An efficient reversible data hiding scheme based on SMVQ

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Abstract: Data hiding technique can hide a certain amount of secret data into digital content such as image, document, audio or video. Reversible compressed image data hiding can loosely restore the cover image after extracting the secret data from the stego-image. In this paper, we present an efficient reversible image data hiding scheme based on side match vector quantisation. Mapping concept is useful for this scheme because it converts the ternary into binary. The proposed scheme significantly increases the payload size of a block, and the quality analysis of the proposed scheme showed that it contains a better peak signal to noise than other schemes.

Keywords: data hiding, reversible, VQ, SMVQ

1 INTRODUCTION

The image data hiding means that the sender can hide the secret data into the image (called the cover image) by a hiding scheme to generate the stego-image, so the secret data will not be detected by a third party. The stego-image can be passed safely to the receiver. After the receiver received the stego-image, s/he could then extract secret data from the stego-image. Recently, many schemes have been
1 proposed.[1,4–8,11,12,14,15,17,20–23,25]

Least significant bit (LSB) is a simple data hiding scheme. The sender can hide the secret data into the 1-LSB of pixel in the cover image, and the receiver can extract the 1-LSB of pixel in the stego-image to get the secret data. However, the cover image will be destroyed and cannot be restored back to the original image. Consequently, many researchers presented the reversible image data hiding schemes[2,9,24,25] in order to recover the lost quality when hiding the secret data into the cover image.

Considering the transmission time of a lossless image, we usually transmit the compressed image to reduce the cost over the Internet. Nowadays, many lossy compression techniques were proposed, such as Joint Photographic Experts Group (JPEG),[18] JPEG 2000,[19] vector quantisation (VQ)[10] and side match vector quantisation (SMVQ).[13]

VQ was proposed by Linde *et al.* in 1980.[16] First, they trained the codebook by a lot of images, and they used this codebook to compress the image. They divided the image into non-overlapping blocks and computed the Euclidean distance with the codebook to get the most similar codeword (or vector) for each block. Then, they recorded the index of the codeword into an index table, and this index table is transmitted to the receiver after all the blocks have gone through

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the computation. The receiver could use the same codebook to decode this image.

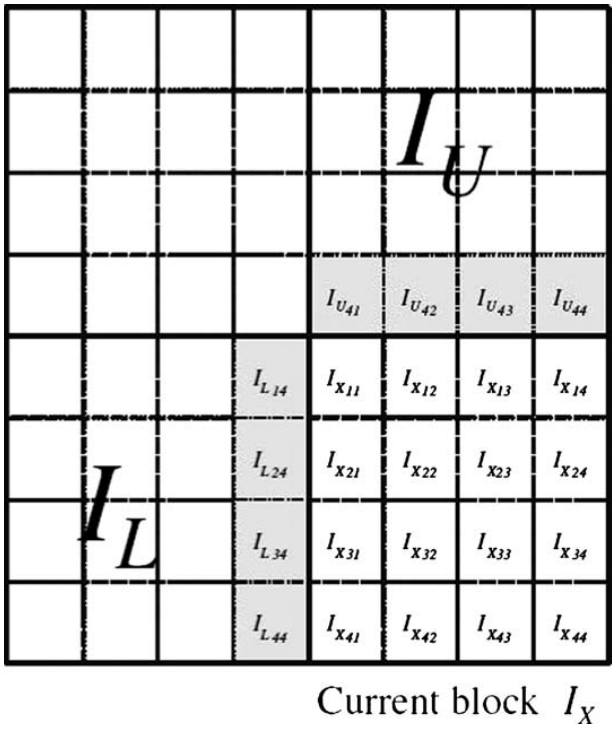
However, the VQ scheme has a well-known problem that is a block effect problem. The edges of image which are compressed by VQ will cause block effect. After restoring this compressed image, the edges in this image are more serrated than edges in the original image. There are many methods proposed to solve the block effect problem, and SMVQ[13] is one of the improvement methods. In this paper, we use SMVQ technique to compress the image for better quality of decompress image.

