Concealing Damaged Coded Images Using Improved FSE with Critical Support Area

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Abstract. The transmission over error-prone networks of block-based coded images may results in the lost of the several images blocks, degrading drastically the visual quality of images. Consequently, if retransmission is not feasible, then applications of error concealment techniques are required to reduce this degradation caused mainly by the missing information. This paper proposes an adaptive and effective method to select the required support area, using suited base functions and optimal expansion coefficients, in order to conceal the damaged blocks in critical error situations. This method outperforms the concealment done by the conventional frequency selective extrapolation approach. It also performs well in current situations where significant loss of information is present and the data of the past reference images are also not 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 7.2 dB.

Keywords: Image, spatial error concealment, video, adaptive frequency selective extrapolation, critical support area, H.264/AVC.

1 Introduction

The original coded image signal can be affected when it is transmitted over error-prone networks. This may lead to loss of information. Therefore, application of error concealment techniques are 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 [1-3]. In the past, several spatial error concealment algorithms restoring missing blocks from surrounding correctly received blocks in the same image have been proposed in the literature [4-12]. Most of these conventional approaches consider the eight neighboring macroblocks availability for suitable operation and performance. However, one problem derived from this is that these methods cannot work well, especially over high burst error condition since a great of neighboring information

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have been corrupted or lost (called 'critical situations'). 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 method to select the required support area, using suited base functions and optimal expansion coefficients, in order to conceal the damaged blocks in critical error situations. This method outperforms the concealment done by the conventional frequency selective extrapolation approach. It also 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 macroblock correctly received or already concealed of the considered lost or corrupted macroblock.

The remainder of this paper is organized as follows. Section 2 reviews existing spatial error concealment schemes used in MPEG-4 H.264/AVC 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.

2 Spatial Error Concealment Methods

2.1 Weighted Average Approach in MPEG-4 H.264/AVC decoder

This well-known and highly influential ancient spatial error concealment technique was proposed in [12] as a non-normative algorithm in the MPEG-4 H.264/AVC standard [1,3,13,14]. 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. A pixel value in a damaged or lost MB is replaced with the reconstructed pixel value using WAI as following:

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

where P indicates a pixel value in a damaged MB, P_T, P_B, and P_L, P_R, are vertically (top, bottom) and horizontally (left, right) neighboring boundary pixels values, and d_T, d_B, d_L, d_R indicate the distance between the interpolated pixel. 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 MPEG-4 H.264/AVC decoder standard, the WAI's method, applied for intra-frames [13,15], 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, whereas it causes noticeable visual degradation in the region including the edges (cf. section 4, figs. 2a-4a).

2.2 Frequency Extrapolation Using DFT

The idea in this approach is to estimate the missing image blocks using the signal extrapolation principle [16,17], which is based on the extending of a signal beyond a limited number of known samples. Various methods have been proposed which solve the extrapolation task for two dimensional signals by applying spectral estimation [6,16-19] and spectral deconvolution [20,21]. For the images EC application, Kaup et al [22-24] proposed a frequency selective extrapolation (FSE) approach based on successive approximation technique [25,26]. So, the image content (see fig. 1a) of the known blocks (support area $\mathcal{R}$) is successively approximated through a parametric model $g(m,n)$ and the missing block (missing area $\mathcal{L}$) is obtained by extrapolation according to an error criterion based on the energy weighted function, described as follows:

$$E_{\mathcal{R}} = \sum_{(m,n)\in\mathcal{Q}} w(m,n)[f(m,n) - g(m,n)]^2, \quad \forall\{Bk \in \mathcal{R}\} \tag{2}$$

where

$$Bk = \sum_{m}^{M}\sum_{n}^{N} f(m,n), \quad \{m,n \in \mathcal{R}\}, k = \{0,1,\ldots,7\} \tag{3}$$

$w(m,n)$ is the weighting function, $f(m,n)$ are the values of the samples in the area $\mathcal{Q}$, $g(m,n)$ is the parametric model and Bk is the MB in the support area $\mathcal{R}$. The parametric model in each iteration is:

$$g^{(v)}(m,n) = \sum_{(p,q)\in\mathcal{P}_v} c_{p,q}^{(v)}\varphi_{p,q}(m,n), \quad \{m,n \in \mathcal{Q}\} \tag{4}$$

$\mathcal{P}_v$ denoting the set of basis functions $\varphi_{p,q}(m,n)$ weighted by the expansion coefficients $c_{p,q}^{(v)}$ used in the iteration v, m,n indicates the row and column index. The number of available basis functions equals the number of samples in the entire area $\mathcal{Q}$.

