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# A NEW ALGORITHM FOR REDUCING THE REQUANTIZATION LOSS IN VIDEO TRANSCODING

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## ABSTRACT

Video transcoders are devices that convert one video bitstream into another type of bitstream, either with or without standard format conversion. One step to be applied in video transcoders is the requantization of the transform coefficients, if an adaptation to a lower data rate is necessary. During this step, the quality is in most cases degraded compared to a single quantization. This is a consequence of non-overlapping quantization characteristics of the input and the output quantizer. In this work we propose a new choice of the reconstruction level for the requantization step depending on the effective quantization curve of both quantization parameters involved. The reconstruction level is calculated such that it is centered in each effective quantization interval after requantization.

Compared to the standard midpoint requantization this leads to quality gains of 3 dB PSNR for most pairs of input and output quantization parameters (QP). The algorithm is useful for intra- and inter-frame coding.

## 1. INTRODUCTION

It is often necessary to adapt encoded video bitstreams according to the transmission environment in order to support as many end devices as possible. This can be done by video transcoding technologies, for which a good overview can be found in [1]. A typical approach for bitrate adaptation is homogeneous transcoding in the domain of the Discrete Cosine Transform (DCT). Efficient implementations are investigated very well for the MPEG-2 standard, e.g. [2, 3]. Here, the bitstream is decoded only up to the reconstruction of the transform coefficients. Then requantization is applied on these coefficients. This avoids the time consuming step of conversion to the pixel domain using the inverse DCT. The requantization leads to a smaller number of levels to be encoded and therefore to a lower data rate. For drift-free transcoding of inter frames (P-frames), additionally the difference between the reconstructed input and output coefficients has to be calculated.

Not very obvious is the fact that requantization introduces an additional error compared to the quantization of the undistorted transform coefficients. This error is often called transcoding loss. It is the effect of superimposing two non-linear quantization characteristics. The first quantization leads to additional distortions after the second quantization. An increased quantization error compared to the quantization of undistorted data is the result. A modeled analysis of this requantization problem for laplacian probability distribution can be found in [4, 5].

We have investigated the effective output quantization characteristics after requantization. In our work, for each interval of this effective quantization characteristic a new reconstruction value is calculated such that it is shifted into the real center of the interval. This decreases the requantization loss especially in those cases, where the state-of-the-art approach performs worst. It can be used in the transcoder and the decoder simultaneously or only in the decoder for displaying.

This work is organized as follows. Section 2 describes the requantization process in details. Then our new requantization scheme is outlined in Sec. 3 and simulation results are given in Sec. 4. Section 5 concludes the work and gives an outlook of the next steps.

## 2. REQUANTIZATION LOSSES

A block diagram of a cascasded transcoder is drawn in Fig. 1. The entropy coding of the input bitstream is reversed and the DCT coefficients are reconstructed by mapping the quantization levels $L_A$ to values $\hat{C}_A$. Afterwards the motion compensated difference of output and input coefficients is added for drift-free transcoding of inter-frame macroblocks. For intra-frame coding, this feedback is zero. The resulting cofficient is then requantized to levels $L_B$ by the output quantizer $Q_B$. For actual coding standards such as JPEG or MPEG-2, this step is implemented as a rounded real-valued division according to the quantization parameter $q_B$ [6]:

$$L_B = \operatorname{sgn}(C_B)\left\lfloor \frac{|C_B|}{2\cdot q_B} + 0.5 \right\rfloor \qquad (1)$$

This non-linear process is lossy due to the floor operation.

The midpoint reconstruction for decoding is then defined as:

$$\hat{C}_B = L_B \cdot 2 \cdot q_B \qquad (2)$$

It is the state-of-the-art approach typically implemented as table-lookup, because of the limited range of different QP values. These steps have to be performed both at the transcoder and the decoder for reconstructing the reference frames.

