SELECTIVE REQUANTIZATION FOR TRANSCODING OF MPEG COMPRESSED VIDEO

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ABSTRACT

This paper addresses the problem of bit-rate conversion of MPEG compressed video. We present selective requantization, a method for reducing the requantization errors in transcoding. The proposed method is based on avoiding critical ratios of the two cascaded quantizations (encoding versus transcoding) that either lead to larger transcoding errors or require a higher bit budget. Results show that selective requantization improve the quality of the transcoded images. The presented method is simple to implement and does not require side information.

1. INTRODUCTION

Transcoding is the process of converting a compressed video format into another compressed format. This paper addresses the specific transcoding problem of bit-rate reduction of a previously compressed MPEG video [1, 2]. Transcoding provides flexibility in transmission bit rates in situations such as network congestion, or when the transmission media has a lower capacity than the capacity required by the pre-encoded video.

An important issue in bit-rate conversion is to provide requantization methods for efficient transcoding [3, 4]. In [3], two approaches for adjusting the decision levels of the transcoder's quantizer to improve transcoding quality are proposed. The first uses a mean-squared error (MSE) cost function, and the second uses a maximum a posteriori (MAP) cost function. Both methods uses a Laplacian pdf (probability density function) to model the distribution of the original DCT coefficients. The Laplacian parameter for each AC coefficient is estimated from either the first generation coefficients or the original coefficients. In the latter case, the parameters have to be transmitted as additional side information. In [4], a rate-distortion method is proposed using a Lagrangian optimization algorithm to derive the quantizer step size for transcoding each macroblock. This method improves picture quality. However, the optimization algorithm has added computational complexity and may impose extra delay in transcoding.

In this paper, we address the transcoder's performance and present selective requantization, a simple method to reduce the requantization errors in transcoding [5]. The organization of this paper is as follows. Section 2 discusses issues related to transcoding such as requantization and transcoder structure. Section 3 studies the extra error introduced by requantization. Section 4 presents the proposed selective requantization method. Section 5 provides experimental results. Finally, Section 6 concludes the paper.

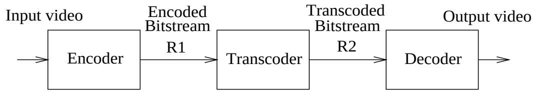

Figure 1: A basic video coding system including a transcoder.

2. TRANSCODING OF MPEG COMPRESSED VIDEO

Figure 1 shows a basic block diagram of a video coding system that includes a transcoder. The encoder compresses an input video at a bit rate $R1$, then subject to certain constraints, the transcoder converts this compressed video at a bit rate $R2 < R1$. Next, the decoder decompresses the transcoded video bitstream for display.

In MPEG standards, the quantizer step size includes two components, a quantization coefficient specifying a minimum step size for the particular DCT coefficient, and a quantization scaling parameter $qscale$ for bit-rate control. In this paper, transcoding is achieved by requantizing the DCT coefficients. In its simplest case, the requantization process can be expressed as

$$x_{q_2}(u,v) = Round\left(\frac{x_{q_1}(u,v) \times qscale_1 \times w_1(u,v)}{qscale_2 \times w_2(u,v)}\right) \qquad (1)$$

where $x_{q_1}(u,v)$ is the quantized input DCT coefficient (encoder) and $x_{q_2}(u,v)$ is its requantized version (transcoder), $qscale_1$ is the input quantization scaling parameter and $qscale_2$ is the value required to meet the target bit rate. Usually, the quantization coefficients $w_1(u,v)$ (encoder) and $w_2(u,v)$ (transcoder) are the same and may be omitted.

Figure 2 shows the block diagram of the transcoder used in this paper. For constant bit-rate (CBR) transcoding, we use the $TM5$ rate control algorithm [6] while for variable bit-rate (VBR) transcoding, the rate control is disconnected. The transcoder uses a feedback loop to compensate for drift errors that result from

