RATE CONVERSION OF MPEG CODED VIDEO BY RE-QUANTIZATION PROCESS

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ABSTRACT

In this paper, we propose rate conversion method by re-quantization in which MPEG coded video at high bitrate is converted into MPEG bitstream at lower bitrate without decoding to obtain reconstructed picture. Quantization step required for re-quantization is determined by local and global quantization step which are closely related to the activities in the pixel domain. The simulation results show that very similar rate distortion curves to those of transcoding have been obtained, and the difference in SNR is relatively small, about 0.4dB at 1 Mbit/s in MPEG1 using master bitstream at 4Mbit/s, and 1dB at 3 Mbit/s in MPEG2 using master at 9 Mbit/s. Since proposed method is very simple and requires much less hardware implementation cost than transcoding, it has a significant advantage as rate conversion tool.

1. INTRODUCTION

Video coding technology such as MPEG is becoming very important in order to achieve effective use of network bandwidth and storage capacity for video transmission and retrieval in such applications as multi-channel broadcasting and DVD(Digital Video Disc). In addition, since editing and forwarding of video are indispensable in TV broadcasting, for example, the characteristics of multi-generation MPEG coding have also been focused in terms of coding conditions[1,2,4] in order to maintain high picture quality over the generations. In the multi-generation coding using transcoding, MPEG coding is repeated several times in which each time it is required to decode bitstream to obtain pixel domain data and encode the picture after such processing as editing.

Another important aspect in video transmission and storage is rate conversion as shown in Figure 1. For example, in TV broadcast applications, studio quality video is stored as a master video compressed at very high bitrate in order to use it for forwarding video to other stations, and video data which is rate converted into lower bitrate is transmitted to viewers at home. This is the one of the examples that shows that video may be required to be transmitted and stored to heterogeneous networks and different storage media at corresponding bitrates. One of the MPEG2 functions solves rate conversion issue, in which scalability functions such as SNR, spatial, and temporal scalabilities are used to perform bitrate scalability as well as quality scalability in SNR, spatial and temporal domain. This however has limitations that target bitrate should be determined before encoding the source input video, and generally only 2 or 3 bitrate hierarchy can be allowed if conformed to MPEG2 profiles and levels[7].

There are several approaches to perform rate conversion at arbitrary bitrate. One is the use of transcoder mentioned above in which decoder and encoder are required as a rate converter. In this case, the original bitstream is decoded into pixel domain and then the decoded picture is encoded at certain bitrate using the encoder. Although this method can provide the rate converted bitstreams at arbitrary bitrates, very large implementation cost is required. Recently other methods are reported in order to decrease this cost where rate conversion is performed through selection of coded DCT coefficients[3]. In these methods, the original bitstream is decoded up to VLD(Variable Length Decoding) and the quantized DCT coefficients are extracted. Then two types of rate conversion are proposed, one is called "number partitioning" of quantized DCT coefficients in which certain number u of nonzero DCT coefficients from highest frequency data are replaced by 0 and the other is "area partitioning" in which higher frequency coefficients above band v are forced to 0. Then the rate converted bitstream is obtained using the selected coefficients.

This paper proposes rate conversion method using re-quantization process with a simple architecture in which only VLD/VLC and quantizer/inverse quantizer are required to convert the coded video bitstream into desired bitrate conforming to current standards.

Experimental results are also shown for images compressed by MPEG1 and MPEG2 standards with the comparison of other rate conversion methods. It can be seen that proposed rate conversion method provides very similar performance to that of transcoding yet much less implementation cost, and thus allows very effective rate conversion tool.

2. PROPOSED RATE CONVERSION ALGORITHM

2.1. Rate Conversion By Re-quantization

In the following, we discuss the proposed algorithm for rate conversion of MPEG coded bitstream using re-quantization process.

Figure 2 shows the basic block diagram of rate conversion. At first, MPEG coded video bitstream 1 at bitrate $R1$ with quantization step $Q1$ is retrieved from the storage media, for example. Then bitstream 1 is decoded at VLD and quantized DCT coefficients are extracted with coding information such as quantizer scale, macroblock type and motion vectors. Then, in the inverse quantizer IQNT, DCT coefficients are recovered. These coefficients are re-quantized by a quantizer

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QNT with a new quantization step $Q2$. The quantized coefficients are coded again in VLC with other coding information including the quantization step $Q2$ and modified macroblock information according to coded DCT coefficients, and it outputs the rate converted bitstream 2 at bitrate $R2$.

