Visually Lossless Compression for Color Images with Low Memory Requirement using Lossless Quantization

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Abstract*: In this paper a novel method is proposed to compress color images with no loss in quality. For the compression of the color image non uniform quantizers are used. These non uniform quantizers are implemented for different areas. The blocks are classified, predicted, encoded and decoded to get the resulted output. The blocks are classified based on principle component analysis. The output provides a compressed image with high quality. Inorder to improve the compression ratio vector quantization for color images is proposed. This provides good quality images with high PSNR values. The algorithm uses low memory requirement.

***Index Terms*: PCA, non uniform quantizers.compression ratio,vector quantization, PSNR values.**

I. INTRODUCTION

Image Processing is a form of signal processing. The input is an image. The output is an image or a set of characteristics or parameters related to image. Image compression deals with reducing the amount of data required to represent a digital image by removing of redundant data. The objective of image compression is to reduce irrelevance and redundancy of the image data in order to be able to store or transmit data in an efficient form.

Image compression may be lossy or lossless. Lossless compression is preferred for archival purposes and often for medical imaging, technical drawings, clip art, or comics. This is because lossy compression methods, especially when used at low bit rates, introduce compression artifacts. Lossy methods are especially suitable for natural images such as photographs in applications where minor (sometimes imperceptible) loss of fidelity is acceptable to achieve a substantial reduction in bit rate. The lossy compression that produces imperceptible differences may be called visually lossless.

The main goal of image compression is, bit-rate or compression rate which is the best image quality. Scalability generally refers to a quality reduction achieved by manipulation of the bitstream or file (without decompression and re-compression). Other names for scalability are progressive coding or embedded bitstreams. Region of interest coding are the parts of the image that are encoded with higher quality than others. Compressed data may contain information about the image which may be used to categorize, search, or browse images which is the meta information. Such information may include color and texture statistics, small preview images, and author or copyright information.

Compression algorithms require different amounts of processing power to encode and decode. Some high compression algorithms require high processing power. The quality of a compression method often is measured by the Peak signal-to-noise ratio. It measures the amount of noise introduced through a lossy compression of the image, however, the subjective judgment of the viewer also is regarded as an important measure, perhaps, being the most important measure. Image compression model consists of a source encoder, a channel encoder, the storage or transmission media, a channel decoder, and a source decoder. The source encoder reduces or eliminates any redundancies in the input image, which usually leads to bit savings. Source encoding techniques are the primary focus of this discussion. The channel encoder increase noise immunity of source encoder's output, usually adding extra bits to achieve its goals. If the channel is noise-free, the channel encoder and decoder may be omitted. At the receiver's side, the channel and source decoder perform the opposite functions and ultimately recover the original image.

The important components of source encoder are mapper, quantizer, symbol encoder. Mapper transforms the input data into a non visual format designed to reduce interpixel redundancies in the input image. This operation is generally reversible and may or may not directly reduce the amount of data required to represent the image. Quantizer reduces the accuracy of the mapper's output in accordance with some pre-established fidelity criterion. Reduces the psychovisual redundancies of the input image. This operation is not reversible and must be omitted if lossless compression is desired. Symbol(entropy)encoder: creates a fixed- or variable-length code to represent the quantizer's output and maps the output in accordance with the code. In most cases, a variable-length code is used. This operation is reversible.

II. RELATED WORK

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For lossless and near lossless image compression median edge detector (MED), together with context modeling and Golomb Rice coding are used [1]. The overall complexity of this pixel-based algorithm is thus rather high.

To visually lossless compress color images and documents a 1D-ADPCM is used to reduce the spatial redundancies and applied Lloyd-Max quantization for quantizing the residual error between the original and predicted pixels [2]. The algorithm did not require line memory for data buffer and was multiplication-free. Although it achieved the compression ratio from 3.0:1 to 4.0:1, compression distortion was visible in some images with specific patterns.

In H.264/AVC codec [3], visually lossless compression for images can be achieved by using a very small quantization level or a very high target PNSR in intra mode. But it is hard to find a common quantization level or target PSNR to have both visual losslessness and high compression ratio for all images.

