ERROR RECOVERY IN JPEG2000 IMAGE TRANSMISSION

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ABSTRACT

In this paper, the problem of bit-errors recovery in JPEG2000 images transmission is addressed, with particular attention to errors in the high-frequency components. In the HL and LH sub-bands, differently from the LL band, interpolation based recovering results to be often ineffective when more than few adjacent wavelet coefficients are missing. The solution proposed is then to apply a wavelet patch repetition procedure by predicting the similitude between the contour structure in the damaged area and its surroundings. To this aim, the correlation in the *spatial structure*, that is the contour information, existing between different sub-bands has been analyzed and exploited. Accordingly, the patch used to conceal the corrupted region is that obtained by minimizing a correlation measure with the spatial structure extracted from an adjacent not corrupted sub-band. Objective and subjective improvements have been obtained.

1. INTRODUCTION

Visual data are the heavily used in a wide range of applications, spanning from home entertainment to industrial systems. In the next future the new multimedia application will be the "mobile entertainment", that will be possible thanks to the introduction of the new 3G mobile system, solving the problems relevant to the bandwidths necessary for the transmission. However, a major point is to prevent quality degradation and decoding synchronization problems due to bit-errors during transmission.

In this framework, the new standard JPEG2000 will be of fundamental importance. It will be quite soon issued by the ISO/ITU-T standardization committees as the future standard for compression of still images. It is based on the discrete wavelet transform (DWT), scalar quantization, context modeling, arithmetic coding and post-compression rate allocation. Effort has been made to make this new standard suitable for today and tomorrow applications by providing features unavailable in previous standards, but also by bringing the bitstream more resilient to bit-errors and data losses. The entropy coding is done in blocks, typically 32x32 or 64x64 at the original image resolution (dimensions halved for each sub-band decomposition level). Segments from various blocks of a sub-band are collected into a packet and preceded by a resynchronization packet header that enables the decoder to reestablish block synchronization when bit errors occur within the packet body. Then, bit-errors in the packet body results with the loss of some wavelet coefficients relevant to a code-block in the affected sub-band [1]. When the SNR scalability feature is used, the error does not integrally affect the coefficients, but only the relevant bitplane and the subsequent that are then useless [2].

To combat these problems, appropriate ARQ techniques can be sometimes applied in image transmission, since no real-time constraints are usually present, except in broadcast transmission where the required backward link to the sender is usually not available. Then, in this configuration an efficient error concealment technique can be quite useful in order to improve the signal quality.

The effects of errors depend on which sub-band is damaged. In particular, if errors are located in the LL band, then a heavy visual degradation is perceived in the decoded image. On the other hand, error recovery can take advantage of efficient and well-known techniques developed for error recovery in block based image coding standards [3]. In fact, the LL band can be considered like a sub-sampled version of the original image and recovery techniques for smooth image perform well.

On the contrary, errors in the high-frequency components heavily affect the image quality and the recovering is a quite difficult task. In fact, interpolation techniques in the wavelet domain (but also in the spatial domain) have proved to be ineffective, in the case the damaged area involves more than few adjacent wavelet coefficients. To solve this problem, we then propose a concealment algorithm based on the recovery of the missing wavelet coefficient by means of an appropriate coefficients patch repetition strategy. The basic idea is to select appropriate wavelet patterns from the damaged area surroundings, using some prediction rules based on the structure (contour geometry) of this area. To this aim, the correlation in the spatial structure between different sub-bands is exploited.

2. PROPOSED CONCEALMENT

A certain amount of spatial correlation can be observed in the HL and LH sub-bands along the low-pass direction. Based on that, in [4] isolated coefficient losses are recovered by a liner interpolation of the two available adjacent coefficients along the low pass direction. The one-step correlation factor is in fact about 0.5, justifying this approach. At greater distance the spatial correlation rapidly decreases bringing difficult the coefficients recovery in more than two-coefficients-wide areas. Then, in greater regions recovering, we propose to exploit also the correlation between adjacent sub-bands, together with the spatial correlation. Since also in this case the correlation is weak, we suppose that at least a correlation in the spatial structure (that is the contour geometry) is present between equivalent areas (same spatial position) in adjacent sub-bands. Based on that we developed two distinct concealment techniques.