2.2. Quatization Noise of Rate Conversion

Here we discuss quantization noise both for normal coding and for rate converted video signal. Hereafter we consider a simple model for the analysis of these noise. Firstly, we assume source input video is coded with constant quantizer step $Q1$ at bitrate rate $R1$ in the first stage. Then the coded video is rate converted into bitstream at $R2$ using re-quantization process with constant quantization step $Q2$. Here we also assume rate conversion is oriented toward down conversion, i.e. $Q1 < Q2$, where $Q1$ and $Q2$ are positive integer.

Let $En(Q1)$ be quantization error by normal coding with $Q1$ and $Eq(Q1,Q2)$ be overall error by rate conversion with $Q2$ after normal coding with $Q1$. Figure 3 shows the quantization representation diagram for both normal coding and rate conversion. In the figure, "x" represents input value for the quantizer, whereas "o" represents quantized value. Consider the case when DCT coefficient lies in between $nQ1$ and $(n+1)Q1$. Although both linear and nonlinear quantizer can be used in MPEG2, for example, we only consider linear quantization case for its simplicity. Similarly, as for quantization representation, we only consider midrise type quantization without deadzone, though MPEG use midrise quantizer with deadzone for non-intra coded block.

Then the quantization error $En(Q1)$ is given as

$$\mathrm{En(Q1)} = \frac{1}{\mathrm{Q1}}\int_{\mathrm{nQ1}}^{\mathrm{(n+1)Q1}} \left\{ \mathrm{x} - (\mathrm{n}+\frac{1}{2})\mathrm{Q1} \right\}^2 d\mathrm{x} = \frac{\mathrm{Q1}^2}{12} \tag{1}$$

In the case of rate conversion, the quantized *value* $(n+1/2)Q1$ in the normal coding is re-entered into quantizer. Suppose this value lies in between $mQ2$ and $(m+1)Q2$, then quantization error $Eq(Q1,Q2)$ after re-quantization is given as

$$\begin{aligned}\mathrm{Eq(Q1,Q2)} &= \frac{1}{\mathrm{Q1}}\int_{\mathrm{nQ1}}^{\mathrm{(n+1)Q1}} \left\{ \mathrm{x} - (\mathrm{m}+\frac{1}{2})\mathrm{Q2} \right\}^2 d\mathrm{x} \\ &= \frac{\mathrm{Q1}^2}{12} + \mathrm{reqnt\_err}^2\end{aligned} \tag{2}$$

where *reqnt_err* is given by

$$\mathrm{reqnt\_err} = (\mathrm{n}+\frac{1}{2})\mathrm{Q1} - (\mathrm{m}+\frac{1}{2})\mathrm{Q2} \tag{3}$$

Since re-quantized DCT coefficient by $Q2$ lies in between $mQ2$ and $(m+1)Q2$, i.e.

$$\mathrm{mQ2} \le (\mathrm{n}+\frac{1}{2})\,\mathrm{Q1} \le (\mathrm{m}+1)\,\mathrm{Q2} \tag{4}$$

Therefore *reqnt_err* can be bounded by

$$-\frac{1}{2}\mathrm{Q2} \le \mathrm{reqnt\_err} < \frac{1}{2}\mathrm{Q2} \tag{5}$$

Using Equation(5), quantization error $Eq(Q1,Q2)$ is bounded [4]by

$$\mathrm{Eq(Q1,Q2)} = \frac{\mathrm{Q1}^2}{12} + \mathrm{reqnt\_err}^2 \le \frac{\mathrm{Q1}^2}{12} + \frac{\mathrm{Q2}^2}{4} \tag{6}$$

As for SNR based on the quantization error, SNR in the case of normal coding with $Q2$ for 8 bit data is given by

$$\mathrm{SNR\_normal(Q2)} = -10\log\left(\frac{\mathrm{Q2}^2}{12} / 255^2\right) \tag{7}$$

