

PIXEL LEVEL INTERLEAVING SCHEMES FOR ROBUST IMAGE COMMUNICATION

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Abstract

Interleaving schemes have proven to be an important mechanism in reducing the effect of network errors on image transmission. Current interleaving schemes spatially de-correlate neighboring image blocks by putting them into packets that are far distant apart from each other in the transmission sequence. Most of the existing schemes while achieving good performance on random packet losses, do not work well in the case of bursty packet losses. In this paper, we propose two interleaving schemes where the de-correlation process is applied not only at a block level, but also at a pixel or coefficient level (that is, on the information within the blocks) in the compressed domain. The decorrelation is achieved via a k -way shuffle of pixels among the blocks and using the spatial properties of different space filling curves, k depends on the total number of blocks in the image. Our results show that despite of decorrelation of coefficients in the triangular interleaving scheme the compression ratio is within 92% to -98% of the JPEG standard compression. We also show that when comparing with the existing interleaving schemes, our techniques provide improved image quality and low mean square error in transmitted images in the presence of random as well as burst packet losses in networks.

1. Introduction

Image information loss and its recovery is still one of the biggest concern on today's digital communication networks. Network errors, which are mainly introduced in the form of packet loss due to network congestion, can have adverse impact on the image quality if no action is taken. Several approaches have been proposed in order to recover or at least ameliorate the effect of packet loss during data transmission [5]. Error Concealment (EC) with block interleaving is among the most important techniques. EC based techniques ex-

exploit the fact that neighboring blocks are highly correlated. Under this assumption, EC techniques attempt to fill in the corrupted area (lost block) by using information from adjacent error free blocks. When the lost area represents a large portion of the image information, the reconstruction process becomes inadequate [1]. In order to avoid this kind of situations, spatially correlated information has to be protected against random and burst packet loss by implicitly spreading the loss over relatively distant portions of the transmitted image rather than concentrating it in the same region. To facilitate the reconstruction of the transmitted image at the receivers location, it is necessary to establish a connection between the coding and packetization process with the error behavior of the network. In other words, packet should be organized in such a way that highly correlated blocks are being protected (according to the error model of the network). This means that neighboring blocks should not be put in the same packet or in P consecutive number of packets, so that packet information and information among successive packets are as much de-correlated as possible. The value P depends on the actual packet loss behavior of the network (the heavier the congestion, the bigger the number P). Since Internet is based on datagram delivery, which means that no bandwidth is reserved for specific connections. The capacity may be exceeded and queues within the network may grow until eventually are full, at which point packets will be dropped by the network. Once a packet has been randomly lost (because of the buffer overflow), it is likely that the next packet also be lost, especially if the inter-arrival time is less than the service time. Therefore, packet losses are correlated and might occur in burst. Correlated losses decrease effectiveness of the most of the existing error concealment techniques. For a detailed discussion on the packet loss and bit error behavior for the Internet, please refer to [2]. For ATM networks, the main source of error is lost cells due to network congestion and buffer overflow [3].

In exiting interleaving schemes, adjacent blocks (which in general are highly correlated) are inserted in different packets, so that packet information and information among successive packets is as much de-correlated as possible¹. This means that in the case of a packet loss during transmission, the probability that a missing block be surrounded by error free blocks is higher and the EC scheme can be more effective on the reconstruction process. Traditional interleaving schemes do a very good job in de-correlating packet information and block information, but once a packet is lost the whole block is also lost. The objective of this work is to provide an additional advantage to the these traditional block interleaving schemes by de-correlating the information inside the blocks, in such a way that, when a packet is lost, partial information about the lost block should be available at the receiver end. The EC techniques can be applied at the receiver to partially lost blocks. The main idea is to exchange information among neighboring blocks before the transmission into different and distant packets, protecting in this way the information against random as well as burst packet losses. If an error occurs, its effect is shared among neighboring blocks, so that we do not lose all the information inside the blocks neither we lose all the blocks around the neighborhood. The spatial de-correlation process within the blocks is applied in the frequency domain, i.e., after the block has been DCT-transformed and quantized. In this paper, we present the effect of these interleaving schemes on the compression ratio using different space filling curves.

In section 2, we describe the two methods for block information de-correlation, Triangular and Pixel interleaving. Section 3 analyzes the effect of the proposed interleaving schemes on the compression ratio, and presents some results of transmitted images under congestion. Finally conclusions are presented in Section 4.

2. Proposed Interleaving Scheme

In this section we describe the two interleaving schemes. The proposed interleaving schemes are fully compatible with the current JPEG image compression standard. This means that none of its original encoding steps are eliminated or altered in any way. The Interleaving scheme is only an additional step between the quantized DCT blocks and the variable length coding (VLC) process.

