MPEG-2 Transcoding Method for Reducing Re-quantization Noise Based on a Two-tiered Quantizer Matrix

(2 段階型量子化マトリックスを用いた量子化雑音の少ない MPEG-2 トランスコード手法)

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Abstract We developed an MPEG-2 transcoding method on the basis of a two-tiered quantizer matrix that reduces re-quantization noise. The proposed method changes the quantization matrix to decrease the re-quantization noise, instead of changing the value of the quantization parameters as conventional methods do. Using this two-tiered matrix makes it possible to reduce re-quantization noise in the high-frequency domain. The main feature of the proposed method is that it does not cause any differences in image quality between adjacent macroblocks, which the conventional method does. Experimental results show that our proposed method produces transcoding scores of structural similarity (SSIM) and video quality model (VQM) that are 0.044 and 0.0938, respectively, better than those of the best conventional method. The proposed method always produced superior SSIM and VQM scores when the bit reduction ratio was smaller than 0.1015 for all the tested sequences.

Key words: re-encoding, transcoding, MPEG-2, quantization noise

1. Introduction

Recently, many kinds of video services have begun to provide compressed video content to consumers. High-quality and real-time transcoding technologies are needed for such visual applications, and many approaches to high performance transcoding have been studied^{1)~4)}. The most important factor in transcoding is to reduce re-quantization noise mixed during the transcoding procedure. It is well known that repeating all decisions made during the first encoding procedure is an effective method for reducing re-quantization noise during the transcoding procedure^{5)~8)}. These decisions include those made on characteristics, such as picture type, macroblock type, motion vector, DCT type, and quantization parameters. Transcoders that use these characteristics are suitable for real-time video transcoding because they do not require the computation time normally needed for such factors as motion search and macroblock mode selection. However, this does not en-

able bit reduction because all decisions made, including those concerning quantization parameters, are repeated during the transcoding procedure.

Fig. 1 PSNR example of encoding and transcoding in MPEG-2.

An example of re-quantization noise in the transcoding procedure is shown in **Fig. 1**, which illustrates the relationship between picture bits and PSNR as it relates to inter-frame MPEG-2 encoding. The solid line indicates the dependence of peak signal-to-noise ratio (PSNR) on the number of picture bits in the first encoding, and Q is the quantization parameter of the first encoding. The short dotted line indicates the PSNR of conventional transcoding, which uses all the informa-

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tion of the first encoding procedure except the quantization parameter. The input image of the transcoder is already compressed by the first encoding, where the first encoder's quantization parameter, Q , is equal to 10. Qt denotes the quantization parameter of conventional transcoding. The PSNR of the first encoding, where $Q = 10$, is almost the same as that of conventional transcoding, where $Qt = 10$. This means that no additional noise is caused by the transcoder when the transcoding parameter value is equal to the first encoding parameter. This also shows that no additional noise is incurred in conventional transcoding when Qt is equal to double Q . If the Q/Qt ratio is between 0.5 and 1.0, there is a clear degradation in the PSNR characteristic. In the following section, we will describe the reason PSNR degradation occurs in conventional transcoders.

2. Re-quantization noise in transcoder

In this section, we briefly review quantization and de-quantization procedures to understand the re-quantization noise generated by transcoders.

The quantization and de-quantization procedures for intra macroblocks in MPEG-2 TM5¹³⁾ are shown in Eq. (1) and (2).

$$k_{i,j} = \text{int} \left(\frac{32x_{i,j} + \text{sign}(x_{i,j}) \cdot Q \cdot (p/q) \cdot WI_{i,j}}{2 \cdot Q \cdot WI_{i,j}} \right) \quad (1)$$

$$\hat{x}_{i,j} = \text{int} \left(\frac{k_{i,j} \cdot Q \cdot WI_{i,j}}{16} \right) \quad (2)$$

$$\text{where } \text{sign}(x_{i,j}) = \begin{cases} 1 & x_{i,j} > 0 \\ 0 & x_{i,j} = 0 \\ -1 & x_{i,j} < 0 \end{cases}$$

$$p = 3, \quad q = 4$$

The quantization and de-quantization procedures for inter macroblocks, are shown in Eq. (3) and (4).

$$k_{i,j} = \text{int} \left(\frac{16x_{i,j}}{Q \cdot WN_{i,j}} \right) \quad (3)$$

$$\hat{x}_{i,j} = \text{int} \left(\frac{((2 \cdot k_{i,j} + \text{sign}(k_{i,j})) \cdot Q \cdot WN_{i,j})}{32} \right) \quad (4)$$

where $x_{i,j}$, $k_{i,j}$, $WI_{i,j}$, $WN_{i,j}$, and Q denote the (i, j) th coefficient of the DCT output, the quantized value of the DCT output, the intra quantization matrix, the inter quantization matrix, and the Qstep value, respectively. The quantization noise, mixed in the CODEC, is the difference between $x_{i,j}$ and $\hat{x}_{i,j}$.

