Signal Processing: *Image Communication* 26 (2011) 117–129

Contents lists available at ScienceDirect

Signal Processing: *Image Communication*

journal homepage: www.elsevier.com/locate/image

Quantizer offset selection for improved requantization transcoding

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ARTICLE INFO

Article history:
Received 21 April 2009
Accepted 24 February 2011
Available online 4 March 2011

Keywords:
Video processing
Transcoding
Requantization
Quantizer offset
H.264/AVC

ABSTRACT

In this paper, we provide an analysis of the requantization problem in order to improve the requantization process. This analysis is based on theoretical R–D results of requantized Laplacian sources instead of minimizing requantization errors as commonly found in the literature. We derive the effective quantizer characteristic by applying superposition to the quantizer characteristics of encoder and transcoder. Further investigation shows that the effective quantizer has a periodic property. Using the memoryless property of the probability distribution function and the periodic property of the effective quantizer characteristic, we derive expressions for entropy and distortion. Based on the theoretical R–D model, requantization for fine and coarse quantized signals is investigated. The analysis of the R–D behavior shows that a heuristic can be derived which improves the requantization process. Finally, the results from the R–D analysis are verified for requantization transcoding of H.264/AVC video streams. We show that the transcoding process for H.264/AVC video streams, which corresponds to coarse quantization, is improved with gains up to 1 dB.

1. Introduction

The quantizer is an important coding tool when optimizing coding performance of image and video compression schemes. The design of a quantizer typically consists of a classification and a reconstruction [1,2]. The classification in the encoder maps a transform coefficient to a quantization index while the reconstruction in the decoder generates a reconstruction level based on the quantization index. The classification is typically controlled by a quantizer step size Q and a quantizer offset ε. Because encoder issues are non-normative, the classification can be tailored for better R–D performance.

Transcoding is an efficient way for reducing the bit rate of compressed video streams [3–5]. A bit rate reduction is often required by constraints imposed by networks and/or devices. Two classes of techniques are available for reducing the bit rate: requantization transcoding [6,7] and dynamic rate shaping (DRS) [8,9]. These techniques only have access to the compressed video stream which already contains quantization noise as a result of the quantization process in the encoder.

The quantization process in the encoder changes the probability distribution of the transform coefficients with the result that the quantizer in the transcoder should be changed accordingly. So, the outcome of the requantization operation is the result of first-step quantization in the encoder followed by second-step quantization in the transcoder. The requantization problem can be represented by the effective quantizer characteristic which is constructed by applying superposition to the quantizer characteristics of both quantizers [10]. Often, the quantizer offset is fixed for encoding and transcoding and therefore does not result in good R–D performance as shown later in this paper.

A theoretical analysis of the requantization problem is presented in [11] for MPEG-2 intra-coded pictures. The author derived efficient techniques for requantization transcoding based on this analysis. Two requantization methods are compared: minimum distortion and maximum a

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doi:10.1016/j.image.2011.02.003

posteriori. The results show that the latter method outperforms the first method.

The authors of [12] present a novel heuristic for requantization of JPEG compressed images. The heuristic is based on an error analysis of the requantization problem for sources with a Laplacian distribution. The requantized images are typically smaller and result in improved visual quality.

An adapted reconstruction based on the quantization in encoder and transcoder is presented in [10]. After requantization, the reconstruction level is centered in each effective quantizer bin. This method results in a substantial gain in visual quality for most pairs of quantizers; the presented technique, however, is not compliant with the specification since both quantizer step sizes need to be signaled in the transcoded video stream.

The author of [13,14] investigates the requantization problem and derives conditions for *perfect requantization*. This is achieved when the outcome of requantization is equivalent to the outcome of direct quantization. This implies conditions on the quantizer design of the encoder and the transcoder. However, these conditions usually result in coarse quantization which leads to constraints that are too restrictive for practical bit rate transcoding.

The authors of [15] investigate the rounding problem for requantization transcoding. They provide a theoretical analysis of the requantization problem by calculating entropy and distortion for different rounding methods. They derive a heuristic for the quantizer design based on the observations from the analysis. The main difference with our approach is that their approach is based on a fixed quantizer offset.

