Adaptive Spatial Concealment of Damaged Coded Images

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Abstract. The transmission over error-prone networks of still images or videos coded by block-based techniques like JPEG and MPEG respectively, may lead to block loss degrading, particularly the visual quality of images. Working under this environment, such as wireless communication where retransmission may be not feasible, application of error concealment techniques is consequently required to reduce degradation caused by the missing information. This paper surveys algorithms for spatial error concealment and proposes an adaptive and effective method based on edge analysis that performs well in current situations where significant loss of information is present and the data of the past reference images are not also available. The proposed method and the reviewed algorithms were implemented, tested and compared. Experimental results show that the proposed approach outperforms existing methods by up to 8.6 dB on average.

Keywords: Image, spatial error concealment, video, directional interpolation.

1 Introduction

When data is being sent from one source to any receiver, there are some factors that can affect the original signal, such as noise disturbance, shadowing or network node congestion [1]. This may lead to loss of information. Therefore, application of error concealment technique is required if no retransmission is possible. Error concealment (EC) techniques for compressed image or video attempt to exploit correctly received information to recover corrupted regions that are lost. These techniques can enhance the perceptual quality of video on the receiver side. Indeed, the main idea of error concealment is to utilize neighboring correctly received data of the current frame or the reference frame to recover the corrupted regions. There are three main classes of these techniques; spatial, temporal, and hybrid (spatial/temporal) [2,3]. In this work, spatial techniques are only treated.

Several spatial error concealment algorithms restoring missing blocks from surrounding correctly received blocks in the same image have been proposed [4-14]. Most of these conventional approaches consider the eight neighboring blocks availability (fig. 1) for suitable operation and performance. However, one problem

J.A. Carrasco-Ochoa et al. (Eds.): MCPR 2012, LNCS 7329, pp. 94–106, 2012.

derived from this is that these methods cannot work well, especially over high burst error condition since a great of neighboring information have been corrupted or lost. This has therefore prompted the needed to design new error concealment methods or improve the existing ones, which allow a suitable quality image reconstruction over bursty error environments, such as current wireless communication systems. Thus, in this paper we propose an adaptive and effective spatial EC method based on edge analysis that performs well in situations where significant loss of information is present and the data of the past reference images are not also available. The idea is then that this method can alleviate the disadvantages of the conventional methods effectively and provide better performance considering the critical situation of having at least one neighbor of the considered lost or corrupted block.

The remainder of this paper is organized as follows. Section 2 reviews existing spatial error concealment schemes used in H.264 decoders; in section 3 discusses the proposed new method. Implementation, results and discussion are presented in section 4. Finally, in section 5, we draw discussion and give suggestions for future work.

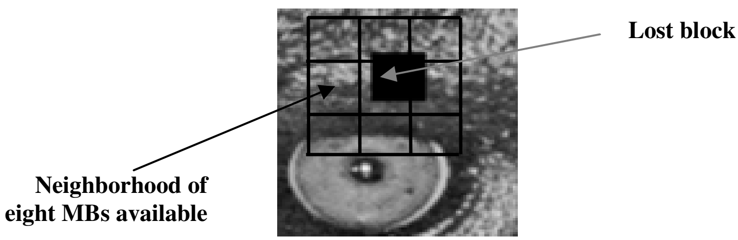
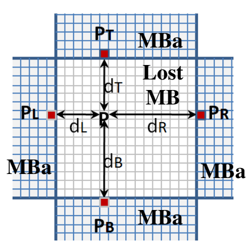


Fig. 1. Lost block with its neighboring MBs

2 Spatial Error Concealment Methods

2.1 Weighted Average Approach in H.264 Decoder

This spatial error concealment technique is proposed in [15] as a non-normative algorithm in the H.264/AVC standard [1,3,16,17]. It uses weighted averaging interpolation (WAI) of four pixel values located at vertically and horizontally neighboring boundaries of a damaged macroblock (MB) consisting usually of 16x16 pixels.



