Hindawi Publishing Corporation
VLSI Design
Volume 2007, Article ID 59493, 7 pages
doi:10.1155/2007/59493

Research Article

Robustness of Transmultiplexed Images

Przemysław Sypka and Mariusz Ziółko

Department of Electronics, AGH University of Science and Technology, Al. Mickiewicza 30, 30-059 Kraków, Poland

Received 31 October 2006; Accepted 9 May 2007

Recommended by Andrzej Napieralski

Transmultiplexation changes the parallel transmission into a serial transmission. Integer-to-integer filters ensure the perfect reconstruction. The paper presents a suitable serialization method which improves the robustness of images transmitted by a transmultiplexer system. The solution is based on blocks of sizes adequate to separation filter orders, used in detransmultiplexation. The proposed method results directly from the detransmultiplexation algorithm. An example of a four-channel transmultiplexer system, equipped with integer filters, is presented and analyzed to illustrate the suggested method. A simple and effective filter design method is also presented.

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 technical solutions 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 surface) domain. Frequency-division multiplexing (FDM) is an important method of combining signals of several users into one signal for the transmission over a single channel. Spreading spectrum solutions, like the code division multiple access, are the most effective.

Transmultiplexer systems combine several suitably upsampled and filtered signals into a single signal by spreading information simultaneously in the original and in the frequency domain. Transmultiplexers have some important applications, in particular in telecommunications, to provide many signals over a single transmission line.

The main task of such systems is preventing image distortions caused by the change of an amplitude and a phase as well as an image leakage from one channel into another [1, 2]. The separation of signals should be perfect and the recovery of each signal should be performed without distortions. This aim can be achieved by a selection of appropriate filters that ensure a perfect image reconstruction in the receiver [3]. In many applications there has been a growing interest in reversible integer-to-integer filter banks. Signals are then invertible in a finite-precision arithmetic and map integers to integers. All calculations are provided without divisions to omit the rounding errors. Due to this property, transmultiplexers of such type have additional advantages, a small memory is needed and a complexity of computations can be low. Systems equipped with integer filters can be used to transmit not only images but also encrypted data, lossless compressed signals, computer software data, or other data where a change in even one single bit is inadmissible. Due to properties like these, there is a clear need to seek for reversible integer-to-integer filter banks.

Most of the modern telecommunications systems send information in packets and frames instead of predefined channels. Such techniques optimize the usage of physical devices and are especially efficient in the case of a bursty transmission, which is more and more common in the era of Internet. In such systems user data are split into packets that can be sent through different paths of the network. Grouping in frames or containers gives extra flexibility in introducing different services like television, Internet, and telephone communication in the same network and cooperating between different kinds of networks. In this sort of transmitting systems some packets can be lost or can be so much delayed that the system treats them as lost packets.

The goal of this paper is to find a serializations algorithm of a combined image which can reduce the error, caused by lost packets. The suitable data preprocessing should be independent on filters coefficients used to image transmultiplexing. The robustness of such services in which loss of the packet does not implicate the error for the whole block due to the coding is considered in this paper. Each packet contains independent information for a very small region of a combined 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 sought. Transmultiplexing is easy to apply because it needs only simple digital processing procedures: upsampling, filtering, and summing. It is easy to avoid delays even for slow transmitters and receivers. 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 fulfilling the perfect reconstruction condition. Another advantage is that combined signal is still an image. Due to this fact it may be easy to apply any image compression method.

Usually 1D instead of 2D filters are used to filter digital images. Such approach has several advantages, and two of them are the most important. Firstly, the design methods and sophisticated theory obtained for 1D signals can be easily adapted to an image processing. Secondly, each task possible to solve by applying the 2D filters can be realized in 1D techniques as well. These advantages encourage us to adapt the ideas developed for 1D transmultiplexer systems to image transmultiplexers.