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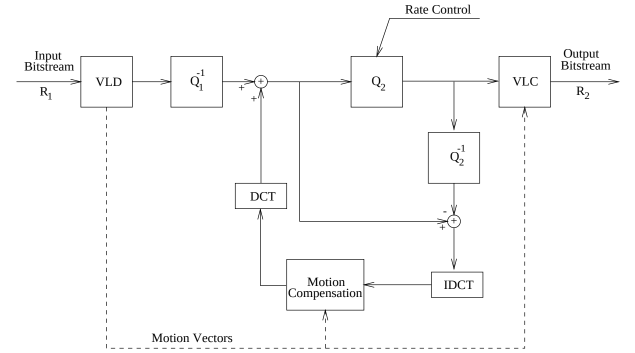

Figure 2: Transcoder structure with drift correction in the spatial domain.

requantizing a motion-compensated compressed video. This is achieved by storing the requantization error of an anchor frame then adding it to its corresponding predicted frame. The requantization process is done on a macroblock by macroblock basis. This reduces delay. Furthermore, the motion vectors of the input bitstream are re-used. This avoids motion estimation, the most computationally intensive operation of the MPEG encoding algorithm. As expected, this significantly reduces the complexity of the system, as compared to a cascaded decoder-encoder system. Macroblock types however can change after requantization. For example, a motion-compensated coded macroblock may be changed to a motion-compensated not coded macroblock if all the DCT coefficients are zero after requantization.

3. PERFORMANCE OF CASCADED QUANTIZATION

Bit-rate conversion of compressed video involves two subsequent quantizations: the first in encoding, and the second in transcoding. In general, cascaded quantizations lead to an extra distortion as compared to direct quantization with the coarser quantizer. We denote this extra distortion as “cascading error”. The cascading error depends on the *ratio* between the finer (encoder) and coarser (transcoder) quantizers [5]. Thus, as the step size of the finer quantizer is encoded in the bitstream and is available to the transcoder, it is possible to use this information to reduce the requantization errors and achieve a higher transcoding quality.

For simplicity, consider the quantization of a non-negative input data value x using a uniform midstep quantizer (suitable for Intra macroblocks) with no dead zone, as shown in Figure 3. Input-output characteristics of the quantizer are mirrored for negative x. The quantizer is completely specified by a set of reconstruction levels, r_k, and a set of decision levels, d_k, given by

$$r_k = kQ, \quad \text{and} \quad d_k = \frac{r_k + r_{k-1}}{2} = (k - \frac{1}{2})Q \tag{2}$$

where Q is the step size of the quantizer and k is an integer representing the level. Thus, given a value x and its reconstruction $q(x) = kQ$, The quantization error, ε, can be expressed as

$$\varepsilon = x - q(x) \tag{3}$$

Let Q_1 and Q_2, where $Q_1 < Q_2$, be the step sizes of the finer quantizer (encoder) and coarser quantizer (transcoder), respectively. Let $\varepsilon_{1,2}$ be the total quantization error that results from quantizing with step size Q_1 followed by step size Q_2, and let ε_2 be the error

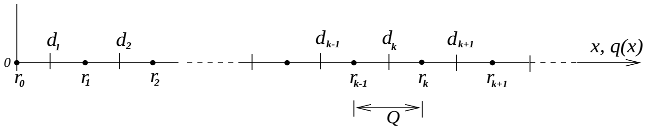

Figure 3: Decision and reconstruction levels of the midstep quantizer.

resulting from direct quantization with step size Q_2. The cascading error ε_c is defined as

$$\varepsilon_c = \varepsilon_{1,2} - \varepsilon_2 \tag{4}$$

In general, the cascading error increases, on average, when many reconstruction levels from the finer quantizer are aligned with decision levels from the coarser quantizer. The maximum cascading error ε_{cmax} depends on the ratio Q_2/Q_1. It can be shown that the magnitude of maximum cascading error is bounded by

$$0 \leq |\varepsilon_{cmax}| \leq Q_1 \tag{5}$$

If the finer quantizer’s cell, corresponding to the original data value, is totally contained in a cell of the coarser quantizer, then cascaded quantization gives the same result as direct quantization with Q_2, i.e., no cascading error is introduced by requantization (Figure 4.(a)). However, if the finer quantizer’s cell overlap with two cells of the coarser quantizer, then cascading error is introduced by requantization if the reconstructed data value after the first quantization and the original data value each fall into a different quantization cell in the coarser quantizer (Figure 4.(b)).