Quantization introduces quality losses on the reconstructed image $\hat{s}(x,y)$, where $x,y$ are the pixel positions within the image. The quality is quantified using the well-known Peak-Signal to Noise Ratio (PSNR) $P(\hat{s})$ given the undistorted image $s(x,y)$ of size $M \times N$:

$$P(\hat{s}) = 10\log_{10}\{M \cdot N \cdot \frac{255^2}{\sum\limits_{x=0}^{M}\sum\limits_{y=0}^{N}(s(x,y)-\hat{s}(x,y))^2}\} \qquad (3)$$

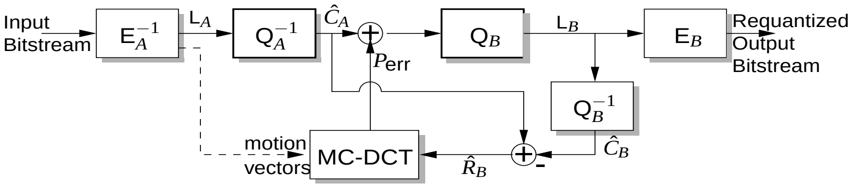


Figure 1: Compressed Domain Homogeneous Video Transcoder using Requantization

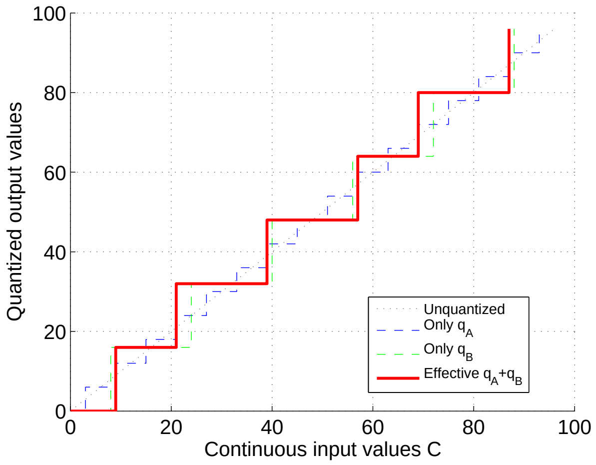


Figure 2: The effective characteristic due to superposition of two quantization processes (QP $q_A = 3$ and QP $q_B = 5$)

Instead of quantizing undistorted input signals, a transcoder has to work on prequantized signals $\hat{C}_A$. This means that the output quantization characteristic using $q_B$ is dependent on the first quantization characteristic using $q_A$ from the input bitstream. The superposition of the two non-linear processes and the resulting effective characteristic is shown in Fig. 2. The red solid line is the effective quantization characteristic and it can easily be noted that it is not evenly distributed. For coefficients where the second quantization characteristic (green, dash-point) intercepts the first one (blue, dashed) a wrong level is calculated. Thus, an additional error is imposed on the signal. This is the requantization loss also called transcoding loss. In these cases, the first quantization changes the effective output value to one level above or below the optimum according to $q_B$. The requantization loss $D$ of an image $\hat{s}_{q_A,q_B}$ using $q_B$ after $q_A$ compared to a singly quantized image $\hat{s}_{q_B}$ in dB PSNR as in Eq. (3) is

$$D = P(\hat{s}_{q_B}) - P(\hat{s}_{q_A,q_B}) \tag{4}$$

For a number of significant combinations of $q_A$ and $q_B$ the quantization loss $D$ is shown dependent on $q_A$ in Fig. 3 for 50 frames of the sequence 'Fastfood'. It can be noted that the maximum of about 3 dB PSNR loss is found for requantizing at $q_B = 2 \cdot q_A$. Requantizing at $q_B = 3 \cdot q_A$ has zero losses, because here both characteristics superimpose without crossing each other.

Figure 4 shows an example of the effect of requantization on the error signal. The dashed green line is the error introduced by quantization of the undistorted frame. It is symmetrically around the error value $E = 0$. For reconstruction values at the midpoint of the interval this results in the

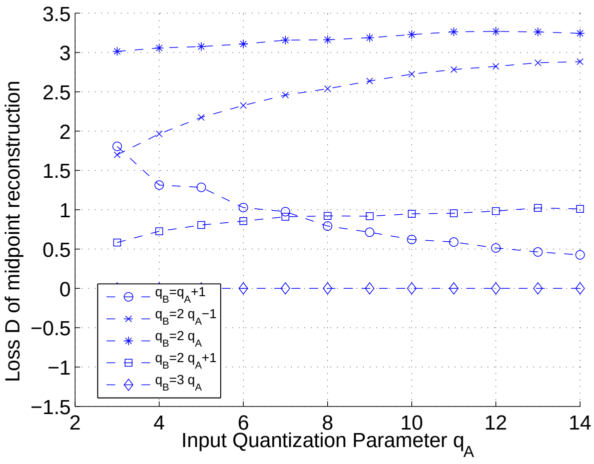


Figure 3: Requantization loss of midpoint reconstruction in dB PSNR for selected combinations of $q_A$ and $q_B$ in dependency of $q_A$ ('Fastfood',QCIF, 50 frames)

