>
<td>PSNR (dB) 30.860</td>
<td>30.428</td>
<td>22.070</td>
<td>28.184</td>
<td>29.618</td>
<td>28.014</td>
</tr>
<tr>
<td></td>
<td>Bit Rate (bpp) 0.563</td>
<td>0.563</td>
<td>0.563</td>
<td>0.563</td>
<td>0.563</td>
<td>0.563</td>
</tr>
<tr>
<td>Proposed IJNC ((N = 512))</td>
<td>Capacity (Bits) 16384</td>
<td>16384</td>
<td>16384</td>
<td>16384</td>
<td>16384</td>
<td>16384</td>
</tr>
<tr>
<td></td>
<td>Bit Rate (bpp) 0.534</td>
<td>0.528</td>
<td>0.583</td>
<td>0.532</td>
<td>0.537</td>
<td>0.498</td>
</tr>
<tr>
<td></td>
<td>Efficiency 0.117</td>
<td>0.118</td>
<td>0.107</td>
<td>0.117</td>
<td>0.116</td>
<td>0.126</td>
</tr>
<tr>
<td>JNC ((N = 512, m = 6))</td>
<td>PSNR (dB) 30.860</td>
<td>30.428</td>
<td>22.070</td>
<td>28.184</td>
<td>29.618</td>
<td>28.014</td>
</tr>
<tr>
<td></td>
<td>Bit Rate (bpp) 0.574</td>
<td>0.573</td>
<td>0.606</td>
<td>0.567</td>
<td>0.567</td>
<td>0.572</td>
</tr>
<tr>
<td></td>
<td>Efficiency 0.107</td>
<td>0.107</td>
<td>0.102</td>
<td>0.109</td>
<td>0.109</td>
<td>0.108</td>
</tr>
<tr>
<td></td>
<td>Capacity (Bits) 7435</td>
<td>6875</td>
<td>957</td>
<td>7107</td>
<td>2304</td>
<td>8175</td>
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<tr>
<td></td>
<td>Bit Rate (bpp) 0.425</td>
<td>0.440</td>
<td>0.599</td>
<td>0.434</td>
<td>0.563</td>
<td>0.406</td>
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<tr>
<td></td>
<td>Efficiency 0.067</td>
<td>0.059</td>
<td>0.006</td>
<td>0.062</td>
<td>0.016</td>
<td>0.076</td>
</tr>
<tr>
<td>SMVQ-based ((N = 512, N_s = 128))</td>
<td>PSNR (dB) 28.192</td>
<td>27.947</td>
<td>21.042</td>
<td>25.881</td>
<td>27.422</td>
<td>25.832</td>
</tr>
<tr>
<td></td>
<td>Capacity (Bits) 16129</td>
<td>16129</td>
<td>16129</td>
<td>16129</td>
<td>16129</td>
<td>16129</td>
</tr>
<tr>
<td></td>
<td>Bit Rate (bpp) 0.44</td>
<td>0.44</td>
<td>0.44</td>
<td>0.44</td>
<td>0.44</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td>Efficiency 0.140</td>
<td>0.140</td>
<td>0.140</td>
<td>0.140</td>
<td>0.140</td>
<td>0.140</td>
</tr>
</tbody>
</table>
In terms of embedding efficiency, the SMVQ-based scheme has the highest efficiency values, and the MFCVQ-based method has the lowest efficiency values. This means that the SMVQ can transmit the most number of embedded secret data when a bit of the binary code stream has been transmitted, while the MFCVQ-based method can transmit the least number of embedded secret data. Our scheme has the second highest efficiency values that are higher than that of the JNC-based scheme by around 0.01.

With regard to the embedding and extracting speed, because our scheme and the JNC-based scheme are based on the index table, if we ignore the VQ encoding process, our scheme and the JNC-based scheme are much faster than the MFCVQ-based and SMVQ-based schemes. Taking the above five attributes into comprehensive consideration, the proposed scheme is a more effective method for its high capacity, high PSNR, high embedding efficiency and low bit rate.

5. **Conclusions.** In this paper, we present an improved joint neighboring coding based reversible data hiding algorithm. The main features of our scheme are as follows: (1) Our scheme can obtain the same PSNR values as the JNC-based scheme. (2) Our scheme does not need the seed area, so it can achieve higher data hiding capacity compared with other algorithms that require the seed area. (3) Our scheme is based on $2 \times 2$ index blocks, which can make full use of the correlation between indices; thus it can reduce the bit rate compared with the ordinary VQ. (4) Our proposed scheme is separated into the VQ encoding process for generating the index table and the data hiding process to embed secret data into the output codestream. Obviously, the proposed algorithm realizes the desired “separation of the encoder and the embedder” requirement stated in [13] which facilitates the individual processing of the encoder and the watermark embedder and the controlling of the corresponding performance.

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**REFERENCES**