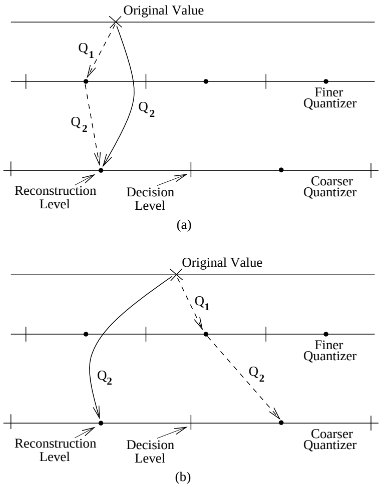

Figure 4: Cascaded quantizations (dashed arrows) and direct quantization (solid arrow). (a) Cascaded quantizations yield the same results as direct quantization. (b) Cascaded quantizations introduce extra distortion, as compared to direct quantization.

4. SELECTIVE REQUANTIZATION

This section presents selective requantization, a simple method that can be used either for VBR or CBR transcoding. The method is based on avoiding critical ratios of Q_2/Q_1 that either lead to larger transcoding errors or require a higher bit budget.

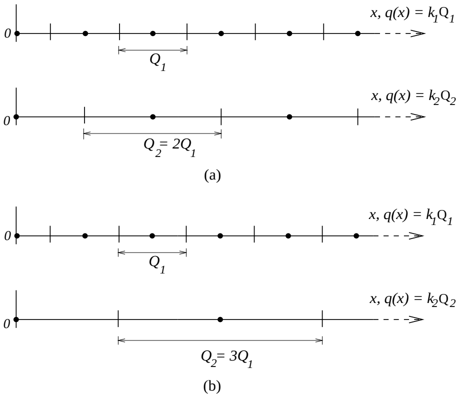

Figure 5: Ratio of coarser quantizer (Q_2) to finer quantizer (Q_1), for midstep quantizers. (a) Even integer ratio ($Q_2/Q_1 = 2$). (b) Odd integer ratio ($Q_2/Q_1 = 3$).

To study how the ratio Q_2/Q_1 affects requantization, for a uniform midstep quantizer, let $r_{k_1} = k_1 Q_1$ be the reconstruction levels of the finer quantizer, and let $d_{k_2} = (k_2 - 1/2)\, Q_2$ be the decision levels of the coarser quantizer. The condition that a reconstruction level from the finer quantizer is aligned with a decision level from the coarser quantizer is given by

$$k_1 = \left(\frac{2k_2 - 1}{2}\right)\frac{Q_2}{Q_1} \tag{6}$$

Equation 6 is satisfied if there exists a ratio Q_2/Q_1 and an integer k_2 that result in an integer k_1. Clearly, an even integer ratio of Q_2/Q_1 satisfies this condition. This is illustrated in Figure 5.(a). The magnitude of maximum cascading error usually reaches its highest bound (Equation 5) when the ratio Q_2/Q_1 is an even integer. Furthermore, the percentage of reconstruction levels from the finer quantizer that are aligned with decision levels from the coarser quantizer depends on the ratio Q_2/Q_1. This percentage may be computed off-line. For example, if $Q_2/Q_1 = 2$, then half of the reconstruction levels from the finer quantizer are aligned with decision levels from the coarser quantizer. Our experiments show that a ratio of 2 for Q_2/Q_1 usually yields larger transcoding errors. Moreover, large drops in bits usually occur at values of Q_2 that are integer multiple of $2Q_1$. This is because more requantized DCT coefficients are mapped to lower quantization levels, and consequently, they are coded with fewer bits. This is illustrated in Section 5.

Equation 6 is not satisfied for all integers k_2 and an odd integer ratio for Q_2/Q_1. In this case, the cells of the finer quantizer are totally contained inside the coarser quantizer cells and consequently, the cascading error is zero. This is illustrated in Figure 5.(b).

