

## APPROACH OF JPEG2000 COMPRESSION STANDARD TO TRANSMULTIPLEXED IMAGES

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### ABSTRACT

A transmultiplexer that combines several images into one image to be sent through a single communication channel is presented. The efficiency of the JPEG2000 image compression standard in 2-D transmultiplexer systems was verified. A method of improving compression by splitting a combined image into subimages is presented in this paper. The splitting method, which comes directly from a combined image calculation algorithm, reduces efficiently high frequencies in compressed subimages.

### KEY WORDS

2-D transmultiplexer, image compression, JPEG2000, filter bank

## 1. Introduction

As the development of the Internet and video services proceeds, there is a growing need for information capacity of communication networks used so far. Some popular methods improve the capacity of information streams. Users of these methods typically share the available transmission media band in the frequency or in the original (i.e. time or plane) domain. Hybrid solutions, like the Code Division Multiple Access, are the most effective. Transmultiplexers combine signals by spreading information simultaneously in the original and in the frequency domain. A set of upsampled and filtrated images is combined to ensure transmission in a single channel. At the receiver's side the transmitted images are split by filtering and downsampling. The main task of such systems is preventing image distortion caused by the change of amplitude and phase as well as image leakage from one channel into another. This aim can be achieved by a selection of appropriate filters that ensure a perfect image reconstruction in the receiver [1]. In this paper, integer FIR filters of the 1-D type are used. Integer-to-integer operations provide an efficient system – images are processed in a finite-precision arithmetic and mapped integers to integers. In other words, it is possible to provide all calculations without divisions to omit the rounding errors. Systems equipped with integer filters can be used not only to transmit images but also for encrypted

data, lossless compressed signals, computer software data or other data where a change of even one single bit is inadmissible.

The compression can be applied in two ways in transmultiplexer. The compression algorithm may be directly applied to 2-D combined signal. The second case is based on the transmultiplexation of pre-compressed input images. In this case compressed images should be processed as 'streams of bits' and after the deserialization only transmultiplexer, which fulfills the perfect reconstruction conditions, must be used. In this case only lossless compression may be applied because any change of the combined image destroys the output images completely. The goal of this paper is to apply the JPEG2000 compression standard to the transmultiplexed image.

## 2. Image Transmultiplexing

Multimedia content is more and more popular in many different types of telecommunications. That is why new and efficient methods of sending several images through a single transmission line are needed. Transmultiplexer is easy to apply because only simple calculations are conducted in the system. A crucial point for overall performance of such systems is the quality of images delivered to the end user. In this context there is no reduction of quality due to the property of perfect reconstruction. Another advantage is that the combined signal may be processed still as an image. Due to this fact it may be possible to apply any image compression method.

Fig. 1 shows the classical structure of the four-channel image transmultiplexer. The input images are upsampled and filtered vertically and summed to obtain two combined images. These combined images are then upsampled and filtered horizontally and summed to obtain the final version of the combined image [2]. In presented system the combined image consists of four times more pixels than each input image. At the receiver's end, the signal is relayed first to two channels of the detransmultiplexation part, where signals are filtered and downsampled horizontally. Then these signals are relayed to four channels where images are filtered and

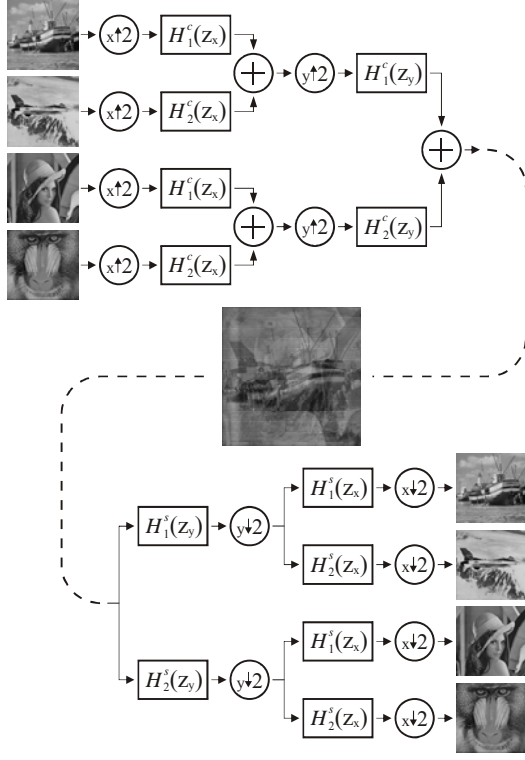


Fig. 1. Scheme of 4-channel image transmultiplexer

downsampled vertically to recover the original images. The analytical algorithm to design combining  $H^c$  and separation  $H^s$  filters for perfect reconstruction is presented in [3].

