New feature-based image adaptive vector quantisation coder

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Abstract

It is difficult to achieve a good low bit rate image compression performance with traditional block coding schemes such as transform coding and vector quantization, without regard for the human visual perception or signal dependency. These classical block coding schemes are based on minimizing the MSE at a certain rate. This procedure results in more bits being allocated to areas which may not be visually important and the resulting quantization noise manifests as a blocking artifact. Blocking artifacts are known to be psychologically more annoying than white noise when the human visual response is considered. While image adaptive vector quantization (IAVQ) attempts to address this problem for traditional vector quantization (VQ) schemes by exploiting image dependency, it ignores the human visual perception when allocating bits. This paper addresses this problem through a new IAVQ scheme based on the human visual perception. In this method, the input image is partitioned into visual classes and each class, depending on its visual importance, is adaptively or universally encoded. The objective and subjective quality of this scheme has been compared with JPEG and a previously proposed image adaptive VQ scheme. The new scheme subjectively outperforms both schemes at low bit rates.

Keywords

image, adaptive, feature, vector, coder, quantization

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ABSTRACT

It is difficult to achieve a good low bit rate image compression performance with traditional block coding schemes such as transform coding and vector quantisation, without regard for the human visual perception or signal dependency. These classical block coding schemes are based on minimising the MSE at a certain rate. This procedure results in more bits being allocated to areas which may not be visually important and the resulting quantisation noise manifests as a blocking artifact. Blocking artifacts are known to be psychologically more annoying than white noise when the human visual response is considered. While image adaptive vector quantisation (IAVQ) attempts to address this problem for traditional vector quantisation (VQ) schemes by exploiting image dependency, it ignores the huamn visual perception when allocating bits. This paper addresses this problem through a new IAVQ scheme based on the human visual perception. In this method, the input image is partitioned into visual classes and each class, depending on its visual importance, is adaptively or universally encoded. The objective and subjective quality of this scheme has been compared with JPEG and a previously proposed image adaptive VQ scheme. The new scheme subjectively outperforms both schemes at low bit rates.

Keywords: vector quantisation, image compression, image coding, pattern classification, digital image processing, low bit-rate coding, feature-based coding, visual perception based coding.

1. INTRODUCTION

Vector quantisation (VQ) owes much of its attractiveness as an image coder to the simplicity of its decoder and the information theoretic justification of the technique[1,2]. The complexity of the search procedure of VQ however restricts it to low bit rate applications. At low bit rates the encoded image exhibits staircase errors. One of the reasons is the use of a stationary codebook to encode a non-stationary source such as an image[3,45,6].

A method to reduce the staircase error is the use of an image based codebook [3] as employed in an image adaptive VQ (IAVQ). There are four problems associated with this scheme: (i) the large computational burden of codebook generation schemes such as Linde, Buzo and Gray algorithm (LBG)[7], (ii) the need to transmit overhead information about the generated codebook, (iii) the disregard for the inherent inter-block correlation in a block-partitioned image and (iv). the use of a bit allocation method that does not allow for the characteristics of the human visual system.

The first problem can be solved by applying a fast clustering algorithm. A number of these schemes have been reported in the literature, notable among which are: real time codebook re-transmission[8], fast pairwise nearest neighbourhood algorithm[9], Mini-max algorithm for IAVQ[10], Kohonen's self organising feature map[11] and the Gold-Washing method[12]. Beside the fast clustering schemes the development of modular VLSI architecture for real time full-search based VQ[13] is another step in this regard.

The overhead bit rate problem becomes important only when the codebook size is big. The general approach to this problem is the use of some lossy coding schemes for codebook transmission, and so far three methods have been reported in this regard: variable rate transform coding scheme[14], JPEG[8,15], and universal codebook based

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VQ with a very large codebook[5]. In situations where the overhead rate is low, applying a lossy scheme does not result in appreciable improvement.

