LOSSLESS JPEG-BASE COMPRESSION OF TRANSMULTIPLEXED IMAGES

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ABSTRACT

A transmultiplexer assigned to combine images into one image to be sent through a single communication channel is presented. The considered system can be equipped with integer-to-integer filters to enable the lossless compression. The efficiency of lossless JPEG compression applied to transmultiplexed signals has been verified.

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 space) 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 a transmission over 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 the amplitude and the phase as well as an 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 transmission efficiency can be improved by applying the compression in two ways. The compression algorithm may be directly applied to 2-D combined signal. The second case is based on a transmultiplexation of pre-compressed input images. In this case compressed images should be processed as 'streams of bits' and after deserialization 1-D transmultiplexer must be used. The goal of this paper is to find or adapt the lossless compression methods to the combined signal in 2-D transmultiplexer.

2. IMAGE TRANSMULTIPLEXING

Fig. 1 shows the classical structure of the four-channel image transmultiplexer. The input images X_i in the i-th channel are upsampled and filtered vertically and summed to obtain two composite sub-images. These composite images are then upsampled and filtered horizontally and summed to obtain the final version of a combined image CI. In the presented system the combined image consists of four times more pixels than the input images. The luminance of the transmitted image CI may be calculated using the formula, which include both, upsampling and digital filtering. The luminance of the combined image can be computed by applying formula:

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

The order of 1-D combination filters H_i^c is K, and their coefficients are indicated by $h_i^c \in \Re^{K+1}$. The operation $\lfloor \cdot \rfloor$

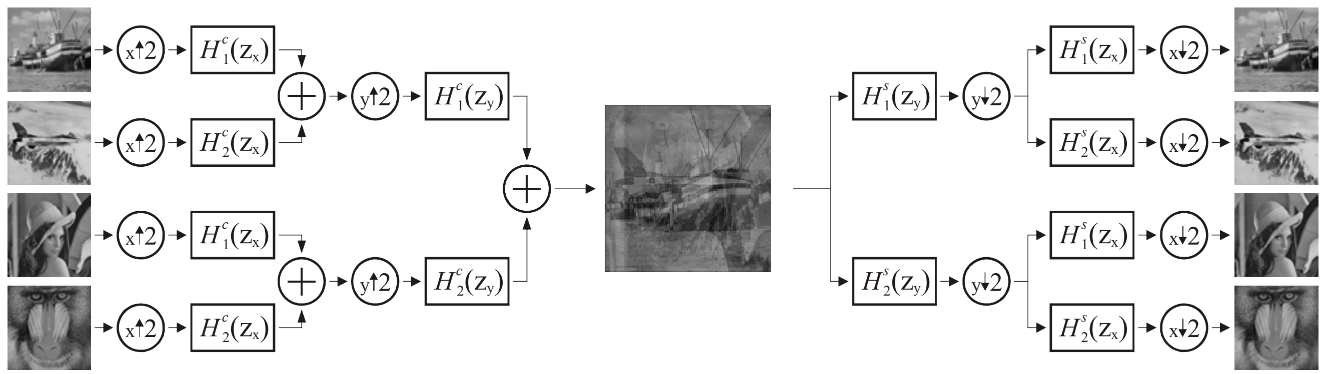

Figure 1 – Scheme of 4-channel image transmultiplexer

returns the greatest integer number equal to or less then the argument. Indexes $p, q \in \{0, 1\}$ substitute upsampling procedures during computations.

The combined image can be sent over a single transmission channel. At the receiver's side, the combined image is relayed first to the two channels of the detransmultiplexation part, where the signals are filtered and downsampled horizontally. Then these images are relayed to the four channels where they are filtered and downsampled vertically to recover the original images.

3. JPEG LOSSLESS COMPRESSION

The primary goal of a lossless compression is to minimize the number of bits required to represent the original image pixels without any loss of information [2]. The lossless compression is demanded for combined images, because 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 channel interferences or luminance distortions.

The lossless JPEG compression method, developed jointly by the ITU-T and the ISO, is one of the wide–spread compression standards. The algorithm is based on differential coding to the predicted residuals, which are then coded with a Huffman method. The predicted residuals usually have lower entropy, so they are more amenable to the compression than original image pixels. In the JPEG lossless compression, a prediction residual R is calculated using previously encoded neighbouring pixels. The predefined prediction residual for pixel x, shown in Fig. 2, were obtained in [3] and [4] by applying formula

$$r = y(c,a,b) - x\,. \tag{2}$$

The pixel luminances for position a, b and c are available to both the encoder and the decoder prior to processing x. The particular choice for the y function is defined in the scan header of the compressed stream so the identical function is used during decoding and encoding process. The prediction residual is computed modulo 2^{16}, but it is not directly Huffman code. It is expressed as a pair of symbols: the category and the magnitude. The category represents the number of bits q needed to encode the magnitude and only this value is Huffman coded. The common magnitude categories for the prediction residual are shown in Tab. I. The list of magnitude categories may be freely increased to record higher values of the prediction residual, but well-designed predictor generates small values of residuals. Normally q does not exceed 16.