The block diagram of a CODEC chain that consists of

two decoders and two encoders is shown in **Fig. 2**. Encoder #1 compresses the input video signals and generates bitstream #1 for the transcoder. The transcoder, which consists of decoder #1 and encoder #2, decodes

Fig. 2 CODEC chain with transcoder.

Fig. 3 Dataflow of CODEC chain ($Q=Qt=10$).

Fig. 4 Dataflow of CODEC chain ($Q=10, Qt=15$).

Fig. 5 Dataflow of CODEC chain ($Q=10, Qt=20$).

Fig. 6 Dataflow of CODEC ($Q=20$).

bitstream #1 and generates bit stream #2. The data flow of this CODEC chain is illustrated in **Fig. 3**. For simplification, in this figure we assume that (1) the macroblock size is 2×2 , (2) the quantization and the de-quantization are done in accordance with Eq.1 and 2 with $p=0$, (3) the quantization parameter value is equal to its quantization step value, and (4) the value for all quantization matrix coefficients is sixteen. In the transcoder shown in the figure, the motion vector mv , the macroblock decision modes and the quantization parameter Q are first extracted from bitstream #1, and at the same time a decoded macroblock is generated by decoder #1. Bitstream #2 is obtained by re-encoding the decoded macroblock using the old motion vector mv , the macroblock type, and the quantization parameter from bitstream #1. The quantization noise $Noise_t$, which is mixed in the second re-quantization procedure, is expressed by the difference between the DCT coefficient of the first and second decoding procedures. In this example, there is no difference between the DCT coefficients because the old motion vector mv , the macroblock type, and the quantization parameter Q are re-used in the second encoding procedure. This re-use makes all the procedures from the IDCT procedure in decoder #1 to the IQ procedure in decoder #2 reversible. The output bitstream #2 is almost the same as the input bitstream #1. This means there is no image quality degradation or bit reduction in the transcoder when the old motion vector, the macroblock type, and the quantization parameter are re-used. An example of a case where the encoder quantization parameters are different is shown in **Fig. 4**. In this example, the quantization parameter of the second encoder, Qt , is equal to 15. This value is larger than the first encoder's quantization parameter, where $Q=10$. The size of bitstream #2 is smaller than that of bitstream #1. However, there is a clear difference between the DCT coefficients of the first and second decoders because the non-reuse of Q makes all the procedures mentioned above un-reversible.

We will show that the noise level of the transcoding using $Qt = 2 * Q$ is almost equals to the noise level of the encoding using $2 * Q$ in **Fig. 5** and **Fig. 6**. Fig. 5 is a transcoding example of $Q=10$ and $Qt=20$. Fig. 6 is a encoding example of $Q=20$. The transcoder adds the quantization noise in two times. The first noise is the DCT coefficient difference between (47,31,25,18) and (40,30,20,10), and the second noise is the difference between (40,30,20,10) and (40,20,20,0). The total noise of the transcoder is the difference between (47,31,25,18) and (40,20,20,0). The encoding adds the quantization noise in once. It is the difference between (47,31,25,18) and (40,20,20,0). This indicates the noise level of the transcoding with $Qt = 2 * Q$ is almost equals to those of the encoding with $2 * Q$.

3. Previous work and problem

A transcoding method called the RQMZT that avoids the image quality degradation described in the previous section has been reported⁷⁾. The basic idea of this method is to avoid the use of Qt , which degrades PSNR.

