A Survey of Reversible Data Hiding for VQ-Compressed Images

Yu-Lun Wang[1], Jau-Ji Shen[1], Min-Shiang Hwang[2,3],
(Corresponding author: Min-Shiang Hwang)

Department of Management Information Systems, National Chung Hsing University[1]
Department of Computer Science and Information Engineering, Asia University[2]
No. 500, Lioufeng Raod, Wufeng Shiang, Taichung 41354, Taiwan
Department of Medical Research, China Medical University Hospital, China Medical University[3]
No.91, Hsueh-Shih Road, Taichung 40402, Taiwan
(Email: mshwang@asia.edu.tw)

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Abstract

Data hiding has been popular over the past decades, and many different methods of the data hiding have been proposed. Nowadays, data hiding in compressed images becomes more and more popular because of the rise of the social media. Thus, we survey the previous research of data hiding of compressed images to provide the representative methods and analyze their capacities and bit rates. Finally, we propose the future work of data hiding in compressed images.

Keywords: Data Hiding; Reversible Data Hiding; VQ Compressed

1 Introduction

Data hiding has been popular due to the importance of the ownership. Through hiding the data in the image, users can prove the ownership by extracting the unique information [5, 17, 40]. Recently, it becomes more and more popular in social media such as Facebook or Twitter, so images or videos spread on the internet more quickly. While a user uploads the multimedia file on the social media, the social media always compress the image into a smaller size. Therefore, more and more researcher start to propose some new method of the compressed image data hiding [1, 16, 19, 25, 38, 39, 43]. Many compressed methods were proposed in the 1980's, such as VQ, BTC (block truncation coding) and LZW (Lemple-Ziv-Welch). In the data hiding in normal images, we pursue higher capacity and PSNR (peak signal-to-noise ratio) value [19, 28]. However, in the data hiding based on compressed images, higher capacity and lower bit rate are the goal that we pursued. Vector quantization is a popular image-compressed method proposed by Gray [12, 13, 14]. Through a machine learning method to get a codebook, the most famous algorithm was proposed by Linde et al.'s [22]. Figure 1 shows the VQ compression method. Each codebook has some index, and every index has some code words whose value are between 0 and 255.

In the compressed procedure, the image is divided into blocks, and each block has 4×4 pixels, total 16 pixels. The smallest difference between the pixels of the block and the codeword of each index is calculated in the codebook. The index value is used to represent each block.

2 Related Work

In image processing, data hiding has been proposed for many years. The target of the approach is to prevent a malicious user from duplicating or spreading the image on the internet. As mentioned earlier, the VQ compressed method [14] proposed in 1984 and the compressed procedure have been introduced.

In 2004, the first approach of VQ compressed image data hiding was proposed by Chang et al.'s [3] based on search-order coding which was proposed by Hsieh et al. [15]. Their methods have the problem of the expanded file size and acceptable capacity. In 2009, the method proposed by Chen et al.'s [4] has lower bit-rate, but the capacity is also much lower. In the same year, Lee et al.'s proposed [24] used a multiple codebook to enhance the capacity. In 2013, the methods proposed by Pan et al.'s [29] and Chang et al.'s [9] get lower bit-rate, but the capacity is lower than 5000. In 2013, Wang et al. [35] proposed the method joined with the state-codebook mapping. In 2015, Lin et l. [26] proposed the method combined with state-codebook and SOC, significantly decreasing the bit-rate. In 2016, Qin et al. [32] proposed the method added with a relative address type (RA type) into the SOC process to make the bit-rate lower.

