Image Compression Based on Genealogical Relation of the TSVQ Indices

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ABSTRACT

The indices obtained by tree-structured vector quantisation (TSVQ) have an interesting property that enables them to give information about the correlation between two image blocks. If two image blocks are highly correlated, they may have an identical index, or the same ancestors. The existence of high inter-block correlation in natural images results in having neighboring blocks with the same genealogy. This characteristic can be used to compress the indices. This paper introduces a novel method to exploit the genealogical relation between the image block indices obtained from a TSVQ. The performance of this scheme in terms of PSNR versus average rate was compared with some other similar image coders. The results show that this scheme has better compression capability in terms of objective and subjective quality over these schemes at bit rates less than 0.3 bpp.

Keywords: Image Coding, Vector Quantisation, Image Processing, Data Compression

1. Introduction

Vector Quantisation (VQ) is an attractive method which can be used to exploit the inter-pixel correlation in natural images. The attractiveness of vector quantisation (VQ) as a source coding scheme derives from its optimality and decoder simplicity. VQ can be described as a mapping of a k-dimensional vector space on a set with finite members, the codebook. Each member of the codebook (codeword) represents a vector in a k-dimensional space and has an associated channel symbol (index) that decoder uses in reproducing the vectors of the vector space [1,2].

In basic VQ images are partitioned into small blocks (vectors). Each block is separately encoded. Therefor basic VQ, as is used with small blocks, is unable in exploiting the inter-block correlation. Two groups of methods have been proposed to achieve this goal. The first group is VQ schemes with memory: predictive, finite state, adaptive VQ [3,4,5]. The second group, which we call it index compressed VQ, is based on basic VQ, and a compression scheme to exploit the correlation of codewords (or indices) [6,7,8,9,10,11]. The results of researchers show that the second group of schemes is able to provide better than the first one at bit rates less that 0.3 bits/pixel [6,7,8,9,10,11].

Based on the method utilized in inter-block dependency removal, the index compressed VQ schemes can be divided into two groups. The first group, such as Address VQ [6,7] and Index Compressed VQ [8,9], uses a lossless, and the second one uses a lossy [10,11] scheme. Address VQ offers a significant improvement over basic VQ and some other VQ coders with memory at low bit rates. However it suffers from high computational complexity in codebook design and decoding process, and extensive memory requirement. The lossy schemes proposed by Poggi [10,11] exhibits unpleasant discontinuities in visually important areas of the coded image. Shanbehzadeh et al presented two index compressed VQ schemes [8,9]. Here for simplicity we call the first and second method IC-VQ (I)[8] and IC-VQ (II)[9] respectively These schemes have the advantage of coder simplicity as basic VQ, without introducing any artifact as Poggi scheme [10,11]. Both these schemes have comparable results with Address VQ and Poggi's scheme at low bit rates.

IC-VQ (I) employs the feature of identically indexed neighboring blocks in index compression, but this method ignores the fact that the identically indexed neighboring blocks are not the only source of inter-block dependency, and also IC-VQ (I) is less effective when the probability of identically indexed neighboring blocks is low. IC-VQ (II) resolves the problems of IC-VQ (I) by considering the fact that

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small areas in natural images require a small codebook for their representation. A problem of IC-VQ (II) is that it assigns a fixed number of bits to areas with varying activities, while more active areas require more bits for their representation than less active areas. In other words, a variable bit assignment procedure depending on the region activity can result in better performance.

This paper introduces a method based on TSVQ [12] indices', IC-VQ (III). The indices obtained by TSVQ have an interesting property that enables them to give information about the correlation between two image blocks. If two image blocks are highly correlated, they may have an identical index, or the same ancestors; for example identical parents, or grand-parents depending on the quantisation levels. The existence of high inter-block correlation in natural images results in having neighboring blocks with the same genealogy. In other words the neighboring blocks of a TSVQ quantised image might have the same predecessor up to a particular stage of the codebook tree map. This characteristic can be used to compress the indices, since if the indices of two neighboring blocks belong to the same generation, the common part of their indices need not be transmitted for both of them.