In RQMZT, some macroblocks are quantized by $Qt = Q$, and the rest are quantized by $Qt = 2 * Q$ instead of $Qt = 1.5 * Q$, which would decrease PSNR for all macroblocks in the frame. When the percentage of the use of $Qt = 2 * Q$ increases, the number of transcoding bits decreases. While the RQMZT method is superior to conventional methods in terms of PSNR, it has a serious problem. That is, in this method, bit reduction is achieved only by the macroblocks that are re-quantized by $Qt = 2 * Q$. Those that are re-quantized by $Qt = Q$ produce no bit reduction. This bit reduction mechanism causes a difference in image quality between adjacent macroblocks that are quantized by $Qt = Q$ and those quantized by $Qt = 2 * Q$. This problem does not degrade PSNR, but many people feel strange when they view such compressed images. We will show an example of this problem in Section 4.

4. Proposed method

To overcome the problem described in the previous section, we propose a transcoding method that reduces image quality degradation and minimizes image quality differences among macroblocks. We call it transcoding method based on a two-tiered quantization matrix (TTQM). Instead of changing the quantization parameter, as in conventional methods, the proposed method changes some elements of the quantization matrix. Quantization matrices $WI'_{i,j}$ for intra-coding and

$WN'_{i,j}$ for non-intra-coding, shown in Eqs. (5) and (6), respectively, are used in this method.

$$WI'_{i,j} = \begin{cases} WI_{i,j} & \text{if } (i+j) < TH_{intra} \\ 2WI_{i,j} + 1 & \text{otherwise} \end{cases} \quad (5)$$

$$WN'_{i,j} = \begin{cases} WN_{i,j} & \text{if } (i+j) < TH_{inter} \\ 2WN_{i,j} & \text{otherwise} \end{cases} \quad (6)$$

where WI is the quantization matrix that was used for intra-coding during the first encoding and WN is the quantization matrix that was used for inter-coding during the first encoding. There is a dead zone in MPEG-2 intra-quantization, so $WI'_{i,j}$ must be $2WI_{i,j} + 1$. The matrix elements that represent the high frequency part are doubled, while those for the lower frequency part are not altered. The TH_{inter} and TH_{intra} factors are thresholds located between the doubled elements and non-changed elements. They depend on the ratio of the transcoding bit rate to the first encoding bit rate. When a transcoding bit rate is almost the same as the first encoding bit rate, TH_{inter} and TH_{intra} are set to 14 or 15. When the transcoding bit rate is slightly higher than half of the first encoding bit rate, they are set to 0 or 1. Doubling the value of the quantization matrix elements has almost the same effect as doubling the value of the quantization parameter. The only difference is that doubling the quantization parameter affects every frequency part of the image, but doubling the higher quantization elements only affects the higher frequency part. We mentioned in previous section that RQMZT can reduce re-quantization noise because the Qt equals Q or $2*Q$. Our method can also reduce re-quantization noise because $Qt*WN'_{i,j}$ equals $Q*WN_{i,j}$ or $Q*2WN_{i,j}$.

A quantization matrix example of the proposed method is shown in **Fig. 7**. It is for a flat quantization matrix in the first encoding procedure. Our method can also be applied to bitstreams compressed using a slant quantization matrix in the first encoder. It is well known that the enlargement of quantization matrix elements of the high frequency part improves encoding quality in video compression. On this basis, the MPEG-2 default setting of the intra quantization matrix is slanted. Our proposed method also enlarges such elements. However there is a large difference between our method and such a simple slanting matrix method. Our method changes $WN_{i,j}$ to $2WN_{i,j}$ instead of the value between $WN_{i,j}$ and $2WN_{i,j}$, which would decrease the image quality for all macroblocks. However, such values between $WN_{i,j}$ and $2WN_{i,j}$ are used in the slanting

matrix method. The use of the values between $WN_{i,j}$ and $2WN_{i,j}$ would increase the re-quantization noise in the slanting matrix method. The performance difference between the proposed method and the other conventional methods, including the simple slanting matrix method, will be measured in Section 5.

Fig. 8 illustrates the mechanism we used to compare the proposed method and three conventional methods (the slanting Q, the RQMZT, and the slanting matrix) in terms of bit-reduction and Q in macroblocks. Here, we assumed the original input image consisted of four macroblocks, the quantization parameter $Q = 10$ was used in the first encoding, and each macroblock was represented by 20 bits. In the slanting Q method, the slanting matrix method, and the proposed method, the bit count of each macroblock was reduced to 15 bits. This bit reduction was achieved in all macroblocks. However, in the RQMZT method, we obtained bit reduction in two macroblocks, #1 and #3, which were re-quantized by $Qt = 20$. No bit reduction was achieved in macroblocks #0 and #2, which were re-quantized by $Qt = 10$. There was no PSNR degradation in macroblocks #0 and #2, but #1 and #3 lost both the high and low frequency information included in the original image.