The idea of transmultiplexing is based on multirate filter banks. Figure 1 shows the classical structure of the four-channel image transmultiplexer. The input images X_i in the ith channel are upsampled and filtered vertically and summed to obtain two combined subimages. These combined subimages are then upsampled and filtered horizontally and summed to obtain the final version of combined image CI. The luminance of the combined image may be calculated using the following formula, which includes both upsampling and digital filtering [3, 4]:

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

The order of 1D combination filters H_i^c is K, and their coefficients are indicated by $h_i^c \in \Re^{K+1}$. The operation $\lfloor\cdot\rfloor$ returns the greatest integer number equal to or less than the argument. Indexes' modifiers $p, q \in \{0, 1\}$ represent upsampling procedures during computations. In order to speed calculations up one should use different sorts of filter coefficients H_i^c. In the presented system the combined image consists of four times more pixels than each input image.

The combined image can be sent over a single transmission channel. At the receiver end, the signal is relayed first to two channels of the detransmultiplexation part, where the signals are filtered and downsampled horizontally. Then these signals are relayed to four channels where images are filtered and downsampled vertically to recover the original images. Pixels' luminance of output images Y_i can be computed applying the following formulas:

$$\begin{aligned}
Y_1(n,m)&=\sum_{k=0}^{K}\sum_{r=0}^{K} h_1^s(k,r)\cdot h_1^s(k,r)\cdot \mathrm{CI}(2n-k,2m-r),\\
Y_2(n,m)&=\sum_{k=0}^{K}\sum_{r=0}^{K} h_2^s(k,r)\cdot h_1^s(k,r)\cdot \mathrm{CI}(2n-k,2m-r),\\
Y_3(n,m)&=\sum_{k=0}^{K}\sum_{r=0}^{K} h_1^s(k,r)\cdot h_2^s(k,r)\cdot \mathrm{CI}(2n-k,2m-r),\\
Y_4(n,m)&=\sum_{k=0}^{K}\sum_{r=0}^{K} h_2^s(k,r)\cdot h_2^s(k,r)\cdot \mathrm{CI}(2n-k,2m-r).
\end{aligned} \tag{2}$$

Let the order of 1D separation filters H_i^s be K, and let their coefficients be indicated by $h_i^s \in \Re^{K+1}$. In some applications a memory organization and arithmetic's mnemonics, especially for FPGA devices, encourage designers to apply 2D data processing instead of 1D, that is, 2D convolution is more efficient in image processing than 1D convolution. 2D FIR filters P_{ij} may be directly calculated from 1D filters:

$$P_{ij}^{c,s}(k,r) = h_i^{c,s}(k)\cdot h_j^{c,s}(r), \tag{3}$$

where $k, r \in \{0, 1, \ldots, K\}$ and $i, j \in \{1, 2\}$ for the case of 4-channel image transmultiplexer. The necessary conditions for the perfect reconstruction need the first coefficients of separation filters h_i^s and the last coefficients of composition filters h_i^c to be equal to zero. This is why indexes k and r in the formula (2) may start from 1. It means that a two-dimensional convolution is based only on previous columns and previous rows. Additionally, in order to speed calculations up one should use shifting by 2 columns and 2 rows during the operation of two-dimensional convolution. The maximal number of nonzero 2D FIR coefficients is K^2.

3. FILTER DESING ALGORITHM

Designing a transmultiplexer system means determining such coefficients of H_i^c and H_i^s filters that fulfil the perfect reconstruction condition, that is, the equivalent luminance of input and output image has exactly the same value. The presented system contains linear and time-invariant elements. This facilitates mathematical modelling. Unfortunately, it is not an easy task to find a suitable bank of filters [5–7], although necessary and sufficient conditions given in the z-domain are known [8, 9]. It is needed to solve the bilinear equations, which result from the perfect reconstruction condition and the mathematical model of the transmultiplexer

Table 1: Coefficients 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

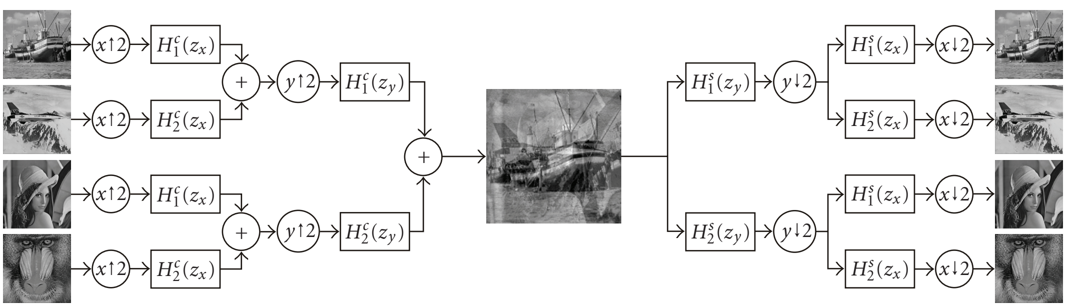


Figure 1: Scheme of 4-channel image transmultiplexer.