TSVQ codebook can be considered as a union of a group of small TSVQ codebooks (subtree codebooks). The small subtree codebooks require less bits to represent their members. If the indices of some neighboring blocks are the children of a subtree, some bit saving can be achieved by indicating the sub-tree and transmitting or storing the common part of the indices. The amount of bit saving is about as much as the difference between the average rate of the original TSVQ tree and the subtree plus some extra overhead to represent the set of neighboring blocks.

This approach leads to a variable rate bit assignment, because low activity areas contain highly correlated blocks, and high activity areas contain blocks with low correlation. Consequently, the quantised version of blocks from low activity areas are more likely to have an identical ancestry than the blocks from high activity areas. This means that the low activity blocks require a smaller subtree for their representation than the high activity blocks. Therefore, the indices of blocks from low activity areas can be reconstructed with less bits when compared with the indices of blocks from high activity areas.

The basic idea of IC-VQ (III) is similar to variable rate VQ, where the bits are allocated to blocks depending on their activity. The differences are the image adaptivity of IC-VQ (III), and the codebook of the VQ used in IC-VQ (III) is fixed rate. The variable bit assignment procedure of IC-VQ (III) is borne out of considering the characteristic of the image block indices in the encoding procedure, rather than designing a universal-based codebook variable rate VQ, such as predictive pruned TSVQ[3] or greedy tree growing TSVQ[13]. IC-VQ (III) first assigns bits uniformly, then this uniform bit allocation is changed into a variable one based on the image block location characteristic. A block located in a busy area requires more bits than a block located in a smooth area of the image. Of course, blocks located in active areas of natural images are normally active. Previous variable rate coders allocate bits to each image block based on its activity and disregard the characteristics of the neighboring blocks.

The differences between IC-VQ (III), and lossless index compressed VQ can be considered from the viewpoint of the size of the codebook subset that the indices of the neighboring image blocks are mapped onto it. IC-VQ (III) maps the neighboring blocks onto the variable size subsets of the VQ codebook. IC-VQ (I) and (II) map the neighboring blocks onto fixed size subsets, and address VQ is a hybrid method, where a fixed size codebook has been used to encode the blocks' indices of low activity areas, and a variable size for the rest. IC-VQ (III) maps the neighboring image blocks onto the subtrees (subsets) of the VQ codebook depending on the area's activity with some extra side information to represent the subtree. A variable size subtree for image areas results in a variable rate. It can be said that IC-VQ (III) belongs to that category of index compression schemes where a variable size codebook is used to encode the neighboring blocks (or to represent the indices).

The rest of this paper is organized as follows. Section 2 presents the genealogical characteristics of indices. Section 3 introduces the method of index transmission or storage based on the indices' genealogical feature. Section 4 discusses the effect of block size and image activity on the performance of IC-VQ (III). Section 5 presents the simulation results and discussion, and the final section is Conclusion.

2. Genealogical Characteristics of Indices Obtained from TSVQ

In TSVQ, the probability of having neighboring blocks with identical ancestors (genealogical probability) can be found, because the information of neighboring blocks for an r bpv quantised image shows the probability of having neighboring blocks with an identical ancestry for $r+1$ bpv, $r+2$ bpv, and so on. Figure 2 illustrates the genealogical index probabilities for a typical image (*Couple*). In that figure, Graph A shows the genealogical probability of having identical ancestors with the block in the north-side, and Graph B shows the genealogical probability of having identical ancestors with the blocks in the north- or west-side. For example for a 7 bpv TSVQ, the results of 7, 6 and 5 bpv show the probability that the index of two neighboring blocks can have an identical index, parents, and grandparents respectively.