Similarly, SNR in the case of rate conversion by re-quantization with $Q2$ is given by

$$\mathrm{SNR\_reqnt(Q2)} = -10\log\left(\left(\frac{\mathrm{Q1}^2}{12} + \mathrm{reqnt\_err}^2\right) / 255^2\right) \tag{8}$$

Therefore, the degradation of SNR, ΔSNR, between normal coding and rate conversion coded by the quantizer Q2 can be given by

$$\begin{aligned}\Delta\mathrm{SNR} &= \mathrm{SNR\_normal(Q2)} - \mathrm{SNR\_reqnt(Q2)} \\ &= 10\log\left((\mathrm{Q1}^2 + 12\,\mathrm{reqnt\_err}^2) / \mathrm{Q2}^2\right)\end{aligned} \tag{9}$$

By applying Equation (5) as a boundary condition, Equation(9) can be bounded as

$$\Delta\mathrm{SNR} \le 10\log\left(\frac{\mathrm{Q1}^2}{\mathrm{Q2}^2} + 3\right) \tag{10}$$

Since $Q1 < Q2$ as mentioned earlier, in the case of $Q1^2 / Q2^2 << 1$, Equation (10) becomes

$$\Delta\mathrm{SNR} \le 10\log(3) \cong 4.8\ \mathrm{dB} \tag{11}$$

2.3. Adaptive Re-quantization and Rate Control

Next we discuss the adaptive quantization and rate control for re-quantization. As for quantization, activity measure is most essential parameter in pixel domain to analyze the complexity of picture by such characteristics as texture, edge, and flat region. This complex measure is used to determine quantization step and bit allocation reflecting HVS(Human Visual System). For example, in TM4[6], minimum block variance in macroblock is used as local activity whereas its average over the picture is used as global activity in the picture. In this model, adaptive quantization is performed through analysis of local activity together with average activity and the quantization step is obtained by multiplying base quantization step by a weighting factor determined by local activity and global activity. The base quantization step is given by bit allocation and buffer control process among macroblock, picture, and GOP(Group of Picture) layers. Since lower activity region is to be perceived more sensitively from HVS point of view and to generate less bit counts than that of higher activity region at the same quantization step, smaller quantization step is used for lower activity region, for example. Therefore, the weighting factor is given as the ratio of local activity to the average activity.

Since these activities can not be obtained in the bitstream unless it is decoded to recover picture, it is necessary to estimate appropriate re-quantization parameters from coded information. As for quantization step obtained from the bitstream, though it depends on both base quantization step and weighting factor, local quantization step and average quantization step well reflect the local activity and average activity, respectively if base quantization step is stable throughout the picture. Therefore, using a simple model discussed above, the ratio of local quantization step to the average quantization step can be used as weighting factor and new quantization step for the rate conversion can be represented as

$$Q2\_mb(j, k) = Q2\_base(j, k) \times \frac{Q1\_mb(j,k)}{Q1\_avg(k)} \qquad (12)$$

where *Q1_mb(j, k)* and *Q2_mb(j, k)* are quantization step before and for re-quantization at macroblock j (j =1,2....T; T=total number of macroblocks in the picture) in k th frame, respectively. *Q2_base(j, k)* is base quantization step for re-quantization. *Q1_avg(k)* is average quantization step over the k th frame.

As for the base re-quantization step *Q2_base(j, k)*, it can be obtained in the same way as normal coding, for example since information regarding to coded bit counts and target bit can be obtained in the decoder or calculated; target bit can be converted by the factor of *R2/R1*, for example.

3. EXPERIMENT

In this section, we present experimental results where we have performed rate conversion for both MPEG1 and MPEG2 coded video using re-quantization discussed in the previous section. The coding algorithms are based on SM3[5] and TM4[6] for MPEG1 and MPEG2, respectively, which are slightly modified to fit current MPEG1, and MPEG2 syntax. The coded picture formats are SIF(352 pels x 240 lines) and ITU-R BT.601 level(704 pels x 480 lines) for MPEG1 and MPEG2, respectively.