2.1. Triangular Interleaving (TRII)

In this scheme, two neighboring blocks exchange partial information (half of the DCT coefficients), and

¹We will refer to this scheme as block interleaving scheme in the rest of this paper.

are put as far as possible from each other during the packetization process. If one of them is lost during transmission half of the block can still be retrieved from the error free block. The interleaving scheme consists of the following steps:

- a An 8x8 block (after DCT-transformed and quantized) is diagonally divided in order to obtain two triangular components, the upper (U) and the lower (L) components (as shown in Figure 1). The main diagonal is added to the U, except for the DC term, which is treated as an independent entity. This data organization has the advantage that can be suitable for both ATM networks and Internet based on TCP/IP protocol. ATM networks have the advantage that priority levels can be assigned to different parts of the transmitted information, so that, highest priority is assigned to the DC term and equal treatment for the U and L components. In the case of Internet, if a user wants to assure that at least the DC terms arrive to the receiver error free, additional protection can added in the form of FEC or ARQ, otherwise it can be put in the L component and rely on EC techniques.

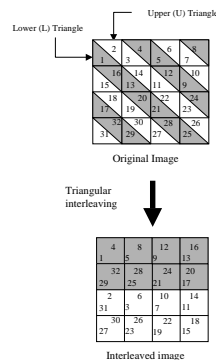


Figure 1. Triangular-block Interleaving Scheme.

- b After block diagonalization, a new set of blocks are created by bringing together the L triangle of the first block with the U triangle of the second block, the L of the third block with the U of the fourth block, and so on until we reach the end of the image following the row prime order scanning of the image blocks. This represents the first scan. The second scan starts by merging the L of the last block of the image with the U of the first block, then continuing in the same way as for the first scan. Other scanning methods can also be applied using space filling curves such as Cantor order, Peano-Hilbert-order, etc [4].
- c After interleaving the blocks, variable length code is then applied (Huffman code) followed by the packetization process. Packets are created differently base on to the type of network we are deal-

ing with. For ATM networks, additional information about which blocks are being sent within the packet must be considered for proper error detection. For the Internet we can use variable length packets, by sending a constant number of blocks per packet, so that the error detection algorithm can be based on the sequence number of the packets.

A very important thing to point out here is that every U and L belonging to the same block b_i are separated by K_i number of packets (K_i -de-correlated) for $1 \leq i \leq T_b$, where T_b is the total number of blocks in the image. Considering that K is a constant, one of the two things needs to happen for a block to be lost: a) Burst packet loss of size K+1. This represents a very congested situation where half of the image is being lost, or b) The packet containing the U and the one containing the L are randomly lost. If we consider uniform random loss, then the probability to lose one block is $1/K^2$ compared to $1/2K$ for the traditional interleaving scheme.

2.2. Pixel Interleaving

The pixel interleaving process is applied after the image blocks have been DCT transformed and quantized. The new blocks are created by taking one frequency pixel at a time from each block following the Cantor-order scanning of the image blocks. The main idea is to consider a group of blocks of size equal to the number of elements in a block, say k (in an 8x8 block, the group of is made of 64 blocks). We then perform a k -way shuffle of all the elements in the group of blocks by taking the first element from block 1, second element from block 2, and so on until we reach the block N. At this point we have created the first new block. We now take the second element from block 1, and continue in order until we reach the k th block again. This operation is done until we reach the last element of the first block. The above procedure is executed until all subgroups of size k in the image have been shuffled. After this procedure, the new blocks are Huffman coded and packetized. This technique totally de-correlates the elements within the blocks, where each block has only one previously owned element. To de-correlate blocks within a group, we use a variable block_offset during the packetization process. Blocks are taken block_offset distant apart, assuring that no important information of the same group is lost. One way to approximate the value of block_offset is by computing the average position of the last non-zero DCT-coefficient among all blocks and add a confident interval such that their sum is not greater than the maximum position of the last non-zero coefficient. For instance, we found that under compression ratio of 20 Barbara keeps an average number of coefficients of 2 per block, and a maximum non-zero DCT of 13, so a good block_offset might be equal to 7. The detection of errors at the receiver can

Triangular				
<i>Image/Compression Quality</i>	8	12	16	20
Lenna	94	94	94	94
Boats	97	96	96	96
Bridge	98	98	97	97
Pixel				
Lenna	85	84	84	83
Boats	86	86	87	87
Bridge	92	91	91	91

Table 1. The percentage of the compression ratio in the case of Triangular and Pixel based interleaving schemes compared to the compression ratio of the noninterleaved JPEG compressed image.

be done in a similar way as in the triangular interleaving.