The image quality differences that cause feelings of strangeness are explained in **Fig. 9** to **Fig. 12**. The simulation conditions and stream information are listed in **Table 1**. Fig. 9 is an enlargement of the original image. **Fig. 10** is an enlarged picture compressed by the first encoder. **Fig. 11** is an enlarged picture transcoded

Q matrix in first encoding

16 16 16 16 16 16 16 16	16 16 16 16 16 ^[32] 32 32	32 32 32 32 32 32 32 32
16 16 16 16 16 16 16 16	16 16 16 16 ^[32] 32 32 32 32	32 32 32 32 32 32 32 32
16 16 16 16 16 16 16 16	16 16 16 ^[32] 32 32 32 32 32	32 32 32 32 32 32 32 32
16 16 16 16 16 16 16 16 ● ●	16 16 ^[32] 32 32 32 32 32 32 ● ●	32 32 32 32 32 32 32 32
16 16 16 16 16 16 16 16	16 ^[32] 32 32 32 32 32 32 32	32 32 32 32 32 32 32 32
16 16 16 16 16 16 16 16	^[32] 32 32 32 32 32 32 32	32 32 32 32 32 32 32 32
16 16 16 16 16 16 16 16	32 32 32 32 32 32 32 32	32 32 32 32 32 32 32 32
16 16 16 16 16 16 16 16	32 32 32 32 32 32 32 32	32 32 32 32 32 32 32 32

TH=15 TH=5 TH=0

Q matrix for proposed TTQM method

Fig. 7 Quantization matrix examples of first encoding and proposed TTQM transcoding for inter macroblocks.

Fig. 8 Comparison of proposed method and three conventional methods in terms of bit-reduction and Q in macroblocks.

by the RQMZT method. Fig. 12 is an enlarged picture transcoded by the proposed method. The size of these figures is 64 x 64 pixels, and sixteen macroblocks are included in each of the figures.

All macroblocks were quantized by $Q = 24$ in the first encoding of the original image. The RQMZT transcoding and the proposed transcoding input the same decoded image compressed by the first encoder. In the

RQMZT method, the quantization matrix was not altered from that of the first encoder. One half of the macroblocks were then quantized by $Qt = 24$, and the others were quantized by $Qt = 48$. In the proposed method, the high frequency elements of the quantization matrix were doubled by using Eq. 5, after which all macroblocks were quantized by $Qt = 24$. When the RQMZT method was used, the left eyes of the two animals in the image were clearer than when the proposed method was used. This was because the quantization parameter of the macroblocks representing the left eyes was the same as that of the first encoding. In contrast, the right eyes were blurrier than those obtained with the proposed method. There was a large quality difference between the macroblocks representing the left eyes and those representing the right eyes. This was because the quantization parameter of the macroblocks representing the right eyes was double that of the first encoding. This difference between the image quality of adjacent macroblocks degrades subjective image quality. Unfor-

Table 1 Stream comparison of 1st encoding, transcoding by RQMZT, and transcoding by proposed method.

	First encoding	Transcoding by RQMZT	Transcoding by TTQM
Input image	Mobile and calendar	Decoded image of first encoding stream	←
Image size	720 x 480	←	←
Picture type	I	←	←
Quantization parameter	$Q=24$	$Qt=24$ or 48	$Qt=24$
Modification of Q matrix	No	No	Yes ($TH=10$)
Output stream size (bytes)	57801	44971	44269
PSNR (dB)	28.257	25.175	24.522
SSIM	0.897535	0.837288	0.839271
VQM	2.5588	3.4710	3.4125
Enlargement of decoded image	Fig.10	Fig.11	Fig.12

Fig. 9 Original image.

Fig. 10 First encoded image.

Fig. 11 Transcoded image by RQMZT method.

Fig. 12 Transcoded image by proposed method.

tunately, measuring this kind of degradation by using PSNR is difficult. The PSNR value is sometimes inconsistent with human visual perception because the noise is simply defined by the total mean squared error between the intensity of the input and the output pixels

in the PSNR calculation.