In 2006, Chang et al. [10] proposed the method based

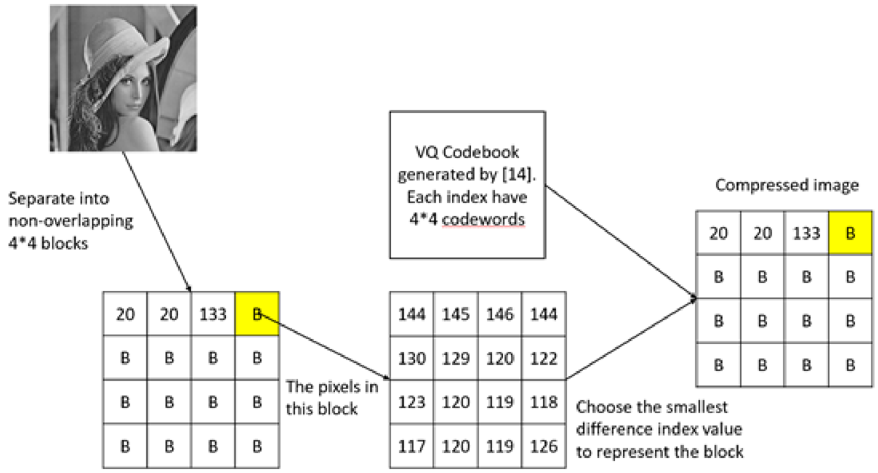

Figure 1: The VQ compression example

on side match VQ compression which was proposed by Kim [20]. In 2010, Lee et al. [23] proposed the method with higher capacity. In 2012, Shie et al. [33] proposed the method with higher capacity and average bit-rate. In 2013, Qin et al. [30] proposed the method based on an index mapping mechanism to have higher capacity. In 2014, Qin et al. [31] proposed the improved method, but the capacity is not good enough. In the same year, Wang et al. [41] proposed the method to increase the capacity, but the capacity is inefficient. In 2009, Chang et al. [7] proposed the method combined with the Joint Neighboring coding (JNC). In the same year, Wang et al. [36] proposed the method also based on JNC. Both methods have higher bit-rate.

In 2015, Kieu et al. [21] proposed the method to improve Chang et al.'s scheme [7]. In 2009, Chang et al. [6] proposed the method based on locally adaptive coding (LAS). In 2010, Yang proposed [42], reduce the bit-rate of Chang et al.'s scheme [6]. In 2011, Chang et al. [8] proposed the improved method to reduce the bit-rate further, but the capacity is still not enough. In 2015, Ma et al. [27] proposed the method based on LAS to improve LAS, decreasing the bit-rate obviously. In 2007, Chang et al. [11] proposed the method to sort the VQ index referring to the counts, which are separated into three clusters to embed data. In 2009, Yang et al. [41] proposed the method to increase the capacity and bit-rate. In 2015, Tu et al. [34] proposed the method with higher capacity. In the section 3, we will describe 5 representative method of the data hiding for VQ compression images. In 2012, Chang [2] proposed the method, which has high payload, but the bit-rate is also high too.

3 Representative Approaches

In the reversible data hiding in VQ compressed images, there are many approaches which have been proposed in the past decade. We will introduce five representative approaches in the following subsections.

3.1 Chang-Chen-Lin's Scheme

In 2004, Chang et al.'s proposed the first reversible data hiding scheme in a VQ compressed image [3]. Their methods are combined with the search-order coding (SOC) technique. Therefore, we will first introduce how SOC working. In 1996, Hsieh and Tsai proposed this method [15] which can compress the image more efficiently. After the VQ compressed process, SOC technique is used to compress images again. The process of the SOC is shown in the Figure 2.

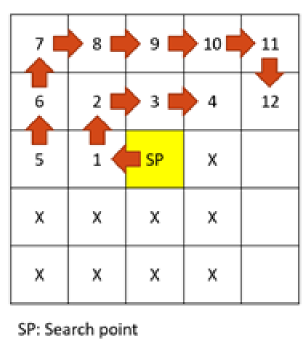

Figure 2: The process of the SOC scheme

The first column and first row will not be used in the SOC process. They choose a search point first, and search by order in the Figure 2. The first index in the search order is the representative bit 00; if the second index in the search order is same as the first index, we skip this index and do nothing. If the index is not the duplicate value compared with the previous index processed, we give the representative bits followed by 01, 10, 11. If the type of the index is SOC type, we add an indicator bit 1 in the head followed by the representative bits. Otherwise,

