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DETECTION OF TRANSMISSION ERRORS IN BLOCK CODED IMAGES

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The effect of cell loss or random bit error during transmission causes image degradation in the case of highly compressed images serious. We use ARQ (Automatic Repeat reQuest) as the error control scheme. Conventional ARQ uses an error detection code (Cyclic Redundancy Check — CRC) to trigger retransmission. Retransmission of all bit errors is not efficient. To improve the throughput, we use an ARQ scheme that detects only those channel errors that would cause serious image degradation — Side Match Test (SMT) [1]. In this study we use the SMT in JPEG and VQ (Vector Quantization) coded images transmitted trough an independent symmetric binary transmission channel without memory.

K e y w o r d s: error detection, JPEG, vector quantization, independent symmetric binary transmission channel without memory

1 INTRODUCTION

To reduce transmission bit rate or storage capacity, different compression techniques have been developed for many applications, such as videoconferencing, videophones, HDTV. Blockbased image and video coding techniques such as Transform Coding (TC) and Vector Quantization (VQ) have been found to be efficient for low bit rate image coding. In block- based image compression methods, the Discrete Cosine Transform (DCT) is currently the most effective and popular technique for image and video representation and transmission. It has been adopted by most emerging image coding standards including JPEG, H.261, H.263, MPEG-1 and MPEG-2 [2,3,4]. In recent years, JPEG and MPEG standards have been widely used to encode images to reduce transmission costs and storage capacity. Both of the two international standards are block-oriented.

In this study, detection of transmission errors in JPEG and VQ coded images is proposed. We use ARQ as an error control scheme for image transmission. Conventional ARQ uses an error detection code (Cyclic Redundancy Check, CRC) to trigger retransmission. These detection codes add redundancy to the transmitted data and thereby reduce the throughput. Retransmission of all bit errors is also inefficient because some bit errors do not cause serious image degradation. To improve the throughput, we use an ARQ scheme to detect only those channel errors that cause serious image degradation. This error detection scheme is called a Side Match Test (SMT) [1]. Description of the SMT is in chapter 3. We applied the SMT to JPEG and VQ coded images.

2 VECTOR QUANTIZATION AND JPEG COMPRESSION STANDARD

2.1 Vector Quantization

Let $\boldsymbol{x} = \left(x_1, x_2, \ldots, x_N\right)^\top$ be an N-dimensional vector with N real components x_I. Vector quantization is based on mapping (substitution) of vector $\boldsymbol{x}$ by N-dimensional vector $\boldsymbol{r}_j = \left(r_1, r_2, \ldots, r_N\right)^\top$. Vector $\boldsymbol{r}_j$ is selected from L reconstruction or quantization levels. Quantization of vector $\boldsymbol{x}$ is a selection of such a vector $\boldsymbol{r}_j$ from the set of vectors of the quantizer which is the most similar to vector $\boldsymbol{x}$. We can describe this as follows [7]:

$$\widehat{\mathbf{x}} = VQ(\mathbf{x}) = \boldsymbol{r}_j\,. \tag{1}$$

It represents the selection operation of $\boldsymbol{r}_j$ for $l \le j \le L$.

The principle of coding and decoding is shown in Fig. 1 [7]. The encoder includes the vector quantizer and the codebook. The same codebook is used also in the decoder. For each input vector $\boldsymbol{x}$, the vector quantizer determines the most similar representative vector $\boldsymbol{r}_j$ from the codebook.

The bit rate (the number of bits for an array element) b hereupon depends only on the codebook size. For binary coding it is defined as [7]:

$$b = \frac{\log_2(L)}{N}\,. \tag{2}$$

The vector quantization codebook was created using the VCDemo software [11]. This catalogue of vectors was made of 'Train' image shown in Fig. 2. We use the block size 4×4 pixels. The number of bits per vector varies from 3 to 12, which means that the bit rate varies from 0.1875 to 0.75 bits per pixel.