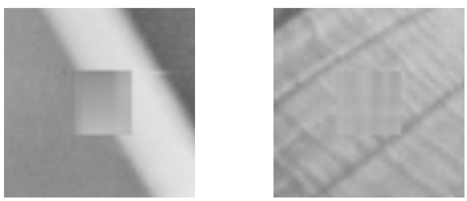
MBa: MB available

Fig. 2. Weighted Averaging Interpolation technique

As shown in Fig. 2, a pixel value in a damaged or lost MB is replaced with the weighted average of the four boundary pixel values located at the top, bottom, left, and right sides, where P indicates a pixel value in a damaged MB, P_T , P_B and P_L , P_R are vertically and horizontally neighboring boundary pixels values, and d_L , d_R , d_T ,d_B indicate the distance between the interpolated pixel. Therefore, the reconstructed pixel value using WAI can be formulated as following:

$$P = \frac{P_R d_L + P_L d_R + P_T d_B + P_B d_T}{d_L + d_R + d_B + d_T} \quad (1)$$

The original WAI's method assumes that the top, bottom, left and right MBs are usually available to apply error concealment process. However, it may be not true for some applications. For instance, in the H.264/AVC decoder standard, the WAI's method applied for intra-frames [16,18] works if at least two neighboring MBs in the horizontal or vertical direction are correct or already concealed. However, one major drawback is that this method does not consider the edge characteristics of images. Thus, this method is relatively effective in the region that has no edge (flat region), whereas it causes noticeable visual degradation in the region including the edges. We can see some examples of this problem in Fig. 3.



a) b)

Fig. 3. a) WAI's method applied to region with an edge. b) WAI's method applied to region with multiple edges.

2.2 Directional Interpolation Approach

The Direction Interpolation (DI) is a spatial error concealment technique proposed by [19] which uses local geometric information extracted from the surroundings to detect edge components. Sobel gradient filter is employed to detect the edge in a simple and fast way. It has perfect performance in edge detection and noise restraining.

Considering a region R of correctly received pixels surrounding the missing MB (see fig.4), the gradient is computed by convolving the f (i, j) pixel in R with Sobel digital masks:

$$S_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \qquad S_y = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} \quad (2)$$

For each f (i, j) pixel, the gradient vector G of pixel is presented with two elements, horizontal gradient g_x and vertical gradient g_y. They are defined as following:

$$g_y = f_{i-1,j+1} - f_{i-1,j-1} + 2f_{i,j+1} - 2f_{i,j-1} + f_{i+1,j+1} - f_{i+1,j-1}\,, \quad \forall\{Bk \in R\} \quad (3)$$

$$g_x = f_{i+1,j-1} - f_{i-1,j-1} + 2f_{i+1,j} - 2f_{i-1,j} + f_{i+1,j+1} - f_{i-1,j+1}\,, \quad \forall\{Bk \in R\} \quad (4)$$

where

$$Bk = \sum_{i}^{M}\sum_{j}^{N} f(i,j)\,, \quad \{i,j \in R\}, k = \{0,1,\ldots,7\} \quad (5)$$

Its magnitude and angular direction are given by

$$G = \sqrt{g_x^2 + g_y^2} \qquad \theta = \tan^{-1}\left({g_x}/{g_y}\right) \quad (6)$$

The value of the gradient angle is rounded to the nearest 22.5° and thus corresponds to one of eight directional categories equally spaced around 180°. There are counters for each of the eight directions, D0 through D7. A voting system is applied to increase the selected category counter by the magnitude of the gradient if a line drawn through the pixel with coordinates (i,j) and angular direction θ which passes through the missing MB.

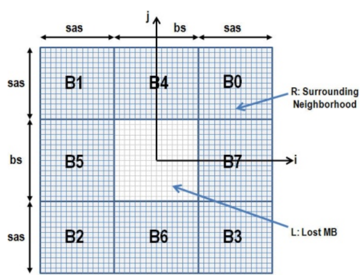
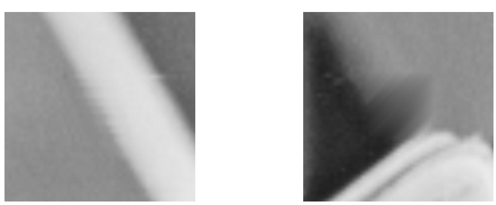


Fig. 4. Missing MB with surrounding neighborhood with texture information

The DI's algorithm of W. Kwok and H. Sun [19], presupposes, as does WAI's method, that all eight neighboring MBs are usually available to apply error concealment process over the damage MB. Considering this assumption, the DI's method can have good performance if there is only a dominant edge orientation in the considered region. However, it causes noticeable visual degradation in the region when multiple edges are present or when the resulting dominant edge orientation is slightly different of each MB of the considered region. In Fig. 5, we can see this problem.



a) b)

Fig. 5. a) Region area with one dominant edge orientation. b) Region area with more than one dominant edge.