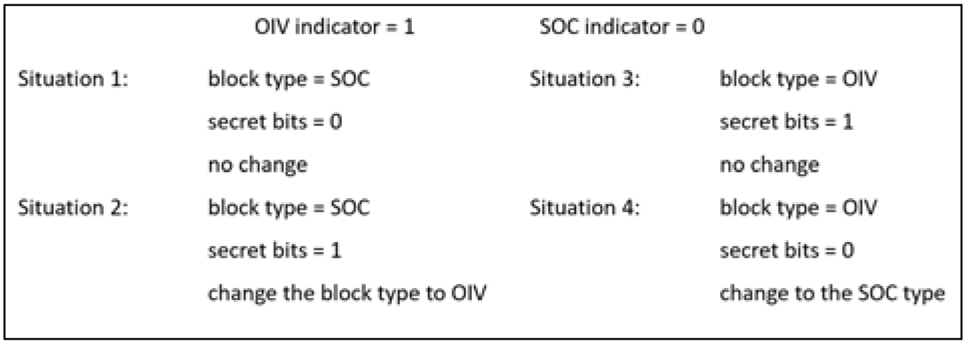

Figure 3: The embedded rule of Chang et al.'s scheme

we add an indicator 0 in the head followed by the original VQ index value. In the Chang et al.'s scheme, they embed the secret bit according to the block type as shown in the Figure 3. In Situation 1, if the secret bit is 1, and the index type is SOC type, we do not change anything in this index. In Situation 2, if the secret bit is 0, and the index type is SOC type, we change the index into the original index value and transform the indicator to 0. In Situation 3, if the secret bit is 0, and the index type is original index value (OIV), we do not change anything in this index. In Situation 4, if the secret bit is 1, and the index type is OIV, we change the index type into SOC type. The change rule is shown in the Figure 4. We can judge whether the SOC type is fake because of the code stream length.

3.2 Chang-Wu-Hu's Scheme

In 2007, Chang et al.'s proposed a new scheme based on the frequency of the index count [11]. In the VQ compressed process, each index has a frequency value; and while the index is used, the frequency value will add 1. After the VQ compressed procedure is finished, they sort the codebook in a descending order according to the frequency value. Then we separate the code book into 3 clusters, and each cluster has $cbs/3$ indexes. In each cluster, cbs represents codebook size, and the remainder of the codebook will be abandoned.

The embedding process is shown in Figure 5. There are four situations in this scheme. First, if the index belongs to the cluster 1, we change the index to belonging to cluster 2 or cluster 3 according to the secret bit. And the length of the index value is always log2cbs. Second, if the index belongs to the cluster 2, we change the index belonging to cluster 1 and do not embed the secret bit in this index. Third, if the index belongs to the cluster 3, we change the index belonging to the cluster 3, and change the index belonging to cluster 1; and we change the length of this index to $\log_2 cbs || \log_2(cbs/3)$. For instance, the first index value is 2, and the secret bit is 1. We change it to the same position in the cluster 3, and change index value to 12. The second index value 1 with secret bit 0 will be changed to 6. The third index value 7 is in the cluster 2, and we change it to cluster 1 with the same position. If the value of the index is 7, we change it to 2. The number in the Figure 4 with underline means this index without secret bits embedding. If next index value 4 with secret bit 1, we change this index to 14. The fifth index value 13 is in the cluster 3, so we change it to an indicator of which length is log2cbs. The codebook size of this example is 15, and the indicator is 0000 followed by the $\log_2(cbs/3)$ bits. The answer of log25 is 3 bits. Therefore, followed by 110, it means 3 in decimal and does not embed any secret bit in this index.

