Requantization Codebook Design Using Particle-pair Optimizer

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Abstract—A new algorithm of optimal requantization codebook design using particle-pair optimizer (PPO) is proposed to provide an effective way for image transmission over multi-speed communication system with minimal transmission delay. PPO is used for optimal codebook design in the first and second quantization respectively. In the second quantization, global distortion is used as the fitness value instead of second quantization distortion. Simulation results demonstrated that the proposed algorithm is able to achieve higher FSNR value with less transmission delay in comparison with conventional codebook optimization strategies.

I. INTRODUCTION

REQUANTIZATION is an important technique for multimedia compression and transmission over multi-speed communication system. The bandwidth of such a system varies from time to time due to the changing connection speed and network traffic. Internet provides an example of multi-speed system. When transmitting from a high bit rate sub-channel to a low bit rate one in a multi-speed communication system, a pre-coded media need to be re-compressed so that the data bit rate could be reduced to meet the need. Requantization is an effective re-compression strategy in minimizing the compression distortion. Requantization will lead to transmission delay. The requirement of less delay time will result in larger distortion of requantized image, and vice versa. A requantization algorithm with high requantization speed can reduce the delay. During requantization, the requantizer decodes the multimedia bit-stream and requantizes it for a higher compression rate, with the distortion in an acceptable range.

Requantization is employed in a large number of multimedia compression applications. Bauschke et al. [1] presented a novel heuristic for requantizing JPEG images with the Laplacian distribution of the AC discrete cosine transform (DCT). Nakajima et al. [2] proposed a rate conversion method by requantizing MPEG bit-stream without decoding. The requantization step required for requantization is determined by the local and global quantization steps, which are closely related to the activities in the pixel domain. Oliver Werner [3] provided an investigation on requantization for transcoding of video signals, especially for MPEG-2 compatible DCT intraframe coding. S. M. Borodkin et al. [4] introduced an optimal way of mapping digital fine greyscale images to a coarser scale using requantization. In [5], J. K. Han et al. proposed a scheme for requantization codebook construction optimization (RCO), which is an iterative manner for a given original quantization codebook of transmitter. Zhou et al. [6] improved this scheme and develops further results regarding the acceleration of the algorithm. This improved scheme is called accelerated requantization codebook optimization (ARCO).

In this paper, particle-pair optimizer (PPO) [7] is introduced in requantization codebook design for grayscale image’s re-compression. PPO is a new algorithm proposed for vector quantization in image coding based on conventional Particle Swarm Optimization (PSO) [8]. Experimental results have demonstrated that PPO performed better with shorter computation time and smaller compression distortion in comparison with other conventional vector quantization algorithms. PPO is applied in requantization codebook design for the aim of improving re-compression performance. Simulation results show that this algorithm of requantization codebook optimization using PPO (PPORCO) can produce higher peak signal-to-noise ratio (PSNR) value than RCO and ARCO with less transmission delay.

This paper is organized as follows. In Section II, we describe a general multi-speed communication system model and illustrate how the requantization process working in it. In Section III, the particle-pair optimizer algorithm is formulated. The scheme of PPORCO is proposed in Section IV. In Section V, the performance of image requantization using PPORCO and ARCO are compared. Finally, the conclusion is given in Section VI.

II. MODEL OF REQUANTIZATION

Figure 1 shows a basic multi-speed communication system model with requantization. This model has two sub-channels whose transmission speeds are different, assuming that the bit rate of $R_1$ is higher than that of $R_2$. For the purpose of reducing data bit rate with minimal distortion, a requantization should be employed as re-compression strategy. In the procedure of transmission, the image is sliced into small blocks and reorganized into the training vectors $V = \{V_1, V_2, ..., V_m\}$, where $L$-dimension vector $V_m$ is generated from the $m$th block. These training vectors are then quantized using first source encoder with codebook $Q_1 = \{X_1, X_2, ..., X_n\}$, $N_1$ is the size of codebook $Q_1$. $V_m$ in the region of $\Omega_i$ is assigned to the codebook vector $X_i$, as is

$\Omega_i$ region of $\Omega_i$.
shown in Fig. 2.

