



Search-order coding method with indicator-elimination property

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ABSTRACT

Vector quantization (VQ) is a widely used technique for many applications especially for lossy image compression. Since VQ significantly reduces the size of a digital image, it can save the costs of storage space and image delivery. Search-order coding (SOC) was proposed for improving the performance of VQ in terms of compression rate. However, SOC requires extra data (i.e. indicators) to indicate source of codewords so the compression rate may be affected. To overcome such a drawback, in this paper, a search-order coding with the indicator-elimination property was proposed by using a technique of reversible data hiding. The proposed method is the first one using such a concept of data hiding to achieve a better compression rate of SOC. From experimental results, the performance of the SOC method can be successfully improved by the proposed indicator eliminated search-order coding method in terms of compression rate. In addition, compared with other relevant schemes, the proposed method is also more flexible than some existing schemes.

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1. Introduction

The size of multimedia is a key factor for storing in mass storage and delivering over networks. Specially, in a wireless network environment, the size of multimedia is highly related to the power consumption of mobile devices and the network bandwidth. Wang and Sun (2007) proposed a cost control method for handling the cost control problem. The compression technique is a good way to significantly reduce the size of multimedia. Image compression techniques can be briefly divided into two types, namely lossless and lossy. Lossless image compression is an important technique for sensitive images (e.g. medical images and military images). This means that a decompressed image must be exactly the same as the original one.

For lossy image compression, to reduce the image size is more concerned than the visual quality. Because human eyes are insensitive to slight image distortion, a lossy image compression technique can be used to significantly reduce the redundancy of the image. Many well-known lossy image compression techniques were proposed to significantly reduce the image size, such as JPEG, vector quantization (VQ) (Gray, 1984), search-order coding (SOC) (Hsieh and Tsai, 1996), etc.

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From the image compression aspect, the image compression techniques can be roughly classified into two types: (1) spatial domain methods (Chen and Chang, 1977; Gray, 1984; Hsieh and Tsai, 1996), and (2) frequency domain methods (Christopoulos et al., 2000; Han and Leou, 1998; Wallace, 1992). For the spatial domain, the target of the compression techniques is the pixel values. For the frequency domain, the frequency domain compression techniques are to convert an image from spatial domain into frequency domain and then to encode the coefficients for reducing the image size. The frequency domain methods have better compression rate than the spatial domain methods but the spatial domain methods have less computational cost and are easy to implement in hardware and software (Li and Drew, 2003; Sayood, 2000). Briefly, spatial domain methods are especially suitable for low-power devices such as digital cameras or personal digital assistants (PDAs).

Vector quantization (VQ) is a well-known and powerful spatial domain based image compression method (Gray, 1984). VQ is a lossy compression method which provides a high compression rate with an acceptable visual quality. The main idea of VQ is to divide an image into non-overlapping blocks and encoding the blocks with a pre-constructed codebook. Here, the pre-constructed codebook is trained by any codebook training algorithm (e.g. LBG algorithm Linde et al., 1980). The compression rate of VQ method is determined by the sizes of the codebook and codewords. For example, if an image sized 512×512 pixels and the codebook consists of 256 sixteen-dimension codewords, then the compression rate is $(128 \times 128 \times \lceil \log_2 256 \rceil) / (512 \times 512 \times 8) = 0.0625$.

Due to the fact that VQ offers a simple and fast implement framework, VQ can be applied to many real-time applications or

low-computational devices, such as the intrusion detection system (Zheng and Hu, 2006), real-time video event detection (Liao et al., 2006; Liao et al., 2006), and mobile devices. In other words, so far many research topics relevant to the VQ technique are still popular and important. As for the issue about the improvement of VQ compression rate, it is one of the most popular researches. Because the characteristic of natural images (i.e. a local area of an image has the similar pixel distribution), an image compressed by VQ can be further improved in terms of compression rate. Side match vector quantization (SMVQ) (Kim, 1992) is a VQ based image compression method which utilizes reconstructed neighboring blocks to predict the possible codewords, and use them to improve the compression rate. Moreover, Hsieh and Tsai proposed search-order coding (SOC) method (Hsieh and Tsai, 1996) to further compress the indices produced by the VQ compression method. The main idea of the SOC method is to reference a part of neighboring indices to find an index that is the same as the current encoding index, and use its search order number to encode the current encoding block. By this way, an extra indicator is required to indicate the source of the index. However, the compression rate of the SOC method can be further improved by eliminating the indicators.

Because the indicators of the SOC method are the extra data used to indicate the source of indices, eliminating the indicators will further improve the compression rate. We are inspired from a data hiding technique to design a novel compression method to eliminate the indicators of the SOC method in order to improve the compression rate. The purpose of a data hiding technique is to deliver secret messages over public networks using a cover media (e.g. an image) to conceal secret data (Chan and Chang, 2007; Chang and Lin, 2006; Chang and Wu, 2006; Lin and Chang, 2006; Pan et al., 2007). Lin and Chang proposed a data hiding method based on SMVQ in 2006 (Lin and Chang, 2006). Lin and Chang's method applied the concept of declustering to divide a codebook into two sets and then used the sets together with embedding rules to encode image blocks for implying the secret data. Lin and Chang's method successfully embeds secret data into VQ index table and the original VQ index table can be approximately restored when the secret data have been extracted. Furthermore, Chang and Lin proposed a reversible data hiding technique (Chang and Lin, 2006) based on side matching and relocation to achieve the reversibility of cover image and secret data delivery.