Using similar analysis for a midriser quantizer (suitable for non-Intra Macroblocks), let $r_{k_1} = (k_1 + 1/2)\, Q_1$ be the reconstruction levels of the finer quantizer, and let $d_{k_2} = k_2 Q_2$ be the decision levels of the coarser quantizer. The equation analogous to Equation 6 is given by

$$(2k_1 + 1) = 2k_2 \frac{Q_2}{Q_1} \tag{7}$$

Clearly, Equation 7 is satisfied for any odd integer ratio of $2Q_2/Q_1$ and odd integers k_2. In this case, additional loss is usually introduced by cascading quantizations. For example, if $Q_1 = 4$ and $Q_2 = 6$, then one-third of the reconstruction levels of the finer quantizer are aligned with decision levels from the coarser quantizer. Our experiments show that a ratio of 3 for $2Q_2/Q_1$ usually leads to larger transcoding errors. On the other hand, Equation 7 is not satisfied for even integer ratios of $2Q_2/Q_1$ and all integers k_2. In this case, direct quantization with Q_2 and cascaded quantizations with Q_1 followed by Q_2 yield the same quantization error.

In this paper, we apply the selective requantization method for CBR transcoding of MPEG-2 compressed video. We use linear mapping for $qscale$ (i.e., $q\_scale\_type = 0$). For simplicity, we assume that the transcoder is using the same quantization matrices that are encoded in the bitstream. The algorithm for selective requantization includes in its code the following conditions

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1. Intra macroblock
   (a) $if((qscale_2 \% (2 * qscale_1)) == 0)$
           $qscale_2 = qscale_2 + 2;$
   (b) $if(((qscale_2 + 2) \% qscale_1) == 0)$
           $if((((qscale_2 + 2)/qscale_1) \% 2)! = 0)$
               $qscale_2 = qscale_2 + 2;$
   (c) $if(((qscale_2 + 2) \% (2 * qscale_1)) == 0)$
           $qscale_2 = qscale_2 + 4;$
2. Non-Intra macroblock
   (a) $if(((qscale_2 + 2) \% qscale_1) == 0)$
           $qscale_2 = qscale_2 + 2;$
   (b) $if(((2 * qscale_2) \% qscale_1) == 0)$
           $if((((2 * qscale_2)/qscale_1) \% 2)! = 0)$
               $qscale_2 = qscale_2 + 2;$
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where the above mathematical operators are similar to those used in the C programming language. In summary, the above items are the result of the previous analysis for midstep (Intra) and midriser (Non-Intra) quantizers. For Intra macroblocks, Item $1.(a)$, avoids even integer ratios of Q_2/Q_1. These ratios usually lead to larger transcoding errors. Item $1.(b)$ selects the next higher $qscale_2$ if it results in an odd integer ratio of Q_2/Q_1. The new value for Q_2 yields zero cascading error. Item $1.(c)$ reduces considerably the number of bits needed to code Intra macroblocks without a significant increase in errors. For Non-Intra macroblocks, Item $2.(a)$, selects the next higher $qscale_2$ if it results in an even integer ratio of $2Q_2/Q_1$. This ratio has zero cascading error. Item $2.(b)$, avoids odd integer ratios of $2Q_2/Q_1$. These ratios usually leads to larger transcoding errors. Our experiments show that Items $1.(c)$ and $2.(a)$ are the most important for Intra and non-Intra macroblocks, respectively, and for the sequences used in this paper.

5. EXPERIMENTS

For VBR Intra-frames transcoding, we use 150 frames (each 352×240) of *Flower Garden*. The sequence is first encoded with an MPEG-2 software encoder and a constant step size $Q_1 = 16$. The resulting bitstream is then transcoded at different Q_2 ranging from 18 to 40, with intervals of 2. In direct encoding, the sequence is encoded directly with Q_2. The peak signal-to-noise ratio (PSNR) is used as an objective measure of the video quality, with the original sequence as reference. Figure 6 shows transcoding average PSNR and bit budget versus Q_2. Notice the PSNR and bit budget for $Q_2 = 32$ and $Q_2 = 34$. The former results in a ratio $Q_2/Q_1 = 2$, which usually leads to larger requantization errors. The PSNR for $Q_2 = 34$ is higher by 0.3 dB with 0.01% bits lower than in the