The sub-optimality of IAVQ which arises from neglecting the inter-block correlation or dependency has been tackled by Shanbehzadeh and Ogunbona[16]. They introduced a method to exploit inter-block correlation by considering the statistical characteristics of indices of a vector quantised image. Shanbehzadeh and Ogunbona[17] have shown that the possibility of having adjacent blocks with about the same index at low bit rates is very high. This characteristics has been used in a simple method to further compress the indices of a vector quantised image and simulation results show that this method outperforms the JPEG compression standard at low bit rates.

The bit allocation method employed in a basic IAVQ assigns identical bits to all image areas without differentiating areas in which the human eye is more sensitive to distortion. In order to have a uniformly distributed distortion it is important to allocate bits based on the areas' activity[4,18,19]. This method of bit allocation may theoretically provide a uniform distortion per unit area, but from human visual perception point of view it is only useful if the characteristics of the human viewer can be considered in distortion measurement. This paper introduces a method to solve this problem, which results in subjective quality improvement at low bit rates.

The new method is based on three modifications of the concept of IAVQ proposed by Golberg et al[3]. First, the image is partitioned into areas motivated by the human visual perception of "visually important". Secondly, the visually important areas are encoded with an image adaptive codebook and the rest with a universal codebook. Finally, the inherent inter-block correlation is exploited by using a modified version of the method proposed by Shanbehzadeh and Ogunbona[16]. This new method has the advantage of a non-stationary codebook while exploiting the human visual perception in bit allocation. Through the use of variable rate coding on the indices an improved compression ratio is obtained.

The rest of this paper is as follows: Section 2 is a review of VQ methods based the human visual perception, Section 3 details the method of partitioning the image into visual clusters and the codebook generation procedure; Section 4 outlines the image block indices compression method. The new scheme is compared with other schemes through a simulation and the results and discussions are reported in Section 5. The conclusion is given Section 6.

2. REVIEW OF HUMAN VISUAL PERCEPTION BASED VQ SCHEMES

A method to improve the subjective quality of image adaptive VQ involves dividing the image into regions based on their visual importance and allocating more bits to visually important regions[20,21,22,23]. In essence, the attending quantisation error is distributed in such a manner that visually important areas are better reconstructed than other areas. Two well known methods in this regard are classified and variable block size VQ[20,23].

In classified VQ each block of the image is classified into a special category[20], and vector quantised using a codebook appropriate for the category. A simple scheme for classification is to partition the blocks into edge and smooth areas. The edge blocks are then vector quantised with a smarter codebook and the smooth blocks with a codebook with a lower rate than that used for edge areas. Other similar methods are those which apply classification in transform domain[21,22]. These schemes have the advantage of a smarter edge detector at the expense of using a linear transform. The downside to these methods is the disregard for the fact that edges are not the only visually important areas in an image. For example in a head and shoulder type image distortion in the face area is subjectively displeasing to a human viewer. The performance of all these schemes are reported to be good at rates more than 0.5 bits/pixel [21,22].

In a scheme introduced by Vaisey[23] the image is partitioned into low activity areas, areas of low, and high visual importance. The low activity areas are quantised using a codebook with long codevectors in the transform domain. This method showed visually good results at 0.325 bits/pixel and a better performance than classified VQ schemes[20,21,22]. Vaisey[23] introduced a heuristic method to detect image block in the areas of low visual importance by using frequency analysis of blocks. There are two disadvantages associated with Vaisey's algorithm. First the frequency analysis scheme is unable to detect the visually unimportant blocks in some cases[23]. Another disadvantage is the use of transform coders with different block size for large smooth areas, and vector quantising the resulting long vectors with different codebooks. This results in high implementation complexity.

