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A method for signalling block-adaptive quantization in baseline sequential JPEG

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Abstract: *The traditional JPEG compression standard doesn't have a means for spatially-variable quantization of transform coefficients. This prevents important features such as region-of-interest (ROI) coding. In this paper, we show how the quantization may be adapted in each block and how we may signal to the decoder in a memory-efficient manner. This allows ROI coding of subject and background. The method takes advantage of unused slots in the Huffman tables. In this paper we show how the encoder may be modified to produce an output that is in compliant with the standard and how the decoder may be modified to correctly recover the adaptively quantized image. Also we show how to use adaptive quantization as a means to perform spatially adaptive filtering of the image.*

I. Introduction

The JPEG standard [1], relies on method of separating an image into chrominance and luminance color planes, each plane is partitioned into 8 × 8 blocks and which are compressed using quantization of discrete cosine transform (DCT) coefficients. The compression is achieved by applying the quantization (Q) matrix, to each set of DCT coefficients . The Q matrix may be varied from image to image and also different Q matrices may be used for the luminance and chrominance color planes. However, the Q matrix must not change within a color plane, i.e., spatially-variable quantization is not allowed in JPEG. This prevents the encoder from varying the quantization within an image or quantizing subject information and background information in image separately to achieve ROI coding and also to get desired output file size. These important features are not available in JPEG standard. if we implement these features in baseline JPEG, then it would lead to useful and significant changes in old JPEG standard.

In this paper we demonstrated a method, of varying the quantization matrix from block to block, and described the signaling of adaptive quantization to the decoder in a way that is compliant with the JPEG standard. To recover the exact image by Adaptive quantization, the decoder should vary the Q matrix exactly as the encoder, over the image. After Adaptive Quantization the encoder must signal to the decoder on each block which Q matrix that it used, also the signalling must be compliant with the JPEG standard if any "standard" decoder is able to process the adaptively-quantized image. Huffman table in JPEG standard has few unused slots for end-of-block(EOB) symbols. Our method has taken advantage of those unused slots for end-of-block (EOB) symbols in the Huffman table. This allow us to signal up to 14 different levels of quantization within a color plane. standard decoder treats all 14 EOB symbols as the same. However, to recover image that is Adaptively Quantized we need to modiy the decoder in a way that it recognizes the EOB symbol and modify the decoding Q matrix appropriately. The modification demonstrated below is simple. There is no need for the encoder or the decoder to keep more than one block in memory at a time, as the EOB symbols by definition come as the end of a 8 × 8 block, This important factor plays a crucial role in hardware design of encoders and decoders, as memory consumes a large amount of chip area in embedded cameras. Adaptive quantization within JPEG has been a subject of interest since it was published. Different methods for signalling the adaptation have been proposed. one method searches up to 64 coefficients in a 8 × 8 block to find the coefficient whose quantized value, whose fractional portion, is closest to 0.5, for example, a fractional value of 10.499 may be rounded to either 10 or 11 approximately with the same error. Sum of quantized coefficients can be made either even or odd by rounding up or down, and the parity of the sum therefore becomes a method of signalling one of two possible Q matrices to the decoder. However, the scheme requires a search to be carried out prior to quantization, and does not extend to more than two Q matrices which might not help in all cases. [5][11]. Since the JPEG standard allows any number of color planes to be stored in the output file, Pennebaker [2] proposed to use an extra "color" plane whose purpose is to contain a spatial map of how the quantization matrices are varied but this requires that the decoder reads more than one color plane at a time to vary the Q matrix appropriately .Few other methods use rate-distortion based thresholding of DCT coefficients. These proposed methods are not suitable for embedded applications. In this paper we show how previously unused slots in the baseline JPEG Huffman table may be used to signal Q matrix adaptation. This allow us to signal up to 14 different EOB codes to be used on each block. In this paper we described the method to construct the Huffman codes to efficiently encode the adaptively-quantized image. We also show how it is compatible with the baseline sequential JPEG standard, so that any standard decoder may decode the adaptively quantized image.

II. Background

Baseline sequential and progressive are two compression formats available in JPEG. The baseline format stores the full resolution of the image in a single sequential scan and it is universally adopted on the other hand progressive format stores several scans of the image. In progressive format each scan has increased resolution over the previous scan. Progressive JPEG is not widely used. In JPEG standard Huffman table is designed to accommodate both progressive and baseline sequential formats. This nature allow us to modify the feature of progressive format to allow signalling of adaptive quantization in baseline sequential format. The below method describes the operation of baseline sequential JPEG compression of a color image.

1) The image is converted from RGB to YCbCr, usually followed by sub-sampling of the Cb, Cr planes.