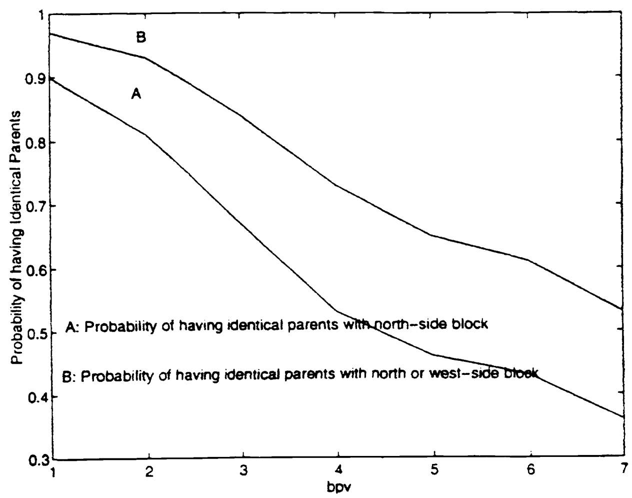

Figure 2: The probability of having blocks with identical ancestry

It can be seen that if two neighboring blocks do not have an identical index, there still exists the probability of having identical ancestry (i.e. parents or grandparents, etc.). This feature can be used in bit saving, because there is no need to transmit the same information (similarity in family generation) for both of the neighboring blocks.

3. Index Transmission or Storage

The new scheme based on TSVQ requires transmitting two groups of information, a map that shows the genealogical relationship of the image block indices, and the bit required to show the genealogical differences. The map of genealogical relationship indicates the subtree to which the neighboring blocks belong.

3.1 The Map of Genealogical Relationship

The map of genealogical relationships consists of information that shows whether two neighboring blocks have an identical index, an identical parent, grandparents or any other identical ancestor. This map can be constructed by finding the neighboring blocks with identical index, then those blocks that do not have an identical index with their neighbors but have an identical parent with their neighboring blocks, and the procedure continues until arriving to the point where all the image blocks have the same patriarch; this point is the root of the tree.

3.2 The information of the genealogical differences

The map of genealogical relationship can produce the indices' information up to a stage that a block has relation with its neighboring blocks, and the rest of the information should be transmitted. For example, let two blocks have the following indices respectively (read from left to right for root to node):

1 1 0 1 1

1 1 0 0 0

Up to three generations, the indices have identical ancestors indicated by 110, and after that all the remaining bits are required for reconstructing any of the two indices. In the case of a binary tree the first bit in the indices, where they are different, has to be transmitted for one of the blocks. If that bit is known for one of the blocks its value is automatically determined for the other. In the above example the difference starts from the fourth bit, and as that bit for the first index is a "1", it should be a "0" for the other block.

4. The effect of block size and image activity on the performance of IC-VQ (III)

Small block size vector quantisation increases the probability of having more identically indexed neighboring blocks and consequently more neighboring blocks with indices having identical ancestors [8,9]. Thus the coding performance of IC-VQ (III) over its counterpart VQ can be improved if small size blocks are used. The other characteristic of images which affects the performance of IC-VQ (III) is the image activity; highly active images have less identically indexed neighboring blocks, or blocks with indices having identical ancestor, and consequently IC-VQ (III) has less performance on these types of images in comparison with images with low to moderate activity.

Four images (Figure 3) with varying activities have been selected to illustrate the above arguments. The results of approximate difference between basic VQ and IC-VQ (III) are presented in Figure 4. First, it can be seen that the difference is always positive which means that IC-VQ (III) based on smaller block size gives better performance over basic VQ coder with the same block size, and secondly the performance of IC-VQ (III) highly depends on the image activity. The coding performance of IC-VQ (III) for less active images is better than highly active images.

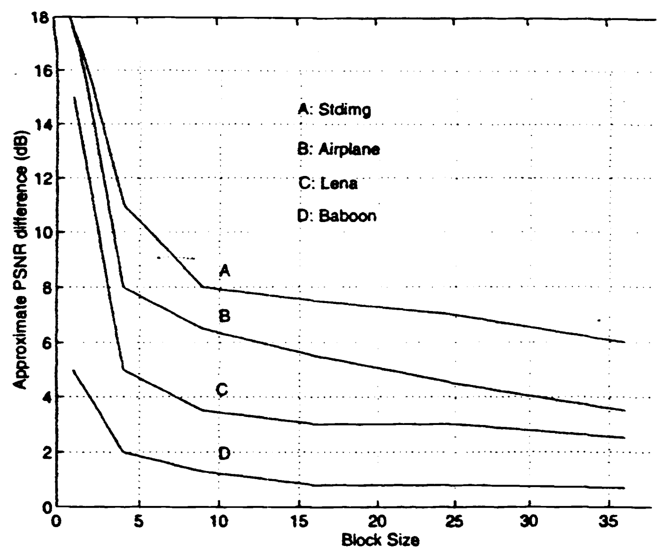

Figure 4: The effect of block size and image activity on the performance of IC-VQ (III)