3. Experimental Results

The proposed interleaving schemes were analyzed according to their compression efficiency and their capacity to naturally conceal network errors during transmission. JPEG standard compression was used as a basis to analyze the effect the proposed interleaving schemes on compression ratio. For the generation of the quantization tables, we used the approach proposed by [4]:

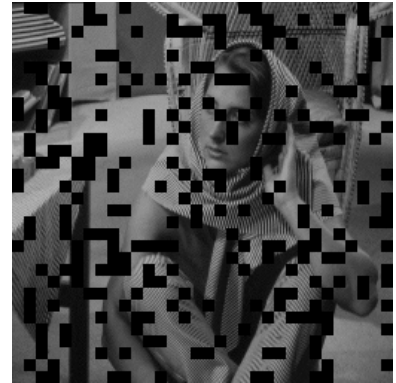
$$Q(i, j) = 1 + [(1 + I + j) * Quality]$$

where Quality specifies the quality factor, and its recommended range is from 1 (lowest compression) to 25 (highest compression). Compression results for both interleaving schemes (triangular and pixel) are shown in Table 1 for 3 different pictures Lenna, Boats, and Bridge. This result represents how much close these interleaved-compressed images are from the regular JPEG compression (no interleaving) for different compression ratios. In the case of triangular interleaving, we are between 93of the JPEG compression. For the pixel interleaving, compression efficiency is between the high eighties for the case of Lenna and Boats, and low nineties for the Bridge image. The mean square error for the block interleaving image is 2200 and for the triangular and pixel interleaved images it is 850.

To evaluate the performance of our interleaving schemes in a lossy network environment, we simulate the transmission of information under network errors in the form of random and burst packet loss. In Figure 2, 50% of the packets has been lost due to bursty losses in the network. Even though the mean square errors (MSE) are not significantly distinct (because missing black blocks were replaced by gray blocks), most of



(a)



(b)



(c)



(d)

Figure 2. a) Lenna image with 25% packets lost in bursts: a) no interleaving b) block interleaving scheme (MSE = 2200), c) triangular interleaving scheme (MSE = 877), d) pixel interleaving scheme (MSE = 843).

the damaged blocks in our interleaving schemes contain some of their original information. This characteristic is very important for later error concealment process at the receiver. The performance of the triangular and pixel interleaving schemes can be appreciated in a more realistic environment, where blocks are lost in a random as well as bursty way. Figure 3 show the results of the losses using block interleaving scheme. Figures 45 show the results of the triangular and pixel interleaving schemes. In the pixel-oriented schemes, we still have some important information (high frequency components) present in the majority of the damaged blocks. On the contrary, in the block interleaving scheme, large portions of the image have been totally lost. Application of EC techniques on this image, is a real challenge. The proposed interleaving schemes can be supportive for the reconstruction of information lost in the frequency domain. In the case of the triangular interleaving, if we lose only one block during transmission for instance, we know that at the decoder, this will be reflected in two neighboring blocks. In one of them the lower diagonal matrix will be absent, while in the other block, the upper diagonal. The idea is that they are missing complementary parts, and in the case of more information available from other neighbors, a good interpolation strategy can be applied to pick the best replacement for the missing part. For the pixel interleaving a similar approach specially for the lower frequency components might be applied on pixel to pixel basis.



Figure 3. Image quality when entire blocks are interleaved in the transmission sequence in the presence of of random and bursty losses.

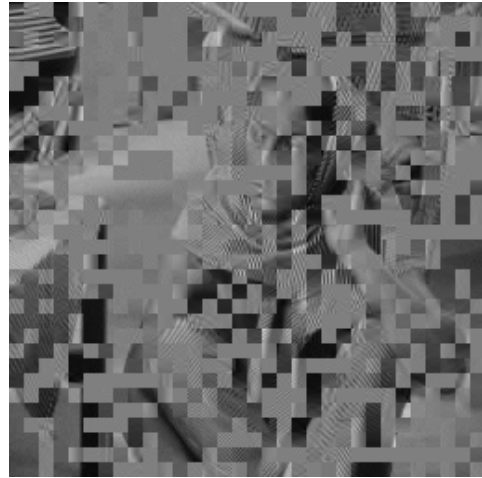


Figure 4. Image quality with triagular interleaving in the presence of of random and bursty losses.



Figure 5. Image quality with the pixel based interleaving in the presence of of random and bursty losses.

4. Conclusions

Two pixel-based interleaving schemes were proposed for de-correlating image information transmitted over a lossy networks. The interleaving schemes are applied in the frequency domain, after blocks have been DCT transformed and quantized. In spite of the pixel level interleaving process, good compression ratio are obtained, specially for the triangular interleaving. Our simulations reveal that under realistic network error conditions (randomly and burst packet loss), the proposed interleaving schemes are able to balance the effect of errors by distributing them along spatially uncorrelated pieces of information in the transmitted image. Under these schemes, received image blocks are likely to maintain some of their original information, making them a valuable tool for error concealment techniques.

References

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