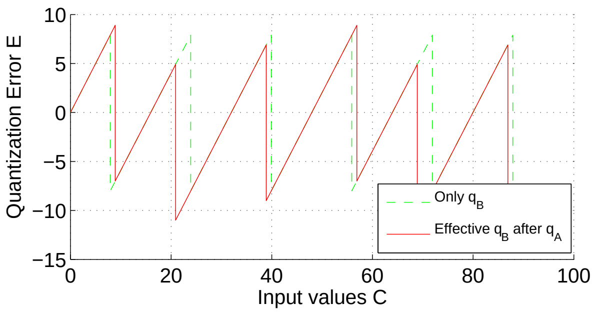


Figure 4: Error signals of requantization (red) vs. quantization of an undistorted signal (green, dashed)

minimum error energy for uniformly distributed input signals. The solid red line in Fig.4 shows the error signal after requantization. It is unsymetrically around $E = 0$ and has different widths of the quantization intervals, e.g. $C = [9;21]$ is smaller than the interval $C = [21;39]$. Because of this, the quantization error is not minimized using the midpoint reconstruction.

## 3. NEW RECONSTRUCTION

As a consequence of the above observations, we developed a new method to improve the transcoding quality. The principle idea behind our approach is to use the information of the QPs $q_A$ and $q_B$ within the transcoder and calculate a new reconstruction level at the center of each effective quantization

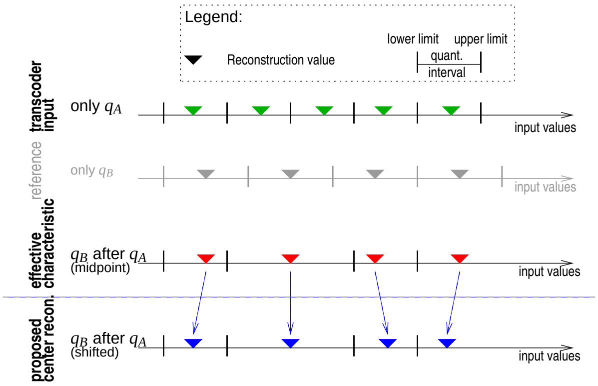


Figure 5: Principle method of the proposed algorithm

interval.

### Shifted Reconstruction

The algorithm can be described as follows:

1. Store $q_A$ of the input bitstream
2. Select $q_B$ used for requantization in block $Q_B$ of Fig. 1
3. Compute the effective quantization characteristic using Eq. (2) successively with first $q_A$ and then $q_B$
4. For each level $L_B$ the new center point $\hat{C}_\mathrm{c}(L_B)$ must be obtained. Given the reconstruction boundaries $C_\mathrm{l}(L_B)$ and $C_\mathrm{h}(L_B)$ of level $L_B$, the real-valued interval center $\hat{C}_\mathrm{c}(L_B)$ can be calculated as
$$\hat{C}_\mathrm{c}(L_B) = C_\mathrm{l} + \frac{C_\mathrm{h}(L_B) - C_\mathrm{l}(L_B)}{2} \tag{5}$$
5. Use the shifted value $\hat{C}_\mathrm{c}$ as new signal value for the reconstruction of the image at the block $Q_B$ in Fig. 1

An example of this algorithm is shown Fig. 5. Vertical bars are the boundaries between the quantization intervals that are mapped into levels. The reconstruction values of each level are drawn as triangles. At the transcoder input, only one quantization has been performed ('only $q_A$') and so the upper reconstruction values are selected. At this point, the values are centered within their intervals. The second line shows quantization of undistorted input using $q_B$. This is the reference for a transcoder, but it is impossible to calculate because of the prequantization. Instead, the third row is found in the transcoder after requantization at $Q_B^{-1}$, showing the effective quantization intervals that have unequal interval widths. In this case, the reconstruction values from midpoint reconstruction are not centered within the intervals. Our proposal is drawn in the lowest row. It shows that the reconstruction values are now shifted into the center of each interval.