We are inspired from a data hiding technique to design an indicator eliminated search-order coding method. The proposed method applies the dissimilar pairing concept and the side match vector quantization concept to cooperate with embedding rules to encode VQ index table to eliminate the extra indicators. From the experimental results, the proposed method significantly improves the compression rate in comparison with the SOC method. In addition, compared with other relevant schemes, the proposed method is also more flexible than some existing schemes.

The rest of this paper is organized as follows. VQ compression, side-match vector quantization, search-order coding, and Lin and Chang's data hiding methods are briefly introduced in Section 2. The proposed indicator eliminated search-order coding method is detailed in Section 3. Section 4 shows the experimental results to illustrate the performance of the proposed method. Finally, some conclusive remarks are appeared in Section 5.

2. Related works

The aim of this paper is to eliminate the indicators of the SOC method. Thus, we briefly introduce the VQ method, the SMVQ method, and the SOC method in Sections 2.1, 2.2, and 2.3, respectively. Furthermore, because the proposed method inspired from

Lin and Chang's data hiding method, this method is illustrated in Section 2.4.

2.1. Vector quantization

Vector quantization (VQ) (Gray, 1984) is a classical quantization technique for signal processing such as lossy data compression, lossy data correction, and density estimation. According to the natural image property, VQ is suitably used for reducing the size of images.

Assume that a codebook C contains n codewords with $k \times k$ dimensions and is denoted as $C = \{cw_0, cw_1, \dots, cw_{n-1}\}$. An input image I is encoded by following steps. First, I is divided into non-overlapping blocks of $k \times k$ pixels and is denoted as $I = \{B_i \mid 0 \leq i < N\}$, where N is the total number of blocks of I . Second, the closest codeword $cw_{\min}$ for a block B_i is found from the codebook by

$$cw_{\min} = \min_{\forall cw_x \in C} \{d(B_i, cw_x)\}, \text{ where} \quad (1)$$

$$d(B_i, cw_x) = \left(\sum_{m=0}^{k \times k - 1} (B_i(m) - cw_x(m))^2 \right)^{1/2}, \quad (2)$$

where $d(\cdot)$ is the Euclidean distance function for calculating the difference between the encoding block B_i and the codeword cw_x . $B_i(m)$ and $cw_x(m)$ are represented m th pixel value and m th dimension in B_i and cw_x , respectively. Third, the current encoding block B_i is encoded by using the order number of the closest codeword $cw_{\min}$. After that, when all blocks in I have been encoded, an index table is produced. The decompression phase is an inverse work of the compression phase. Fig. 1 shows the processes for VQ encoding and decoding.

2.2. Side-match vector quantization

Side-match vector quantization (SMVQ) (Kim, 1992) is one concept used in the IESOC method. The main idea of SMVQ is to use a small size codebook namely the state codebook to improve the performance of VQ in terms of compression rate. Fig. 2 shows the concept of the SMVQ. In Fig. 2, B is a current encoding block and its neighboring border vector is represented as $NBV = \{b_0 = (u_{12} + l_3)/2, b_1 = u_{13}, b_2 = u_{14}, b_3 = u_{15}, b_4 = l_7, x, x, x, b_8 = l_{11}, x, x, x, b_{12} = l_{15}, x, x, x\}$ which is obtained from B 's the upper-side (e.g. block U) and left-side (e.g. block L) adjacent blocks, where 'x' means do not care.

To encode the block B , the neighboring border vector NBV and each codeword cw_x in the codebook are first used to calculate all distances according to the function $(\sum_{j=0,1,2,3,4,8,12} (cw_x(j) - NBV_B(j))^2)^{1/2}$, where x is the index of a codeword in the codebook. Then, a state codebook can be constructed by finding m closest codewords (i.e. small distances). Next, SMVQ computes an Euclidean distance between the most similar codeword in the state codebook and the block B by using the function $(\sum_{j=0}^{k \times k - 1} (cw_{\min}(j) - B(j))^2)^{1/2}$. Here, let $cw_{\min}$ be denoted as the closest codeword. If the Euclidean distance is larger than a predefined threshold, the block is encoded by VQ; otherwise, the block is encoded by SMVQ.

2.3. Search-order coding

In 1996, Hsieh and Tsai proposed the search-order coding method (Hsieh and Tsai, 1996) to further reduce the size of the VQ index table. By observing nature images, a local area of a natural image has the similar pixel distribution. This means that the blocks in a local area may be encoded by the same codeword. Thus, the main idea of the SOC method is to encode a block's codeword index by its neighboring block's codeword index which is found by finding the index from a pre-defined search path. If there contains an index in the search path, then the encoding index can be encoded by

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