3. VISUAL CLUSTERS AND CODEBOOK GENERATION

The ultimate goal of a visual communication system is to provide the human viewer with a subjectively pleasing image information using the least possible bit rate. The human visual system pays more attention to active areas such as edges or boundaries of regions, and low activity areas such as faces, but pays less attention to unstructured regions (textures) such as grass, leaves of trees and hair. This observation suggests a visual perception based bit assignment procedure requiring a partitioning of the image into visual classes. Unfortunately, it is difficult to derive a mathematically consistent expression that will distinguish a block of high visual importance from another of low visual importance. Researchers have thus turned to heuristic methods in achieving this goal. A comprehensive review of the literature on this subject has been written by Jayant et al[24].

In this paper a simple and quick method to divide the image blocks into three groups namely; edges, texture and low activity areas is introduced. Further, the areas of low activity are divided into two classes: one has a low visual importance while the other has a high visual importance. Finally the edge and low activity blocks are classified as a cluster with a high visual importance, while the rest of the blocks are considered as belonging to a low visual importance cluster.

Our classification method proceeds by initially dividing the image blocks into two classes: high activity and low activity. The criterion of classifying a block into a high or low activity class is relative and image dependent. In different images the same block might be in different classes. This relative characteristic guides us to choose an image based measurement for block activity. In the second step of the method, the class of active blocks is partitioned in accordance with the visual importance of the blocks. Edge blocks are considered to be of a high visual importance while texture blocks are of low visual unimportance. Texture blocks are mostly in groups of connected blocks while the edges are mostly surrounded by low active regions. It is these characteristics of the blocks which is used to distinguish them.

An image adaptive greedy algorithm tree structured VQ (GA-TSVQ)[22] has been used to divide the image into high and low active blocks. In an image adaptive GA-TSVQ, the codebook training sequence is the image itself. In sub-section 3.1, the GA-TSVQ scheme is explained and the next sub-section details the method of using this scheme to divide the image into high and low activity areas. Sub-section 3.3 describes the method of finding visually important blocks among the low activity blocks.

3.1. Greedy growing tree structured VQ

A Tree Structured VQ (TSVQ) has a tree shaped codebook with several layers of nodes; the final layer consists of the leaves of the tree. The children of each node are the nodes of the next layer. In an encoding processes using TSVQ, the data vector is compared with the nodes of the first layer. The best matching node shows the best path for the second group of comparisons; the next comparisons are made just within the children of the previously selected node. This algorithm continues until a leaf of the tree is reached. The path traversed to the leaf then forms the index of data vector. There are two kinds of tree structures; balanced and unbalanced (greedy growing algorithm or pruned tree).

In a balanced tree structure all the paths to the tree leaves have the same depth, whereas in a greedy algorithm tree structure (GATS) this is not the case. The balanced tree structure is designed one layer at a time, while the GATS is designed by splitting one node at a time. Two methods of generating a greedy algorithm tree are those of Makhoul et al[2] and Riskin and Gray[18]. The methods differ in the node splitting criterion used; in the one, the node splitting criterion is the distortion, while in the other an impurity function based on the ratio of rate to distortion. The method introduced by Riskin and Gray[18] selects the best node for splitting as that which gives the best trade-off between the rate and distortion. This method shows better performance than the method introduced by Makhoul et al[2].

3.2. Method of partitioning image into high and low activity classes

One property of an image adaptive GA-TSVQ is that more bits are assigned to high activity areas and less bits to low activity areas. It is this property that motivates the method introduced in this paper; an active block can be easily recognised by the number of bits assigned to it. Further there is a need to set up a threshold value to find out the bit rate for dividing the image blocks into high or low activity classes. Based on tests on some images, we chose the bit rate of those clusters having the rate more than the average rate of the tree as the threshold value. Figure 1 shows the test image *Lena* and Figure 2 shows the high activity regions found when a 9 bit/vector image adaptive GA-TSVQ is used. The high activity image blocks are shown in white colour.