Generally if the value of the residual is positive, then the code for the magnitude is its direct representation. If the residual is negative, then the code for the magnitude is the bits' complement of its absolute value. Therefore, code-words for negative residuals always start with a zero bit. For typical grey-scaled images, compression ratios in excess of 1.5 are difficult to achieve [3]. The lossless JPEG compression usually outperforms single Huffman or an arithmetic table coding method.

One cannot expect that the direct introduction of the standard JPEG compression algorithm to combined images will result in efficient methods. The analysis of a formula

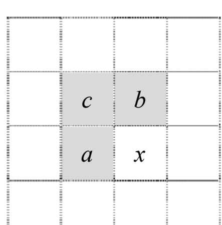

Figure 2 – The standard lossless JPEG prediction kernel

Table I – Prediction residual categories for lossless JPEG compression

Category	Prediction Residual R
0	0
1	$-1, 1$
⋮	⋮
q	$-(2^q-1)\ldots-2^{q-1}, 2^{q-1}\ldots(2^q-1)$
⋮	⋮

	f		*e*	
	d		*x*	

Figure 3 – The modified lossless prediction kernel

0.3123	-0.6040	0.3122	-0.6046
-0.5886	***f*** 1.1382	-0.5884	***e*** 1.1394
0.3122	-0.6039	***c*** 0.3121	***b*** -0.6045
-0.5894	***d*** 1.1397	***a*** -0.5893	***x*** 1.1421

$[\times 10^7]$

Figure 4 – Correlations between pixel x and its neighbourhoods

describing luminance of the composite image (1) relies on an indexation of pixels of the composite image with step two. Therefore it is possible to distinguish small areas 2×2 in the composite image, for which the same pixels of input images are used to determine the luminance but different products of respective filter coefficients H_1^c and H_2^c. These selected areas results directly from the equation (1) with possible combinations of indexes p and q. The lossless prediction of the JPEG compression should be evaluated on such 2×2 areas. A shift of the area by single pixel causes major changes. Both different input images pixels and different products of appropriate filter coefficients are used for prediction. It suggests that the change of the background used for the prediction might be a significant improvement of this method. The further analysis of the formula describing pixels of the composite image implies that the neighbourhood presented in Fig. 3 is the base for filters H_1^c and H_2^c. This observation is supported by correlation coefficients between pixels (see Fig. 4) used in prediction kernels. The only single change will be in a context of all input images summed with appropriate weights. It has to be stressed that sharp changes in input images i.e. existing edges will be spread because of the composition. One should expect that prediction would be more efficient using a predictor

$$r' = y'(f,d,e) - x = \alpha\cdot f + \beta\cdot d + \gamma\cdot e - x \quad (3)$$

where coefficients α, β, γ may be the same as in the JPEG lossless compression standard.

4. FINAL TEST

To verify the conception of the lossless compression, four transmultiplexer filter banks H^c and H^s providing a perfect reconstruction were designed. The method described in [5] was used to design filters. We assumed $M = 2$ (number of channels), $\tau = 1$ (delay) and

$$P = \begin{bmatrix} 1 & 0 \\ 1 & 1 \end{bmatrix}. \quad (4)$$

Taking into account the above assumptions, transmultiplexer filter coefficients were calculated applying an algorithm:

A. assume an integer matrix

$$G_1^c = \begin{bmatrix} h_1^c(1) & h_1^c(0) \\ h_2^c(1) & h_2^c(0) \end{bmatrix} \text{ such that } \det G_1^c = \pm 1 \quad (5)$$

B. calculate a matrix

$$G_2^c = G_1^c \cdot P \cdot X \cdot P^{-1} = \begin{bmatrix} h_1^c(3) & h_1^c(2) \\ h_2^c(3) & h_2^c(2) \end{bmatrix} \quad (6)$$

where

$$X = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix} \quad (7)$$

C. calculate a matrix

$$G_1^s = \left(G_1^c\right)^{-1} = \begin{bmatrix} h_1^s(1) & h_2^s(1) \\ h_1^s(2) & h_2^s(2) \end{bmatrix} \quad (8)$$

