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Enhanced Spatial Error Concealment with Directional Entropy based Interpolation Switching

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Abstract— **This paper describes a spatial error concealment method that uses edge related information for concealing missing macroblocks in a way that not only preserves existing edges but also avoids introducing new strong ones. The method relies on a novel switching algorithm which uses the directional entropy of neighboring edges for choosing between two interpolation methods, a directional along detected edges or a bilinear using the nearest neighboring pixels. Results show that the performance of the proposed method is subjectively and objectively (PSNR wise) better compared to both 'single interpolation' and to edge strength based switching methods.**

I. INTRODUCTION

Wireless video transmission is a topic that has attracted a lot of attention recently with more consumer devices and mediums becoming available which are able to accommodate such transmissions. Video transmission over wireless networks can suffer from packet erasures due to the fluctuating channel conditions. Error concealment is the process of recovering or estimating the information lost due to such transmission errors. To accomplish this recovery concealment methods employ the correlation that exists between a damaged macroblock (MB) and its adjacent macroblocks in the same or previous frame(s). Temporal concealment methods estimate missing motion vectors and then use these for motion compensated temporal replacement of the lost MBs, while spatial concealment methods rely on spatially adjacent macroblocks for estimating missing pixels usually through an interpolation process. Although temporal concealment methods are capable of very good results [1], there are cases where spatial concealment can be preferable, including intra coded frames where motion information is not readily available, frames involving scene changes where temporal correlation can be very poor and cases where the motion capture process during encoding has failed.

Previous work on spatial error concealment (SEC) includes methods that estimate missing spatial information in the frequency domain [2], hybrid methods [3][4] that employ the DCT domain to produce, in the case of [3] smoothing constraints for the estimation of missing pixels, or, in the case of [4] an interpolation mask, as well as spatial domain approaches [5]-[14]. The latter category includes the method of [5] which replaces missing pixels with weighted averages of the nearest border pixels of adjacent MBs, with the weights being inversely proportional to the distance of source and destination pixels. This method forms part of the spatiotemporal error concealment feature implemented in the H.264 joint model (JM) reference software decoder [6].

The above spatial concealment methods [3]-[6] more or less result in smooth approximations of the missing pixels/MBs. Although this can lead to satisfactory image/video quality in smooth or even highly textured areas it can create disturbing artifacts in the presence of edges. A number of methods try to mitigate this problem by interpolating missing pixels along estimated edge directions. The methods described in [7]-[10] estimate the most likely edge orientations in the neighborhood of the missing MB by applying edge detecting filters to the adjacent blocks/MBs. Linear interpolation along detected edges that pass - when extended - from the missing MB is then performed in the methods of [7][8]. In [9] and [10] edge orientation estimation is followed by a more computationally expensive projection onto convex sets. In [11] interpolation is done recursively for bands of missing pixels, using border pixels of surrounding MBs and already concealed pixels of the recovered MB. The concept of sequential error concealment is also followed in [12]. In order to exploit the strengths of multiple methods [13] proposes an adaptive SEC strategy which switches between methods (the method of [5], the BNM method of [14] and directional interpolation), based on multiple edge strength thresholds provided by a previous edge detection. This poses the problem of finding appropriate thresholds that do not compromise the performance of directional interpolation at those instances where it performs well.

With the human visual system being highly sensitive to edge distortions - including both impairments on existing edges and the creation of false edges [15] - it is important to conceal the missing MBs in a way that preserves existing edges but which also avoids creating new strong ones. In areas of increased spatial activity or textured areas directional interpolation can result in the creation of false edges or the emphasis of relatively weak edges. In such cases a smooth approximation for the missing MB can give better subjective (and objective) quality. In this paper we propose a SEC method that uses the directional entropy of neighboring edges for deciding between directional interpolation (DI) (ensuring edge preservation) and bilinear interpolation (BI) (avoiding the creation of false strong edges). The motivation

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behind the proposed approach lies on the suggestion made in [16] according to which edges do not individually influence our visual perception but rather interact with other neighboring edges and as a result the perceived strength of an edge is smaller when it is relatively crowded with other edges and greater when the edge is isolated. We employ the directional entropy to capture this property within the neighborhood of a missing MB and switch to the appropriate interpolation approach. The remainder of this paper is structured as follows. Section II describes the proposed method. Section III gives results and compares the performance of the proposed algorithm with that of other methods. Section IV concludes the paper.