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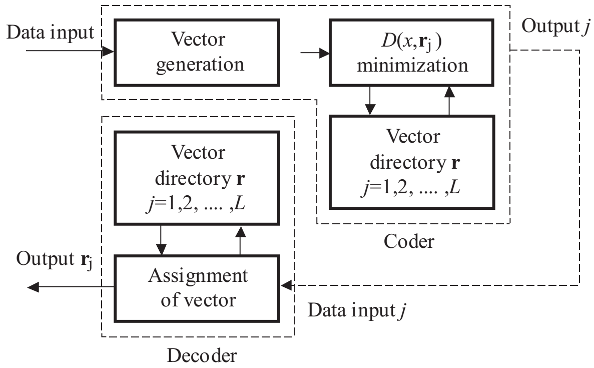

Fig. 1. Block scheme of encoder-decoder for VQ principle.

Fig. 2. Picture 'train' used for creation of VQ codebook.

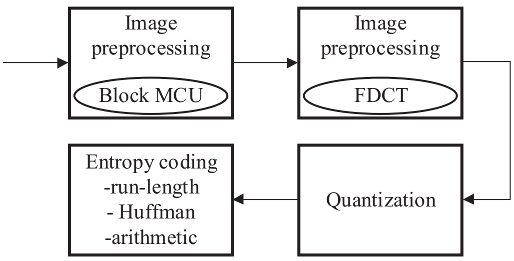

Fig. 3. Block scheme of JPEG standard.

2.2 JPEG Overview

Unlike other compression methods, JPEG is not a stand-alone compression algorithm, but we can consider it as a package of compression techniques. JPEG standard represents a lossy data compression method as it uses some relatively irrelevant (for human eye indistinctive) details to fade. For instance, the human eye is more susceptible to intensity change in contrast to small colour changes, which are practically unrecognizable. The JPEG standard is based on entropy coding of quantized coefficients of discrete cosine transform using block size 8×8 pixels. JPEG was created especially for compression of colour and

monochrome images of any size and compression ratio (number of bits per pixel). JPEG standard recognizes 4 coding methods (modes):

- *Sequential* – each image element is coded in 1 transition from left to right, top down,
- *Progressive* – the image is coded within a number of transitions through the original,
- *Hierarchical* – we can obtain images of different resolution,
- *Lossless* – to preserve the lossless image.

In this paper we deal explicitly with sequential DCT coding (the most frequently used). The sequence of compression steps using JPEG

2.2.1 JPEG and Channel Errors

By the transmission of JPEG compressed still images through a channel, transmission errors could occur. In JPEG image compression, after DCT and quantization of coefficients, Variable Length Code algorithms (VLC) are used. VLC are lossless data compression methods. They are more efficient for data reduction in comparison with codes with a fixed word length. The disadvantage of VLC is that all data following an erroneous bit are not decodable till the nearest synchronization codeword. That can cause high quality degradation of the reconstructed image as shown in Fig. 4 (b).

To reduce the quality degradation effect of the transmission errors, the *restart markers* are used. They ensure resynchronization of the image and also mark a point in JPEG data flow at which the decoder is to be reset. The restart markers are included into entropy coded segments. The JPEG standard uses 8 different restart markers RSTm [6]. Restart markers are 8 bit codes [8], [9]. These restart markers can occur only in MCU (Minimal coding unit). MCU is a group of 8x8 blocks. We suppose that a MCU contains only 1 block. A restart interval is defined as a block of data containing a restart marker followed by a fixed number of MCUs. The only exception is the first restart interval of the image, which skips the initialization restart marker and begins whit the MCU data. In this study we suppose the use of restart markers after each block. The restart markers do not improve the image quality as shown in Fig. 4(c).

In image transmission using JPEG four types of errors can occur:

- one block is hit by the bit error,
- EOB (End Of Block) codeword is not recognized in the image decoding process,
- EOB (End Of Block) codeword is wrongly recognized in the image decoding process,

a) b) c)

Fig. 4. Image 'Lena', when the EOB codeword is not recognized while decoding (a) original image, (b) after transmission without the restart markers, bit error rate (BER) = 0.01 %, bit rate 0.8 bpp, $MSE = 1777.9$, number of bit errors = 7, (c) after transmission with the restart markers and the bit error rate (BER) = 0.05 % and bit rate 0.8 bpp, $MSE = 207.7$, number of bit errors = 35.