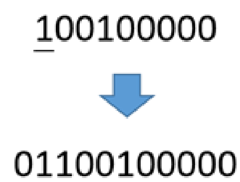

Figure 4: The change rule of Situation 4

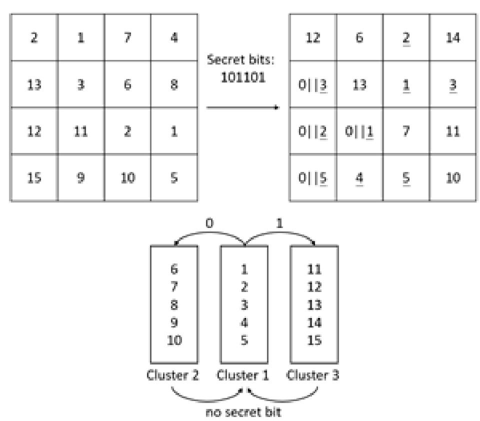

Figure 5: The example of the embedding process of Chang et al.'s method

In the extraction phase, they can accord to the index of the cluster it belongs to decide whether this index has secret bits or not. If the index belongs to cluster 2 or cluster 3, we can change it to cluster 1 with the same position to recover the original index value. If not, we can determine whether this index belongs to cluster 2 or cluster 3 according to the indicator. For example, if first 4 bits are 0000, we can easily judge that this index belongs to original cluster 3, and the index value is correctly recovered. If the first secret bits are not 0000, we change it to cluster 2 in the same position to recover it.

3.3 Chang-Kieu-Chou's Scheme

In 2009, Chang et al.'s proposed a novel method based on locally adaptive coding (LAS) [6]. LAS method was proposed by Bentley et al. in 1986. We show the process of this method in Figure 6. In the LAS method, it is classified into two situations. In Situation 1, if the word has not been appeared, then we add this word in the list. In Situation 2, if the word has been added in the list, we output the position of the position of the word in the list and move the word to the head of the list.

String: THE CAR ON THE LEFT HIT THE CAR I LEFT		
Input	List	Output
THE	{THE}	1.THE
CAR	{CAR, THE}	2.CAR
ON	{ON, CAR, THE}	3.ON
THE	{THE, ON CAR}	3
LEFT	{LEFT, THE, ON, CAR}	4.LEFT
HIT	{HIT, LEFT, THE, ON, CAR}	5.HIT
THE	{THE, HIT, LEFT, ON, CAR}	3
CAR	{CAR, THE, HIT, LEFT, ON}	5
I	{I, CAR, THE, HIT, LEFT, ON}	6.I
LEFT	{LEFT, I, CAR, THE, HIT, ON}	5

Figure 6: The example of the LAS

In Chang et al.'s scheme, we use LAS method, and the embedding process is shown in Figure 7.

Index value: 45, 200, 150, 45, 150, 100, 120, 200, 120, 30				
Secret bits: 0100				
Input	List	Secret bits	Indicator	Output
45	{45}	X	0	$0\|\|(45)_2$
200	{200, 45}	X	0	$0\|\|(200)_2$
150	{150, 200, 45}	X	0	$0\|\|(150)_2$
45	{45, 150, 200}	0	0	$0\|\|(3)_2$
150	{150, 45, 200}	1	1	$1\|\|(150)_2$
100	{100, 150, 45, 200}	X	0	$0\|\|(100)_2$
120	{120, 100, 150, 45, 200}	X	0	$0\|\|(120)_2$
200	{200, 120, 100, 150, 45}	0	0	$0\|\|(5)_2$
120	{120, 200, 100, 150, 45}	0	0	$0\|\|(2)_2$
30	{30, 120, 200, 100, 150, 45}	X	0	$0\|\|(30)_2$

Figure 7: The example of Chang et al.'s scheme

There are 3 situations in the embedding process. In Situation 1, we scan the index value in scan order. If the current value is not in the list, we add this value in the list and output an indicator 0 and the index value without embedding any secret bit. In Situation 2, if the current value is in the list and the secret bit is 0, we move the index value to the head which is in the list and output the indicator 0 and the original position of the index value in the list. In Situation 3, if the current value is in the list, and the secret bits is 1, we move the index value to the head and output indicator 1 and the value of the index.