Another issue of lossless or visually lossless compression is the number of line memory used for compression. More line memory permits higher flexibility for predicting the current pixels and leads to more accurate estimated pixels. This helps achieving higher compression ratio. But increasing the line memory requires a larger buffer for compression. This will occupy more resources, especially when the frame size becomes larger. For this reason, most of the lossless compression algorithms use only one line memory [4].

The architecture for block-based video applications is usually based on a processor engine, connected to an external background SDRAM memory where reference images and data are stored. The required memory bandwidth for MPEG coding is reduced up to 67% by identifying the optimal block configuration and embedded data compression is applied up to a factor four [5].

Vector Quantization [6] [7] has been observed as an efficient technique for image compression. VQ compression system contains two components: VQ encoder and decoder.

II. PROBLEM DESCRIPTION

Image and video compressions are required to reduce the number of bits needed to represent the content of the original data. Compression methods are classified into lossy, visually lossless and lossless compression, based on the quality distortion between the compressed data and its original data. Comparing to visually lossless and lossless compression, lossy compression obtains larger attention, due to its higher achievable compression ratio. But when a strict limitation is applied to the bandwidth, very high lossy compression is required to get a very low bit-rate. In those cases, the compressed images and videos are seriously suffered from coding artifacts.

A novel visually lossless compression method is used to achieve high compression level with very low line memory requirement. The main idea for the proposed codec based on the difference in error perceptibility for various areas. Figure shows an example of the error perceptibility when the original image is compressed using JPEG standard with the fixed scaling factor of 2 for every block.

Although using the same quantization, the compression errors are more perceptible in flat areas (such as the ceiling areas) than detail/structure areas (such as the window areas). In random areas (such as the roof areas), thecompression errors become imperceptible. To be unrecognized, only a small compression error is permitted in flat areas while larger error can be permitted in the detail areas.

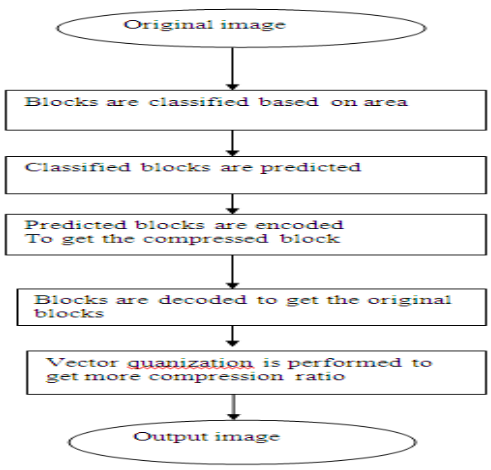
Different compression levels should be applied for these areas to further exploit the error perceptibility of HVS. The paper first classifies the blocks of pixels into flat, detail and random areas based on the prediction error and principle component analysis (PCA). Each block type is then compressed with different non-uniform quantizers. These quantizers are chosen to ensure that the compressed images are visually lossless comparing to their original image while still achieving high compression ratio.

The compression ratio is increased by compressing the indices of Vector Quantization and residual codebook is generated. The indices of Vector Quantization are compressed by exploiting correlation among image blocks, which reduces the bit per index. A residual codebook similar to Vector Quantization codebook is generated that represents the distortion produced in Vector Quantization. Using this residual codebook the distortion in the reconstructed image is removed, thereby increasing the image quality. Thus the PSNR value is increased.

III. PROPOSED SYSTEM

Conventional codecs consist a block predictor step to remove spatial redundancies, an adaptive encoder to reduce visual redundancies and an adaptive decoder to reconstruct the compressed block for later coding. To exploit the different error perceptibility of HVS, the paper proposes an additional block classifier to determine the block type. The information about the block type is used to control the block size of the block predictor and the nonuniform quantizers of the adaptive encoder.

A. System Design



B. Block classification

The classification is based on the prediction error. Each block type is later compressed by different quantizers. Edge blocks should be distinguished from random blocks and be compressed with a finer quantizer. The proposed codec uses PCA to detect the structures of the block. The compound image is first divided into 8x8 blocks. Then blocks are classified into four types: smooth, text, hybrid and picture according to their different statistical characteristics.