For the compression images, we can also hide the secret data into them and transmit them quickly to the receiver over the Internet. In 2005, Chang and Wu presented a data hiding method based on SMVQ and VQ.[6] They produced two mapping tables by random number generators. If the distance by the block and codeword was smaller than a threshold $THSM_{\mathrm{VQ}}$, they used SMVQ to hide secret data; otherwise, they used VQ to hide secret data. When VQ is used, they would check whether the distance was greater than threshold; if such condition holds true, they would not hide the secret data. In the extracting stage, the compressed code is used to extract the secret data. In this method, the stego-image cannot be reversed, its quantity of secret data is low and the mapping table is a hard overhead.

According to SMVQ, Chang *et al.* proposed a reversible scheme in 2006.[5] They calculated the stego-pixels by converting equation. In their method, they converted the stego-image into the original compressed cover image during the extraction of the secret data. The work has shown a great promise; however, the researchers were still plagued by a terrible scarcity of the payload size.

In 2010, Chiou *et al.*[8] proposed a capacity-enhanced reversible data hiding scheme based on SMVQ. Their method is relatively simple and hides more payload size than Chang *et al.*'s scheme. But we believe that our proposed method is capable of hiding more payload size than the Chiou *et al.*'s method.

In this paper, we proposed an efficient SMVQ-based reversible data hiding scheme. We calculated the most hiding size with a block, and translated the binary string (secret data) into ternary string. We have hidden the ternary string into the cover image. Compared with the related works, the proposed scheme is more efficient and capable of carrying larger data hiding amount. Therefore, our scheme has



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shown better promises than Chang and Wu's method[6] and Chang *et al.*'s[5] scheme.

The rest of our paper is organised as follows: in Section 2, the related schemes are reviewed. We present our method in Section 3 and Section 4 contains the experimental results and discussion. Finally, the conclusion of this paper is given in Section 5.

2 RELATED WORKS

In this section, we will introduce the basic concept of SMVQ, namely Chang *et al.*'s and Chiou *et al.*'s schemes.

2.1 SMVQ

SMVQ is an improvement scheme of VQ,[10] and two codebooks are useful for it. In SMVQ, the first row and the first column of blocks in the image are compressed by the main codebook, and other blocks (called residual blocks) in the images are compressed
by the subcodebook. In Fig. 1, for the current block 2
I_X which we want to compress, we use the upper-side block I_U and left-side I_L of I_X to obtain the subcodebook from the main codebook. We then compute the distortion between the grey values in I_U
or I_L and the codeword in the main codebook. Next, 3

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we select N least side-match distortions as the subcodebook, and we compress the current block by this subcodebook.

Now, we will introduce how to compress the current block I_X in detail. We first compute the upper-side distortion using the following equation:

$$I_{UD}(c) = \sum_{j=1}^{4} \left(I_{U_{4j}} - c_{1j}\right)$$

Then we compute the left-side distortion $I_{LD}(c)$ by the following equation:

$$I_{LD}(c) = \sum_{i=1}^{4} \left(I_{L_{i4}} - c_{i1}\right)$$

The side-match distortion of codeword c is shown as:

$$SMD(c) = I_{UD}(c) + I_{LD}(c)$$

After comparing $SMD(c)$ with all the codewords in the main codebook C, we take N codewords with the least side-match distortion as the subcodebook, where N is a multiple of 2 smaller than the size of the main codebook. Then we decide the I_X's best codeword by the VQ method. We repeat this process until all the residual blocks are compressed. When we want to decompress this image, the first row and the first column of blocks will be restored by VQ. Then we can use these blocks to generate the subcodebook to reconstruct the other blocks.

2.2 Related reversible data hiding schemes based on SMVQ

In this subsection, we will first introduce Chang *et al.*'s scheme, then we will describe the Chiou *et al.*'s scheme, which is an improvement method of Chang *et al.*'s scheme.