3.4 Tu and Wang's Scheme

In 2015, Tu and Wang's proposed an improved method based on the referred frequency [34]. Their scheme is similar to Chang et al.'s scheme [6], and the difference is that they use the index of the cluster 2 and cluster 3 to embed secret bits. The different part is shown on Figure 8. If the original index value belongs to cluster 2, we want to change it to cluster 1 and also embed some secret bits in this index. We change it to the cluster 1 in the same position followed by an indicator and secret bits. The indicator 0 means this index originally belongs to the cluster 2. And if the index originally belongs to cluster 3, the bit of the indicator will be 1. This method can decide how many secret bits we want to embed in each index, but the bit rate will change according to the secret bits we embed. More secret bits we embed mean the bit rate is less efficient.

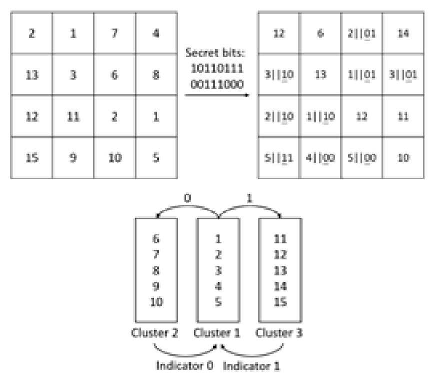

Figure 8: The example of the embedding

3.5 Qin and Hu's Scheme

In 2016, Qin and Hu's proposed a scheme based on an improved SOC method [32]. In ISOC, they make some difference after the SOC process is finished. If the index does not change to the SOC type, we compare it with the left or the upper index. Equation (1) shows the action of the index.

$$d = |X - X'|. \tag{1}$$

Users will define a threshold value T. While d is not greater than $T/2$, we change this index to the relative addressing type (RA type). Table 1 shows the different length and indicator of each type.

Table 1: The summary of the ISOC

Index Type	Indictor	Encode Data	Coding Length
OIV	11	$(X)_{10}$	$2 + \log_2 N$
SOC	0	$(m*)_{10}$	$1 + \log_2 m$
RA	10	$(d)_{10}$	$2 + \log_2 T$

X = search point value;
m = search order times;
d = difference calculate by Equation (1);
N = codebook size;
T = threshold defined by user;
m* = search order of the search point.

In Qin and Hu's scheme, after the ISOC process is finished, we embed each secret bit in each index. There are five situations in the embedding procedure.

First, if the index type is SOC type and the secret bit is 0, we do not change anything in this situation. Second, if the index type is SOC type and the secret bit is 1, we change it to the RA type; and this situation is classified to two cases. In case 1 we calculate the value d by Equation (1).

If d is less or equal than $T/2-1$, the encode bitstream will be $2+\log_2 T$. In the other hand, if d is greater than $T/2-1$, the encode bitstream will be $2+\log_2 T+\log_2 m$. In Situation 3, if the index type is RA type and the secret bit is 1, we do not change anything in this situation. In Situation 4, if the index type is RA type and the secret bit is 0, we change the index type to SOC type and the encode bitstream is $1+\log_2 m+\log_2 T$. In Situation 5, if the index type is OIV type, we do not do anything in this index. The summary of the embedding phase is shown as Table 2.

4 Comparisons

In the comparison part, we do the experiment of the representative scheme. The same codebook and the same secret bitstream are used in the experiment. The image size of the experiment is 512×512 and the codebook size is 256. In the VQ compression phase, the each non-overlapping block is 4×4, so each index has 8 codewords. Equation (2) shows the compression rate how to be calculated.

$$\text{bit rate} = \frac{\text{codestream}}{(H \times W)} \quad (2)$$

where the *codestream* means the code length after the embedding process is finished. The H and W mean the height and weight of the original cover image, respectively. We show the experiment result of these 5 representative methods in Tables 3 and 4 to display the capacity and compression rate, respectively. We can discover that method 1 index usually embeds 1 bit only; if we embed more bits in the index, the compression rate of the compression file will be significantly increased.