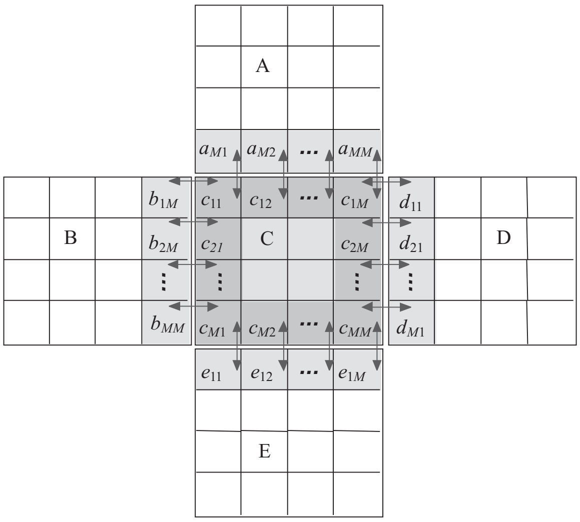

Fig. 5. The principle of comparison of image blocks by the side match test algorithm.

- blocks are divided or unified preserving the overall number of blocks.

3 SIDE MATCH TEST SMT

3.1 SMT Overview

This section describes the Side Match Test method. The adjacent image pixels typically exhibit correlation. We detect block errors using the 'Side Match Test' to calculate the mean square error between each pair of pixels in four adjacent blocks.

A comparison criterion is expressed using Mean Square Error. In Fig. 5 the tested image block is denoted by C. Matching boundary points of neighbouring blocks are marked with arrows. The value of MSE_{AC} (3) defines MSE of boundary points of the block A (pixels $a_{M1} \div a_{MM}$) and the group of matching pixels of the block C being tested (pixels $c_{11} \div c_{1M}$). Likewise MSE_{BC} (4) defines MSE of neighbouring boundary points of the block B (pixels $b_{1M} \div b_{MM}$) and the block C (pixels $c_{11} \div c_{M1}$), equally MSE_{DC} (5) for blocks D (pixels $d_{11} \div d_{M1}$) and C (pixels $c_{1M} \div c_{MM}$) and MSE_{EC} (6) for blocks E (pixels $e_{11} \div e_{1M}$) and C (pixels $c_{M1} \div c_{MM}$).

$$MSE_{AC} = \frac{1}{M}\sum_{k=1}^{M} |a_{Mk} - c_{1k}|^2, \tag{3}$$

$$MSE_{BC} = \frac{1}{M}\sum_{k=1}^{M} |b_{kM} - c_{k1}|^2, \tag{4}$$

$$MSE_{DC} = \frac{1}{M}\sum_{k=1}^{M} |d_{k1} - c_{kM}|^2, \tag{5}$$

$$MSE_{EC} = \frac{1}{M}\sum_{k=1}^{M} |e_{1k} - c_{Mk}|^2, \tag{6}$$

where M represents the block size ($M = 4$ for VQ, $M = 8$ for JPEG).

The sensitivity of Side Match Test is set using a variable *sensitivity threshold*. It represents a threshold value whose exceeding results in SMT classification of the block C being tested to be unacceptable. Side Match Test indicates tested block as unacceptable when all four MSE_{AC}, MSE_{BC}, MSE_{DC}, MSE_{EC} values are greater than this threshold. Changing the threshold value of SMT affects the number of blocks detected as unacceptable.

SMT algorithm

The flowchart of SMT algorithm is shown in Fig. 6. A decoded erroneous image is the input of SMT. MSE_{AC}, MSE_{BC}, MSE_{DC} and MSE_{EC} are calculated for the first block C. Next, we test whether all four MSE_{AC}, MSE_{BC}, MSE_{DC} and MSE_{EC} are greater than the *sensitivity threshold*. If so — the block C is marked as unacceptable. When at least one of four MSEs is less than the *sensitivity threshold*, we declare block C as good. The last condition forms the main loop of SMT algorithm. Side Match Test ends with the last block of the image.