3 Proposed Method Based on Edge Analysis

The DI's method which is applied for intra-frames [10,19], takes all eight surrounding MBs, as above was mentioned, to restore the lost one. If any of the neighboring MBs is not correctly received, the DI's method doesn't perform well, as we can see in the figures 6.

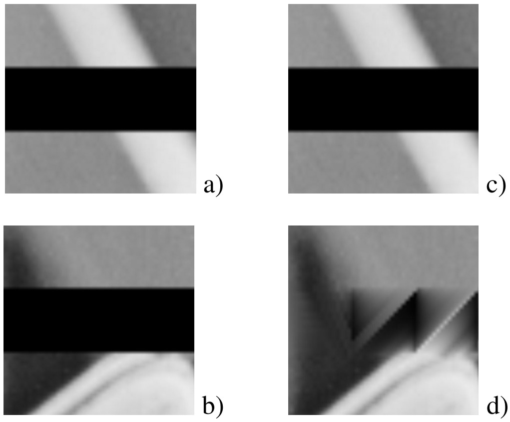


Fig. 6. a-b) Two MBs incorrectly received. c-d) EC applying DI's method.

To alleviate the disadvantages of the DI's method effectively and provide better performance considering critical situations as having at least one neighbor of the considered lost or corrupted MB, we focus on the challenge of providing the necessary conditions to correctly estimate the edge direction and to suitably reconstruct the damaged MB with minimal information.

3.1 Computing Edge Direction

The edge direction of the lost MB is estimated considering only the neighboring correctly received MBs (region R) as it shown in figure 4. Similarly, the gradient is computed convolving the pixels from region R with Sobel filter (eq. 2). Then the local edge gradient components for each pixel f(i,j) correctly received (region R) is computed by equations (3) and (4). This means $\{Bk \neq 0\}$. The magnitude and angular direction are given by computing equation (5). The direction of the surviving gradient is quantized in steps corresponding to a 22.5°. The voting mechanism only takes into account those pixels at (i,j) which belong to the correctly received MBs. This is described by the following pseudo-code

```
DO [∀ f(i,j) pixel coordinates in R, where {Bk∈R , Bk≠0}] {
     If [line drawn through f(i,j) with angle θ intersects L ] {      (7)
          Dk = Dk + G;   }    }
```

After all the pixels in the surrounding neighborhood have "voted", the counter containing the largest value determines which direction to use in the interpolation.

$$k_{max} = arg\max_{k}(D_k) \tag{8}$$

3.2 MB Reconstruction Using Adaptive Interpolation

In order to compute the dominant edge of the region R, a series of one-dimensional linear interpolations are carried out along the direction to obtain the pixel of the lost MB. If a projective line, representing dominant angular direction, passes through the pixels around the border of the horizontal MBs (B5,B7) and/or vertical MBs (B4,B6) which have not been correctly received or concealed, then the closest correctly received MB to the considered lost MB (L), is selected instead. For instance, a dominant angular direction of 0° is shown in figure 7. For the pixel p(x,y) belonging to the lost MB, the dominant angular direction edgDir of R passes the boundary pixels of MBs B5 and B7, then MB B5 will be selected to replace B7 (fig. 7a). Similarly, under the same principle, in fig. 7b, MB B7 will replace B5. If MBs B5 and B7 are incorrectly received, then the algorithm will find the closest neighboring MB for each one from B1,B2,B0 and B3 (fig.7c). This method promotes efficiency in the condition that horizontal, vertical and diagonals neighbors are not available.