II. PROPOSED METHOD

A block diagram of the proposed SEC approach is shown in Figure 1. Directional interpolation consists of edge detection, edge-direction classification/ranking and 1D interpolation. The first two steps take place all the time while the third one is only applied if the switching algorithm decides accordingly.

A. *Directional Interpolation*

Edge detection takes place in the neighborhood of a missing macroblock with the aim of identifying adjacent edges that might pass through. A Sobel filter is employed followed by non maximal suppression and hysteresis thresholding. The 3x3 Sobel filter provides edge magnitude and edge direction data for the pixels of each reliable neighboring MB. All edge direction values are quantized in 8 directional categories from 0° to 157.5° using a step of 22.5° similar to the method of [8] (Figure 2a). The classification process steps over each pixel in the 8 pixel wide boundary of the reliable neighboring MBs to find the directional limits that define which edge directions cross the missing MB from that specific pixel. The direction of the edge at the specific pixel (if present) is then examined and if within these limits its strength is added to the corresponding directional category. At the end of classification, ranking of the directional categories is performed based on the calculated edge strength value. Edge directions with less than 70% the strength of the one ranked first are marked as weak while the rest are considered strong. Weighted 1D interpolation along the winning edge direction is applied for each missing pixel with weights being set inversely proportional to the distance of the missing pixel from the source pixels. The source pixels are the two pixels lying on the one-pixel wide external boundary of the missing MB which are intersected by the edge of the specific interpolation direction that passes from the missing pixel (Figure 2a). If the selected direction crosses the boundary at a non integral position then the nearest pixel is selected.

B. *Bilinear Interpolation*

Bilinear interpolation (Figure 2b) is done according to [5]. It replaces each missing pixel with a weighted average of the nearest pixels on the boundary of the 4-neighboring MBs. The weights used are inversely proportional to the distance of source and destination pixels.

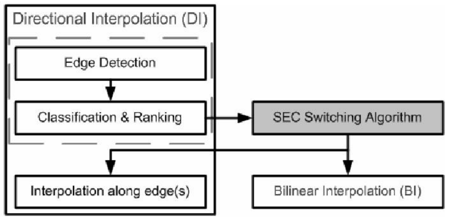
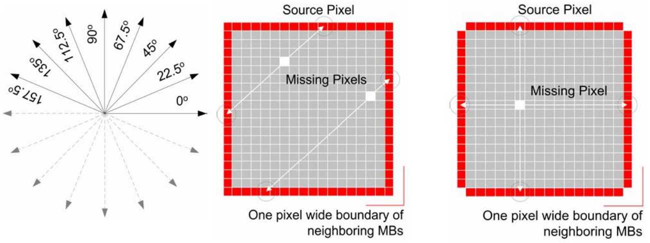


Figure 1. Block diagram of the proposed SEC approach.



(a) (b)

Figure 2. The two interpolation methods employed a) directional interpolation along a specific edge direction (e.g. 45^0); b) bilinear interpolation.