The luminance of combined image  $C$  for input images  $X_i$  can be computed by applying the following formula

$$\begin{aligned}
 C(2n+p, 2m+q) = & \\
 & \sum_{k=0}^{\lfloor K/2 \rfloor} \sum_{r=0}^{\lfloor K/2 \rfloor} h_1^c(2k+p) \cdot h_1^c(2r+q) \cdot X_1(n-k, m-r) + \\
 & \sum_{k=0}^{\lfloor K/2 \rfloor} \sum_{r=0}^{\lfloor K/2 \rfloor} h_2^c(2k+p) \cdot h_1^c(2r+q) \cdot X_2(n-k, m-r) + \\
 & \sum_{k=0}^{\lfloor K/2 \rfloor} \sum_{r=0}^{\lfloor K/2 \rfloor} h_1^c(2k+p) \cdot h_2^c(2r+q) \cdot X_3(n-k, m-r) + \\
 & \sum_{k=0}^{\lfloor K/2 \rfloor} \sum_{r=0}^{\lfloor K/2 \rfloor} h_2^c(2k+p) \cdot h_2^c(2r+q) \cdot X_4(n-k, m-r).
 \end{aligned} \quad (1)$$

The order of 1-D combination filters  $H_i^c$  is denoted as  $K$ , and their coefficients are indicated by  $h_i^c$ . The operation  $\lfloor \cdot \rfloor$  returns the greatest integer number equal to or less than the argument. Indexes  $p, q \in \{0, 1\}$  substitute upsampling procedures during computations.

### 3. JPEG2000 Compression

JPEG2000 is a crucial improvement and modernization of JPEG standard [4]. Using this algorithm, it is possible to

obtain the higher compression ratio with lower distortions of images. It can be expected that it will become soon the main image compression standard. JPEG2000 algorithm is based on the discrete wavelet transform, which can be coded much more efficient than original pixels. A wavelet transform allows to keep information existed in an image using the small number of coefficients, which can be additionally quantized or sometimes even skipped. Even a large quantization step size allows to keep satisfying quality of reconstructed images.

In a first step, a luminance of image pixels is shifted by  $2^{B-1}$  value, where  $2^B$  is the number of grey tones in the image. The wavelet transform supported by the Cohen–Daubechies–Feauveau 9-7 kernel is computed for such scaled image. Coefficients and frequency characteristics of the CDF 9/7 filters are presented in Fig. 2. An image is split into four subbands as the result of the wavelet transform: an approximation of lower resolution, horizontal, vertical and diagonal components. Applying successively  $M$ -times wavelet transform for each calculated approximation results in  $M$ -level wavelet decomposition. The JPEG2000 standard does not enforce the number of levels for wavelet transform.

The wavelet transform calculated in a described manner consists of the same number of coefficients as pixels in the image, but only a small part of them contain important information for the reconstruction. To limit the number of bits necessary for wavelet coefficients representation in the level  $w_m(u, v)$ , they are additionally quantized according to an equation

$$q_m(u, v) = \text{sign}[w_m(u, v)] \cdot \left\lfloor \frac{|w_m(u, v)|}{\Delta_m} \right\rfloor. \quad (2)$$

The step size of a quantization  $\Delta_m$  for  $m$ -subband is calculated regarding to the formula

$$\Delta_m = 2^{R_m - \varepsilon_m} \cdot \left( 1 + \frac{\mu_m}{2^{11}} \right), \quad (3)$$

where  $R_m$  is the nominal dynamic range of the subband  $m$ ,  $0 \leq \varepsilon_m < 2^5$  and  $0 \leq \mu_m < 2^{11}$  specify its terms of an exponent and a mantissa for a given level. The quantization threshold is additionally scaled by  $\times 2$  for