[3]. There are various possible methods to solve this issue. One can use numerical procedures to determine filter coefficients by minimizing an appropriate defined quantity criterion [6, 7]. Sometimes it is possible to obtain solutions for simple systems. In general, however, there are no known methods to solve the obtained set of equations. What is more, it is difficult even to examine the existence and the uniqueness of solutions. It is generally known that if filter orders are sufficiently large, there are solutions and there are many of them. The previous design methods (see, e.g., [5, 7]) created filters with real-value coefficients. The perfect reconstruction condition was fulfilled only theoretically because of the finite precision of digital calculations. Practically, output signals were a slightly different than input ones.

The presented algorithm was based on the method described in [3]. We assumed $M = 2$ (number of channels), $\tau = 1$ (delay), $K = 4$ (filter order) and

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

Taking into account the above assumptions, transmultiplexer filter coefficients were calculated applying the following algorithm.

(A) Assume an integer matrix

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

(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

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

(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) Define values of remaining filter coefficients

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

The obtained coefficient values of the combining filters H_i^c and the separation filters H_i^s for assumed integer matrixes G_1^c are presented in Table 1.

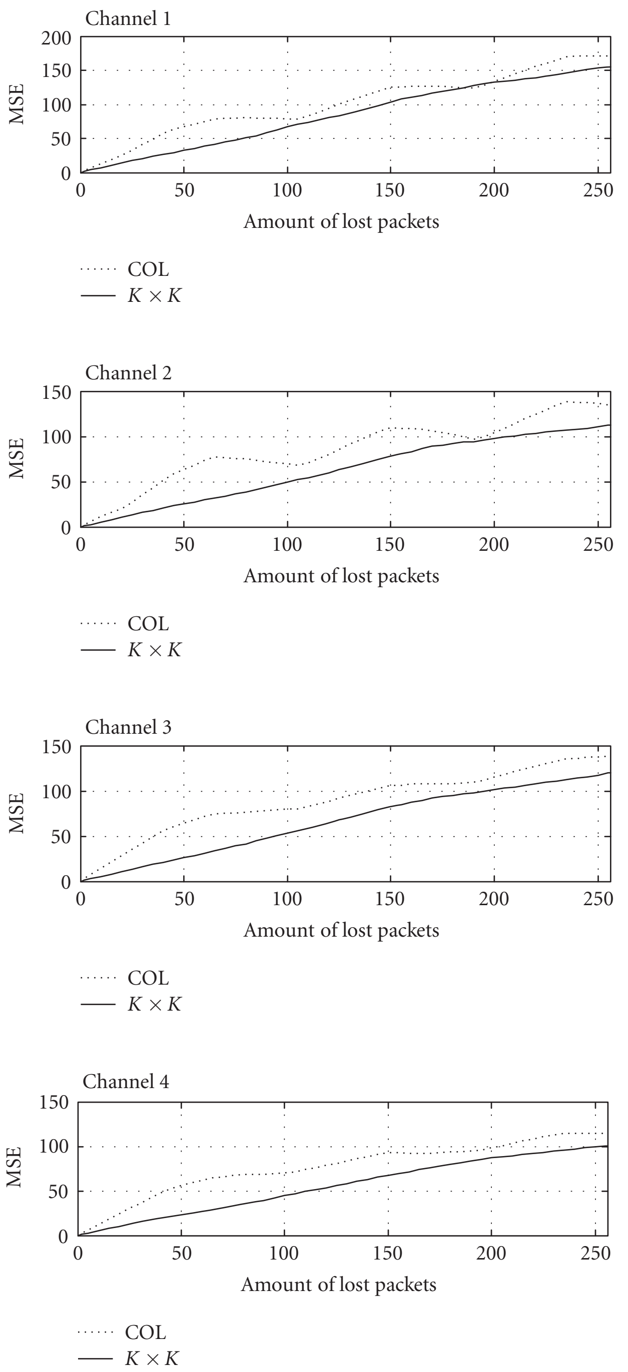


Figure 2: The relationship between the error and the amount of lost packets, continuous case.