Using this algorithm, the quantization error of the effective characteristic is symmetric around the reconstruction value. This leads to a lower error energy. However, a decoder must perform the same steps as the transcoder in order not to introduce mismatching prediction for inter-frames. Therefore additional information about the first QP $q_A$ has to be embedded into the bitstream.

### Decoder only

Another possibility is to use the algorithm only at the decoder as shown in Fig. 6. In order to achieve this, the prequantization value has to be transmitted along the bitstream by the transcoder. Then the decoder can perform all the steps presented above but only for displaying the frames. In parallel the decoder has to perform the midpoint reconstruction for usage as reference for inter-frames in order to avoid encoder-decoder mismatch.

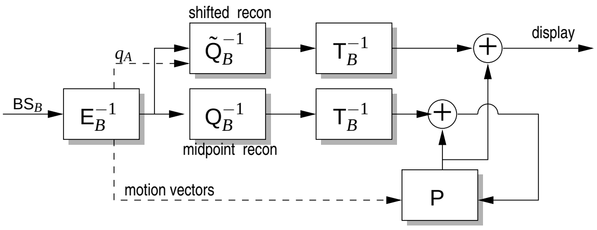


Figure 6: Block diagram of a modified decoder where the proposed shifted reconstruction is used in block $\tilde{Q}_B^{-1}$

### Efficient Implementation

The range of QP is limited in todays coding standards to a few values. This makes the algorithm efficient, if precalculating all values in advance and then storing them in a table. The algorithm itself then only consists of a table lookup for each level and therefore needs the same complexity as the midpoint reconstruction.

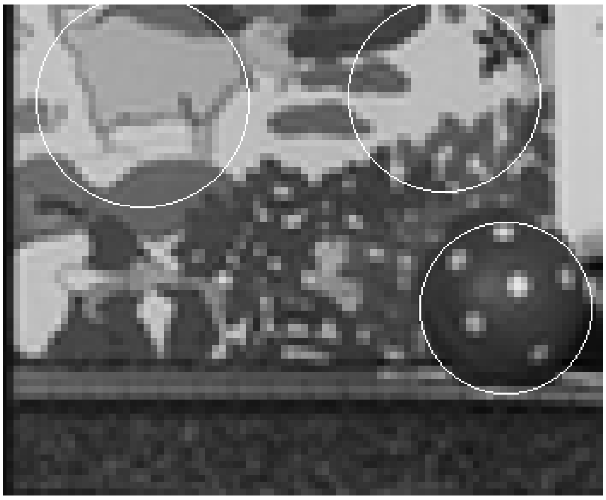
## 4. SIMULATIONS

For evaluation of our algorithm, we conducted a series of experiments on a great number of sequences, both for intra-frame and for inter-frame coding. 50 frames of the sequences from the Video Quality Experts Group (VQEG), e.g. 'Mobile', 'Fastfood', or 'Car Race' in Quarter Common Intermediate Format (QCIF) were used.