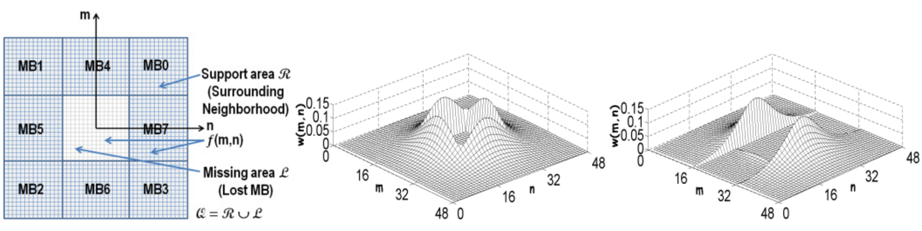

Fig. 1. a) Representation of missing and support area. Weighting function: b) Isolated lost block, c) Consecutive lost block.

The FSE algorithm of Kaup et al [22-24], presupposes, as does WAI's method, that all eight neighboring MBs (support area $\mathcal{R}$) are usually available to apply error concealment process over the damage MB (missing area $\mathcal{L}$). Considering this assumption, the FSE method can have good performance if there is only a dominant edge orientation in the considered support area $\mathcal{R}$. 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 support area $\mathcal{R}$ (cf. section 4, figs. 2b-4b).

3 Proposed Method

The FSE's method which is applied for intra-frames [22-24], takes all eight surrounding MBs (support area $\mathcal{R}$), as above was mentioned, to restore the lost one (missing area $\mathcal{L}$). If any of the neighboring MBs is not correctly received, the FSE's method doesn't perform well (cf. section 4, figs. 2b-4b). To alleviate the disadvantages of the FSE's method effectively and provide better performance considering critical situations as having at least one correctly received or concealed neighbor MB, we focus on the challenge of providing the necessary conditions to correctly estimate the signal in the available support area $\mathcal{R}$ through a suited base functions and an optimal expansion coefficients to suitably reconstruct the damaged MB with minimal information.

3.1 Computing Basis Functions and Expansion Coefficients

For emphasizing closer regions to missing area $\mathcal{L}$, Kaup et al [22-24] use a weighting function $w(m,n)$ (see eq.2) based on an isotropic model $\rho(m,n)$.

$$w(m,n) = \begin{cases} \rho(m,n) = \hat{\rho}^{\sqrt{\left(m-\frac{M}{2}\right)^2+\left(n-\frac{N}{2}\right)^2}}, & 0 < \hat{\rho} < 1, \{m,n \in \mathcal{R}, \forall Bk \in \mathcal{R}\} \\ 0, & \{m,n \in \mathcal{L}\} \end{cases} \quad (5)$$

Figure 1b depicts the resulting weighting function for a single lost MB. This lost MB is located in the center of this weighting function having zero intensities and all surrounding MB's area has a certain weight defined by ρ.

Kaup et al [22-24], also treat the consecutive macroblock loss. The resulting weighting function $w(m,n)$ on the available support area $\mathcal{R}$, for the case of consecutive macroblock loss, is shown in figure 1c. In this figure, the macroblock MB7 is not available and macroblock MB5 has been concealed (extrapolated). Then, in order to include the MB5 in the concealment procedure, Kaup et al [22-24] limit their influence by assigning a weight of 0.1 trying to prevent the spread of approximation errors. It is known that the influence of the weighting function decreases radial symmetrically with distance from the center of the lost area at $(M/2, N/2)$, then, we compute the contribution of each sub-area (surrounding MBs) in the support area $\mathcal{R}$ in terms of energy: $MB0 = MB1 = MB2 = MB3 = 0.14096 \times 10^{-4}\ J/Hz$, and for horizontal and vertical macroblocks: $MB4 = MB5 = MB6 = MB7 = 1.6858 \times 10^{-4}\ J/Hz$. Based on this results, we propose to use the information of the concealed neighbors MB's throughout the support area $\mathcal{R}$, under the same conditions as the correctly received MB's. So, we apply the weighting function in the area of the concealed MB without limiting its influence. Our FSE algorithm optimization allows the concealment of the lost MB for any error pattern structure present in the Intra frame. The implemented optimization algorithm is described as follows:

1. Establishment of the weighting function

In the proposed method, the resulting weighting function is variable because it depends on the available support area $\mathcal{R}$ for each lost MB that needs to be concealed. This condition can be represented as follows:

$$w_{Bk}(m,n) = \begin{cases} \rho(m,n) = \hat{\rho}^{\sqrt{\left(m-\frac{M}{2}\right)^2+\left(n-\frac{N}{2}\right)^2}}, & 0 < \hat{\rho} < 1, \{m,n \in \mathcal{R}\} \\ & \{\forall Bk \in \mathcal{R} \wedge Bk \neq 0\} \\ 0, & \{m,n \in \mathcal{L}\} \end{cases} \quad (6)$$

Bk is the MB correctly received or concealed in the variable support area $\mathcal{R}$.