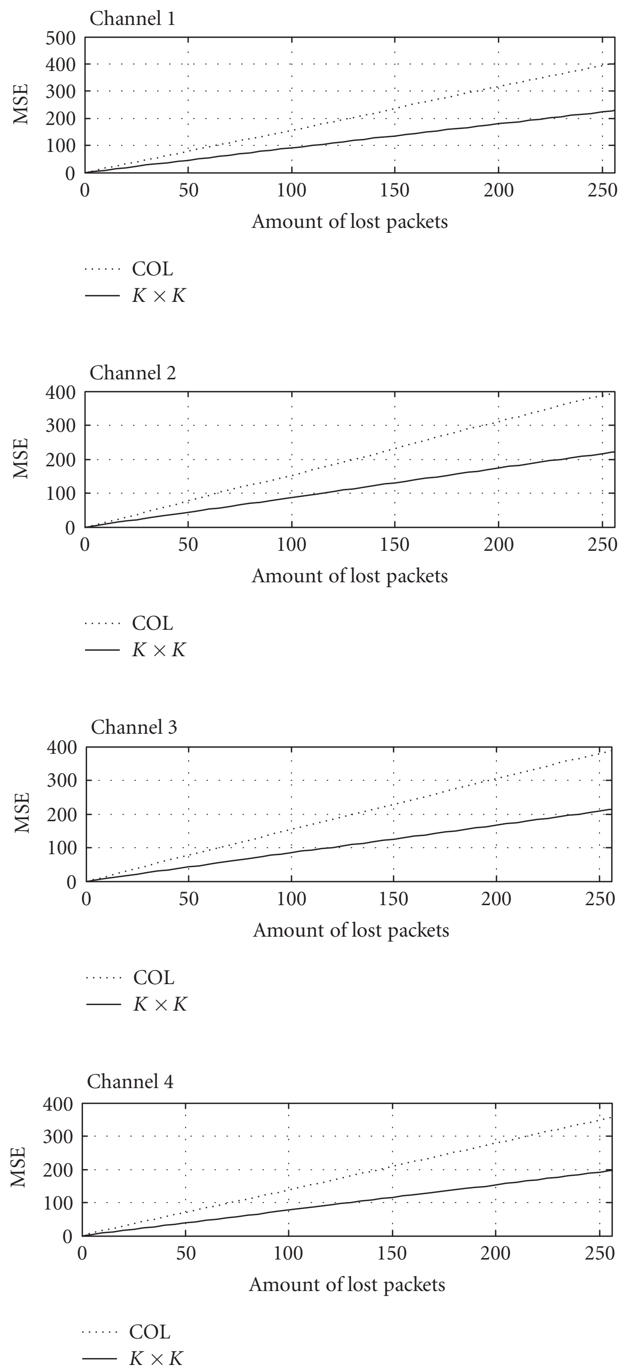


Figure 3: The relationship between the error and the amount of lost packets, random case.

4. PACKET TRANSMISSION

Asynchronous transfer mode (ATM) is a worldwide-deployed backbone technology. This standards-based transport medium is used within the core, at the access, and in the edge of telecommunications systems to send any kind of data at high speeds. ATM has been widely adopted because of its exceptional flexibility in supporting the broadest array of technologies in all over the world, including DSL, IP Ethernet, frame relay, SONET/SDH, and wireless platforms. Legacy equipment and the new generation of operating systems and platforms cooperate efficiently. ATM freely and easily communicates with both, allowing carriers to maximize their infrastructure investment. Data are sent in the packets with 48 bytes of user's information and 5 bytes of header information for routing and assembling [10, 11]. The same packet standard is in the distributed queue dual bus—access protocol for MAN networks.