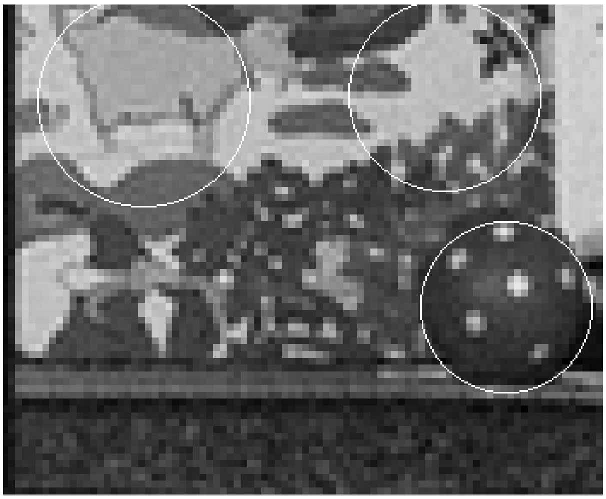
### Intra-Frame Coding

The quantization loss $D$ for intra-only coding is shown in dependency of $q_A$ in Fig. 8. We used the same parameters, especially $q_B$, as for Fig. 3 where the midpoint quantization is used. The shifted reconstruction performs better than the midpoint reconstruction. This is most significant for the case where $q_B = 2 \cdot q_A$. Here, the performance is over 3 dB PSNR higher, than the midpoint requantization (Fig. 3). This can also be seen in the magnified part of output images shown in Fig. 7 using $q_A = 3$ and $q_B = 6$. The undistorted original image is very smooth and noise-free in contrast to the midpoint reconstruction. Using the shifted reconstruction, the noise is less apparent especially in regions close to edges, for example in the encircled areas.

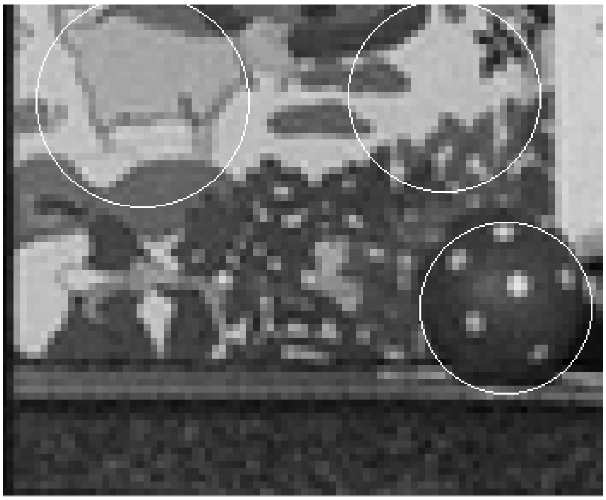
In some cases the loss $D$ in Fig. 8 is negative indicating better performance than the reference. This effect is found in a number of combinations of $q_A$ and $q_B$, e.g. $q_B = 2 \cdot q_A$. More combinations with this behaviour can be found in a diagram showing the quality in dB PSNR for a fixed $q_A = 6$ in dependency of $q_B$ as in Fig. 8. Better performance than the reference can be found for quantization step sizes 14, 16 and 24. The reason is the non-uniform distribution of image signals, typically a laplacian distribution. The amplitude probability of a coefficient is monotonically decreasing with increasing distance to the maximum at a zero amplitude. Our algorithm implicitly shifts the value in direction of zero-amplitude for these combinations and thus to values with a higher probability compared to the reference. This reduces



(a) Original



(b) Midpoint Reconstruction



(c) Shifted Reconstruction

Figure 7: Zoom into output image of ’Mobile’ for $q_A = 3$ and $q_B = 6$

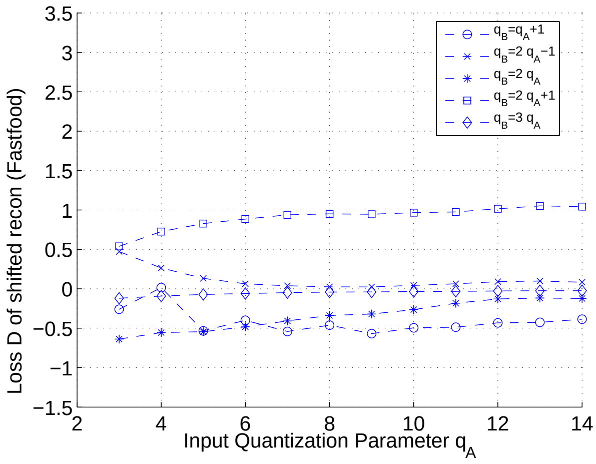


Figure 8: Requantization loss for a choice of $q_B$ as function of $q_A$ compared to quantization on undistorted data using $q_B$ (simulated: QCIF, 50 frames); negative loss means better performance than the reference (see text)

the overall error variance and therefore the error energy and results in a better quality than the reference.

The results are also valid, if the proposed scheme is only applied at the decoder, because no mismatch is introduced due to feedback.