C. *Interpolation Switching*

Once the edge detection and classification/ranking steps have finished the switching algorithm takes over. The entropy of the edge direction data in the neighborhood of the missing MB is calculated and used as a measure of "directional activity". The entropy calculation takes into account only edge pixels i.e. those pixels that have edge related information. A large directional activity indicates that no specific edge direction is perceptually prevalent since edges of different directions interact with each other. The directional entropy is given by the following formula:

$$H_d = -\sum_{x \in EP} p(d_x) \log_2 p(d_x) \tag{1}$$

where EP is the set of pixels x in the neighborhood of the missing MB that have associated edge data and d_x is the directional category of the edge at the specific pixel x. The maximum possible entropy for 8 directional categories is 3 bits which corresponds to all directions being equally probable. An entropy threshold of 2.6 bits was found to give good results for a large number of sequences. Figure 3c,d show how this entropy changes for the macroblocks adjacent to those missing in the two corrupted frames of the 'foreman' sequence shown in Figure 3a and 3b. Note that macroblocks with a clear dominant edge direction have a low directional entropy (dark colors) while MBs cluttered with edges have a higher such entropy (light colors). One can notice that while DI performs well when a dominant edge exists (Figure 3a) it suffers when that's not the case (Figure 3b) where BI gives better results. The proposed method on the other hand performs very well in both cases (Figure 3c,d) switching successfully between the 2 interpolation methods. The full SEC switching algorithm is as follows:

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If (num of strong edge directions = 0) OR (num of strong edge
directions > 2) OR (directional entropy > threshold)
    apply BI
else apply DI.
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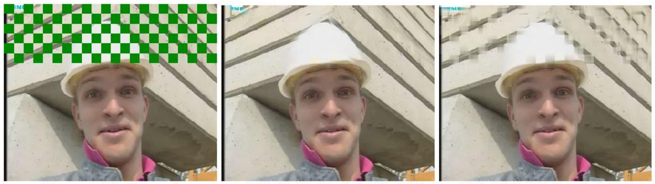
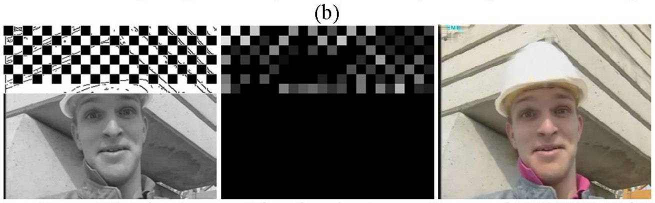
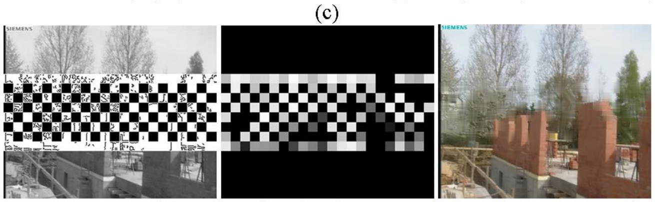


(a)

(b)



(c)



(d)

Figure 3. Motivation, concept and performance of the proposed SEC approach (see section IIc for description). Errors correspond to one slice of 66 MBs being erased (dispersed FMO was used during encoding).

III. RESULTS AND COMPARISONS

Results with the proposed SEC method are presented for the sequences 'foreman', 'Stefan', 'art, and 'bus'. The proposed method (SWDI) is compared to a DI approach with no switching similar to [7], [8] and [18], BI as in [5][6] and a partial implementation of the method in [13] using the same classification thresholds but with the BNM case substituted by BI (this method is referred to as CMP in the comparisons). In all cases only source pixels on the external one-pixel wide boundary of the missing MB are used for interpolation of the missing values. All CIF resolution test sequences have been encoded using the H.264 joint model version 8.4 at 1Mbits/sec with 1 intra coded frame (IDR) every 12 P frames, using dispersed flexible macroblock ordering (FMO) [17] and slice sizes of 66 macroblocks. Errors in the form of slice erasures have been introduced randomly to the coded bit stream at a rate of 4%. 10 different random error patterns were used with each sequence. With each error pattern a different set of IDR frames is affected. Results are presented only for the affected IDR frames in the form of average frame peak signal to noise ration (PSNR) - i.e. average PSNR for the specific IDR frame across those error sequences in which it has been affected - and average PSNR of all such spatially concealed IDR frames. In the following it is assumed that concealment of missing MBs in a specific affected frame proceeds in the manner described in [6] and that previously concealed MBs in the neighbourhood of the missing MB are only used if less than two correct exist.