In the experiments, at first video is coded straightforwardly, at 4 Mbit/s for MPEG1 and at 9 Mbit/s for MPEG2 as master bitstreams. Then each master bitstream is converted to the one at desired bitrate through re-quantization process, and SNR is calculated with respect to source input video. *Q1_mb(j, k)* and *Q1_avg(k)* are obtained at VLD processing of the master bitstream. As for *Q1_avg*, we use *Q1_avg(k-c)* where *(k-c)* is the most recently decoded frame with the same picture coding type(I, B, P) since the correlation between *Q1_avg(k-c)* and *Q1_avg(k)* is high if there is no scene change. *Q2_base* is obtained following rate control in TM4 except that target bit is converted using *R2/R1* factor. After re-quantization, quantized DCT coefficients are coded by VLC in the same way as normal coding. If the status of the macroblock is changed due to number of DCT coefficients, the macroblock information is changed accordingly, e.g. macroblock type is changed from Motion Compensated Coded to Motion Compensated Not Coded if there is no significant DCT coefficients after re-quantization. As for other information such as motion vectors and motion compensation modes like forward prediction, they are decoded at VLD and directly forwarded to VLC without any modification.

For comparison, we also performed simulation for normal coding, transcoding and rate conversion by DCT coefficients partitioning[3]. In normal coding, video is coded from source video at several bitrate from 4 Mbit/s to 1 Mbit/s by MPEG1, for example.

In the case of transcoding, master bitstream coded at 4 Mbit/s (MPEG1 case) by normal coding is decoded to obtain reconstructed picture and then coded again at desired bitrates. In order to avoid degradation caused by different coding parameters from master bitstream[2,4], we haven't changed coding structure[I,P,B-picture] during transcoding.

In DCT coefficient partitioning, we have simulated both number of coefficients partitioning and area partitioning for the master bitstream to convert the bitrate. In the experiments, these parameters used in [3] are set to $u = 2$ to 48 for number partitioning and $v = 2$ to 13 for area partitioning in the both case of MPEG1 and MPEG2 to obtain wide range of bitrates. Here, u is the number of nonzero DCT coefficients from highest frequency data to be replaced by 0. For example, only highest two nonzero DCT coefficients are forced to zero if $u = 2$. In the case of area partitioning, DCT coefficients are partitioned into 15 diagonal frequency bands following zig zag scanning order. v is the frequency band beyond in which all the higher DCT coefficients beyond this band are forced to zero. For example, highest three DCT coefficients (frequency bands 14 and 15) are forced to zero if $v = 13$.

Figure 4 and Figure 5 show the simulation results (ISO's test sequence Flower Garden) of various rate conversion methods including normal coding at various bitrates for MPEG1 and MPEG2, respectively. In Figure 4, it can be seen that transcoding and re-quantization have similar rate distortion curves to normal coding, and the difference between transcoding and re-quantization is very small, up to about 0.4dB. The SNR degradation ΔSNR of re-quantization when compared with normal coding is about 0.5dB at 1 Mbit/s.

Regarding to DCT coefficients partitioning methods, the area partitioning method achieves better performance than that of number of coefficients partitioning, about 2 dB better at 2 Mbit/s, for example, This is due to the fact that the area partitioning method always preserves the DCT coefficients which are below the frequency band specified by v, whereas number partitioning method does not guarantee the possibility of loss of very low frequency components which greatly affect picture quality in terms of SNR and subjective one. Although these two methods are very simple in terms of implementation since only VLD and VLC are the key components in them, both of them show much larger degradation than the other rate conversion methods, 6 to 8 dB lower at 2 Mbit/s, for example.

In the case of MPEG2, basic characteristics of the SNR performance is similar to that of MPEG1, i.e, the difference between transcoding and re-quantization is small and both of them show similar distortion curves to normal coding, whereas, the SNR degradation of both of DCT coefficients partitioning methods is very large at lower rates. As for ΔSNR, SNR difference between normal coding and re-quantization, it is about 1.5dB at 3 Mbit/s as shown in Figure 5 which is well in the range modeled earlier.

It can be seen from the figure that there is a tendency that the rate distortion curve of re-quantization drops faster than transcoding at lower bitrate, though it is little bit difficult to see this tendency in MPEG1 case. This is caused by the fact that re-quantization scheme uses open loop type coding where there is no feedback from master video and only prediction error part is re-quantized in the case of motion compensation mode blocks so that error becomes accumulated after many prediction pictures. On the other hand, transcoding uses master video each time to perform motion compensation so that prediction error is confined to each picture and not accumulated so much as re-quantization unless master video is severely degraded.