5. Simulation Results and Discussion

This section presents the simulation results and discussion of the new scheme. The results are based on 512x512 size image and block size of 4x4. The effects of block size for the case of index compression by IC-VQ (III) is discussed in section 4. The result for IC-VQ (III) has been compared with IC-VQ (II) based on TSVQ, and predictive pruned TSVQ (PPTSVQ), and address VQ. The results obtained are based on the test image, *Lena* (512x512 pixels) using 4x4 pixels block size. The PSNR has been calculated using the following formula:

$$\mathrm{PSNR} = 10\log_{10}(255^2/\mathrm{mse})$$

where mse is the mean square error.

5.1 Comparison between IC-VQ (III) and IC-VQ (II)

Figure 6 presents the results of IC-VQ (II) (graph labeled "A"), and IC-VQ (III) (graph labeled "B") based on TSVQ. It can be seen that IC-VQ (III) has a better performance than IC-VQ (II) in all ranges of bit rates. The differences at low bit rates is low, because the codebook size for the both codecs is small and results in little differences between the low and high activity areas of the image, therefore the variable rate bit assignment procedure is less effective. At higher rates the difference is about 0.7 dB, and at the same PSNR (30.5 dB) the difference in rate is about 0.07 bpp. The reason for the difference at higher rates is that the image blocks have more choices to find the best match from the codebook, consequently the possibility of mapping the neighboring blocks onto a small and fixed size subset of the original codebook decreases, and IC-VQ (III) alleviates this problem by a variable mapping the neighboring blocks.

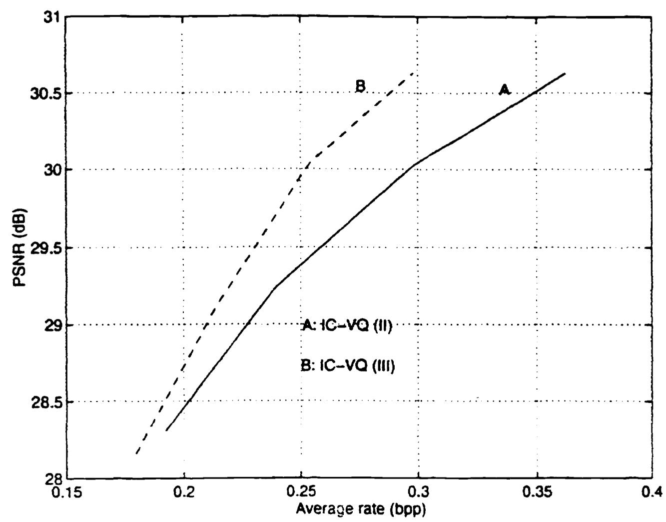

Figure 5: Results of IC-VQ (II) and (III)

5.2 Comparison between IC-VQ (III) and predictive VQ

Figure 6 presents the results of PPTSVQ (graph labeled "A") proposed by Lookabaugh 1993[3] and IC-VQ (III) (graph labeled "B"). The results indicate that IC-VQ (III) is able to produce better performance at rates less than 0.3 bpp. Between 0.1 and 0.15 bpp the difference varies from 4 to 1 dB. The reason for the differences between PPTSVQ and IC-VQ (III) at very low bit rates is that the predictive coder relies on prediction and a small codebook size to represent all the image blocks with any activity. This approach has two problems. Firstly, prediction does not perform well on high activity areas such as edges. Secondly, a small codebook cannot represent a wide variety of block shapes. In the case of IC-VQ (III), at very low bit rates, the most performance improvement derives from exploiting the inter-block correlation, rather than a small codebook. The variable bit allocation of IC-VQ (III) is image adaptive while it is not the case for PPTSVQ.