\[ X_i = Q_1(V_m) \text{, when } V_m \in \Omega_i \quad (1) \]

The bit-stream \( I(Q_1) \) of quantized image is then fed into the first sub-channel whose bit rate is higher. When \( I(Q_1) \) is transmitted over the second sub-channel with lower bandwidth, the data bit rate is required to be reduced. A requantization is needed as follows:

- \( I(Q_1) \) is decoded into quantized vectors \( V^1 = \{V_1^1, V_2^1, \ldots, V_m^1, \ldots, V_M^1\} \) by first source decoder. The distortion of first quantization is:

\[ D_1 = \sum_{i=1}^{N_1} \sum_{V_m \in \Omega_i} d^2(X_i, V_m) \quad (2) \]

where \( d(X_i, V_m) \) is the Euclidean distance between \( X_i \) and \( V_m \).

- \( V^1 \) are requantized by second source encoder with codebook \( Q_2 = \{Y_1, Y_2, \ldots, Y_1, \ldots, Y_N_2\} \) into bit-stream \( I(Q_2) \). \( N_2 \) is the size of codebook \( Q_2 \). \( V_m^1 \) in the region of \( \Psi_j \) is represented by codevectors \( Y_j \).

\[ Y_j = Q_2(V_m^1), \text{ when } V_m \in \Psi_j \quad (3) \]

- After transmitting into the sub-channel with lower bit rate, the requantized vectors \( V^2 = \{V_1^2, V_2^2, \ldots, V_m^2, \ldots, V_M^2\} \) are regenerated by second source decoder. The distortion of second quantization is:

\[ D_2 = \sum_{j=1}^{N_2} \sum_{\Psi_j \in \Psi_i} d^2(Y_j, V_m^1) \quad (4) \]

The global quantization distortion is defined as:

\[ D_g = \sum_{i=1}^{N_1} \sum_{V_m \in \Omega_i} P(X_i, Y_j) d^2(Y_j, V_m) \quad (5) \]

where

\[ P(X_i, Y_j) = \begin{cases} 1, & \text{if } X_i \in \Psi_j \\ 0, & \text{else} \end{cases} \]

Note that in most cases \( D_g \) is larger than \( D_2 \) due to \( Q_2(I(Q_1(V_m))) \neq Q_2(I(V_m)) \) caused by partition mismatch between \( \Omega_i \) and \( \Psi_j \). This problem of mismatch is illustrated in Fig. 2. In the first quantization, \( V_m \) is assigned to codevector \( X_i \) since it is in the region of \( \Omega_i \). During the requantization, \( X_i \) is in the region of \( \Psi_j \), which results in that \( V_m \) is assigned to \( Y_j \). However, \( V_m \) should be assigned to \( Y_j \), and belong to region \( \Psi_m \), due to \( d(Y_j, V_m) < d(Y_j, V_m) \). Therefore, the problem of mismatch occurs and the distortion increases. It could be illustrated that \( D_g = D_2 + \bar{D} \), where \( \bar{D} \) is the distortion caused by partition mismatch and defined as:

\[ \bar{D} = \sum_{i=1}^{N_1} \sum_{V_m \in \Omega_i} \{d(Q_2(Q_1(V_m)), V_m) - d(Q_2(V_m), V_m)\} \]

Fig. 1. Basic multi-speed communication system with requantization.

Fig. 2. Requantize the training vectors.

The problem of partition mismatch is inevitable since \( V_m \) is assigned based on \( Q_1(V_m) \) during the process of requantization. The potential solution is the fitness value used in optimization is evaluated by other ways instead of \( D_g \) in the requantization process. The distortion by partition mismatch \( \bar{D} \) is determined to the distribution of original training vectors \( V_m \) and the shape of region \( \Omega_i \) after the first quantization.