2. Initialization of the parametric model

The parametric model is initialized as Kaup et al [22-24], $g^{(0)}(m,n) = 0$.

3. Initialization of the approximation weighted residual error

The initialization $\{v = 0\}$ of the approximation weighted residual error is done by the following:

$$r_{w_{Bk}}^{(v)}(m,n) = w_{Bk}(m,n) \times r^{(v)}(m,n), \quad \{m,n \in \mathcal{R}\}, \forall\{Bk \in \mathcal{R} \wedge Bk \neq 0\} \quad (7)$$

where

$$r^{(v)}(m,n) = \left[f(m,n) - g^{(v)}(m,n)\right] \quad (8)$$

4. Iterative Procedure of Frequency Successive Approximation

4.1. Best Fitting Basis Function Determination

Based on the equation 2 as well as the conditions presented in equations 6 and 7, and using the 2D Discrete Fourier Transform (DFT) base functions, the maximal decrease of the weighted error criterion to select the best fitting basis function in the frequency domain (by DFT of $r^{(v)}(m,n)$: $\boldsymbol{R}^{(v)}(m,n)$ and $w_{Bk}(m,n)$: $\boldsymbol{W}_{Bk}(m,n)$) can be expressed as follows:

$$\Delta E_{\mathcal{R}_{Bk}}^{(v)} = \frac{\boldsymbol{R}_{w_{Bk}}^{(v)}[p,q]^2}{\boldsymbol{W}_{Bk}[0,0]}, \quad \forall\{Bk \in \mathcal{R} \wedge Bk \neq 0\} \quad (9)$$

4.2. Expansion Coefficients Determination

After doing some mathematical simplifications from equation 2, the expansion coefficient update Δc for each iteration v can expressed in the frequency domain as:

$$\Delta c = MN \frac{\boldsymbol{R}_{w_{Bk}}^{(v)}[u,v]}{\boldsymbol{W}_{Bk}[0,0]}, \quad \forall\{Bk \in \mathcal{R} \wedge Bk \neq 0\} \quad (10)$$

The expansion coefficient $c_{u,v}^{(v+1)}$ is then update by

$$c_{u,v}^{(v+1)} = c_{u,v}^{(v)} + \Delta c \quad (11)$$

4.3. Updating the Parametric Model

The parametric model $g^{(v)}(m,n)$: $\boldsymbol{G}^{(v)}(m,n)$ is updated for each iteration v based on the proposed conditions mentioned before, allowing obtain suitable base functions and optimal expansion coefficients to correctly estimate the available support area $\mathcal{R}$.

4.4. New Approximation Error Determination

To obtain the weighted residual error signal in the next iteration $v+1$, the following equation is computed:

$$\boldsymbol{R}_{w_{Bk}}^{(v+1)}[p,q] = \boldsymbol{R}_{w_{Bk}}^{(v)}[p,q] - \frac{1}{MN}\Delta c \boldsymbol{W}_{Bk}[p-u, q-v], \quad \forall\{Bk \in \mathcal{R} \wedge Bk \neq 0\} \quad (12)$$

4.5. The Final Parametric Model

After all iterations are done, the final parametric model is obtained by an inverse DFT. This parametric model is then, the closest approximation to the signal data in the available support area $\mathcal{R}$:

$$g[m,n] = IDFT_{M,N}\{G[p,q]\} \quad (13)$$

Finally, the proper concealed lost MB is obtained from the parametric model which is optimized for the available support area $\mathcal{R}$.

4 Implementation and Results

In order to evaluate the performance of the proposed approach and to compare it with three other spatial concealment methods, experiments were conducted using corrupted representative Intra Images with significant losses (20% to 42%) and with different errors distributions. Table 1, summarizes the details of our experiments. It is important to highlight that the select images are a major challenge for the EC algorithms. They show multiples edges and rich textures than need to be suitably concealed.