Figure 1: Test image *Lena*

Figure 2: High Activity regions of *Lena* shown in white cclour

In Figure 2, it can be seen that high activity regions consist of two parts, edges and texture. The edge areas are the boundaries between *Lena* and the background or the boundaries between background objects. The texture areas are some parts of *Lena's* hat and hair. A block is considered to be a texture if all of its surrounding blocks are high activity blocks. This definition arises from the observation that texture blocks are normally in connected regions, such as hair, grass, and fur, etc.. Figure 3 shows the result of using this definition in finding texture regions. It is noteworthy that our method found 208 texture blocks, while Vaisey's method[23] found only 84 texture blocks for the same image (*Lena*). The results obtained depend on the setting of the threshold value. In fact it is possible to find more texture blocks by playing with threshold value; however the price to be paid is the possibility of mistaking an edge block for a texture block. In our experiments we found that the possibility of this error is low, but it may lead to the appearance of unpleasant spots in visually important regions of the image.

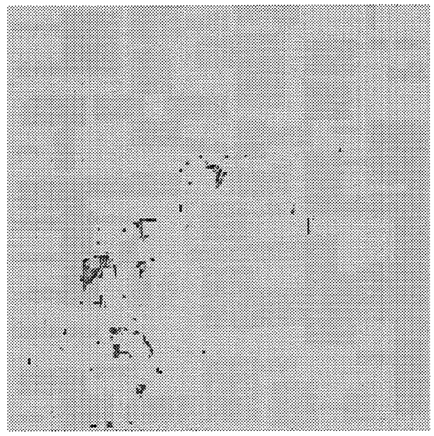


Figure 3. Texture blocks found using the new definition of texture region.

A question may come to mind is the codebook generation time of the GA-TSVQ. While one of the disadvantages of IAVQ is codebook generation time, applying another IAVQ scheme to find the low and high active areas raises further questions. The codebook generation time of a tree shaped codebook is much less than for a full search VQ (FSVQ) scheme[24]. Figure 4 shows a comparison between the codebook generation time of a tree shaped codebook and a FSVQ. This figure indicates the computational advantage of codebook generation method for tree shaped codebooks over FSVQ.

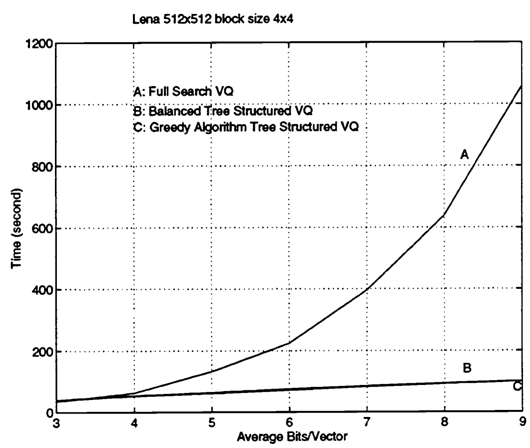


Figure 4 Comparison of codebook generation times of FSVQ and tree shaped VQs.

3.3. Method of finding visually important blocks among low activity blocks

We now consider the other areas of low visual importance: low activity blocks with low intensity. The fact that the distortion visibility of the human eye in low intensity areas is less than in areas with median intensity[24] can be used in dividing the smooth areas into two classes of low and high visual importance. In smooth areas the intensity of all the pixels in each block are close to the dc value of the respective blocks; we have used the dc value of a smooth block as the criterion of classifying it as either of the two visual classes. The high visual importance blocks of low and high activity classes are used to construct the final high visual importance class, and the rest are considered as low visual importance blocks. Figure 5 shows the visually important blocks with original colour and the others in white colour.

Figure 5. Visually important regions shown in original colour.

3.4. Codebook Generation

For each of the image classes we need to generate a codebook; the training sequence images used in the generation are partitioned into visual classes as explained in Sections 3.2 and 3.3. Universal codebooks for texture blocks and smooth blocks with low intensity are generated via the LBG algorithm[7]. An image adaptive codebook is generated for the visually important regions. The codebook size areas of low visual importance are smaller than those of the high activity areas. Because there is no mathematical tool to determine the optimum size of each of codebooks, a heuristic method based on observations has been used. Experiments with the sensitivity of the eye to distortion in areas of low visual importance in several images has led the authors to conclude that a universal codebook size of between 4 and 16 can reproduce those areas with less objectionable noise.