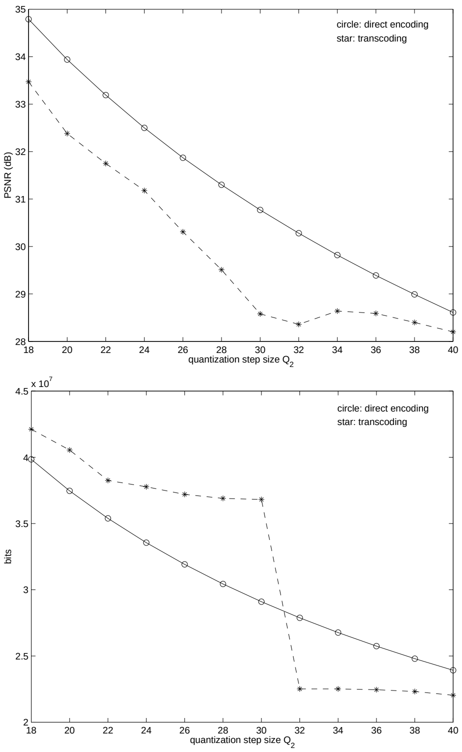

Figure 6: Intra-frame Transcoding average PSNR (top) and bit budget (bottom) of *Flower Garden* for $Q_1 = 16$ and Q_2 ranging from 18 to 40 with intervals of 2.

case of $Q_2 = 32$. Furthermore, notice the PSNR and bit budget for $Q_2 = 30$ and $Q_2 = 34$. Both values of Q_2 yield almost the same PSNR. However, the reduction in bits by choosing $Q_2 = 34$ over $Q_2 = 30$ is about 39%. This is important in CBR transcoding where the saving in bits can be used on coding other macroblocks such that the overall video quality is improved.

For CBR Intra-frame transcoding, we use 150 frames of the sequences *Flower Garden* and *Football*. The sequences are initially encoded at 8Mb/s. Table 1 shows the average PSNR for different transcoding output bit rates. Two cases are shown: transcoding using selective requantization (PSNR$_S$) and normal transcoding (PSNR$_N$). Here, Δ is the difference between PSNR$_S$ and PSNR$_N$. In normal transcoding, the value Q_2 determined by the rate control algorithm is directly used for requantization. Notice the improvement achieved using selective requantization. For example, the increase in PSNR of *Flower Garden* is 1.8 dB at a transcoding output bit rate of 7Mb/s, and 1.3 dB at a bit rate of 6Mb/s. Note that the performance of this method differs for different transcoding bit rates. For CBR transcoding of Intra and Inter frames, Table 2 shows the PSNR of normal transcoding and of transcoding using selective requantization for five sequences: *Flower Garden* (Flr.), *Football* (Ftb.), *Table Tennis* (Ten.), *Miss America* (Mis.), and *Salesman* (Slm.) with a group of pictures (GOP) structure N=15, M=3. Transcoding input and output bit rates are respectively 2Mb/s and 1.5Mb/s. It can be seen that selective requantization outperforms normal transcoding.

In summary, results show that selective requantization improve the quality of the transcoded sequence. The proposed method is more advantageous for Intra-frame transcoding.

Table 1: Average PSNR for Intra-frame transcoding of *Flower Garden* and *Football*. Selective requantization (PSNR$_S$) versus normal transcoding (PSNR$_N$). The input bit rate is 8Mb/s.

Bit Rate	PSNR$_S$ (dB)	PSNR$_N$ (dB)	Δ (dB)
Flower Garden			
7	29.1	27.3	1.8
6	28.0	26.7	1.3
5	27.3	26.6	0.7
4	26.6	26.2	0.4
Football			
7	36.0	34.1	1.9
6	35.1	33.6	1.5
5	34.4	33.5	0.9
4	33.7	33.4	0.3

Table 2: Average PSNR for transcoding of five sequences with a GOP structures N=15, M=3. Selective requantization (PSNR$_S$) versus normal transcoding (PSNR$_N$).

	Transcoding PSNR (dB)				
Case	Flr.	Ftb.	Ten.	Slm.	Mis.
PSNR$_S$	25.9	29.8	33.9	38.6	41.5
PSNR$_N$	25.8	29.6	33.4	38.0	40.9
Δ	0.1	0.2	0.5	0.6	0.6

6. SUMMARY

In this paper, we addressed the problem of bit-rate conversion of a previously compressed video. We studied the performance of cascaded quantization and presented selective requantization, a simple method to improve the transcoding of MPEG video. The proposed method is based on avoiding critical ratios of Q_2/Q_1 that either lead to larger errors or require a higher bit budget. The method is easy to implement and does not require side information.

7. REFERENCES

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