As it is shown in the Table 1, we compared the performances of the following spatial error concealment methods: WAI method [12,15], FSE method with all MBs correctly received [22-24], FSE method for consecutive macroblock loss (FSE weighted 0.1) [22-24] 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). According to the results shown in the Table 1, in general, the proposed method outperforms existing methods by up to 7.2 dB on average.

Table 1. Performance of the spatial error concealment methods

Image Intra	Error distribution	% losses	WAI	FSE (all MBs)	FSE weighted 0.1	Our method
Lena	Bursty	42.48	22.82 dB	10.93 dB	26.37 dB	26.59 dB
	Checkerboard	41.02	23.13 dB	23.42 dB	---	28.34 dB
	Uniform	21.97	25.83 dB	30.71 dB	---	30.71 dB
Baboon	Bursty	42.48	21.15 dB	10.43 dB	22.21 dB	22.35 dB
	Checkerboard	41.02	21.35 dB	21.24 dB	---	23.13 dB
	Uniform	21.97	24.02 dB	26.04 dB	---	26.04 dB
Foreman	Bursty	38.38	22.65 dB	9.52 dB	26.84 dB	27.25 dB
	Checkerboard	35.88	23.06 dB	23.52 dB	---	30.09 dB
	Uniform	20.20	26.00 dB	32.67 dB	---	32.67 dB

Figures 2-5 present some concealed images Intra applying the spatial error concealment methods discussed in this paper. The error distributions are the bursty and checkerboard for these figures. 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 or concealed neighboring MBs to compute the frequency selective extrapolation. Moreover, it selects the proper neighboring MBs according to the formulation done in section 3.1. 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 FSE's method [22-24] presents good results when all 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 frequency selective extrapolation and the reconstruction of the lost MB.

a) b) c)

Fig. 2. Error distribution: checkerboard. Concealed image Intra of "Lena" with the: a) WAI, Y-PSNR=23.13dB; b) FSE all 8 MB's, Y-PSNR=23.42dB; c) Our method, Y-PSNR=28.34dB.

a) b) c)

Fig. 3. Error distribution: bursty. Concealed image Intra of "Baboon" with the: a) WAI, Y-PSNR=21.15dB; b) FSE all 8 MB's, Y-PSNR=10.43dB; c) Our method, Y-PSNR=22.35dB.

a) b) c)

Fig. 4. Error distribution: checkerboard. Concealed image Intra of "Foreman" with the: a) WAI, Y-PSNR=23.06dB; b) FSE all 8 MB's, Y-PSNR=23.52dB; c) Our method, Y-PSNR=30.09dB.

For consecutive macroblock loss, our method has on average of Y-PSNR=0.27 dB which is superior to FSE weighted 0.1 [22-24] (see Table 1). The figure 5 shows that the FSE weighted 0.1 method generates blocking effects, this is due to the weight assigned of 0.1 to MB5 in the support area. It is also shown that our method has better performance in avoiding error propagation.

a) b)

Fig. 5. Error distribution: bursty. Concealed image Intra of "Foreman" with the: a) FSE weighted 0.1, Y-PSNR=26.84dB; b) Our method, Y-PSNR=27.25dB.

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 to select the required support area, using suited base functions and optimal expansion coefficients, in order to conceal the damaged blocks in critical error situations. This method outperformed the concealment done by the conventional frequency selective extrapolation approach. It also performed well in current environments, where the images Intra are corrupted with different errors distributions covering up to 42% of the image area. Compared with three spatial error concealment algorithm, WAI [12,15], frequency selective extrapolation with all 8 MB's [22-24] and frequency selective extrapolation with weighted 0.1 [22-24], the adaptive proposed technique has the best results against several errors distribution, according to the metric Y-PSNR. The proposed method provide better performance considering the critical situation of having at least one neighbor macroblock correctly received or already concealed of the considered lost or corrupted macroblock. The proposed method can be combined with temporal replacement algorithms to provide improved error concealment for block-based video sequence coding.