4. IMAGE ENCODING

The encoding process consists of three parts. At first the image is adaptively divided into three visual classes and then each class is vector quantised by its corresponding codebook. Finally, the information about block classes and indices are compressed and transmitted. The first part has been explained in section 2 and the second part is a simple procedure of vector quantising an image by a full search VQ scheme[1]. In this section we focus on the third part: lossy compression of information to be transmitted.

Two groups of information need to be transmitted, the address of visual classes, and the indices of vector quantised blocks. The straight forward method of transmitting these information suffers from a high amount of overhead information and neglects the inter-block correlation. Here, a method to reduce the overhead information of visual classes is introduced. and a method of transmitting the indices of vector quantised blocks is given.

4.1. Transmission of visual class information

In natural images the blocks of visual classes are mostly in groups of adjacent blocks as evidenced in Figures 3 and 5. This characteristic has been used in compressing the blocks' class information. If two symbols, zero and one, are used to represent the visual classes, run-length coding can compress this information efficiently. The low visual importance classes are two groups. Again two symbols are used to represent these two groups. The generated streams of two symbols from the two steps are concatenated and run-length coded. In all cases, a row or column scanned version of blocks for class information storage or transmission is considered. The choice of row or column scanning depends on the correlation in each direction. In most cases under test the difference between these two cases were marginal. In this paper a row scanned version has been used.

4.2. Image block indices transmission

The resulting block indices can be losslessly compressed by using a scheme proposed by Shanbehzadeh and Ogunbona[17]. As a result of the high inter-block correlation in natural images, the local distribution of neighbouring blocks' indices is such that each image block has a high probability of having only blocks with a specific indices as neighbour. The probability of having a block with any of the rest of the indices is otherwise low. Figure 6 shows the frequency distribution of a given index having other indices as its neighbour. This distribution has been obtained by using indices generated from four standard test images after full search vector quantisation with a universal codebook[17]. It is this characteristic of block indices that is exploited in the lossless index compression scheme described by Shanbehzadeh and Ogunbona[17].

Now, each block index can either be identical to its immediate predecessor in a row or column, or it can have a different value. If an index is identical to its predecessor in a row or column, its value can be reconstructed from it, otherwise the index has to be transmitted. A map indicating the relationship of indices to their predecessors in both rows and columns, herein called an index similarity map, can be easily generated. This map is constructed as follows. Along each row (following a zig-zag scan), each index is compared with its predecessor and a "1" is assigned in its place if they are identical, otherwise a "0" is assigned. Next, using the map generated from the row-wise comparison, we perform a column-wise comparison. Each index along a column is compared with its predecessor and "1"' is assigned in its place if they are identical, otherwise a "0" is assigned. Note that in the second comparison we only consider those indices which did not pass the identity test in the first step. It is computationally efficient to concatenate the similarity map with the stream generated for the visual class information and compress them in one stage.

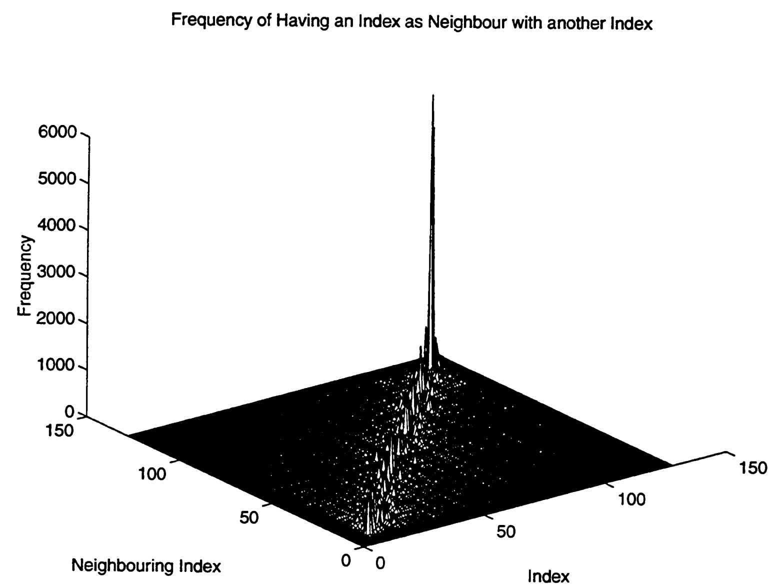


Figure 6.