5. ROBUSTNESS

To verify the properties of a transfer system some examples were analyzed. Four sets of test images [12]:

(i) boats, F-16, Lena, and baboon,
(ii) aerial, Barbra, couple, and frog,
(iii) bridge, man, peppers, and washsat,
(iv) golldhill, monarch, tank, and Zelda,

with 512×512 pixels resolution in 256 greyscale levels were selected for the analysis. Each set of reference images was transmultiplexed using each of designed filter banks (see Table 1). Sixteen combined images were calculated, each of them with resolution 1024×1024 pixels. Each packet consists of 48 bytes, which is equivalent to 24 records of 16-bit length, so each of combined images was divided into 43 691 packets.

Two cases of packet loss in transmission systems were considered: continuous (i.e., temporary) and random. In both cases up to 256 packets were lost, which is equivalent to the loss of 6 columns of the combined image (almost 0.3% of bitstream). One line (1024 pixels) is equivalent to 42.667 packets. Packets were removed starting from the centre of combined image. In random case packets were removed from all parts of combined image. Data from lost packets were filled by zeros. The mean square errors (MSE) were calculated and compared for transmitted signals.

The combined image can be serialized in many different ways before transmission. The standard method for images is the row or column order. The zig-zag order is used in some applications, especially to avoid the boundary effects. Due to 2D integer filtering the loss of pixels in the combined image usually causes that the result of 2D convolution does not fit into 8-bit resolution. In this case the reconstructed pixels take the extreme values of 0 or 255 and are clearly visible as an unpleasant "salt and pepper" noise. It may cause the rapid growth of the MSE. This is why, based on the mathematical model of detransmultiplexation (2), the data serialization before the transmission should be based on $K \times K$ blocks which are directly connected with the separation filter orders. In this case, the loss of packets leads to the lower number of wrongly calculated pixels in output images.

To provide simulations and tests in MATLAB environment, the column serialization was chosen (COL in Figures 2 and 3). Such choice does not influence the correctness of the analysis. It results from the properties of 2D convolution. Average values of calculated MSE for each combined image are presented in Figure 2 for the case of the continuous loss and in Figure 3 for the case of the random loss. In the considered case the loss of a single packet causes the wrong calculation of 26 pixels in output images. Meanwhile, in the case of $K \times K$ block serialization only 12 pixels are calculated wrongly. This situation is explained in Figure 4, the column serialization on the left-hand side and the $K \times K$ block-based serialization that on the right-hand side.

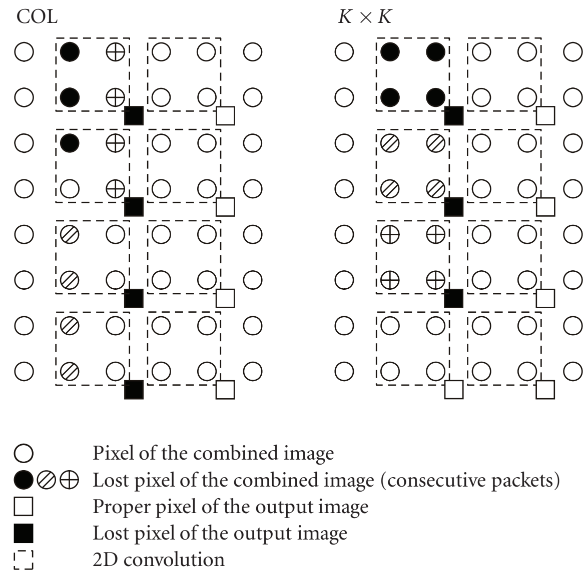


Figure 4: Scheme of lost pixels, 4 pixels per packet, $k = 2$.