However, as for subjective quality, there is no significant differences among normal coding, transcoding, and re-quantization even at 1 Mbit/s for MPEG1 and at 3 Mbit/s for MPEG2, in terms of coding noise at each picture and accumulated noise observed temporal domain, where I picture cycle is 15 frames for MPEG1 and 12 for MPEG2 as modeled in

SM3 and TM4. We have also performed simulation on the other ISO's test sequences like Mobile and Calendar, and Bicycle. In these test sequences, we found that the results in terms of SNR and subjective quality show about the same characteristics as Flower Garden.

4. CONCLUSIONS

In this paper, we have presented rate conversion method using very simple re-quantization which does not require implementation cost heavy DCT and ME operations. In the course of adaptive quantization, weighting factor which is essentially determined by local and average activities has been represented by local and average quantization steps. Although at lower bitrate, there is a tendency that re-quantization method degrades a little more rapidly than transcoding, it is shown that the performance of both methods are very similar and the degradation from normal coding is very small. Furthermore, when compared with DCT coefficient partitioning, significant improvement is obtained in re-quantization, though both of the methods have similar implementation cost.

We conclude that rate conversion by re-quantization process provides a significant advantage over conventional rate conversion methods such as transcoding which requires much more implementation costs than that of proposed method.

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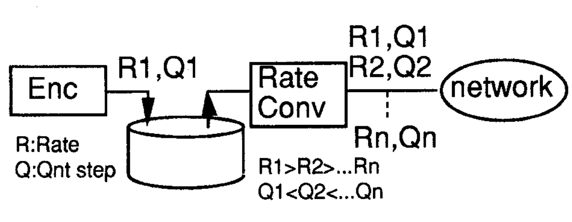

Figure 1 Rate conversion scheme

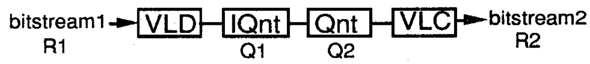

Figure 2 Block diagram of rate conversion by re-quantization

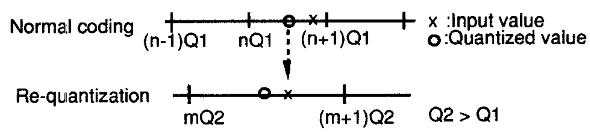

Figure 3 Re-quantization model

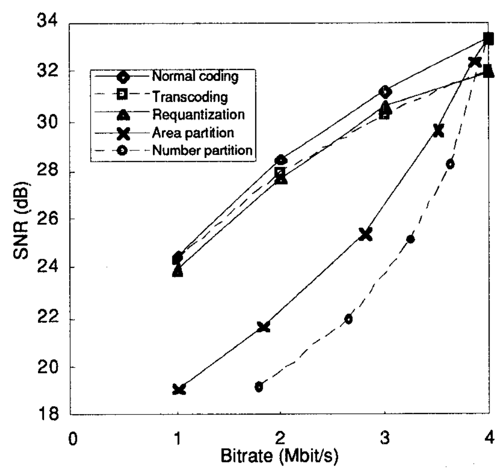

Figure 4 Comparison of SNRs for normal coding and rate conversion using MPEG1

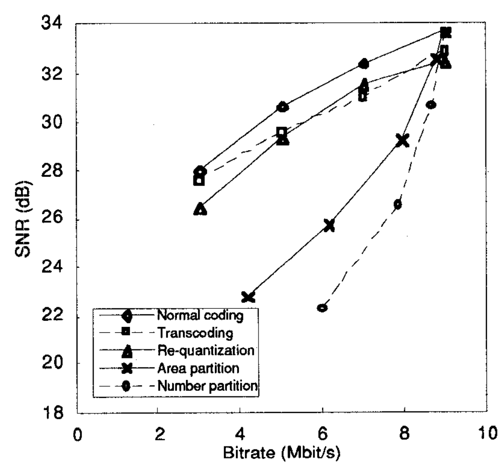

Figure 5 Comparison of SNRs for normal coding and rate conversion using MPEG2