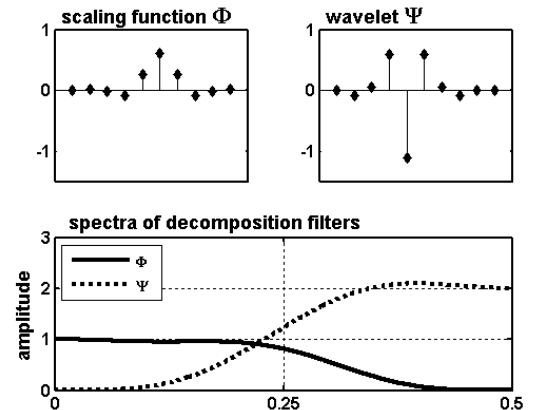


Fig. 2. Characteristic of CDF 9/7 wavelet.

Table 1. Coefficients of transmultiplexer filters

$H^c$		$H^s$	
1	0	0	0
1	-1	0	-1
2	1	1	1
-2	1	-1	-2
0	0	-1	-2

horizontal and vertical subbands and  $\times 4$  for a diagonal.

In a ‘lossless’ compression the step size of quantization is  $\Delta_m = 1$  for all subbands. The JPEG2000 standard does not specify any given quantization step for a lossy compression. However, the number of bits describing an exponent and a mantissa has to be known for decoding. In case when the parameters  $\varepsilon_m$  and  $\mu_m$  are defined for each  $m$ -level separately it is so called an explicit quantization, in case of defining  $\varepsilon_M$  and  $\mu_M$  only for the last level of decomposition it is an implicit quantization. In such case quantization parameters for each level  $m$  are interpolated in a way

$$\begin{aligned} R_m &= R_M, \\ \mu_m &= \mu_M, \\ \varepsilon_m &= \varepsilon_M + m - M. \end{aligned} \quad (4)$$

In the last step, the quantized coefficients of the wavelet decomposition are coded arithmetically with the run-length strings of symbols.

In this paper the coding algorithm was simplified by applying Huffman coding instead of arithmetic coding. The Huffman code allows obtaining compression ratios comparable with arithmetic coding. Coding algorithms were taken from [5].

## 4. Example

To verify the efficiency of the JPEG2000 compression method, some examples were analyzed. One of them is presented below. Four test images (boats, F-16, Lena and baboon) with  $512 \times 512$  pixels resolution in 256 grayscale levels were selected for the analysis. The combined image has  $1024 \times 1024$  pixel resolution. The combining filters  $H_i^c$  and the separation filters  $H_i^s$  were designed by algorithm presented in [6]. The obtained coefficient values are presented in Table 1. Transmultiplexing does not provide distortions because digital filters have integer coefficients and satisfy the requirements of the perfect reconstruction.

When the lossy compression, like JPEG2000, is used for combined images, it is difficult to define an acceptable loss of detransmultiplexed images. Finally errors from the lossy compression may make output images unacceptable or even unrecognized, due to the channel interferences or luminance distortions. Properly reconstructed images typically should have PSNR values of 30 dB or more. The JPEG2000 algorithm enables a very flexible choice of compression parameters. The following compression

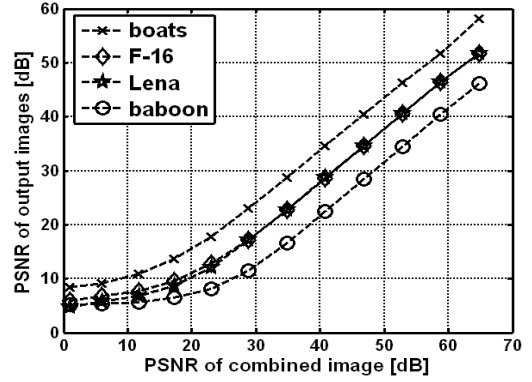


Fig. 3. Relationship of distortions of combined image and output images, ‘explicit case’

parameters  $M = 5$ ,  $R_M = 8$ ,  $\varepsilon_M = \{0, \dots, 11\}$  and  $\mu_M = 2048$ , were chosen after conducting many experiments. The parameters were applied in two, described below, cases, allowing the combined image compression.