The pixels of each block are first grouped into three classes: low-gradient pixels, mid-gradient pixels and high-gradient pixels according to pixel's gradient value. The energy of picture blocks is mainly concentrated on low frequency coefficients when they are DCT transformed.

Classification is done by using the formula:

$$X_{1c} = \mathrm{MED}(C,A,B)$$

where

$$\mathrm{MED}(C,A,B) = \begin{cases} \min(A,B) & if\ C > \max(A,B) \\ \max(A,B) & if\ C > \min(A,B) \\ A+B-C & \text{otherwise} \end{cases}$$

The prediction error is calculated for the whole block as

$$\frac{1}{64}\sum_{i=1}^{64}|Xi - Xic|$$

For pixels in random blocks, it is hard to predict its value from surrounding pixels. So the prediction error in these blocks is very high. This error is small for flat blocks and medium for blocks with details. The classification is thus based on the prediction error. Each block type is later compressed by different quantizers. There is an exception for sharp edge blocks where the prediction error is also very high. If the same coarse quantizer for random block is applied to these blocks, recognizable distortions along the edges can be observed.

C. Block prediction

The main purpose of block prediction is to remove the spatial redundancies. This section will consider prediction modes used for different block types. The 2x32 blocks are divided into smaller sub-blocks for sequential coding. 1x4 sub-block prediction is applied for flat and detail blocks while 2x4 subblock prediction is applied for random blocks. Pixelbased prediction and coding were implemented to achieve more accurate prediction for lossless compression. But it required a large number of bits to indicate the prediction mode for every pixel.

The proposed algorithm uses block-based mode indication to save the mode indicating bits. Based on the experiments, 1x4 sub-block is chosen for flat and detail areas. This option permits small prediction error in all sub-blocks and requires a modest number of bits for indicating modes. For random areas, the prediction error is very high. In these areas, bigger sub-block of 2x4 pixels helps saving more bits needed for indicating the type of quantizer which is used later. The predicted pixels are subtracted from the original pixels to form the residual errors.

$$d_i = X_i - X_{ip}$$

These residual errors are then quantized to d_{iq} in the encoding phase. For decoding, the quantized residual errors are added back to the predicted pixels to formulate the reconstructed pixels

$$X_{iR} = X_{iP} + d_i$$

For random blocks, high quantization error is still undistinguishable and coarse quantizer can be used. This quantizer permits larger residual signal so the block size can be extended to 2x4 pixels.

D. Adaptive Encoding

After being sub-block predicted, the residual error will be quantized and encoded to form the bit-stream. For flat areas, prediction error is usually small. This error should be quantized with very fine quantization level to avoid large error, which is easily observed in these areas. For detail and random areas, prediction error is usually large. But these areas permit larger imperceptible quantization error than flat areas. That means larger quantization levels can be applied in these areas while the distortion is still visually lossless. The quantizer in this section is thus non-uniform with very fine quantization levels in the low value areas and with coarser quantization levels in the higher value of residual error.

The quantized residual signal is obtained by approximating the residual error by its centroid value

$$diq = Q(di) = \begin{cases} li\ \ if\ \ xi \le di < xi+1 \\ -li\ \ if\ -xi+1 \le di < \ -xi \end{cases}$$

Quantizers for flat, detail and random blocks have different quantization step sizes Δx_i . This makes the non-uniform quantizers adapt to the block types. The maximum quantization interval is 63. But not always all quantization intervals are occupied. If the all residual error of the block is small, only some quantization intervals are needed. Using all intervals in these cases will waste the number of bits to encode the quantized value. Only a sufficient number of intervals should be implemented. This number of used intervals *N* is determined based on the maximum values max_d of all residual values $|di|$ in the sub-block. Each Mode is indicated by a Huffman code based on its occurrence probability. The quantized residual error of all pixels in the block is then encoded using a fixed-length coding scheme. If Mode = M, then M bits are needed to code each quantized residual signal. A similar scheme is used for encoding the residual error of 2x4 sub-block. Fig. 3.9 shows an example of the bit structure with Mode = 5 for 1x4 flat blocks. The encoded bits for residual errors are shown in Fig. 3.10. The residual error for each pixel in this example requires five bits to represent the quantized error and 4 bits to represent the sub block mode.