2.2.1 Chang et al.'s scheme

In Chang *et al.*'s scheme,[5] they hide the one bit in each block. Before explaining this method, we shall define the following notations: the main codebook $C=\{c_i|i=1, 2, \ldots, N\}$, the subcodebook $SC=\{sc_j|j=1, 2, \ldots, n\}$, the sub-indices $S=\{s_j|j=1, 2, \ldots, s\}$ and the secret data $B=\{b_l\}l=1, 2, \ldots, r\}$, where $b_l=\{0, 1\}$, and $0 \leqslant l \leqslant r$.

Their method is divided into three phases, and we will introduce the phases briefly below:

1. Preprocessing phase: they use SMVQ to generate the compressed cover image.
2. Hiding phase: for each residual block that does not belong to the blocks in the first column and the first row, they calculate the Euclidean distance between the block and the subcodebook K to obtain the most similar codeword k_x. They do not change anything unless the secret data b_l is 0. When $b_l = 1$, they find out the second similar codeword k_y and calculate the approximate codeword by the following equation:
$$\text{Approximate codeword} = \left\lfloor \frac{2 \times k_x + 1 \times k_y}{3} \right\rfloor$$
Then, they repeat Phase 2 for the other blocks in the compressed image.
3. Extracting and reversing phase: the blocks which belong to the first row and the first column are decompressed by VQ, and SMVQ is used to decompress the residual blocks. For current block, the Euclidean distance is being computed. The secret data are set as 1 unless the distance is not equal to 0. The k_x could also recover the current block into the cover block by an approximate equation.

2.2.2 Chiou et al.'s scheme

In 2010, Chiou *et al.*[8] proposed an enhanced capacity method. This method can hide more secret data than Chang *et al.*'s method. For a $n^{1/2} \times n^{1/2}$ block, they can hide the one bit in each pixel in this block. We will introduce their method by the following two steps.

Step 1. Hiding phase: for each residual block, we hide the bit in every pixel in this block. For each secret bit, if the bit is equal to 0, the pixel value of the block in the stego-image will be the same as the corresponding value in the vector value. Otherwise, in default, the pixel is equal to the corresponded value plus 1. After all secret bits were compared which we want to hide in the block, they are restored into the stego-image. Then the $\boxed{4}$ above process is repeated until the whole stego-image is generated.

Step 2. Extracting and reversing phase: in the stego-image, they reversed the blocks which belong to the first column and the first row by the VQ. For residual blocks, they extracted the secret data by the corresponding codeword in the subcodebook. If the pixel in the current block in the stego-image is equal to the corresponding vector in the codeword, the secret bit is 0; otherwise, the

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secret bit is 1. After extracting the secret data in the current block, they restored this block with the corresponding block. The above processing is repeated until the whole stego-image is extracted with the secret data and recovered. Finally, we can get the whole secret data and reverse the SMVQ-compressed cover image.

3 THE PROPOSED METHOD

In this section, we will introduce our proposed method. In our scheme, the secret data compressed by SMVQ in the compressed image are being hidden. We divided the cover image into $m \times m$ non-overlapping blocks. Each block has a corresponding index value in the index table. We have hidden the secret data into the blocks except the blocks belonging to the first column or the first row in the cover image.

In codebook training process, we check whether value of codeword is 0 or 255. If it equals to 0 or 255, we will discard this codeword and retrain another. Thus, values of codeword are never 0 or 255. In other words, the minimum and the maximum values of codeword are 1 and 254. This process will help us to avoid the overflow and underflow problems.

We have defined these notations: the main codebook $C=\{c_i|i=1, 2, \ldots, N\}$, the subcodebook $SC=\{sc_j|j=1, 2, \ldots, n\}$, where $sc_j=\{sc_{jk}|k=1, 2, \ldots, m\}$, and the sub-indices $S=\{s_j|j=1, 2, \ldots, s\}$, and the secret data $B=\{b_l|l=1, 2, \ldots, r\}$.