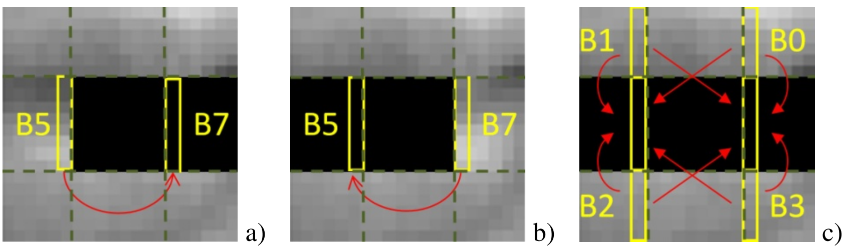


Fig. 7. Adaptive interpolation of the lost MB

The following represents, in generic form, the interpolation process to obtain the pixel values of the lost MB taking into account only those MBs which have been correctly received or concealed:

For **angular direction 0°:**

$$p(x,y) = \frac{f_{(i,j)}^{D5} \times Distant_{(i,j)}^{D7} + f_{(i,j)}^{D7} \times Distant_{(i,j)}^{D5}}{Distant_{(i,j)}^{D5} + Distant_{(i,j)}^{D7}}, \quad \begin{cases} (x,y) \in lost\ intra\ MB \\ B5 \neq 0, B7 \neq 0 \end{cases} \tag{9}$$

where $f_{(i,j)}$ is the estimated pixel and $Distant_{(x,y)}$ is the distance between the estimated pixel and the missing one $y(x,y)$.

When any of the horizontal neighboring MBs to the lost MB (L) is incorrectly received, the following equations are evaluated:

$$p(x,y) = f_{(i,j)}^{D5}, \quad \begin{cases} (x,y) \in lost\ intra\ MB \\ B5 \neq 0, B7 = 0 \end{cases} \tag{10}$$

$$p(x,y) = f_{(i,j)}^{D7}, \quad \begin{cases} (x,y) \in lost\ intra\ MB \\ B5 = 0, B7 \neq 0 \end{cases} \tag{11}$$

When both of the horizontal neighboring MBs to the lost MB (L) are incorrectly received, the following equation is evaluated:

$$p(x,y) = \min_{(i,j)\in N} Dist\left(f_{(i,j)} \rightarrow p_{(x,y)}\right), \quad \begin{cases} (x,y) \in lost\ intra\ MB \\ N = \{B1, B2, B0, B3\}, \forall B_i \neq 0 \end{cases} \tag{12}$$

For **angular direction 90°:**

$$p(x,y) = \frac{f_{(i,j)}^{D4} \times Distant_{(i,j)}^{D6} + f_{(i,j)}^{D6} \times Distant_{(i,j)}^{D4}}{Distant_{(i,j)}^{D4} + Distant_{(i,j)}^{D6}} \ , \quad \begin{cases} (x,y) \in lost\ intra\ MB \\ B4 \neq 0\ , B6 \neq 0 \end{cases} \tag{13}$$

When any of the vertical neighboring MBs to the lost MB (L) is incorrectly received, the following equations are evaluated:

$$p(x,y) = f_{(i,j)}^{D4} \ , \quad \begin{cases} (x,y) \in lost\ intra\ MB \\ B4 \neq 0\ , B6 = 0 \end{cases} \tag{14}$$

$$p(x,y) = f_{(i,j)}^{D6} \ , \quad \begin{cases} (x,y) \in lost\ intra\ MB \\ B4 = 0\ , B6 \neq 0 \end{cases} \tag{15}$$

When both of the vertical neighboring MBs to the lost MB (L) are incorrectly received, the following equation is evaluated:

$$p(x,y) = \min_{(i,j)\in N} Dist\left(f_{(i,j)} \to p_{(x,y)}\right) \ , \quad \begin{cases} (x,y) \in lost\ intra\ MB \\ N = \{B1, B0, B2, B3\}\ , \forall B_i \neq 0 \end{cases} \tag{16}$$

For angular directions different to 0° y 90°, the two estimated pixel values $f_{(i,j)}^{DA}$, $f_{(i,j)}^{DB}$, $A, B \in k$, $k = \{0,1,\ldots 7\}$ which are needed to obtain the interpolated pixel value $p(x,y)$, is computed by the following equations:

Option 1: estimated pixel position $f_{(sas,x1)}^{Dk}$

$$x1 = \left(\frac{j + (sas - i)}{\tan\left(edgDir \times \left(rad(22.5^0)\right)\right)} \right) , \quad \begin{cases} & x1 \geq sas \\ if & and \\ & x1 \leq sas + bs + 1 \end{cases} \tag{17}$$