2.1. Patch repetition and deformation (PRD)

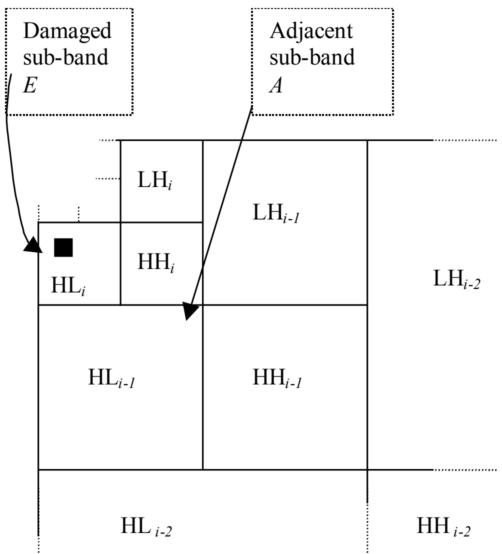

Fig. 1. Damaged and adjacent sub-bands *E* and *A*.

Let consider two adjacent sub-bands, such as those in the same decomposition level $LH_i \leftrightarrow HL_i$ or those in different ones $LH_i \leftrightarrow LH_{i-1}$ or $HL_i \leftrightarrow HL_{i-1}$. In order to analyse the *spatial structure* correlation between such bands, a first thresholding of the wavelet coefficient values is performed, then the similitude in the resulting contours is evaluated block by block (blocks of 4x4 coefficients have been considered). Taking two blocks in the two bands in the same position, the number of matching contour pixels is computed and divided by the maximum number of contour pixels in the two blocks. The relevant correlation measure is the following:

$$\rho = \frac{\sum_i p_i}{\max(p_a, p_e)}, \quad (1)$$

where p_i is the number of matching contour pixels in the two blocks, and p_e and p_a is the number of contour pixels in the two blocks.

From several experiments, the maximum correlation has been found for the bands couples $LH_i \leftrightarrow LH_{i-1}$ or $HL_i \leftrightarrow HL_{i-1}$. Table I shows the resulting correlation factors for the images “Lenna”, “Peppers”, “Porec” and “Test”. The first two images are well-know natural images, while the others belong to the JPEG2000 test set. The correlation factor has been found always greater than 0.75, meaning a significant structure inter-band correlation.

Table I. Spatial structure inter-band correlation ($LH_i \leftrightarrow LH_{i-1}$ or $HL_i \leftrightarrow HL_{i-1}$) factor (ρ) relevant to four test images.

Image	ρ
Lenna	0.76
Carmen	0.85
Porec	0.83
Test	0.78

In the concealment framework, let then consider the damaged sub-band *E* and the adjacent *A*, as shown in Fig. 1. The aim is to find a wavelet pattern $S_{E,opt}$, in the surroundings of the damaged area, that is the most similar in terms of spatial structure to the lost one B_E. Accordingly, we named the corresponding blocks (those relevant to the same image area) in *A* as $S_{A,opt}$ and B_A, respectively. The selection procedure is performed by searching for the S_A block ($S_{A,opt}$) that presents the maximum structure correlation with block B_A. Once it has been found the corresponding block in the damaged sub-band is used for the concealment:

$$S_{E,opt} \leftarrow S_{A,opt} \quad \text{where} \quad S_{A,opt} : \max_{S_A \in W}(\text{corr}(S_A; B_A)), \quad (2)$$

where *W* is the area surrounding B_A used for the search of $S_{A,opt}$, and corr(*x*,*y*) function computes the structure correlation between blocks *x* and *y*. A typical size of *W* is three times the dimension of B_A. If more than one $S_{A,opt}$ exists, then the one that minimizes the MSE with B_A is selected.