III. PARTICLE-PAIR OPTIMIZER

The procedure of basic PSO is shown in Table I, in which the velocity and position update equations are:

\[ v_i^{k+1} = \omega v_i^k + c_1 r_1(Pbest - x_i^k) + c_2 r_2(Gbest - x_i^k) \]
\[ x_i^{k+1} = x_i^k + v_i^{k+1} \]

(6)

where \( i \) is the number of dimension and \( k \) is the number of iteration. The parameter \( \omega \) is the inertia weight, whose value
is usually set to be slightly less than 1. Learning factors $c_1$ and $c_2$ determine how much the particle should learn from the experience of its past and that of other particles. Values $r_1$ and $r_2$ are two random numbers with uniform distribution in the interval of [0,1]. $P_{best}$ is the optimal particle position with best fitness value the particle ever reaches. $G_{best}$ is the global optimal particle position of the particle swarm.

The performance of PSO decreases obviously as the dimension of solution space increases. To overcome these drawbacks, particle-pair optimizer is proposed. As shown in Fig. 3, two particles, called particle-pair, search in the solution space as a tiny swarm by performing conventional PSO update operation in each iteration. In PPO two particle-pairs are used for searching independently. In each particle-pair, particle with better fitness value is selected and merged into a new elitist particle-pair, so that the new swarm can benefit from both searching experience. This elitist particle-pair performs another PSO algorithm and the particle position with better fitness value is selected as the global optima. The iterative procedure of PPO is shown in Table II.

![Image](image1.png)

**Fig. 3. The particle-pair optimizer.**

**IV. REQUANTIZATION CODEBOOK DESIGN USING PPO**

As shown in Table III, PPO is applied twice in PPORCO for codebook design by using LBG [9] to evaluate the fitness value. The LBG (Linde-Buzo-Gray) algorithm, also referred as K-means, is a conventional vector quantization codebook design algorithm.

In Step 1, the original image is sliced into small blocks and re-arranged into L-dimension training vectors. In Step 2, the position of each particle in both particle-pairs is initialized by selecting $N_2$ codevectors stochastically from training vectors. These particle positions can be seen as the initial codebook. In Step 3, the PPO is applied to optimize the codebook $Q_1$. In each iteration of PPO algorithm in PPO, the LBG algorithm is applied to evaluate the distortion $D_1$ defined in Eq. (2). The global optimal particle position is selected as $Q_1$. In Step 4, the position of each particle in second PPO is initialized directly from $Q_1$ by the way of random selection. In step 5, PPO algorithm is applied again, in which the global distortion $D_2$ is used as the fitness value instead of the second quantization distortion $D_2$.

The computation time of requantization is reduced because no operation of image reconstruction is needed in PPORCO.

**V. SIMULATION RESULTS**

The quality of codebook design is presented in terms of PSNR, which is defined as follow:

$$PSNR = 10 \log_{10} \frac{255^2}{\frac{1}{M} \sum_{i=1}^{M} d_{\text{min}}^2(V_m)}$$

where the maximum value of grayscale is 255 and $d_{\text{min}}(V_m)$ is the minimum Euclidean distance between $V_m$ and its corresponding codevector.
PPORCO is stable on all four original images. In PPORCO, every original image is sliced into $4 \times 4$ pixels blocks and re-arranged into $N$ pixels in size. In PPORCO, the parameter $Q$ is set to $0.1$ and let $Q = 15$. The size of codebook $Q_1$ is $N_1=256$ and that of $Q_2$ is set to $N_2=8,16,32,64$ and 128 respectively. Ten runs are performed for each requantization image from codebooks $Q_1$ and $Q_2$ using PPORCO. The requantization speed of PPORCO is high and the quality of image is satisfactory due to the high PSNR value and stable requantization performance.

PPORCO works more efficiently because in PPO a particle can learn not only from its own experience, but also from the experience of the swarm. The particle can jump out of the local optimum area and move toward the global optimal position. Applying PPO in requantization codebook design can reduce the dependence of initial codebook selection in comparison with other algorithms.

### VI. CONCLUSION

A new algorithm of requantization codebook design using particle-pair optimizer (PPORCO) is proposed in this paper. Due to the high optimization efficiency of PPO, PPORCO can obtain higher PSNR value with less computation time in comparison with conventional codebook optimization strategies like RCO and ARCO. A multi-speed communication system employing PPORCO as its re-compression strategy can transmit images in a high quality with less transmission delay.

### REFERENCES