2) Each of the Y , Cb, Cr planes are partitioned into blocks of size 8 × 8.

3) The DCT of each 8 × 8 block is calculated. Let x(i, j) denote the (i, j)-the pixel in block, and X(u, v) the (u, v)-th frequency in the DCT and X(1, 1) is the "DC" coefficient, and remaining are "AC" coefficients. The quantization of DCT coefficients using a 8 × 8 matrix Q as follows:

$$X_Q(u,v)=\text{round}\left\{\frac{X(u,v)}{Q(u,v)}\right\}\quad u,v=1,\ldots,8. \qquad ..(1)$$

Y , Cb, Cr planes may have different Q matrices but they do not vary spatially.

4) The quantized block X_Q is scanned in "zig-zag" order. DC value of the previously coded block is subtracted from the quantized DC coefficient and then it is stored . The scan of AC coefficients is stored in (R, S) format, where R is the number of consecutive zeros followed by the non-negative value S indicating the size of the next non-zero value. If V is the value of the quantized coefficient, then

$$S = \log_2\lfloor |V| \rfloor + 1 \qquad \ldots(2)$$

Here $\lfloor . \rfloor$ is the floor function also two special symbols are also allowed

1).a ZRL symbol represents a run of 16 consecutive zeros.

2).EOB symbol indicates and represent that all subsequent coefficients in the scan are zero.

5) Each scan is Huffman coded, where AC coefficients are organized as a 16×11 structure in the Huffman table. This structure is designed to accommodate 16 different R values and 11 values of S. This structure is shown in table I . The Huffman code for each (R, S) pair in a scan is emitted, followed by S additional bits to indicate the actual value of the coefficient.

TABLE I
HUFFMAN TABLE LAYOUT FOR AC COEFFICIENTS IN BASELINE SEQUENTIAL MODE. ENTRIES MARKED "X" CONTAIN CODES FOR OTHER VALUES.

R \ S	0	1	2	· · ·	9	10
0	EOB	x	x	x	x	x
1	Not used	x	x	x	x	x
⋮	Not used	x	x	x	x	x
14	Not used	x	x	x	x	x
15	ZRL	x	x	x	x	x

From Table I slot for R = 0, S = 0 is used for the EOB symbol, while R = 15, S = 0 indicates 15 consecutive zeros followed by a size 0(ZRL symbol) but the slots for S = 0 and R = 1 to 14 are reserved for the progressive format and are not used in baseline sequential format. We utilized those unused slots for signalling adaptive quantization to decoder thus making it JPEG standard-compliant..

In JPEG standard if S = 0 and R = 15 then 16 consecutive zeros are appended to the zig-zag scan in reconstruction. Otherwise the symbol is treated an EOB. all slots in Table I with S = 0 and R < 15 are considered to be the same EOB symbol. Therefore, additional codes for different conditions may adopted by using the 14 unused slots in Table I.

III. Quantization

In the Quantization, The Q matrix is fixed across the color plane. This limits the possibilities of ROI coding. We have overcomed the limitation by signalling to the decoder with proper EOB codes exploiting the unused slots in Huffman table , to say which Q was used. But if we use a standard decoder then it dequantizes an input block with a improper Q matrix. Suppose that the DCT of an 8 × 8 block, X(u, v), 1 ≤ u, v ≤ 8, is quantized at the encoder using matrix Q as in eq.(1). At the decoder, the quantized matrix X Q is used to reconstruct the DCT matrix X using the equation

$$\dot{x}(u,v) = Q(\dot{u},v)XQ(u,v),$$
$$u,v = 1,\ldots,8. \qquad \ldots(3)$$

$\dot{x}$ will not the same as X due to rounding. If we let P = αQ, where α is a scale factor, then the effect of dequantizing X_Q with P instead of Q is as follows:

$$\begin{aligned}\tilde{X} &= P(u,v)Xq(u,v)\\ &= \alpha Q(u,v)\text{round}\left\{\frac{X(u,v)}{Q(u,v)}\right\}\\ &= \alpha X(u,v) + \alpha Eq(u,v)\end{aligned} \qquad \ldots.(4)$$

where $Eq = Q\,\text{round}\{X_Q/Q\} - X$ is the quantization error introduced by rounding.

If we apply P = αQ, we can see that scaling factor is same for every element instead if we choose P = H ◦ Q, where ◦ denotes the elementwise product of H and Q. Here H acts as filtering matrix.

$$\tilde{x}(u,v) = H(u,v)X(u,v) + H(u,v)E_q(u,v) \qquad .....(5)$$

we see that dequantization with H ◦ Q is equivalent to filtering by H in the DCT domain ignoring the noise term. We may therefore use adaptive quantization as a means to perform spatially adaptive filtering of the image.