TABLE I. shows the PSNR performance of the 4 concealment methods for the 'foreman' sequence using one of the random error patterns. Row 1 of the table shows the IDR frames that were affected by the specific error pattern. The PSNR of the respective error free (EF) IDR frames is also shown. TABLE II. TABLE III. show similar results for the rest of the test sequences. The average PSNR performance for all concealed IDR frames across all error patterns for each sequence is shown in TABLE IV. The duration of all test sequences is 300 frames. The total number of IDR frames for each sequence is 25.

TABLE I. PSNR OF AFFECTED IDR FRAMES FOR ONE ERROR PATTERN. 'FOREMAN'

PSNR (dB)	Frm. 12	Frm. 36	Frm. 108	Frm. 120	Frm. 132	Frm. 144	Frm. 216	Frm. 264	Avg.
EF	38.84	41.68	41.44	41.76	41.67	40.49	40.41	41.85	41.02
BI	31.08	31.32	30.47	28.79	27.87	30.36	29.40	35.85	30.64
DI	**33.50**	**32.57**	32.74	32.84	32.58	30.89	29.72	34.62	32.43
CMP	32.70	31.51	31.74	31.83	30.95	30.72	29.43	**36.06**	31.87
SWDI	33.43	32.15	**32.82**	**32.88**	**33.37**	**31.41**	**29.94**	35.96	**32.75**

TABLE II. PSNR OF AFFECTED IDR FRAMES FOR ONE ERROR PATTERN. 'STEFAN'

PSNR (dB)	Frm. 12	Frm. 36	Frm. 144	Frm. 180	Frm. 204	Frm. 228	Avg.
EF	36.04	36.75	35.60	35.66	36.08	35.35	35.91
BI	**22.28**	30.89	26.35	30.78	28.30	29.98	28.10
DI	21.23	31.22	25.73	**31.76**	27.75	30.60	28.05
CMP	22.27	31.13	26.40	31.10	28.46	30.20	28.26
SWDI	22.27	**31.27**	**26.52**	31.70	**28.51**	**30.67**	**28.49**

TABLE III. PSNR OF AFFECTED IDR FRAMES FOR ONE ERROR PATTERN. 'BUS'

PSNR (dB)	Frm. 24	Frm. 36	Frm. 72	Frm. 204	Frm. 216	Frm .240	Frm. 252	Avg.
EF	38.06	38.00	37.90	36.89	36.93	38.05	38.14	37.71
BI	24.02	26.01	28.24	31.23	23.98	27.98	24.10	26.51
DI	24.25	25.31	29.40	31.05	24.56	28.08	24.46	26.73
CMP	24.81	26.12	29.58	31.30	25.47	28.59	24.87	27.25
SWDI	**24.97**	**26.40**	**29.91**	**31.42**	**25.49**	**29.56**	**25.64**	**27.63**

TABLE IV. AVERAGE PSNR PERFORMANCE FOR ALL CONCEALED IDR FRAMES ACROSS ALL ERROR PATTERNS

PSNR (dB)	Foreman	Stefan	Bus	Art	Average
BI	30.75	26.25	27.09	28.52	28.15
DI	32.49	25.74	27.14	28.63	28.50
CMP	32.08	26.34	27.83	28.76	28.75
SWDI	**32.84**	**26.35**	**27.97**	**28.80**	**28.99**

The results show that the proposed algorithm performs significantly better compared to the method adopted in the JM decoder (BI) or a constant DI approach. It also outperforms a detailed edge strength based switching method as the one suggested in [13]. Looking at the tables it becomes evident that one of the advantages of the proposed method is the fact that it doesn't experience dips in performance as do the JM and constant DI approaches, but rather performs either better or somewhere in between.