⟹ The availability of the B4, B1 and B0 MBs is analyzed to obtain the estimated pixel value following the equations:

$$f_{(i,j)}^{Dk} = f_{(sas,x1)}^{D4D1D0} \ , \quad \{B4 \neq 0\ , B1 \neq 0\ , B0 \neq 0 \tag{18}$$

$$f_{(i,j)}^{Dk} = f_{(sas,x1)}^{D4D0} \ , \quad \begin{cases} B4 \neq 0\ , B1 = 0\ , B0 \neq 0 \\ if\ x1 == sas \\ \Longrightarrow \ x1 = sas + 1 \end{cases} \tag{19}$$

$$f_{(i,j)}^{Dk} = f_{(sas,x1)}^{D4D1} \ , \quad \begin{cases} B4 \neq 0\ , B1 \neq 0\ , B0 = 0 \\ if\ x1 == sas + bs + 1 \\ \Longrightarrow \ x1 = sas + bs \end{cases} \tag{20}$$

$$f_{(i,j)}^{Dk} = f_{(sas,x1)}^{D4} \ , \quad \begin{cases} B4 \neq 0\ , B1 = 0\ , B0 = 0 \\ if\ x1 == sas \\ \Longrightarrow \ x1 = sas + 1 \\ elseif\ x1 == sas + bs + 1 \\ \Longrightarrow \ x1 = sas + bs \end{cases} \tag{21}$$

$$f_{(i,j)}^{Dk} = f_{(sas,x1)}^{D0}\,, \quad \begin{cases} B4 = 0\,, B1 = 0\,, B0 \neq 0 \\ if\ x1 \geq sas\ \ and\ x1 < 2 \times sas \\ \Longrightarrow\ \ x1 = x1 + bs + 1 \\ elseif\ x1 \geq 2 \times sas\ \ and\ \ x1 \leq sas + bs \\ \Longrightarrow\ \ x1 = sas + bs + 1 \end{cases} \tag{22}$$

$$f_{(i,j)}^{Dk} = f_{(sas,x1)}^{D1}\,, \quad \begin{cases} B4 = 0\,, B1 \neq 0\,, B0 = 0 \\ if\ x1 > sas\ \ and\ x1 \leq 2 \times sas \\ \Longrightarrow\ \ x1 = x1 - bs + 2 \\ elseif\ x1 > 2 \times sas\ \ and\ \ x1 \leq sas + bs + 1 \\ \Longrightarrow\ \ x1 = sas \end{cases} \tag{23}$$

$$f_{(i,j)}^{Dk} = f_{(sas,x1)}^{D1D0}\,, \quad \begin{cases} B4 = 0\,, B1 \neq 0\,, B0 \neq 0 \\ if\ x1 > sas\ \ and\ x1 \leq sas +\ (bs/2) \\ \Longrightarrow\ \ x1 = x1 - (bs/2) \\ elseif\ x1 > sas +\ (bs/2)\ \ and\ \ x1 < sas + bs + 1 \\ \Longrightarrow\ \ x1 = x1 + (bs/2) \end{cases} \tag{24}$$

If the B4, B1 and B0 neighboring MBs are incorrectly received or concealed, then the neighboring MBs B6, B2 and B3 will be considered to obtain the estimated pixel value. To do this, the equations 18 to 24 are evaluated replacing the following variables: B4 by B6, B1 by B2, B0 by B3; D4 by D6, D1 by D2, D0 by D3 and $f_{(sas,x1)}^{Dk}$ by $f_{(sas+bs+1,x1)}^{Dk}$.

Option 2: estimated pixel position $f_{(sas+bs+1,x2)}^{Dk}$

$$x2 = \left(\frac{j + (sas + bs + 1 - i)}{\tan\left(edgDir \times \left(rad(22.5^0) \right) \right)} \right), \quad \begin{cases} & x2 \geq sas \\ if & and \\ & x2 \leq sas + bs + 1 \end{cases} \tag{25}$$

⟹ The availability of the B6, B2 and B3 MBs is analyzed to obtain the estimated pixel value following the equations 18 to 24 and replacing the next variables: B4 by B6, B1 by B2, B0 by B3; D4 byr D6, D1 by D2, D0 by D3, x1 by x2, and $f_{(sas,x1)}^{Dk}$ by $f_{(sas+bs+1,x2)}^{Dk}$.