3.1 Hiding phase

For each element sc_{jk} of a codeword, we define three statuses to hide the secret data: $sc_{jk}+1$, $sc_{jk}+0$ and $sc_{jk}+1$. Thus, a codeword will have $3m$ combinations. On the other hand, the secret data are a binary string, and the status is either 0 or 1. Hence, we can compute the most hiding bits h_b for a codeword sc_j by the following equation:

$$h_b = \lfloor \frac{m \times m \log 3}{\log 2} \rfloor \tag{1}$$

According the above equation, the h_b will exceed the size of the codeword. Thus, we translate the binary string into the ternary string by the following equation:

$$(b_{l+o}, b_{l+1}, \ldots, b_{l+h_b-1})_2 = (t_0, t_1, \ldots, t_{m \times m-1})_3, \quad \text{where } 0 \le l \le r \tag{2}$$

In our hiding phase, for each block, we can get the corresponding codeword sc_j from the index table, and we hide $(t_0, t_1, \ldots, t_m)$ into the block. The value in t_i $(0 \leqslant i \leqslant m)$ can be 0, 1 or 2. When mapping to the status of the codeword, 0 is equal to $sc_{jk}+0$, 1 is equal to $sc_{jk}+1$ and 2 is equal to $sc_{jk}-1$. In other words, if t_i is equal to 0, we would restore the sc_{jk} into the stego-image; if t_i is equal to 1, we would restore $sc_{jk}+1$ into the stego-image; if t_i is equal to 2, we would restore $sc_{jk}-1$ into the stego-image. After hiding all the residual blocks, we can get a whole stego-image.

It will not be overflow or underflow problem in our hiding phase, because the minimum and the maximum values of codeword are 1 and 254. When we need to plus 1 or subtract 1 for hiding, the maximum or minimum value of hiding data is 255 or 0, respectively.

When the difference in the most similar codeword between the compressed cover image and the stego-image is not equal, we do not hide any secret data in this block. We would hide index to the block at the moment. Actually, the probability of having that difference is zero in our experiment.

3.2 Extracting and reversing phases

When a receiver receives a stego-image from a sender, s/he could start to extract secret data and reverse the cover image.

1. S/he divides the image into $m^{1/2} \times m^{1/2}$ non-overlapping blocks. The blocks which belong to the first row and the first column are compressed by VQ and their corresponding index table is generated.
2. The residual blocks are compressed by SMVQ. For each residual block, s/he generates the subcodebook $SC=\{sc_j|j=1, 2, \ldots, n\}$ from the main codeboook using its upper and left-side blocks. S/he could find the codeword sc_x which has the shortest Euclidean distance compared with the current block.
3. The receiver subtracts the codeword sc_x from the current block. If the difference is 0, t_i is equal to 0; if the difference is 1, t_i is equal to 1; if the difference is -1, t_i is equal to 2. After comparing all the differences in this block, the receiver can get a set $(t_0, t_1, \ldots, t_m)$. Then this set can be translated by equation (2), and s/he would get a real secret string $(b_{l+0}, b_{l+1}, \ldots, b_{l+hb})$.
4. Steps 2 and 3 are repeated until the whole stego-image is calculated, and the secret data are

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extracted and recovered. Finally, the receiver gets the whole secret data and the original SMVQ-compressed cover image.

3.3 An example

We use one block as the example to introduce our proposed scheme. In our scheme, for a 4×4 pixel block A in the compressed image that has a hiding capacity of 25 bits, we have $h_{\mathrm{b}}=25$ with $b_1=$ 0001101000110010010100101. The block A is (147, 115, 169, 163, 133, 165, 166, 148, 134, 168, 139, 151, 146, 183, 171, 109). According to equation (2), we convert $(0001101000110010010100101)_2$ into (002011 $0110001202)_3$, then we replace $(0020110110001202)_3$ into $(+0+0-1+0+1+1+0+1+1+0+0+0+1-1+0-1)_3$. Finally, we can get a block after hiding the secret data and restore the block into the stego-image. The block A after hiding is (147, 115, 168, 163, 134, 166, 166, 149, 135, 168, 139, 151, 147, 182, 171, 108).