### Inter-Frame Coding

The scheme can be used also for inter-frame encoding even if the feedback due to the motion compensation distorts the new signal. However, the distortion is relatively small compared to the output quantization, and therefore the distortion introduces problems only in some cases. Results for 50 frames of ’Fastfood’ encoded as ’IPPP…’ are shown in Fig. 10. Two different cases are distinguished.

The upper row depicted by ’x’ marks is the quality for the case where transcoder and decoder use the new scheme equivalently. For most of the combinations of $q_A$ and $q_B$ where midpoint reconstruction has the greatest losses, the shifted reconstruction performs significantly better (squares). Only for the quantization step sizes 26 and 34 it has a lower quality. In these cases the intersection of both quantizer intervals next to amplitude zero is very small. Furthermore the distorting effect of the feedback due to motion compensation becomes stronger because of the increased distance between $q_A$ and $q_B$. Both facts together increase the probability that another level $L_B$ is chosen for the coefficient than the original one. But then, the shifted reconstruction value increases the distance of the reconstruction point to the real value.

The second case marked by diamonds is if only the decoder uses the shifted reconstruction for displaying but not for feedback. It can be seen that here the quality gain is not so high, but it performs better than the midpoint scheme for most values of $q_B$. The same problems as above can be found at the step sizes 26 and 34. This is another hint that the shifted point is non-optimal here, due to the feedback of the requantization error.

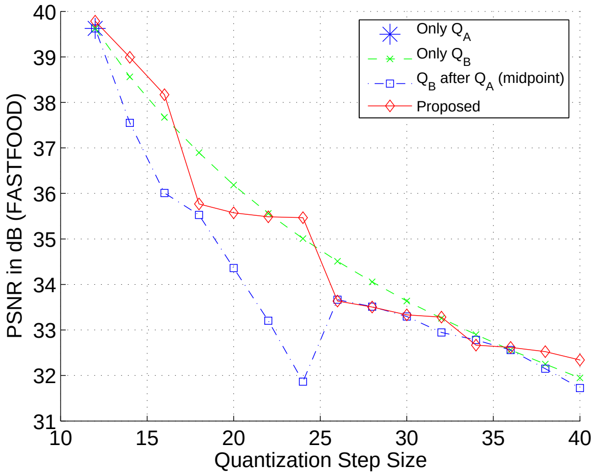


Figure 9: Results for intra-frame transcoding

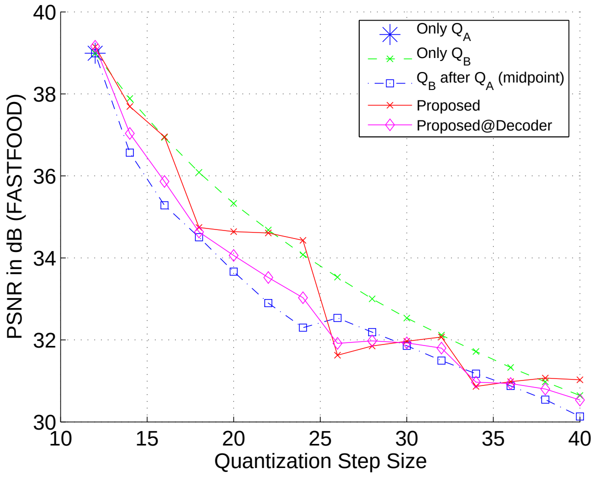


Figure 10: Results for inter-frame transcoding; also the decoder-only case is shown

## 5. CONCLUSION

Based on the works of [4] and [5] we explained, why requantization using the state-of-the-art midpoint reconstruction defined in Eq. (2) leads to requantization losses. We propose to use a shifted reconstruction value at the center of each effective quantization interval for a video transcoder and the successive decoder. This implies no more computational complexity than the standard algorithm because only a lookup into a different precalculated table is required. The approach is not standard compatible. The decoded image quality is increased for intra-coding by up to 3 dB PSNR. For inter-frames, our approach performs also well, but the gain is smaller. Only for a few known combinations of $q_A$ and $q_B$ its performance is worse.

Alternatively, our algorithm can be used only at a decoder for displaying without increasing the complexity. The performance of this approach results in smaller quality gains, but again it is better than the standard scheme. The transcoder has then only to transmit the prequantization $q_A$.

Further improvements may be done, if choosing the reconstruction according to the probability density function of the signal.

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