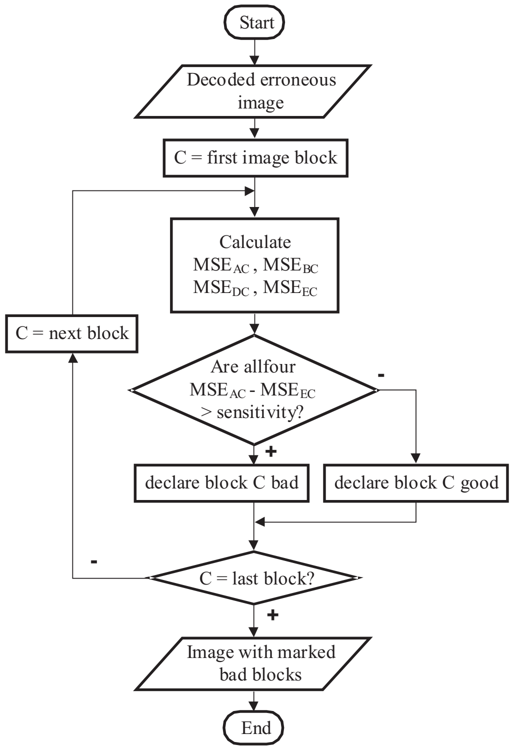

Fig. 6. The flowchart of 'Side Match Test' algorithm.

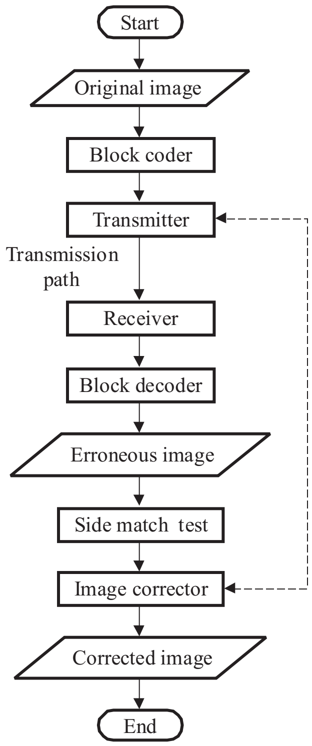

Fig. 7. The scheme of image transmission through the channel using SMT.

3.2 Image Transmission

Block scheme of the image transmission through the channel is shown in Fig. 7. Original image is coded in the block coder and sent through the transmission path to the receiver. We decode the image on the receiver side using a block decoder. We recognize unacceptable blocks using Side Match Test. Using image corrector we request transmission of the erroneous blocks from the sender. Corrector replaces erroneous blocks with the good ones.

4 SIMULATION

4.1 Simulation Assumptions

For simplicity, the following assumptions are made:

- we apply a new ARQ scheme, which uses SMT to detect image errors,
- blocks, which had been detected as erroneous, were retransmitted without an error,
- the images 'Lena', 'Baboon' and 'House' of the size 256×256 pixels and 8 bit depth-depth, were used for simulation,
- the erroneous images were generated using the VCDemo software [11] that simulates an independent symmetric binary channel without memory,
- the PSNR (Peak Signal to Noise Ratio) is employed in this study as the objective quality measure for the images.

Assumption made only for JPEG coded images:

- the header of a JPEG image is received correctly (or a self correction code can be used),
- when using SMT, the restart capability of JPEG images is enabled, *ie* a restart marker is inserted after each block of the Y component of the JPEG compressed image bit stream,
- in CRC simulation we use a 16 bit code,
- our simulation is for BER(Bit Error Rate) = 0.05 %.

The assumption made only for VQ coded images:

- our simulation is for BER (Bit Error Rate) = 0.05 %.

The PSNR is defined [10] as:

$$PSNR = 10 \log\left(\frac{v_{\max}^2}{MSE}\right), \tag{7}$$

where $v_{\max}$ is the maximum (peak-to-peak) value of the signal to be measured. MSE is the Mean Square Error, typically computed [10] as:

$$MSE = \frac{1}{M \cdot N} \sum_{I=0}^{N} \sum_{j=i}^{M} [x(i,j) - \overline{x}(i,j)]^2 , \tag{8}$$

where N, M are dimensions of the image (in pixels), $x(i,j)$ is the value of the Y component of the pixel (i,j) of the original image, $\overline{x}(i,j)$ is the value of the Y component of the pixel (i,j) of the image, that is compared with the original image