IC-VQ (III), in terms of codebook design is much simpler than the predictive coder because it is based on the basic TSVQ. The design process of PPTSVQ in its simplest form involves calculating the prediction coefficients, generating the residual of vectors between the predicted values and the original vector, generating the tree-shaped codebook for the residual vectors and then pruning the tree. The method of optimizing the codebook of the predictive pruned TSVQ is complex and requires several iterations [3,13].

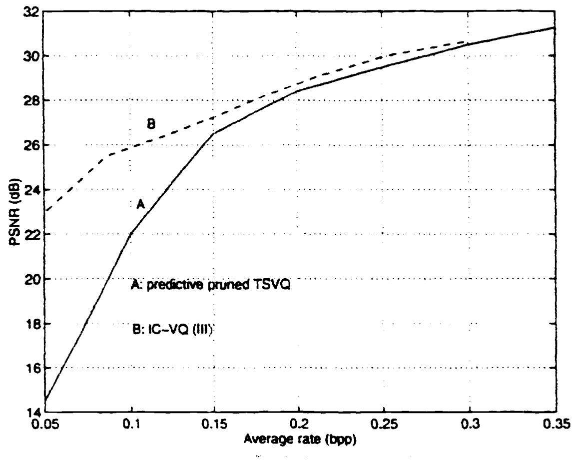

Figure 6: Results of IC-VQ (III) based on TSVQ, and PPTSVQ

In terms of simplicity of encoding, both encoders are using tree-structured codebooks which have the same block quantisation time; the difference is that in the predictive coder, the residual has to be obtained, and in IC-VQ (III) a comparison between the index of each block with the indices of two of its neighbors has to be performed plus Huffman coding of the genealogical map. As a conclusion, the encoding procedures of these two schemes do not have significant differences, but in terms of design procedure and coding performance at bit rates less than 0.3 bpp, IC-VQ (III) is preferable.

5.3 Comparison among IC-VQ (III) and Address VQ

Address VQ shows about 0.5 dB better results than IC-VQ (III). However the problems associated with address VQ in terms of codebook generation, memory requirement and search complexity make IC-VQ (III) preferable for application.

6. Conclusion

A novel method of image coding capable of providing significant results at low bit rate is proposed. This method compresses the indices of quantised images based on the fact that neighboring blocks, in natural images, are highly correlated, and this correlation exhibits itself among the indices of neighboring blocks in a way that neighboring blocks are mapped onto a small subset of the original VQ codebook; the size of the small codebook depends on the neighboring blocks' activity. The genealogical relationship among the indices has been used to exploit this characteristic.

The performance of this scheme in terms of PSNR versus average rate was compared with IC-VQ (II), some predictive VQ coders, and address VQ. The results show that this scheme has better compression capability in terms of objective quality over most of these schemes at bit rates less than 0.3 bpp, and gives a comparable result with address VQ with much less complexity.

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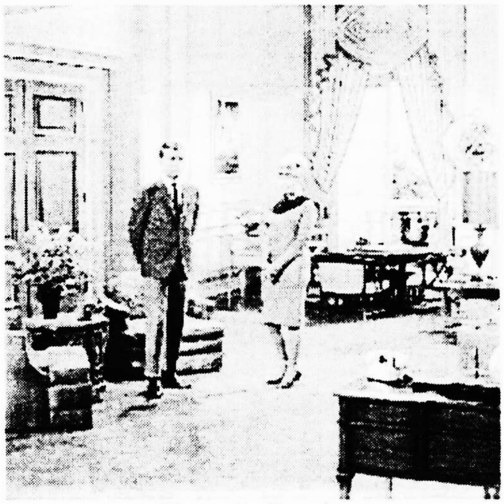

Figure 1: Couple

Stdimg

Airplane

Lena

Baboon

Figure 3: Four images for testing the performance of IC-VQ (III)