If the B6, B2 and B3 neighboring MBs are incorrectly received or concealed, then the neighboring MBs B4, B1 and B0 will be considered to obtain the estimated pixel value. To do this, the equations 18 to 24 are evaluated replacing the following variables : x1 by x2 and $f_{(sas,x1)}^{Dk}$ by $f_{(sas,x2)}^{Dk}$.

Option 3: estimated pixel position $f_{(y3,sas)}^{Dk}$

$$y3 = \left(i + (sas - j) \right) \times \tan\left(edgDir \times \left(rad(22.5^0) \right) \right), \quad \begin{cases} & y3 > sas \\ if & and \\ & y3 < sas + bs + 1 \end{cases} \tag{26}$$

⟹ The availability of the B5, B1 and B2 MBs is analyzed to obtain the estimated pixel value. The considerations of the option 1 are also realized.

Option 4: estimated pixel position $f^{Dk}_{(y4,sas+bs+1)}$

$$y4 = \left(i + (sas + bs + 1 - j)\right) \times \tan\left(edgDir \times \left(rad(22.5^0)\right)\right), \quad \begin{cases} & y4 > sas \\ if & and \\ & y4 < sas + bs + 1 \end{cases} \tag{27}$$

⟹ The availability of the B7, B0 and B3 MBs is analyzed to obtain the estimated pixel value. The considerations of the option 2 are also realized.

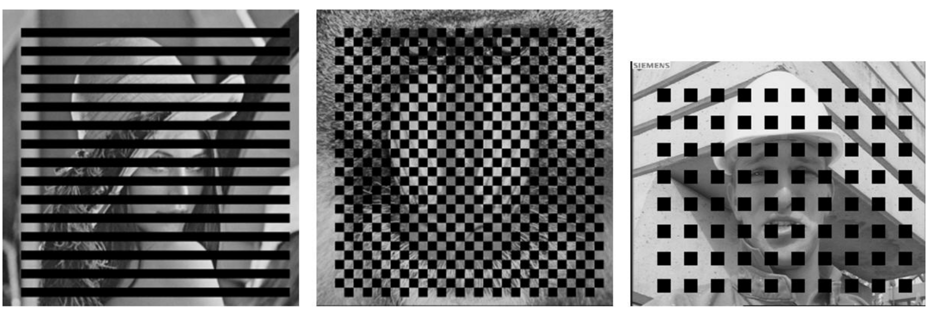
After obtention of the two estimated pixel values, the interpolated pixel value of the lost MB is computed by the following equation:

$$p(x,y) = \frac{f^{DA}_{(i,j)} \times Distant^{DB}_{(i,j)} + f^{DB}_{(i,j)} \times Distant^{DA}_{(i,j)}}{Distant^{DA}_{(i,j)} + Distant^{DB}_{(i,j)}}, \quad \{(x,y) \in lost\ intra\ MB \tag{28}$$

where $f^{DA}_{(i,j)}$, $f^{DB}_{(i,j)}$ are the estimated pixels and $Distant^{DA}_{(i,j)}$, $Distant^{DB}_{(i,j)}$ are the distances between the estimated pixels and the missing one $y(x,y)$.

4 Implementation and Results

In order to evaluate the performance of the spatial concealment methods under significant losses (20% to 42%) and with different errors distributions, representative images Intra have been selected: Lena, Baboon and Foreman51. Relative to corrupted images, different error distributions are simulated, as shown in fig. 8. They are: bursty, checkerboard and uniform distributions, respectively. It is important to highlight that, in real communications, consecutive blocks corrupted usually happen.



a) b) c)

Fig. 8. Errors distributions: a) bursty:Lena, b) checkerboard:Baboon, c) uniform:foreman51

We compare the performances of the following spatial error concealment methods: weighted average, directional interpolation and our proposed method. In order to evaluate the quality of reconstruction of an image Intra we use the peak to signal-to-noise ratio of its YUV color space luminance component (Y-PSNR). The results are shown in Table 1.

According to the results shown in the Table, in general, the proposed method outperforms existing methods by up to 8.6 dB on average.