The Video Quality Expert Group (VCEG), and ITU-T have developed recommendations for objectively measuring video quality⁹⁾. We used the structural similarity (SSIM)¹¹⁾¹²⁾ and the video quality model (VQM)¹⁰⁾ are

used for the video quality measurements. The SSIM compares local patterns of pixel intensities that have been normalized for luminance and contrast. The SSIM index has been shown to fit the mean opinion score (MOS) better than PSNR does in experimental measurements of 334 compressed scenes¹¹⁾. SSIM is widely used as a quality evaluation standard for many compression methods. VQM is also closely correlated with the characteristics of the human visual systems and was standardized by ANSI in 2003. Please note that the VQM is different from PSNR and SSIM; increasing of the VQM value indicates that the video quality is worsening. The PSNR of our proposed method, shown in Table 1, was lower than that of RQMZT. However, the SSIM and VQM of our proposed method was better than that of RQMZT in that even the stream size of the proposed method was smaller than that of RQMZT.

5. Experimental results

In this section, we compare the performance of our proposed method with those of the conventional methods. To simulate our proposed method, we modified an MPEG-2 TM5 encoder to enable it to input all decisions made during the first encoding procedure. We prepared three conventional methods. The first one was RQMZT, which is described in Section 3. The second was a simple slanting matrix method, mentioned in Section 4. This method is similar to the proposed method in modifying the Q matrix, but it uses the Q matrix $W'_{i,j}$, which is calculated by Eq. 7 instead of Eq 5, to enlarge the high frequency elements of the Q matrix. This means that the Q matrix $W'_{i,j}$ increases in proportion to a rise in $i + j$.

$$W'_{i,j} = \min(W_{i,j} + (i + j) \cdot TH_{slop}, 255); \quad (7)$$

$W'_{i,j}$ equals $W_{i,j}$ when $TH_{slop} = 0$. When TH_{slop} increases, the slanting angle of the $W'_{i,j}$'s elements increases. Equation 7 is commonly used for both intra- and inter-quantization matrices. Quantization matrix examples of this simple slanting matrix method are shown in Fig. 13. The third method is a slanting Q method that enlarges the quantization parameter Q to decrease the generation of bits without modifying the Q matrix.

In our simulation, the first encoder used a fixed Q value for each frame in a video sequence. The parameters for the first encoding and transcoding simulation are listed in Table 2 and Table 3. We used three video sequences¹⁴⁾ 720 x 480 pixels in size for our comparison.

The input images of the proposed transcoder and these three conventional transcoders were obtained by MPEG-2 compression with a quantization parameter of $Q = 16, 24$, or 36 using an MPEG-2 default quantization matrix. The proposed transcoder and the slanting matrix encoder used the quantization parameter Qt , where $Qt = Q$. The former used a two-tiered quantization matrix that enabled the TH to change from 0 to 15, and the latter used a simple slanting matrix that enabled the TH to change from 0 to 10. The RQMZT transcoder and the slanting Q transcoder used the same Q matrix as that used in the first encoding. To decrease the generation of bits, these four transcoders took different approaches. The proposed transcoder chose a small TH of the matrix modification, and the slanting matrix encoder chose a one. The RQMZT transcoder increased

Table 2 First encoding condition.

Sequence	Boat, Mobile and calendar, Plane
Q	16 or 24 or 32 (fixed in a picture)
Q_scale_type	0 (linear)
Quantization matrix	MPEG-2 default setting (slanting matrix)
GOP	IPPP(N=15)
No. of frames	30

Table 3 Transcoding condition.

Transcoding method		Proposed TTQM	Conventional method		
			RQMZT	Slanting matrix	Slanting Q
Qt	Q=16	16	16 or 32	16	16,18,..,32
	Q=24	24	24 or 48	24	24,26,..,48
	Q=32	32	32 or 60	32	32,34,..,60
Quantization matrix		Modified by Eq.5 or Eq.6	Default setting	Modified by Eq.7	Default setting
TH		0 to 15	-	0 to 10	-
Re-use		Q,mv	mv	Q,mv	mv

16 16 16 16 16 16 16 16
16 16 16 16 16 16 16 16
16 16 16 16 16 16 16 16
16 16 16 16 16 16 16 16
16 16 16 16 16 16 16 16
16 16 16 16 16 16 16 16
16 16 16 16 16 16 16 16
16 16 16 16 16 16 16 16