E. Adaptive Decoding

For the decoding, the reverse process will be implemented. The first 30 bits are read from the bit stream to determine the framesize. Then two more bits are extracted to find the block types. Based on this block types, the decoder will use the corresponding mode code for the sub-block as well as the quantizer for decoding. Next, the Huffman code for the subblock will be read to determine the mode value. If Mode = M, then the next M bits are extracted and use the fixed-length code to indicate the quantized residual error d_{iq}. This value is added back to the predicted pixel X_{iP} to get the reconstruct

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pixel X_{iR}. The next M bits are extracted for the next pixel decoding until all the pixels in the sub-block are reconstructed. The decoder continues decoding the next subblock until all sub-blocks in the 2x32 block are decoded, then it repeats the process until all blocks in the frame are reconstructed.

The proposed codec requires two line memory for the prediction and encoding. This permits achieving more accurate prediction and high compression Ratio. For zero line memory both the block classification and block prediction can only use the available pixels in the same line, so that it does not require buffering any original or coded pixels of the above rows. One more advantage of the proposed codec using zero line memory is that the compression and decompression can be done in a parallel scheme for each row of the image. This helps reducing the processing time and makes the compression more robust to package loss over channel transmission. The bit-stream structure and prediction are represented below. At first, the image is divided into separate 1x32 blocks. These 1x32 blocks are then also classified into flat, detail or random blocks based on the prediction error and PCA.

F. Vector Quantization

The compression ratio is increased by compressing the indices of Vector Quantization and residual codebook is generated. The indices of Vector Quantization are compressed by exploiting correlation among image blocks, which reduces the bit per index. A residual codebook similar to Vector Quantization codebook is generated that represents the distortion produced in Vector Quantization. Using this residual codebook the distortion in the reconstructed image is removed, thereby increasing the image quality. Thus the PSNR value is increased.

IV. RESULTS

The experimental result is given below. The compressed image and the original images are shown as in the figure. The original image after decompression is having high compression ratio.

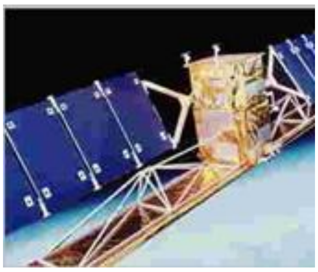


Fig: Encoded image

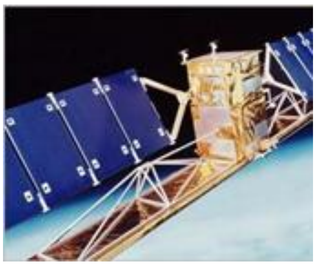
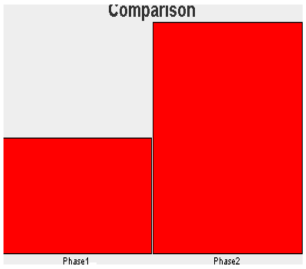


Fig:Decoded image

The image compression using vector quantization results in High quality images with high psnr values. The analysis result shows this.



V. CONCLUSION

The proposed methods using two line memory and zero line memory are simulated for a wide range of 10-bit bit-depth color images. The simulation results show that there is no visual loss in quality between the compressed images and their original one. The average compression ratio is 3.35:1 with the range from 30:1 to 1.8:1, depending on the image types. Similar simulations for the proposed codec using zero line memory also validate the visually lossless characteristic of the proposed method.

The average compression ratio in this case is 2.51:1 with the range from 9.31:1 to 1.59:1. Average PSNR values of the compressed images are 56.56 dB and 54.05 dB for the cases of using two line memories and zero line memory, respectively. These very high values also validate the visual losslessness of the proposed algorithms.

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