The MSE for the column serialization in the case of the continuous loss of packets has unusual and interesting properties (see Figure 2). In some cases the increase of amount of the lost packets during transmission does not increase the MSE. The reason of such anomaly is presented in Figure 4. Lost pixels of the consecutive column of the combined image (denoted as circles with a plus sign) are within the same subsection of the two-dimensional convolution where others pixels have been lost before (denoted as circles with a cross). So the calculated pixel of an output image usually is out of the 8-bit range again, likewise it was before, and has to be marked as wrong (denoted as a black square). In the extreme case, the loss of all pixels in the range of size $K \times K$ may not cause the growth of MSE (see Figure 2, channel 1). But on the other hand increasing the amount of lost pixels within the subsection may cause that yet a wrongly calculated luminance would fit into the 8-bit resolution. In such situation it is possible to observe the reduction of MSE (see Figure 2, channel 2). These properties strongly depend on filter coefficients and contents of input images. In the case of serialization based on $K \times K$ blocks such phenomena does not exist.

The reduction of MSE in case of $K \times K$ block-based serialization is clearly seen in the case of a random loss of transmitted packets. Figure 5 presents the output images obtained in different channels in the extreme case of 256 lost packets.

6. CONCLUSIONS

The transmultiplexing system enables us to transmit a number of images through one common transmission channel. With appropriately selected filters for transmultiplexer and detransmultiplexer, images reconstructed from a combined image have no distortions. The main advantage lies in a great variety of realizations that are available by the proper digital filter design.