This paper begins with an investigation of requantization in Section 2. We compare direct quantization and requantization and define different types of requantization errors. We also elaborate on the conditions for perfect requantization. In Section 3, the analysis of the effective quantizer, which results from the superposition of the quantizers in encoder and transcoder, shows that the effective quantizer has a *periodic property*. Furthermore, it is well-known that Laplacian sources satisfy the *memoryless property* for exponentially decreasing functions. Using these properties, we derive expressions for entropy and distortion. These can be used for further investigation of the behavior of the requantization process. We examine the requantization problem for both fine and coarse first-step quantization and derive a heuristic for improving the requantization process. By applying the proposed requantization theory to H.264/AVC in Section 4, we show that H.264/AVC requantization can be improved by adapting both quantizer step size and quantizer offset in the transcoder. We observe gains of about 1 dB compared to requantization transcoding with a fixed quantizer offset. Finally, the paper is concluded in Section 5.

2. Requantization

In this section, we start with a comparison of direct quantization and requantization. We define different requantization errors and show for which cases the

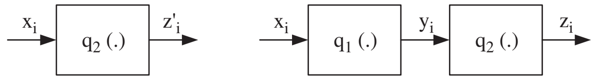

Fig. 1. Direct quantization (Q_2,ε'_2) vs. requantization (Q_1,ε_1 and Q_2,ε_2).

outcome of direct quantization is equal to the outcome of requantization. Afterwards, we elaborate on perfect requantization where no requantization errors occur. Finally, we point out the typical problems of perfect requantization in hybrid compression systems.

2.1. Problem formulation

The requantization problem investigates the difference between direct quantization and requantization. The reference in the comparison is direct quantization. Both scenarios are presented in Fig. 1.

Direct quantization applies a coarse quantization to the original transform coefficients. The quantizer characteristic is determined by the quantizer step size Q_2 and the quantizer offset ε'_2. Let x_i be the transform coefficient and let $q_2(.)$ be the reference quantizer. Then the outcome of the reference quantizer is denoted as z'_i:

$$z'_i = q_2(x_i) = sgn(x_i)\cdot\left\lfloor\frac{|x_i|}{Q_2}+\varepsilon'_2\right\rfloor\cdot Q_2, \tag{1}$$

where $sgn(a)$ is the sign of a, $|a|$ is the absolute value of a and $\lfloor a \rfloor$ is the largest integer not larger than a.

Requantization applies a first-step quantization in the encoder followed by a second-step quantization in the transcoder [11]. The quantizers are characterized by the quantizer step sizes Q_1 and Q_2 and the quantizer offsets ε_1 and ε_2. Let x_i be the transform coefficient, and let $q_1(.)$ and $q_2(.)$ be the first-step and second-step quantizers. Then the outcome of both quantizer processes are denoted as y_i and z_i:

$$y_i = q_1(x_i) = sgn(x_i)\cdot\left\lfloor\frac{|x_i|}{Q_1}+\varepsilon_1\right\rfloor\cdot Q_1 \tag{2}$$

and

$$z_i = q_2(y_i) = sgn(y_i)\cdot\left\lfloor\frac{|y_i|}{Q_2}+\varepsilon_2\right\rfloor\cdot Q_2. \tag{3}$$

Ideally, the outcome of requantization should be identical to the outcome of direct quantization: $z_i = z'_i$. However, this is often not the case. This results from the requantization errors which are introduced by the requantization process. The requantization process has only access to the already quantized coefficients instead of the original transform coefficients.

2.2. Requantization errors

The quantizers can be characterized by the quantizer step sizes Q_1 and Q_2 and quantizer offsets ε_1 and ε_2. Alternatively, the quantizers can be described by the set of decision levels $\{d\}$ and the set of reconstruction levels $\{r\}$. The quantizer in the encoder is described by $\{d_{1,i}\}$ and $\{r_{1,i}\}$ where $i \in \mathbb{Z}$, while the quantizer in the transcoder is described by $\{d_{2,j}\}$ and $\{r_{2,j}\}$ where $j \in \mathbb{Z}$. In the figures, the