### 4.1 ‘Explicit’ compression

In the first analysed case, the JPEG2000 compression was applied directly into a combined image. Fig. 3 presents experimentally found relations between distortions in a combined image, caused by a lossy compression, and distortions in output images. One may conclude, while choosing an acceptance threshold for output images ( $\geq 30$  dB), that a transmultiplexed image can be reconstructed with the error not worst than 49 dB. In case of PSNR equal 46.8 dB ( $\varepsilon_M = 8$ ) only the image baboon in the channel 4, which contains high frequencies, is reconstructed slightly under the acceptance threshold (28.5 dB). The relationship between distortions in a combined image and obtained compression ratios is shown in Fig. 4. The presented relation shows that a useful compression ratio will be not higher than 1.6. Only in such case, the needed quality of output images is provided. It is caused by the compression algorithm, which reduces high frequencies from the image. The high

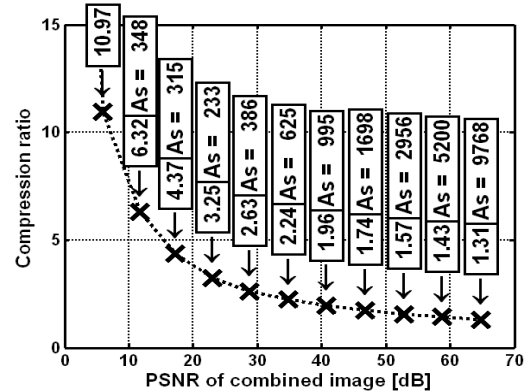


Fig. 4. Relationship between distortions of combined image, compression ratio and amount of symbols to be coded (As), ‘explicit’ compression

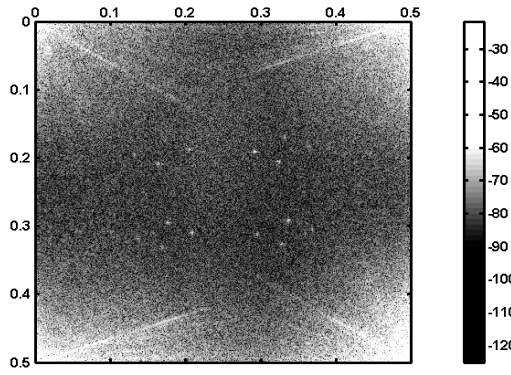


Fig. 5. Amplitude [dB] of spectrum of combined image

frequencies are important in the combined image, because of upsampling operations and they cannot be removed (see Fig. 5).

#### 4.2 ‘Implicit’ compression

It is possible to improve the compression ratio by pre-dividing a combined image into four subimages with even, odd and mixed pixels. The distinction goes directly from the equation (1) with possible combinations of indexes  $p$  and  $q$ . It is also justified by a hardware implementation of transmultiplexers in electronic circuits, i.e. FPGA [7]. In this case the computation of the combined image exploits the parallel processing opportunity as much as possible. The subimages obtained in this way have a lower content of high frequencies (see Fig. 6.).

Fig. 7 presents experimentally found relations between distortions in a combined image, caused by a lossy compression, and distortions in output images in an ‘implicit’ case. It can be concluded, that a combined image is reconstructed with the lower error than in a case of whole combined image compression. It is necessary to reconstruct a combined image on the level of around 47 dB to limit the output images errors on the level higher than 30 dB. It is a better result than in previous case and

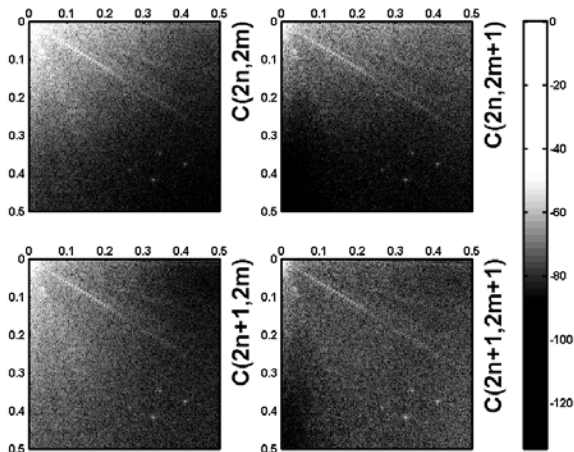


Fig. 6. Amplitude [dB] of spectrum of combined subimages

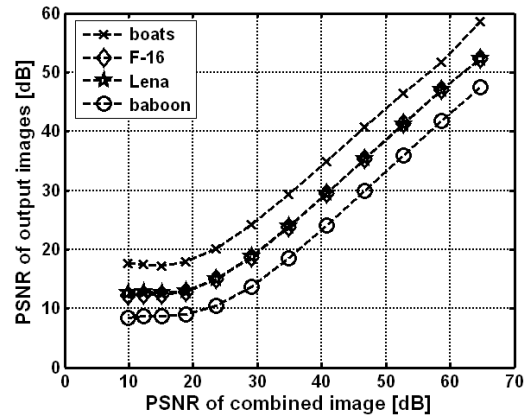


Fig. 7. Relationship of distortions of combined image and output images, ‘implicit case’