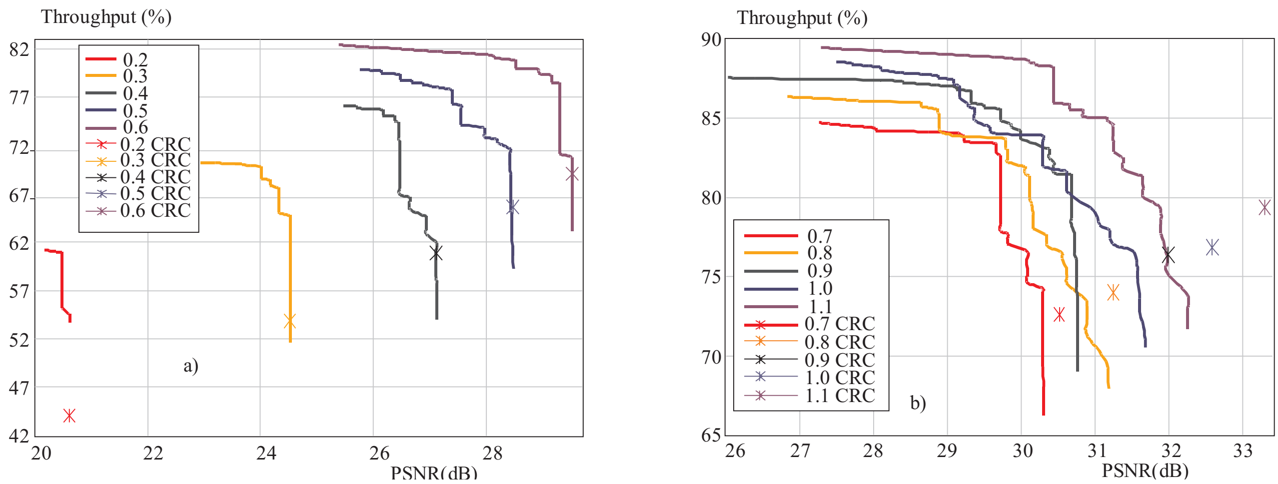

Fig. 8. Throughput dependences of PSNR for the JPEG coded image 'Lena' using SMT+ARQ (curves) and using CRC16+ARQ (cross lines): (a) bit rates 0.2–0.6 bpp (b) bit rates 0.7–1.1 bpp.

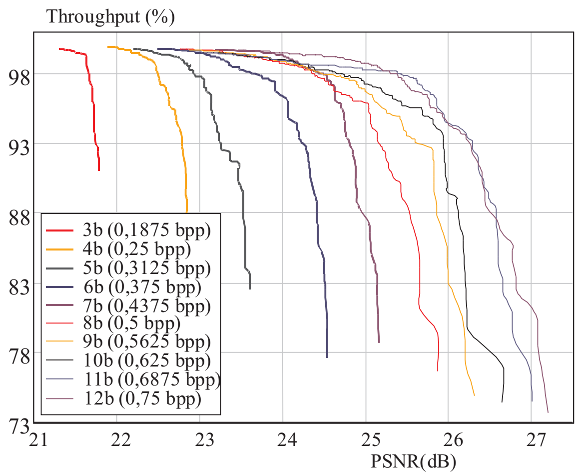

Fig. 9. Throughput dependencies of PSNR for the VQ coded image 'Lena' using SMT+ARQ for bit rates 0.1875–0.75 bpp.

4.2 Relative Throughput

We define the throughput as follows [1]:

$$TRP = \frac{n}{n + n_{bad}} \cdot \frac{N_{info}}{N_{info} + N_{CRC}} \cdot \frac{d_{info}}{d_{info} + d_{rst}} \cdot 100\% \,, \tag{9}$$

where n is the number of all blocks of the image,
n_{bad} is the number of retransmitted blocks (blocks detected as erroneous), ppb is the number of pixels per block (for JPEG images $ppb = 64$, for VQ images $ppb = 16$), br is the bit-rate of the compressed image, N_{info} is the information block length (bit), $N_{info} = br \cdot ppb$,
N_{CRC} is the CRC frame length (bit) for 1 block (16 bits for JPEG images [1], 0 bits for VQ), d_{info} is the number of information bits per image, $d_{info} = br \cdot n \cdot ppb$,
d_{rst} is the additional information (bit) to prevent desynchronization (restart markers — only in JPEG),
$d_{rst} = n \cdot 8$, for VQ images $d_{rst} = 0$, $N_{CRC} = 0$ when using SMT and $d_{rst} = 0$ when using CRC.

Expression (9) can be simplified as follows:

$$TRP = \frac{n}{n + n_{bad}} \cdot \frac{br}{br_a} \cdot 100\% \,, \tag{10}$$

where br_a is actually the 'additional bit rate'.