The steps performed in the concealment procedure can be summarized as follows (see Fig. 2):

- Extraction of the contour structure in the sub-band *A* within the area *W* (wavelet coefficient thresholding);

- Search for the block in W with the maximum structure correlation with B_A. If more than one has been found, that minimizing the MSE measure with the B_A is selected;
- Get the corresponding bock in the E;
- The selected block is then deformed;
- The deformed block is used to conceal the error.

The deformation procedure is performed by comparing the wavelet coefficient values in B_A with that located in $S_{A,opt}$. If the difference is greater than an appropriate threshold, then the coefficients in the same position in block $S_{E,opt}$ are set to zero. In this way we exploit again the correlation between the two different sub-bands.

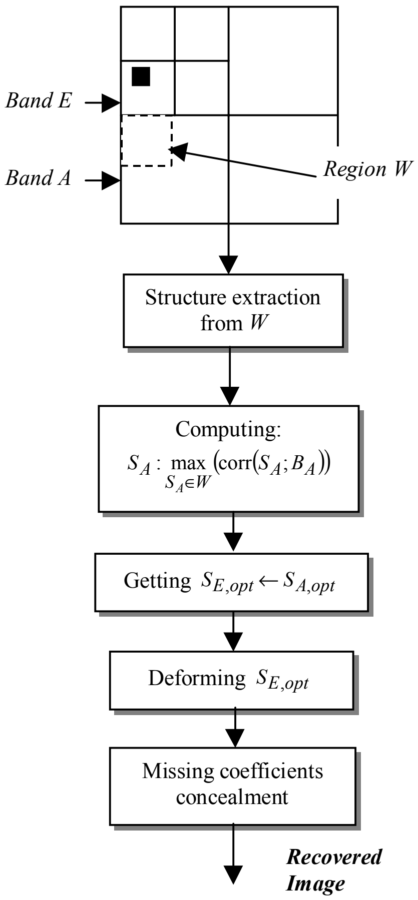

Fig. 2. Scheme of the PRD concealment algorithm.

2.2. Contour propagation (CP)

The proposed approach is based on the *smoothness of the edges*: natural object's contours show a slow direction variation (continuity and low values of the curve derivatives). Based on this propriety, it is highly likelihood that a contour ending in the border of the damaged area continues inside the block, maintaining approximately the same direction. Based on that, we exploit the information in the adjacent band $LH_i \leftrightarrow HL_i$ in order to exstimate the direction of the contour gradient in the external border of the lost area. In particular, the gradient is computed as the *arctg* of the ratio of the HL_i coefficient with the LH_i one. The direction of the gradient is then quantized in eight main directions, as shown in Fig. 3(a).

For each lost wavelet coefficient in the internal perimeter, the three adjacent positions d_i in the surrounding are considered. Then, those of d_i where the relevant computed edge direction points to the missing coefficient position are used for the concealment. In particular, that with the maximum gradient is propagated into the missing coefficient position.

Figure 3(b), shows the coefficients considered in the recovery of each missing coefficient in the internal missing block perimeter. Once the internal perimeter has been recovered, then the same procedure is performed again. This time the inner missing perimeter is considered for the recovering.

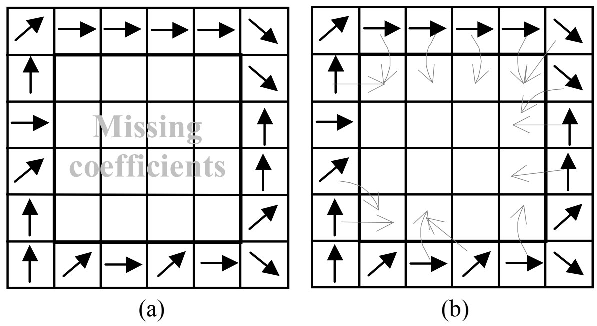

Fig. 3. (a) missing coefficients block and external perimeter with gradient direction; (b) propagation of the gradient from the external perimeter to the internal one.