This method of storage or transmitting class information and index similarity map sharply reduces the overhead information that would otherwise have required 2 bits/block for visual class and 2 bits/block for indices similarity map.

5. SIMULATION RESULTS AND DISCUSSION

The most important factor in a visual perception based coder is its subjective quality. The commonly employed subjective quality criterion is the mean opinion score (MOS) versus bit rate[26], which requires many expert judgment on the quality of images. This scheme is difficult and expensive; thus we propose a simple two stage method to give a subjective quality comparison of the new coder with two other schemes. In first stage of this method, the coded image is divided into two visual classes and the PSNR versus rate in the visually important class is considered as one component in the subjective quality measure. The result of this step is insufficient because we can assign very little bits to areas of low visual importance and improve the coding performance in areas of high visual importance. In order to avoid this, a second component of the subjective measure is considered as the PSNR versus the rate over the whole image.

In our simulations we have used two codebooks of size 4 for two classes of low visual importance. The generated codevectors for the visual parts are assigned 8 bits/pixel and transmitted or stored. In figures 7 to 10, the new coder and the scheme proposed by Goldberg et al.[3] are compared. In Figures 7 and 8 the indices of both image coders are not compressed. In figures 7 and 9 the comparisons of the objective quality in the visually important areas are given and in Figures 8 and 10 the comparisons of the objective quality over the whole image in terms of PSNR versus bits/pixel are shown. The results in Figures 9 and 10 are with index compression. In all four cases the overhead information of visual classes are compressed. It can be seen that the new visual perception based coder outperforms the Goldberg et al[3] scheme in visually important areas, and has about the same or better results in some regions when considering the whole image.

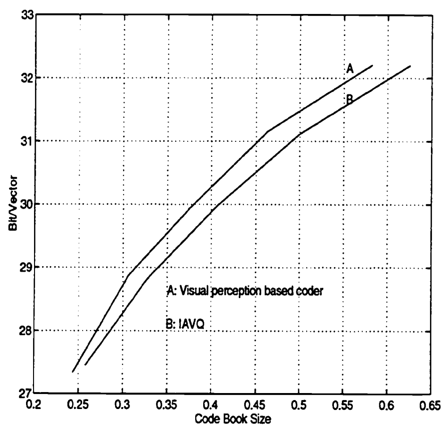


Figure 7. Comparison over visually important areas

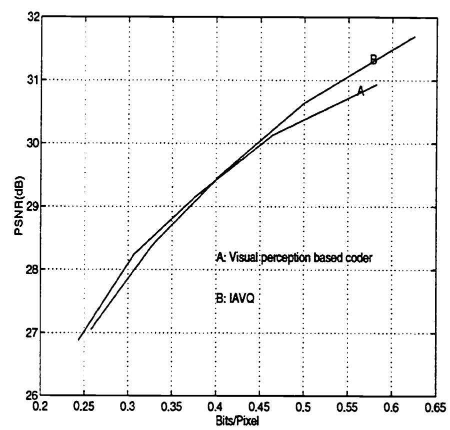
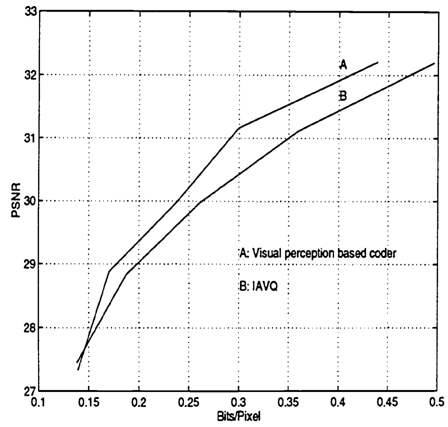