5 Conclusions and Future Work

Because of the rising of the social media, the compressed techniques are always used in the process of uploading images. This effect leads to the data hiding embed secret data in the compressed image becoming more popular. In this paper, we sort out the basic requirement in the data hiding for compressed images and compare five representative methods with different hiding techniques.

For the future development, according to the capacity requirement. How to embed more secret data with the similar bit-rate is the challenging issue. After separation, the number of blocks will be less than the number of original images pixels. We think that we can embed the secret data from the codeword in the codebook, which is the future work.

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Table 2: The summary of the Qin and Hu's scheme after the embedding phase finished

Original Index Type	Secret Bits	Indicator after Changed	Index Type after Changed	Coding Length after Changed
OIV	X	11	OIV	$2 + \log_2 N$
SOC	0	0	SOC	$1 + \log_2 m$
	1	10	RA	$2 + \log_2 T$ (Case 1)
				$2 + \log_2 T + \log_2 m$ (Case 2)
RA	0	0	SOC	$1 + \log_2 T + \log_2 m$
	1	10	RA	$2 + \log_2 T$

m = search order times;
N = codebook size;
T = threshold defined by user.

Table 3: The experiment result of the capacity comparison (Codebook size: 256; Block size: 4×4)

Schemes	**Trained Images**			**Non-trained Images**			
	Lena	Boat	Peppers	Mandrill	Barb	Goldhill	Zelda
Chang et al.'s Scheme [3]	16384	16384	16384	16384	16384	16384	16384
Chang et al.'s Scheme [11]	14262	12776	13792	11826	13199	14304	15799
Chang et al.'s Scheme [6]	16148	16137	16133	16139	16147	16153	16201
Tu et al.'s Scheme [34]	16384	16384	16384	16384	16384	16384	16384
Qin et al.'s Scheme [32]	9964	8776	9772	4577	8794	8804	10015

Table 4: The experiment result of the bit rate comparison (Codebook size: 256; Block size: 4×4)

Schemes	**Trained Images**			**Non-trained Images**			
	Lena	Boat	Peppers	Mandrill	Barb	Goldhill	Zelda
Chang et al.'s Scheme [3]	0.4941	0.5087	0.4941	0.5655	0.5102	0.5119	0.4922
Chang et al.'s Scheme [11]	0.5092	0.5246	0.5147	0.5199	0.5135	0.5071	0.5003
Chang et al.'s Scheme [6]	0.5552	0.5479	0.5606	0.5617	0.5617	0.5399	0.5536
Tu et al.'s Scheme [34]	0.5162	0.5275	0.5198	0.5348	0.5242	0.5159	0.5045
Qin et al.'s Scheme [32]	0.4641	0.4909	0.4721	0.5608	0.4914	0.4948	0.4695

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Biography

Yu-Lun Wang study in the Department of Management Information Systems, Chung Hsing University.

Jau-Ji Shen received his Ph.D. degree from National Taiwan University in 1988. His research interests include digital image, software engineering, information security, and data base technique. His work experiences include the Director of National Formosa University Library and the Associate Dean of Management School in Chaoyang University of Technology. Now, he is a professor in the Department of Management Information Systems, National Chung Hsing University.

Min-Shiang Hwang received the Ph.D. degree in computer and information science from the National Chiao Tung University, Taiwan in 1995. Dr. Hwang was the Chairman of the Department of Information Management, Chaoyang University of Technology (CYUT), Taiwan, during 1999-2003. He was a distinguished professor and Chairman of the Department of Management Information Systems, NCHU, during 2003-2011. He obtained the 1997, 1998, 1999, 2000, and 2001 Excellent Research Award of National Science Council (Taiwan). His current research interests include information security, cryptography, image compression, and mobile computing. Dr. Hwang has published over 200+ articles on the above research fields in international journals.