4. EXPERIMENTS

The proposed methods were tested with several pictures, characterized by different resolution and complexity. Simulations were performed on gray level images, while the extension to color images can be simply achieved by operating on luminance and chrominance information separately. The results presented in this paper include the following pictures: "Lenna", "Peppers", "Porec" and "Test" with a dimension of 256x256 pixels. The first two images are well-know natural images, while the others belong to the JPEG test set. The "Porec" image is a landscape with a written *porec* in foreground, while the "Test" image is a compound document composed of text, photographs, and computer graphics. During the experiments we used three and four decomposition levels, with code-blocks of 32x32 pixels. The concealment was performed on the HL and LH sub-bands in the last decomposition level, since they are the most important after the LL band. The losses were simulated by deleting the 4x4 blocks of in the last decomposition level, for a loss rate of approximately 12,8%.

Fig. 4 compares the resulting PSNR for the corrupted images and those obtained by applying the proposed concealment algorithms. The MSE was computed respect to the JPEG2000 coded image without errors at about 3 bpp. It results that both the methods allow to obtain significant improvements, with better results with the CP method. In fact, with this method we obtained an improvement of about 2 dB, while with the other the improvement was of 1 dB. This can be justified by the fact that even if a significant inter-band correlation exists on different decomposition levels, it is not always possible to find a similar wavelet patch in the surroundings of the damaged block. This is in accordance with the low spatial correlation found in the wavelet high-frequency bands.

In Fig. 5, it is shown the average PSNR obtained with all the four test images varying the dimension of the lost coefficients while the loss percentage was left to 12,8%. It results that in greater missing blocks the benefits of the concealment decreases, due to the decrease of the spatial correlation. It results that it is not convenient to apply the concealment if the damaged area is greater or equal to that of 8x8 block.

4. CONCLUSIONS

Two new concealment techniques have been presented, aimed at restoring the lost high-frequency visual information in the transmission of JPEG2000 coded images over unreliable networks. The approach proposed is based on jointly exploiting the intra- and inter-band correlation. In the first technique the structure inter-band correlation is used to select a wavelet patch in the area surrounding the missing block, while the second approach is based on propagating contour information within the missing block. The experiments showed that proposed techniques allow to significantly improving the video quality.

5. REFERENCES

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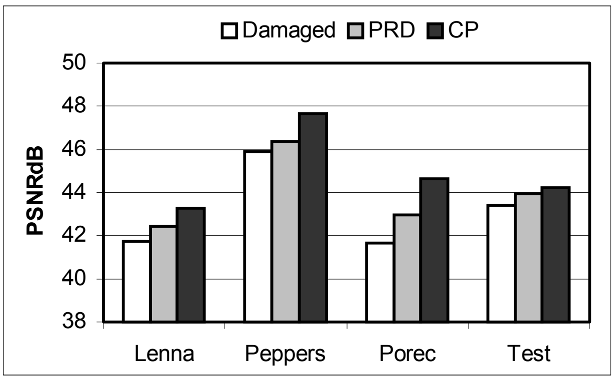

Fig. 4. Objective results for the proposed techniques with four test images.

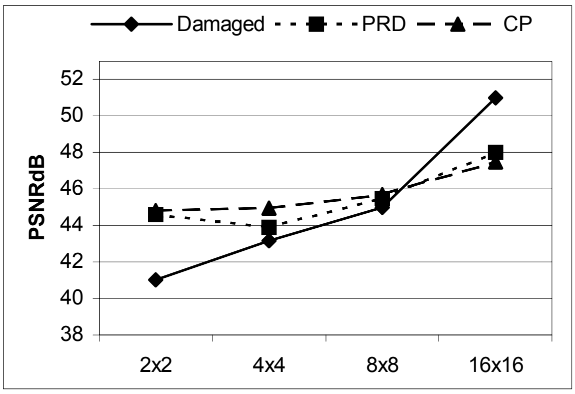

Fig. 5. Objective results for the proposed techniques varying the dimension of the missing coefficient area.