Table II – Coefficient of transmultiplexer filters

Bank 1				**Bank 2**				**Bank 3**				**Bank 4**			
$G_1^c = \begin{bmatrix} 2 & 1 \\ 1 & 1 \end{bmatrix}$				$G_1^c = \begin{bmatrix} 1 & 1 \\ -1 & 0 \end{bmatrix}$				$G_1^c = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$				$G_1^c = \begin{bmatrix} 2 & -3 \\ 1 & -2 \end{bmatrix}$			
H^c		H^s		H^c		H^s		H^c		H^s		H^c		H^s	
1	1	0	0	1	0	0	0	1	0	0	0	-3	-2	0	0
2	1	1	-1	1	-1	0	-1	0	1	0	1	2	1	2	-3
3	2	-1	2	2	-1	1	1	1	1	1	0	-1	-1	1	-2
-3	-2	2	-3	-2	1	-1	-2	-1	-1	-1	1	1	1	1	-1
0	0	2	-3	0	0	-1	-2	0	0	-1	1	0	0	1	-1

Table III – The highest compression ratios for transmultiplexed images

	Bank 1	Bank 2	Bank 3	Bank 4	Compression
Combined image for set 1	1.3030	1.5342	1.5431	1.2131	single Huffman coding
	1.2345	1.4858	1.4190	1.3079	standard lossless JPEG
	1.6674	**1.9711**	**2.1516**	**1.7791**	**JPEG–base lossless compression**
Combined image for set 2	1.2981	1.4967	1.5690	1.2217	single Huffman coding
	1.2233	1.4064	1.4217	1.2908	standard lossless JPEG
	1.5957	**1.8621**	**2.0558**	**1.6792**	**JPEG–base lossless compression**
Combined image for set 3	1.2910	1.5171	1.5241	1.2090	single Huffman coding
	1.2191	1.4774	1.4475	1.2926	standard lossless JPEG
	1.6346	**1.8821**	**2.2317**	**1.7292**	**JPEG–base lossless compression**
Combined image for set 4	1.3217	1.5393	1.5392	1.2204	single Huffman coding
	1.2479	1.5180	1.4709	1.3305	standard lossless JPEG
	1.7237	**2.0202**	**2.3571**	**1.8514**	**JPEG–base lossless compression**

D. calculate a matrix

$$G_2^s = -P \cdot X \cdot (P)^{-1} \cdot G_1^s = \begin{bmatrix} h_1^s(3) & h_2^s(3) \\ h_1^s(4) & h_2^s(4) \end{bmatrix} \quad (9)$$

E. remaining filter coefficients values

$$h_1^c(4) = h_2^c(4) = h_1^s(0) = h_2^s(0) = 0 \,. \quad (10)$$

Designed transmultiplexer filters are presented in Tab. II. Four sets of test images [6]:

- boats, F-16, Lena and baboon,
- aerial, Barbra, couple and frog,
- bridge, man, peppers and washsat,
- golldhill, monarch, tank and Zelda,

with 512×512 pixels resolution in 256 grayscale levels were selected for the analysis. Each set of reference images was transmultiplexed using each of designed filter banks. Sixteen composite images were calculated, each of them with resolution 1024×1024 pixels. The compression ratios of combined images for a single Huffman coding are also presented in Tab. III (upper, grey values) for a comparison. Each of the composite images was compressed using a standard lossless JPEG method with all predictors presented in [3] and [4] and the highest compression ratios are presented in Tab. III, middle values. Given results confirm that it is difficult to obtain a higher coefficient than 1.5. By analysing the results one can claim that the compression ratio depends on the transmultiplexer filter bank H_i^c more than on a composite image. It should be stressed than the highest compression ratios were obtained using a simple single-prediction with pixel c. It contradicts a statement that a usage of the predictor based on a number of pixels higher than one, causes a higher compression ratio.

The best results of the compression with a modified prediction kernel are presented in Tab. III (bold fonts). In this case only a simple single-prediction with pixel e was used for a bank 4, which was designed with an assumption

$$\det G_1^c = -1 \,. \quad (11)$$

5. CONCLUSIONS

In the case of filter banks from 1 to 3 the compression ratios are higher for Huffman coding than for a standard JPEG algorithm. The compression ratio using a modified predictor kernel was increased by 38.3 % on average (60.3% in maximum and 27.4% in minimum) in a comparison with the standard JPEG algorithm for given examples. In a comparison with the Huffman algorithm a ratio was improved respectively by: 35.3%, 53.1% and 22.9%. The highest compression ratios were obtained for the bank 3, in which filter coefficients are the lowest and the context of input images is scaled with the lowest grade.

6. ACKNOWLEDGMENT

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7. REFERENCES

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