Q matrix in first encoding

16 16 16 16 16 16 16 16	16 17 18 19 20 21 22 23	16 18 20 22 24 26 28 30
16 16 16 16 16 16 16 16	17 18 19 20 21 22 23 24	18 20 22 24 26 28 30 32
16 16 16 16 16 16 16 16	18 19 20 21 22 23 24 25	20 22 24 26 28 30 32 34
16 16 16 16 16 16 16 16	19 20 21 22 23 24 25 26	22 24 26 28 30 32 34 36 ●●
16 16 16 16 16 16 16 16	20 21 22 23 24 25 26 27	24 26 28 30 32 34 36 38
16 16 16 16 16 16 16 16	21 22 23 24 25 26 27 28	26 28 30 32 34 36 38 40
16 16 16 16 16 16 16 16	22 23 24 25 26 27 28 29	28 30 32 34 36 38 40 42
16 16 16 16 16 16 16 16	22 23 24 25 26 27 28 29	30 32 34 36 38 40 42 44

TH=0 TH=1 TH=2
Q matrix for slanting matrix method

Fig. 13 Quantization matrix examples of first encoding and slanting matrix transcoding.

Fig. 14 Relationship between (PSNR, SSIM, VQM) and bitrate for “Boat” compressed by first encoder using $Q=16$.

Fig. 15 Relationship between (PSNR, SSIM, VQM) and bitrate for “Mobile and calendar” compressed by first encoder using $Q=24$.

Fig. 16 Relationship between (PSNR, SSIM, VQM) and bitrate for “Plane” compressed by first encoder using $Q=32$.

the frequency of using $Qt = 2Q$, and decreased the frequency of using $Qt = Q$ to decrease the generation of bits. The slanting Q transcoder selected a large Qt , where $Qt > Q$.

The relationship between the three evaluation scores (PSNR, SSIM, and VQM) and the bitrate for the three tested sequences are shown in **Fig. 14** to **Fig. 16**. The input sequence was compressed by the first encoder, where $Q=16$. Concerning the PSNR results, the proposed method and the RQMZT were superior to other methods when the transcoding bit rate was slightly lower than the first encoding bit rate. When the transcoding bit rate was slightly higher than half of the first encoding bit rate, the slanting- Q method was superior to other methods. In terms of SSIM and VQM re-

sults, the proposed method was superior to other methods, especially when the amount of bit reduction was small. As the transcoding bit rate became smaller, the advantage of the proposed method decreased with regard to SSIM and VQM.

We compared our proposed transcoding method with conventional methods using three evaluation scores when the bit reduction ratio was 0.2. The simulation results are listed in **Table 4**. The score improvements obtained with the proposed method vis-a-vis that of the best results obtained by the conventional methods are shown in the right-hand “improvement in proposed method” column. Since we reversed the sign of the VQM improvement score in this column, positive values mean that the proposed method is superior to the

Table 4 Video quality scores of proposed method and three conventional methods when bit reduction ratio = 0.2

Input (First encoding result)				Proposed method	Conventional methods			Improvement in proposed method
Scene	Q	Bitrate [kbps]	PSNR SSIM VQM	PSNR SSIM VQM	RQMZT PSNR SSIM VQM	Slanting Matrix PSNR SSIM VQM	Slanting Q PSNR SSIM VQM	PSNR SSIM VQM
Boat	16	2536	35.6288	33.7494	33.6698	33.6477	33.6097	0.0796
			0.9057	0.8856	0.8742	0.8808	0.8754	0.0048
			1.3468	1.5139	1.6574	1.5773	1.6724	0.0634
	24	1691	33.7743	32.0325	31.7889	31.8491	31.7046	0.1833
			0.8747	0.8503	0.8338	0.8455	0.8376	0.0047
			1.5945	1.7863	1.9812	1.8570	1.9950	0.0707
Mobile and calendar	32	1335	32.5717	30.7050	30.4234	30.6537	30.5002	0.0513
			0.8511	0.8155	0.7990	0.8172	0.8092	-0.0018
			1.5945	2.0300	2.2234	2.0633	2.2281	0.0333
	16	7796	30.0456	27.2195	27.5851	27.5472	27.6184	-0.3989
			0.9204	0.8919	0.8866	0.8870	0.8832	0.0049
			2.2916	2.7907	2.9894	2.9195	3.0462	0.1288
Plane	24	4953	27.4701	25.3610	25.4351	25.4537	25.3596	-0.0927
			0.8839	0.8549	0.8424	0.8473	0.8393	0.0077
			3.0264	3.4650	3.8189	3.6675	3.8972	0.2025
	32	3554	25.8666	24.1975	24.0667	24.1439	23.9872	0.0537
			0.8522	0.8238	0.8033	0.8150	0.8042	0.0088
			3.0264	3.9939	4.4429	4.2305	4.5312	0.2367
Average	16	2159	36.3857	34.1192	34.1292	34.2277	34.2466	-0.1274
			0.9323	0.9186	0.9116	0.9154	0.9084	0.0033
			1.1249	1.3147	1.4591	1.3475	1.4322	0.0328
	24	1503	34.4949	32.2901	32.0606	32.3392	32.2763	-0.0491
			0.9165	0.9025	0.8905	0.8985	0.8900	0.0039
			1.3454	1.5678	1.7777	1.6112	1.7283	0.0434
Average	32	1216	33.2281	30.9312	30.6390	30.9653	30.9042	-0.0341
			0.9051	0.8878	0.8729	0.8843	0.8754	0.0036
			1.3454	1.7869	2.0071	1.8201	1.9650	0.0333
	Average	2971	32.1667	30.0672	29.9775	30.0919	30.0229	-0.0371
			0.8935	0.8701	0.8571	0.8656	0.8580	0.0044
			1.8551	2.2499	2.4841	2.3437	2.4995	0.0938