When the receiver receives the stego-image, s/he starts to extract the secret data and restore A. First, s/he finds the least difference codeword sc_{x}, where sc_{x} is (147, 115, 169, 163, 133, 165, 166, 148, 134, 168, 139, 151, 146, 183, 171, 109). S/he subtracts sc_{x} from A and gets the difference set $(+0+0-1+0+1+1+0+1+1+0+0+0+1-1+0-1)$. Then s/he translates this as $(0020110110001202)_3$. Finally, the receiver performs the conversion equation (2) to gain the real secret data $(0001101000110010010100101)_2$.

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4 EXPERIMENTAL RESULTS AND DISCUSSION

In this section, we will use five standard 512×512 grey-level images to do our experiments. We compress them by SMVQ to hide the secret data to compare and discuss the experimental results. In the experiments, we divided the blocks to 4×4, the size of the main codebook is 256 codewords and the size of the subcodebook is 128 codewords. We used the random generator to generate the secret data.

Table 1 The relative PSNRs (with/without hidden secret data) for the cover images (at the same 0.44 bpp)

Images	PSNRs without hidden (dB)	PSNRs with hidden (dB)
Lena	31.0741	31.0164
Baboon	22.6943	22.6854
Boat	28.4740	28.4400
Peppers	27.6866	27.6593
F16	28.3786	28.3526

Figure 2a shows the cover images, Fig. 2b shows the cover images after SMVQ and Fig. 2c shows the results after hiding the secret data. Figure 3 shows the results for SMVQ-compressed Lena (Fig. 3a), Chang *et al.*'s method (Fig. 3b), Chiou *et al.*'s method (Fig. 3c) and the proposed method (Fig. 3d). Images have always shown satisfactory results.

In Table 1, we compared the peak signal to noise (PSNR) with the stego-images and the compressed cover images. The PSNR is calculated as follows:

$$\mathrm{PSNR} = 10 \times \log\left(\frac{255^2}{\mathrm{MSE}}\right)$$

$$\mathrm{MSE} = \frac{1}{m \times n}\sum_{\mathrm{i}=1}^{\mathrm{m}\times\mathrm{n}} (M_{\mathrm{i}} - I_{\mathrm{i}})^2$$

where $m \times n$ is the image size of the cover image M and the stego-image I.

PSNR values without hidden data images are lower than original images since the without hidden data images are compressed by SMVQ, and the without

Table 2 Comparison among the proposed scheme, Chang *et al.*'s scheme and Chiou *et al.*'s scheme

	Chang *et al.*'s scheme		Chiou *et al.*'s scheme		The proposed scheme	
Images	Payload size bits	PSNR (dB)	Payload size bits	PSNR (dB)	Payload size bits	PSNR (dB)
Lena	16 129	31.0088	258 064	31.3436	403 225	31.0164
Baboon	16 129	22.5746	258 064	22.6884	403 225	22.6854
Boat	16 129	28.2303	258 064	28.4481	403 225	28.4400
Peppers	16 129	27.4717	258 064	27.6042	403 225	27.6593
F16	16 129	28.0276	258 064	28.3950	403 225	28.3526

Table 3 The proposed scheme compared with 1-bit and 2-bit LSB schemes by using the compressed image for LSB

	1-bit LSB scheme		2-bit LSB scheme		The proposed scheme	
Images	Payload size bits	PSNR (dB)	Payload size bits	PSNR (dB)	Payload size bits	PSNR (dB)
Lena	262 144	31.0348	524 288	30.8698	403 225	31.0164
Baboon	262 144	22.6878	524 288	22.6614	403 225	22.6854
Boat	262 144	28.4537	524 288	28.3586	403 225	28.4400
Peppers	262 144	27.6634	524 288	27.5399	403 225	27.6593
F16	262 144	28.3638	524 288	28.2773	403 225	28.3526