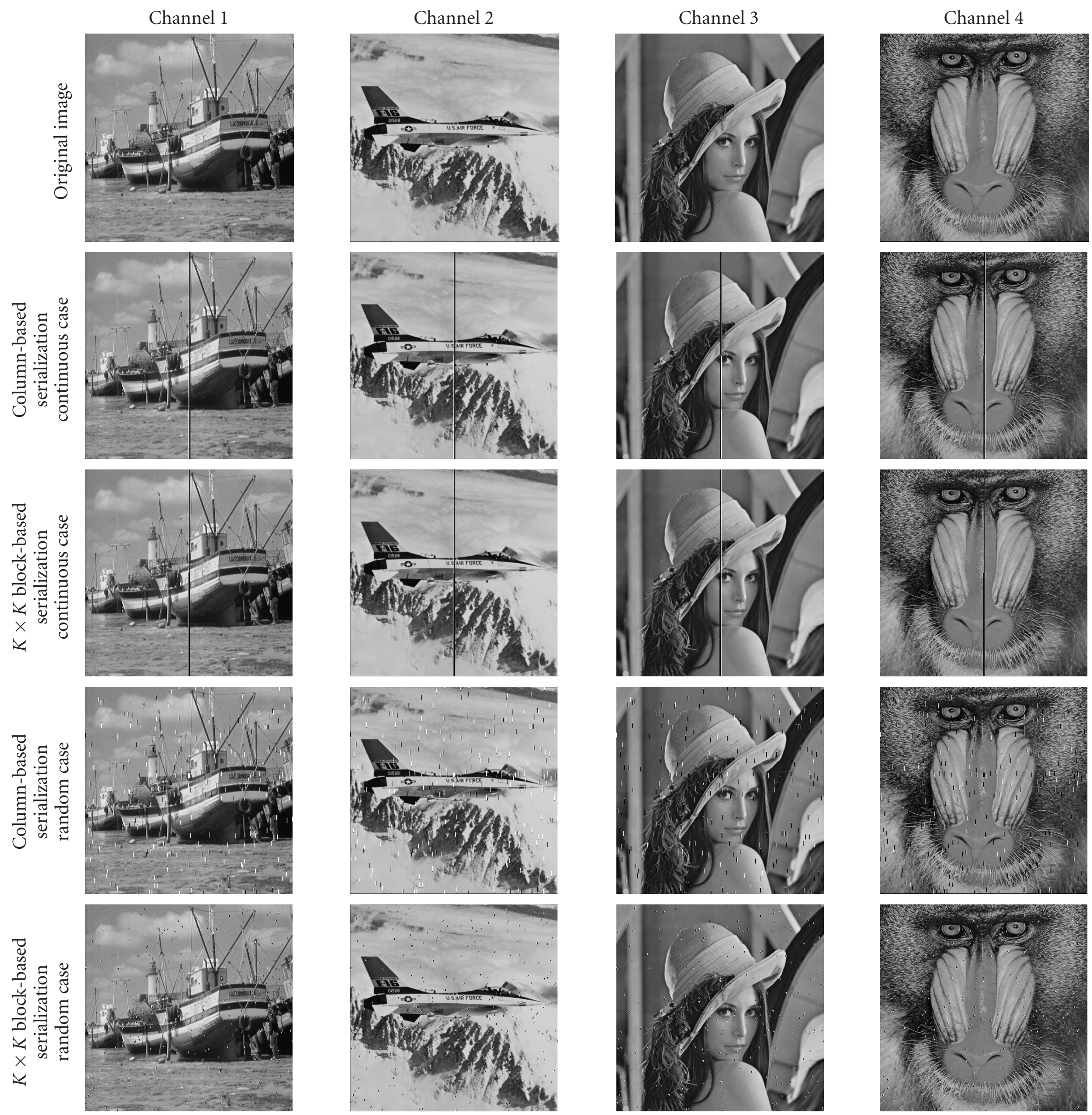


Figure 5: Comparison of images with 256 lost packets during transmission.

The proper data order can minimize errors under random or temporary loss of the combined image. The suitable data serialization before transmission causes the reduction of MSE for the case of a continuous and random packet loss of the combined image. Additionally the quality of output images may be improved by applying an appropriate filter, like for instance a median filter, to reduce the "salt and pepper" noise, which results on lost packets.

ACKNOWLEDGMENT

This work was supported by MNiSW under Grant 3 T11D 010 27.

REFERENCES

[1] N. J. Fliege, *Multirate Digital Signal Processing*, John Wiley & Sons, New York, NY, USA, 1994.

[2] P. P. Vaidyanathan, *Multirate System and Filter Banks*, Prentice-Hall, Eaglewood Cliffs, NJ, USA, 1993.

[3] P. Sypka, B. Ziółko, and M. Ziółko, "Integer-to-integer filters in image transmultiplexers," in *Proceedings of the 2nd International Symposium on Communications, Control and Signal Processing (ISCCSP '06)*, Marrakech, Morocco, March 2006, CD-ROM.

[4] P. Sypka, M. Ziółko, and B. Ziółko, "Lossless JPEG-base compression of transmultiplexed images," in *Proceedings of the 12th IEE Digital Signal Processing Workshop and the 4th Signal*

Processing Education Workshop (DSP/SPE '06), pp. 531–534, Teton National Park, Wyo, USA, September 2006.

[5] A. N. Akansu, P. Duhamel, X. Lin, and M. De Courville, "Orthogonal transmultiplexers in communication: a review," *IEEE Transactions on Signal Processing*, vol. 46, no. 4, pp. 979–995, 1998.

[6] T. Liu and T. Chen, "Design of multichannel nonuniform transmultiplexers using general building blocks," *IEEE Transactions on Signal Processing*, vol. 49, no. 1, pp. 91–99, 2001.

[7] T. Liu and T. Chen, "Optimal design of multi-channel transmultiplexers," *Signal Processing*, vol. 80, no. 10, pp. 2141–2149, 2000.