other methods in every evaluation. The average SSIM and VQM scores of the proposed method were found to be about 0.0044 and 0.0938 better, respectively, than those of the best scoring conventional method for the tested video sequences.

We calculated the upper limit by which the proposed method was superior to the best scoring conventional method in terms of SSIM and VQM for several input bitstreams. The results are shown in **Table 5**. The "Bit reduction ratio" column means the ratio of the bitstream reduction size to the input bitstream size in this table. They indicate that the proposed method was superior to the best scoring conventional method when the bit reduction ratio was smaller than 0.2531 at the lower limit average of the SSIM score. In the VQM score, the proposed method was superior when the bit reduction ratio was smaller than 0.3211. This also indicates that the proposed method was always superior in terms of both SSIM and VQM scores when the bit reduction ratio was smaller than 0.1015 for all the tested sequences.

6. Conclusion

An MPEG-2 transcoding method using a two-tiered quantization matrix that reduces re-quantization noise is proposed. Instead of changing the value of the quan-

Table 5 Upper limit of bit reduction ratio at which proposed TTQM method was superior to best of other methods.

Scene	Q	Input stream bitrate (kbps)	Upper limit of TTQM dominated			
			SSIM		VQM	
			Bitrate (kbps)	Bit reduction ratio	Bitrate (kbps)	Bit reduction ratio
Boat	8	5160	3550	0.3120	3220	0.3760
	16	2536	1786	0.2957	1634	0.3557
	24	1691	1281	0.2425	1167	0.3099
	32	1335	1084	0.1880	1009	0.2442
Mobile and calendar	8	15578	11719	0.2477	12258	0.2131
	16	7796	5398	0.3076	5102	0.3456
	24	4953	3284	0.3370	3072	0.3798
	32	3554	2444	0.3123	2188	0.3844
Plane	8	4256	3824	0.1015	2732	0.3581
	16	2159	1412	0.3460	1505	0.3029
	24	1503	1081	0.2808	1095	0.2715
	32	1216	925	0.2393	951	0.2179
Cheer leader	8	12814	10320	0.1946	9536	0.2558
	16	6568	5041	0.2325	4624	0.2960
	24	4274	3314	0.2246	3036	0.2897
	32	3240	2544	0.2148	2328	0.2815
Race	8	5908	3526	0.4032	3226	0.4540
	16	2319	1617	0.3027	1356	0.4153
	24	1364	1113	0.1840	924	0.3226
	32	1018	876	0.1395	718	0.2947
Show	8	9374	8099	0.1360	6064	0.3531
	16	4733	3342	0.2939	3072	0.3509
	24	3107	2214	0.2874	2066	0.3350
	32	2366	1770	0.2519	1654	0.3009
Average		4534	3398	0.2531	3105	0.3211

tization parameters as conventional methods do, our transcoding method modifies the higher frequency elements of the quantization matrix to avoid losing image information for the lower frequency parts in the input image. Experimental results show that our proposed method produces transcoding SSIM and VQM scores

that are about 0.0044 and 0.0938 better, respectively, than those of the best conventional method without causing any difference in image quality between adjacent macroblocks. When the bit reduction ratio was smaller than 0.1015, the proposed method was always superior to the best conventional method.

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