Table 4 The proposed scheme compared with 1-bit and 2-bit LSB schemes by using the cover image for LSB

	1-bit LSB scheme		2-bit LSB scheme		The proposed scheme	
Images	Payload size bits	PSNR (dB)	Payload size bits	PSNR (dB)	Payload size bits	PSNR (dB)
Lena	262 144	51.1227	524 288	44.1987	403 225	31.0164
Baboon	262 144	51.1365	524 288	44.1829	403 225	22.6854
Boat	262 144	51.1344	524 288	44.1652	403 225	28.4400
Peppers	262 144	51.1303	524 288	44.1898	403 225	27.6593
F16	262 144	51.1372	524 288	44.2166	403 225	28.3526

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5 hidden data images are lossy. By our experimental results, we hide the secret data according to the codeword. The pixel values with hidden secret data images are changed. After SMVQ was performed, with hidden secret data images may lead to better
6 PSNR in some cases.

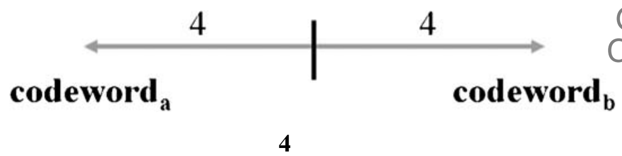
The PSNR values do not have much difference after hiding the secret data, as shown in Table 1. Because the cover image is compressed by SMVQ, the codebook after we hide the secret may lead to the better visual quality of stego-image. Such trend is the reason why the PSNR of Lena's stego-image is higher with hidden data than without.

In Table 2, we compared our proposed scheme with Chang *et al.*'s and Chiou *et al.*'s schemes.[5,8] In Table 2, the payload size means the size of hiding data. By comparing the payload size, our proposed method could hide more secret data than other two schemes. For PSNR, our scheme has a better visual quality than Chang *et al.*'s scheme. However, the PSNR in our scheme is lower than that in Chiou *et al.*'s scheme. Although we cannot get a better visual quality, the greatest difference from our scheme and Chiou *et al.*'s scheme is 0.05 dB. We believe that such value is a small difference and will not greatly affect visual quality by human eyes.

In contrast with 1-bit and 2-bit LSB methods,[3] even though our PSNR is smaller than 1-bit LSB, the payload size is much bigger. Compared with 2-bit LSB, even though the payload size is smaller, our PSNR is better. The results are shown in Table 3. Both of our PSNR and our payload size are lower than 1-bit and 2-bit LSB methods by using cover image (without compressing) for LSB data hiding. The results are shown in Table 4. In this paper, our hiding target is the compressed images by SMVQ. Thus, in Table 3, for the compressed images by SMVQ, the PSNR of our proposed method is better than 2-bit LSB but lower than 1-bit LSB.

In our proposed method, because we hide secret data into the pixels of the stego-image by plus or minus 1, or no change, the size of compressed cover image and stego-image is the same. In the worst case of our proposed scheme, the maximum difference in Euclidean distance between compressed cover image and stego-image is 4. Therefore, it would be equally possible to get the most similar codeword because Euclidean distance has always been bigger than 8 among codewords. Actually, the probability of the worst case is zero in our experiment since the gap

$$\sqrt{\sum_{i=1}^{16}(\pm 1)^2} = \sqrt{16} = 4$$



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between the codewords is always bigger than 8. This concept is illustrated in Fig. 4.

5 CONCLUSIONS

In this paper, we proposed our practicable schemes, a binary to ternary conversion policy development of the efficiency is visible and the quality of the proposed schemes is acceptable. Therefore, the proposed schemes are efficient and acceptable with its extra powerful storage. In this concept, there are many spread such as quaternary and quinary. Hence, we have enhanced the ability of data hiding.

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