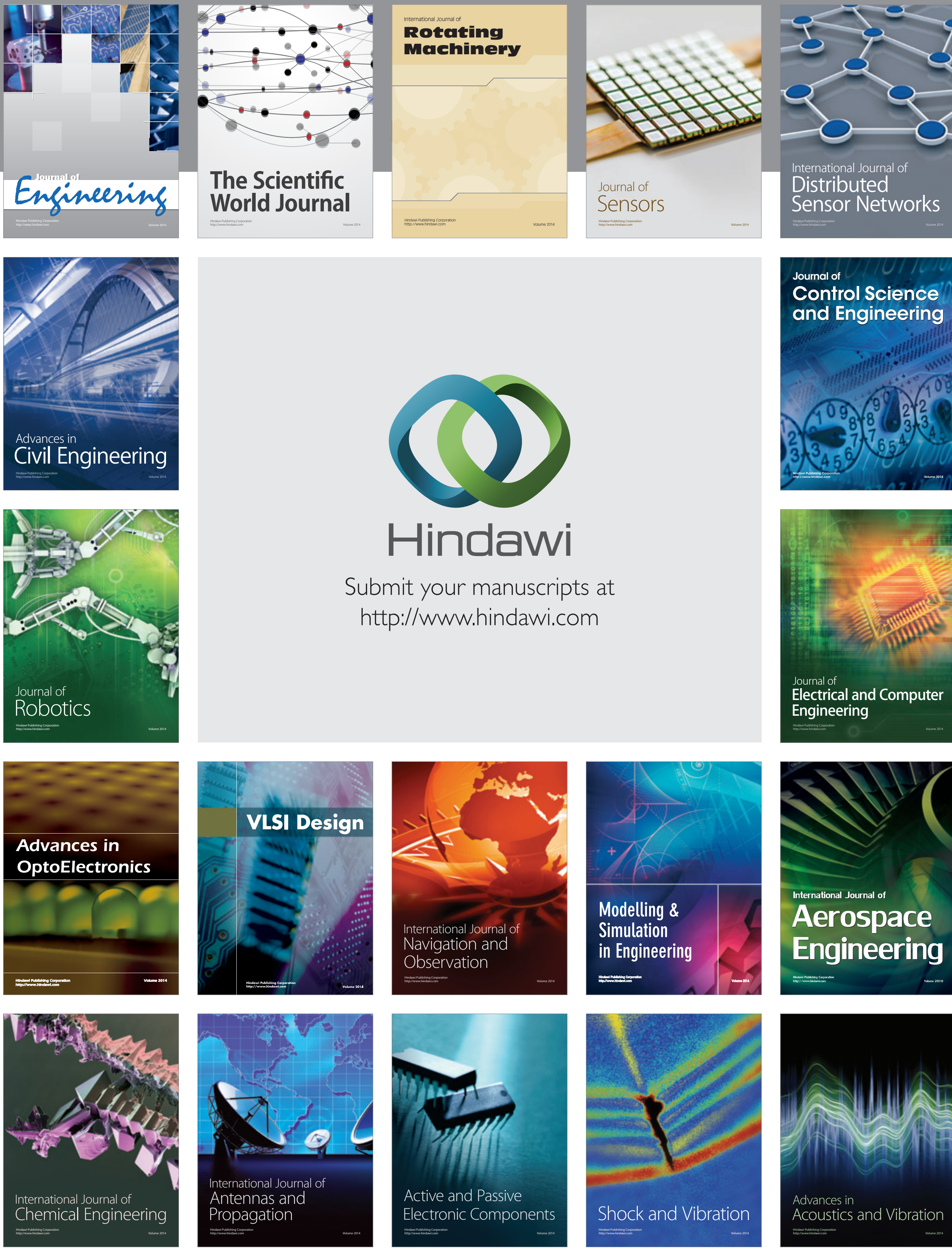
[8] M. Vetterli and J. Kovacevic, *Wavelets and Subband Coding*, Prentice-Hall, Eaglewood Cliffs, NJ, USA, 1997.

[9] P. P. Vaidyanathan, *Multirate System and Filter Banks*, Prentice-Hall, Eaglewood Cliffs, NJ, USA, 1993.

[10] H. Nassar and H. A. Mahdi, "Queueing analysis of an ATM multimedia multiplexer with non-pre-emptive priority," *IEE Proceedings Communications*, vol. 150, no. 3, pp. 189–196, 2003.

[11] U. Assmus, "Asynchronous transfer mode (ATM) signal transmission networks," *Fernseh-und Kino Technik*, vol. 58, no. 3, pp. 113–119, 2004.

[12] Reference images, University of Southern California, Signal & Image Processing Institute, Electrical Engineering Department, http://sipi.usc.edu/database/.


Journal of Engineering
The Scientific World Journal
International Journal of Rotating Machinery
Journal of Sensors
International Journal of Distributed Sensor Networks
Advances in Civil Engineering
Journal of Control Science and Engineering
Hindawi
Submit your manuscripts at
http://www.hindawi.com
Journal of Robotics
Journal of Electrical and Computer Engineering
Advances in OptoElectronics
VLSI Design
International Journal of Navigation and Observation
Modelling & Simulation in Engineering
International Journal of Aerospace Engineering
International Journal of Chemical Engineering
International Journal of Antennas and Propagation
Active and Passive Electronic Components
Shock and Vibration
Advances in Acoustics and Vibration