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References

1. Richardson, I.E.G.: H.264 and MPEG-4 Video Compression, Video Coding for Next – generation Multimedia. John Wiley & Sons, Ltd. (2004)
2. Wang, Y., Zhu, Q.-F.: Error Control and Concealment for Video Communication: A Review. Proceedings of the IEEE 86(5), 985–995 (1998)
3. Kumar, S., Xu, L., Mandal, M.K., Panchanathan, S.: Error Resiliency Schemes in H.264/AVC standard. Visual Communications & Image Representation 17(2) (2006)
4. Alkachouh, Z., Bellanger, M.G.: Fast DCT-Based Spatial Domain Interpolation of Blocks in Images. IEEE Trans. Image Processing 9(4), 729–732 (2000)
5. Wang, Y., Zhu, Q.F., Shaw, L.: Maximally Smooth Image Recovery in Transform Coding. IEEE Trans. Communication 41, 1544–1551 (1993)
6. Sun, H., Kwok, W.: Concealment of Damaged Block Transform Coded Images Using Projections onto Convex Sets. IEEE Trans. Image Processing 4(4), 470–477 (1995)
7. Yang, H., Yan, B.: A Novel Spatial Error Concealment Method for Wireless Video Transmission. In: Int. Conf. Wireless Comm., Netw. and Mobile Comp., China, pp. 1–4 (September 2009)
8. Chen, Y., Yu, K., Li, J., Li, S.: An error concealment algorithm for entire frame loss in video transmission. Microsof. Reasearch, 1–4 (December 2004)

9. Wang, J., Zhu, X.: Content Adaptive Intra Error Concealment Method. In: 12th IEEE International Conference on Communication Technology, China, pp. 1224–1227 (January 2010)
10. Ndjiki-Nya, P., Koppel, M., Doshkov, D., Wiegand, T.: Automatic Structure-Aware Inpainting for Complex Image Content. In: Int. Sym. on Visual Computing (November 2008)
11. Seiler, J., Kaup, A.: A Fast Algorithm for Selective Signal Extrapolation with Arbitrary Basis Functions. Journal on Advances in Signal Processing (2011)
12. Varsa, V., Hannuksela, M.M., Wang, Y.K.: Non-normative error concealment algorithms, ITU-T VCEG-N62 (September 2001)
13. Joint Video Team (JVT) of ISO/IEC MPEG & ITU-T VCEG: Draft ITU-T Recommendation and Final Draft International Standard of Joint Video Specification (ITU-T Rec. H.264 – ISO/IEC 14496-10 AVC), Doc. JVT-G050r1 (May 2003)
14. Wiegand, T., Sullivan, G.J., Bjøntegaard, G., Luthra, A.: Overview of the H.264/AVC Video Coding Standard. IEEE Trans. Circ. and Syst. for Vid. Tech. 13(7) (July 2003)
15. H.264/AVC Codec Software: JM14.2 Video Coding Standard
16. Papoulis, A.: A new algorithm in spectral analysis and band –limited extrapolation. IEEE Trans. Circuits Syst. 22, 735–742 (1975)
17. Papoulis, A., Chamzas, C.: Detection of hidden periodicities by adaptive extrapolation. IEEE Trans. Acoustics Speech Signal Process. 27, 492–500 (1979)
18. Aach, T.: Missing data interpolation by transform-based successive approximation. In: Proc. of the Workshop on Spectral Methods and Multirate Signal Processing, SMMSP 2001 (2001)
19. Lakshman, H., Ndjiki-Nya, P., Koppel, M., Doshkov, D., Wiegand, T.: An automatic structure-aware image extrapolation applied to error concealment. In: ICIP (2009)
20. Clark, A.A., Thomas, B.T., Campbell, N.W., Greenway, P.: Texture deconvolution for the Fourier-based analysis of non-rectangular regions. In: British Machine Vision Conference, pp. 193–202 (September 1999)
21. Aach, T., Metzler, V.: Defect interpolation in digital radiography - how object oriented transform coding helps. In: SPIE Medical Imaging 2001, vol. 4322 (February 2001)
22. Kaup, A., Meisinger, K., Aach, T.: Frequency selective signal extrapolation with applications to error concealment in image communication. Int. J. of Elect. Comm. 59, 147–156 (2005)
23. Meisinger, K., Kaup, A.: Minimizing a weighted error criterion for spatial error concealment of missing image data. In: Proc. IEEE Int. Conf. on Image Proc., ICIP 2004, pp. 813–816 (2004)
24. Meisinger, K., Kaup, A.: Spatial error concealment of corrupted image data using frequency selective extrapolation. In: ICASSP 2004, pp. 209–212 (May 2004)
25. Kaup, A., Aach, T.: Efficient prediction of uncovered background in inter frame coding using spatial extrapolation. In: ICASSP 1994, pp. 501–504 (April 1994)
26. Kaup, A., Aach, T.: Coding of segmented images using shape independent basis functions. IEEE Trans. Image Process. 7, 937–947 (1998)