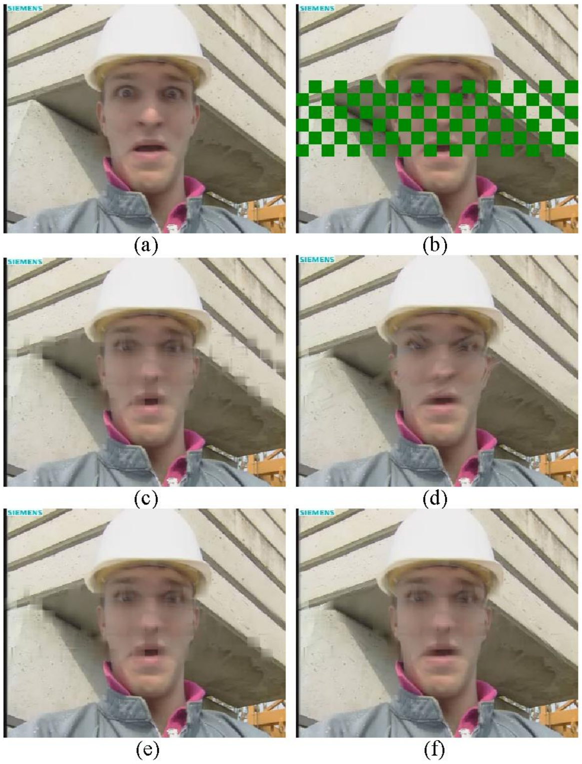

(a) (b) (c) (d) (e) (f)

Figure 4. Spatial concealment results with frame 144 of the 'foreman' sequence. a) Error free frame PSNR 40.49 dB b) corrupted 12.43 dB c) BI 31.53 dB d) DI 34.20 dB e) CMP 33.39 dB f) proposed 34.48 dB.

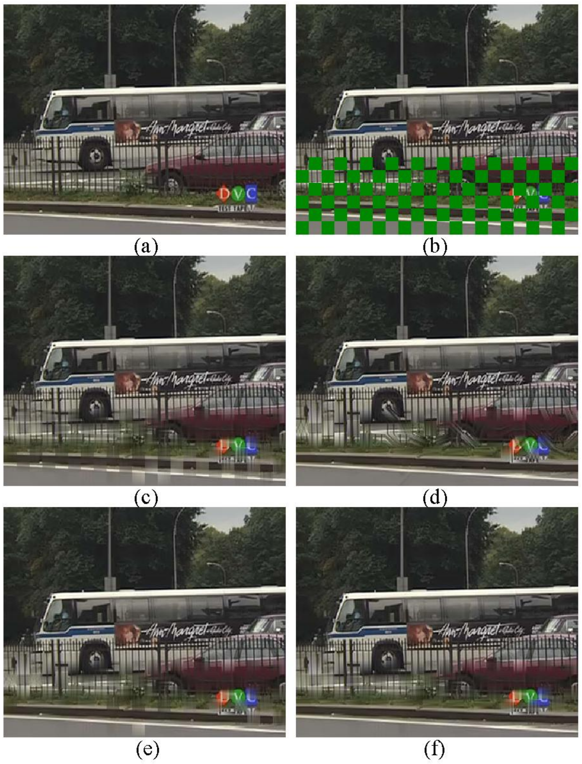

(a) (b) (c) (d) (e) (f)

Figure 5. Spatial concealment results with frame 240 of the 'bus' sequence. a) Error free frame PSNR 38.05 dB b) corrupted 15.94 dB c) BI 27.98 dB d) DI 28.08 dB e) CMP 28.59 dB f) proposed 29.56 dB.

IV. CONCLUSIONS

We have proposed a spatial error concealment method that switches between directional interpolation and bilinear interpolation based on the directional entropy of detected edge pixels in spatially adjacent correctly received macroblocks. The motivation behind this work was the desire to use an edge preserving method without the perceptually disturbing artifacts resulting from the creation of false edges. The proposed strategy exploits the strengths of both implemented SEC methods without compromising the performance of either of them thus leading to performance improvements of over 1 dB for specific concealed frames.

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