The following parameter values have been chosen:
for JPEG coded images
using SMT: $br_a = 8/64 = 0.125$ bpp,
using CRC16: $br_a = 16/64 = 0.25$ bpp,
for VQ coded images
using SMT: $br_a = 0$ bit/bod $= 4/64 = 0.0625$ bpp.

By applying ARQ and SMT, we obtain variable channel throughput. The image quality depends on the SMT threshold value (sensitivity — Chapter 3). Figures 8 (JPEG) and 9 (VQ) compare the throughput for different compression levels (bit rates) of the image 'Lena'. Figure 8 also compares the SMT method with CRC. The sensitivity threshold value varies from 10^2 to 10^4. The horizontal axis is PSNR (dB) and vertical axis is the relative throughput (%). From the graphs we can see that the channel throughput decreases with decreasing sensitivity threshold because the erroneous block detection increases. However we achieve higher image quality. CRC error detection offers almost the lowest throughput, because of the CRC bits utilization. Figure 10 shows an example of the SMT for a JPEG coded image and Figure 11 shows an example of SMT for a VQ coded image.

5 CONCLUSION

In this paper we deal with a method of error detection in block coded images compressed by JPEG standard and vector quantization (VQ) and transmitted through an independent symmetric binary transmission channel without memory. Standard methods of error correction are based on ARQ strategy with CRC detection code. This method decreases the relative channel throughput

Fig. 10. Example of the SMT with sensitivity threshold = 2000 applied to the image 'Lena': (a) original lossless image, (b) JPEG coded image, bit rate 0.6 bpp, $PSNR$ = 30.09 dB, (c) orrupted image, BER = 0.05 %, 22 erroneous blocks, $PSNR$ = 23.83 dB, (d) corrected image using ARQ and SMT, 16 right marked blocks as erroneous, 4 incorrect marked blocks as erroneous, $PSNR$ = 28.71 dB, throughput = 81.17 %.

Fig. 11. Example of the SMT with sensitivity threshold = 1230 applied to the image 'Lena': (a) original, lossless image, (b) VQ coded image, bit rate 0.625 bit/pixel, $PSNR$ = 26.98 dB, (c) erroneous image, BER = 0.5 %, 128 erroneous blocks, $PSNR$ = 21.93 dB, (d) corrected image using ARQ and SMT, 74 right marked blocks as erroneous, 54 incorrect marked blocks as erroneous, $PSNR$ = 25.18 dB, throughput = 96.85 %.

considerably because CRC adds bits into the transmitted data flow. Retransmission of errors that do not cause serious image degradation results in unnecessary throughput regress. The loss of throughput is suppressed using Side Match Test (SMT) method that detects mainly those errors that cause serious image degradation. SMT only detects errors in the received image. We need to use additional data — restart marks (8 bits/block) for JPEG coded images but the amount of additional data is lower than for CRC (16 bits/block). SMT, depending on selected sensitivity threshold, detects some error-free blocks as erroneous. These blocks have to be retransmitted, which causes a decrease of the channel throughput. This occurs, when error-free blocks differ from neighbouring blocks significantly. In this case the sensitivity criteria detects the blocks as erroneous. This disadvantage can be minimized using "optimal sensitivity threshold". The optimization is made for the original image before transmission and the "optimal sensitivity threshold" is that one that detects the minimum error-free blocks as erroneous. Herewith we also discover which error-free image blocks are determined as unacceptable. For these blocks, there are used error-detecting code (CRC) or self-correcting code. We do not apply SMT to them. In spite of this effect, in the case of choosing optimal *sensitivity threshold*, the throughput increases significantly preserving good objective (PSNR) and subjective (visual perception) image quality (Fig. 10 and Fig. 11). We have analyzed SMT on 'Lena' image coded using JPEG standard and VQ method. We cannot compare the VQ and JPEG simulation results because the block size for single methods differs (JPEG 8×8, VQ 4×4). Additionally, applying SMT to JPEG coded image, we need to use therein the aforementioned restarting marks that cause a relative throughput decrease. Even though we tried to compare our results by the same bit rate.

The throughput value using SMT and VQ is higher than using SMT in combination with JPEG standard but the objective image quality using VQ is lower (lower PSNR) (Fig. 8 and Fig. 9) than for JPEG standard.

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