Table 1. Performance of the spatial error concealment methods

Image Intra	Error distribution	% losses	Weighted average	Directional interpolation	Our method
Lena	Bursty	42.48	22.82 dB	10.99 dB	26.87 dB
	Checkerboard	41.02	23.13 dB	25.86 dB	28.44 dB
	Uniform	21.97	25.83 dB	31.29 dB	31.29 dB
Baboon	Bursty	42.48	21.15 dB	10.39 dB	21.96 dB
	Checkerboard	41.02	21.35 dB	22.06 dB	22.70 dB
	Uniform	21.97	24.02 dB	25.58 dB	25.58 dB
Foreman51	Bursty	38.38	22.65 dB	9.01 dB	26.66 dB
	Checkerboard	35.88	23.06 dB	28.01 dB	31.47 dB
	Uniform	20.20	26.00 dB	32.90 dB	32.90 dB

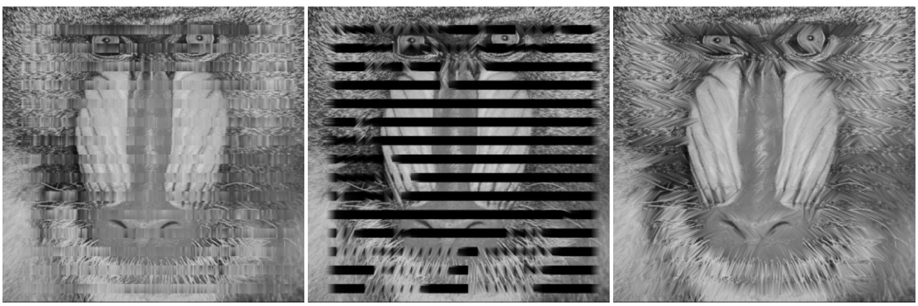
Figures 9-12 present the image Intra concealed applying the spatial error concealment methods discussed in this paper. The error distributions are the bursty and checkerboard. As shown in these figures, the best spatial error concealment method (proposed method) yields the best performance according to Y-PSNR criteria and the visual quality. This can be explained by the fact that our method takes into account only the correctly received neighboring MBs to compute the edge angular direction. Moreover, it selects the proper neighboring MBs according to the formulation done in section 3.2. On the other hand, the WAI's method works well in regions with smooth texture area. However, as we can see in the figures, it causes important visual degradations in the region including edges. The conventional DI's method presents good results when vertical and horizontal neighboring MBs have been correctly received (uniform error distribution). On the contrary, it shows catastrophic results taking into account all eight neighboring MBs without considering their availability to compute the edge angular direction and the reconstruction of the los MB.

a) b) c)

Fig. 9. Error distribution: bursty. Concealed image Intra of "Lena" with the: a) Weighted Average, Y-PSNR=22.82dB; b) Directional Interpolation, Y-PSNR=10.99dB; c) Our method, Y-PSNR=26.87dB

a) b) c)

Fig. 10. Error distribution: checkerboard. Concealed image Intra of “Lena” with the: a) Weighted Average, Y-PSNR=23.13dB; b) Directional Interpolation, Y-PSNR=25.86dB; c) Our method, Y-PSNR=28.44dB.



a) b) c)

Fig. 11. Error distribution: bursty. Concealed image Intra of “Baboon” with the: a) Weighted Average, Y-PSNR=21.15dB; b) Directional Interpolation, Y-PSNR=10.39dB; c) Our method, Y-PSNR=21.96dB.

a) b) c)

Fig. 12. Error distribution: checkerboard. Concealed image Intra of “Foreman51” with the: a) Weighted Average, Y-PSNR=23.06dB; b) Directional Interpolation, Y-PSNR=28.01dB; c) Our method, Y-PSNR=31.47dB.

5 Discussions and Further Work

As opposed to several studies of spatial error concealment that have been more concerned about devising new complex techniques to improve the visual quality with loss of information up to 25%, we investigate how to resolve the problem of significant loss of information (42% of errors with different distributions) due to node congestion or excessive delay in mobile communications. Thus, in this paper we proposed an adaptive and effective method based on edge analysis that performs well in current environments, where the images Intra are corrupted with different errors distributions covering up to 42% of the image area. Compared with two spatial error concealment algorithm, weighted average [15,18] and Directional Interpolation [11,19], the adaptive proposed technique has the best results against several errors distribution, according to the metric Y-PSNR. The proposed method can be combined with temporal replacement algorithms to provide improved error concealment for block-based video sequence coding.

Acknowledgment. This research was supported by grant SIP2012 from IPN.

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