Figure 8. Comparison over the whole image



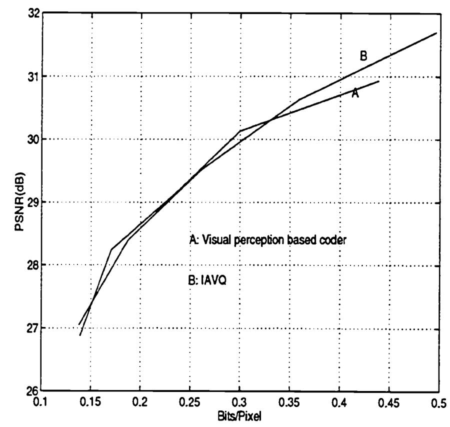


Figure 9. Comparison over visually important areas

Figure 10. Comparison over the whole image

In Figure 11, a performance comparison, in the visually important areas, of the new coder and JPEG standard[15] is shown. At low bit rates (less than 0.22 bits/pixel), the results of the new coder outperforms JPEG. In Figures 11 and 12, we have shown the coded images via new coder at 0.1705 bits/pixel and JPEG at 0.1745 bits/pixel. In an informal subjective test we asked ten students who are not experts to judge which of these two images is subjectively more pleasing to view. In all cases their preference was for the image encoded using the new coder. A reason that can be adduced for the superiority of the new visual perception based coder over JPEG is that JPEG allocates more bits to active areas regardless of their subjective importance. At low bit rates this results in allocating very low amounts of bits to smooth areas, and the consequence is a high blocking effect. This effect can be easily seen in Figure 12.

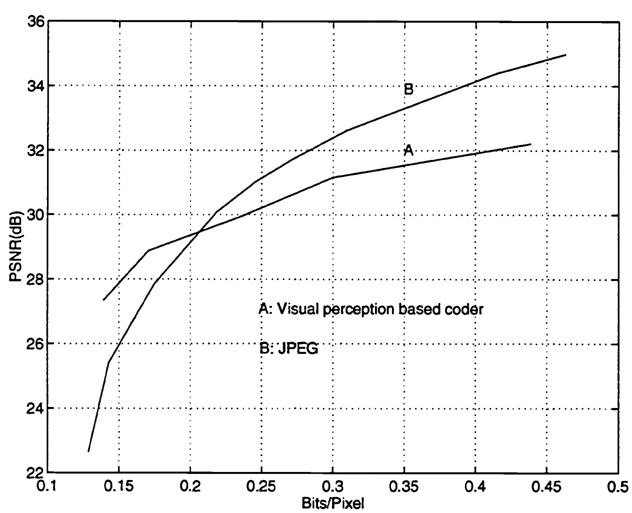


Figure 11. Comparison between the new coder and JPEG in visually important areas

Figure 12. Coded image using the visual perception based coder at 0.1705 bits/pixel

Figure 11. Coded image using JPEG at 0.1745 bits/pixel

6. CONCLUSION

A new VQ coding scheme based on human visual perception for low bit rate coding was proposed. In this scheme the input image blocks are adaptively divided into visual classes and the blocks in the low visual importance class are vector quantised with a universal codebook while those in the high visual importance class are adaptively vector quantised. The information of classes and the indices of image blocks are compressed by a lossless compression scheme and transmitted. A subjective fidelity measure based on a combination of the usual PSNR measure and PSNR measure in visually important areas was introduced. The subjective quality of the new coder using this fidelity measure outperforms the basic IAVQ. The new coder was also compared with the JPEG coding standard at low bit rates; the superiority of the coder under these circumstances was demonstrated.

7. ACKNOWLEDGMENT

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