should guarantee an improvement of the compression ratio. The relationship between distortions in a combined image and the obtained compression ratio in an ‘implicit’ case is shown in Fig. 8. In this case a useful compression ratio is no higher than around 2.1. The comparison of results shows the compression ratio can be improved by 31% in a boundary case (PSNR of output images  $\geq 30$  dB). Output images in the case of the boundary PSNR level are compared in Tab. 2. It should be stressed that the rise of the compression ratio was obtained in spite of a rapid growth of symbols to be coded. In a boundary case 3.5 times more symbols has to be coded.

#### 5. Conclusion

Transmultiplexation changes the parallel transmission into the serial transmission. The important role of high frequencies in the combined image makes the application of standard lossy compression methods impossible. These algorithms, based on a reduction of high frequency components, cause major errors in output images of the transmultiplexer system. This is why providing a very high quality of a reconstructed combined image (PSNR

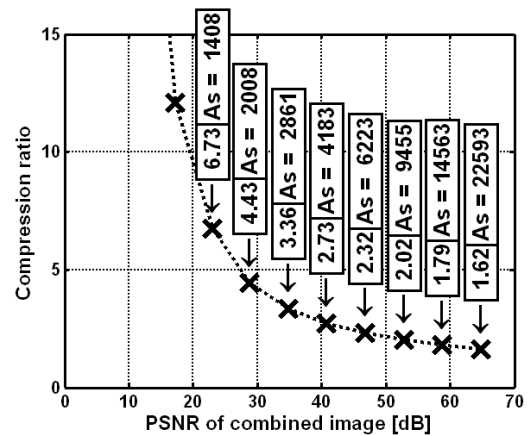



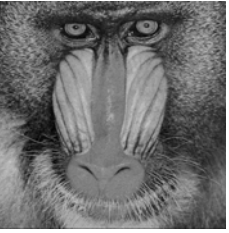



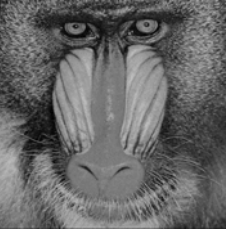



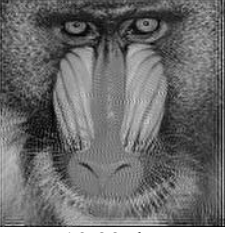


Fig. 8. Relationship between distortions of combined image, compression ratio and amount of symbols to be coded ( $A_s$ ), ‘implicit’ compression

Table 2. Comparison of output images

Compression case	Channel 1	Channel 2	Channel 3	Channel 4
'explicit' case $M = 5$ $\epsilon_m = 8, \mu_m = 2048$ $CR = 1.74$ $PSNR = 46.81$ dB	 40.52 dB	 34.65 dB	 34.67 dB	 28.46 dB
'implicit' case $M = 5$ $\epsilon_m = 8, \mu_m = 2048$ $CR = 2.28$ $PSNR = 46.72$ dB	 40.73 dB	 35.38 dB	 35.37 dB	 29.98 dB
Wavelet Packet Compression [8] $CR = 16$ $PSNR = 42.60$ dB	 24.27 dB	 23.42 dB	 23.79 dB	 19.33 dB

above 50 dB) causes forcing low compression ratios. In a case of applying the JPEG2000 algorithm for typical images i.e. Lena with only low frequencies, the compression ratio is equal to 5.6 if quality on the level of about 47 dB is going to be provided.

The improvement of the compression ratio is possible only if a compression method, taking into account the specific frequency features of a combined image, is applied [8]. In this case the considerable rise of the compression ratio, not possible to provide using the JPEG2000 or others standard algorithms, ( $CR = 16$ ) was followed by the degradation of the quality of output images.

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