A. DC coding and Prediction

Adaptive quantization is the dependent on adjacent blocks,. After quantization, the DC coefficient in baseline sequential JPEG is treated separately from the 63 AC coefficients. The DC coefficient is a measure of the average value of the 64 image samples. Because there is usually strong correlation between the DC coefficients of adjacent 8x8 blocks, the quantized DC coefficient is encoded as the difference from the DC term of the previous block in the encoding order as shown in Figure 3. This may lead to complications. If adaptive quantization is used, prediction will accumulate error when the DC coefficient is dequantized differently than it was quantized. The DC coefficient is unique in this respect: all other coefficients in a block are coded independently of adjacent blocks and therefore varying the Q matrix has no effect. We therefore constrain the quantization change matrix H discussed above so that H(1, 1) = 1, which ensures that eX(1, 1) = X(1, 1) + Eq(1,1).

B. Reduction of artifacts

Adaptive quantization may be applied to remove few JPEG compression artifacts:

1) visible boundaries between 8 × 8 blocks

2) ringing around edges (Gibbs phenomenon) .

For example we may apply a "larger" matrix Q2 for edge blocks and "smaller" matrix Q1 for smooth blocks,.we can determine smooth vs edge blocks by observing the occurrence of last non-zero coefficient early or late in a zig-zag scan compared to a threshold. From above we get Q2(u, v) > Q1(u, v).

IV. Huffman Table Modification

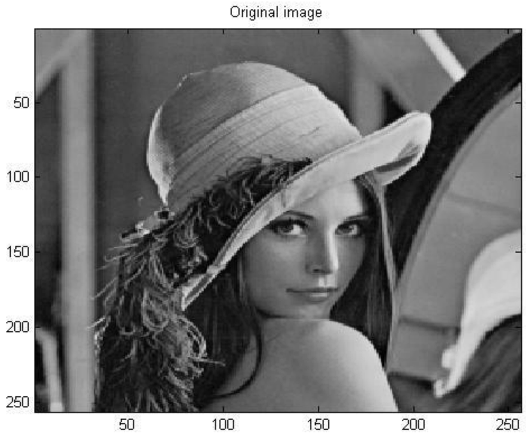
we must modify the entire Huffman codebook to allow for unique decoding . this allow us to use the empty slots in the Huffman table to signal adaptive quantization to the decoder. One method is to substitute a Huffman table for progressive coding in place of the baseline table. This allows us to signal 15 different Q matrices to the decoder. Standard progressive table is shown in Table II. We may or may not use all the empty slots , so we can design Huffman table to support fewer EOB codes.

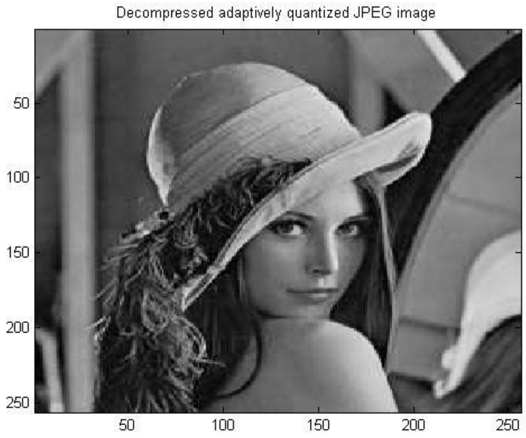
TABLE II
HUFFMAN TABLE LAYOUT FOR PROGRESSIVE ENCODING

R \ S	0	1	2	···	9	10
0	EOB0	x	x	x	x	x
1	EOB1	x	x	x	x	x
⋮	⋮	x	x	x	x	x
14	EOB14	x	x	x	x	x
15	ZRL	x	x	x	x	x

V. EXPERIMENTAL RESULTS

We used the EOB signalling method to apply adaptive quantization on gray scale image. We used two levels of quantization on the luminance (Y) component of the image.MATLAB was used as the programming platform.


Original image


Decompressed adaptively quantized JPEG image

VI. Conclusion

In this paper, we demonstrated a simple method for signalling adaptive quantization to the decoder, using the empty slots in standard baseline Huffman table. The proposed method is efficient as encoder and decoder do not require to keep more than one block in memory at a time. A standard decoder will treat all EOB codes as the same, and if adaptive quantization is performed, will perform frequency-domain filtering upon dequantization. This is useful for ROI coding. which has the advantage of improving image quality in selected regions.

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