Weighted Boundary Matching Error Concealment for HEVC Using Block Partition Decisions

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Review Topic: H-7 = Speech, Image and Video Processing (Image and Video Coding)

***Abstract*—We propose a weighted boundary matching error concealment method for HEVC. It uses block partition decisions to improve a common block matching algorithm that finds blocks with the best matched boundaries from the previous frame to conceal the currently corrupted blocks. The block partition decisions from the co-located block of the corrupted one are exploited. For each partition, a summed boundary weight is computed; the one with the highest weight is chosen to be concealed next. Experimental results show the proposed method performs better than conventional error concealment methods objectively and subjectively.**

***Index Terms*—Temporal error concealment, boundary matching algorithm, HEVC (High efficiency video coding), block partitions.**

I. Introduction

With the growing popularity of high resolution (HD) video, the High Efficiency Video Coding (HEVC) standard [1] has been recently developed jointly by the ITU-T Video Coding Experts Group (VCEG) and the ISO/IEC Moving Picture Experts Group (MPEG) standardization organizations. HEVC, evolved from H.264/MPEG-4 Advanced Video Coding (AVC) [2], aims to address two key issues: increased video resolution and increased use of parallel processing architectures. The HEVC standard is designed to increase coding efficiency for encoding video with higher resolutions and to introduce parallel decoding syntax to expedite the decoding process [3].

To achieve efficient compression for higher resolutions, HEVC provides coding units (CU) ranging from 64×64 to 8×8 and prediction units (PU) that can further split a CU down to 4×4 for finer video quality. Additionally, a CU can be partitioned asymmetrically to keep the shape of an object, such as $M/2 \times M$ or $M/4 \times 3M/4$, where M is 16 or larger for luma. However, since packet loss happens when video is transmitted through an unreliable network, HEVC coded videos are more vulnerable in transmission, as a lost packet with the same size may cause corruption of a larger region in HEVC than in H.264/AVC. Moreover, since HEVC suggests no error concealment (EC) method, it is crucial to develop effective EC for HEVC.

There is little literature on HEVC error concealment. In [4], [5], motion vector (MV) extrapolation based on various CU partition decisions is applied to conceal whole frame loss or CU loss. The CU partitions in a lost frame are evaluated and extrapolated according to the MV correlation from the co-located CUs in [4]. In [5], the extrapolated and overlapped partition size is used to decide an extrapolated MV for a lost CU. Ref. [6] uses co-located CU partitions and MVs in the previous frame to recover the lost CU. The partitions are merged and the MVs are refined based on the residual energy for motion compensation. However, all of them fail to consider the spatial smoothness of the lost CUs, often resulting in boundary misalignments and degrading visual quality.

In this paper, we improve the traditional boundary matching algorithm (BMA) by using partition decisions. We adopt the co-located partition decisions from the previous frame for lost CUs because it is observed that the CU depths and the PU partitions show strong temporal correlations between the previous and current frame [7], [8]. Since each partition often represents an object or block segmentation, we perform a weighted BMA for each partition separately to not only maintain spatial smoothness but also to recover the objects in the lost regions more precisely.

The rest of this paper is organized as follows: The proposed method is described in Section II. The subjective and objective experimental results are shown in Section III. Finally, Section IV summarizes the conclusions.

II. Proposed method

In this section, we present a weighted boundary matching EC method based on the block partition decisions from the previous frame. For each partition, the block matching algorithm is performed separately to conceal the lost partition according to the summed boundary weight. In a frame with lost LCUs, each lost LCU will be concealed sequentially.

For a lost Largest Coding Unit (LCU), we use the partition decisions from the co-located LCU. The proposed weighted BMA includes the following steps:

a) Constructing an initial weighting map: Fig. 1 shows the initial constructed weighting map for a frame with a lost LCU. For a $m \times n$ frame $F \in R^{m \times n}$ with lost LCUs, the weighting map $W \in R^{m \times n}$ is defined as

$$w_{i,j} = \begin{cases} 1, & \text{if } f_{i,j} \text{ is correctly received,} \\ \varepsilon, & \text{if } f_{i,j} \text{ is concealed,} \\ 0, & \text{otherwise,} \end{cases} \tag{1}$$

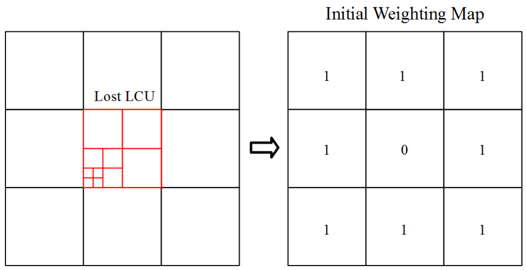

Fig. 1. Constructing an initial weighting map

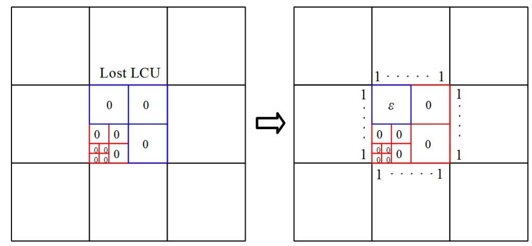

Fig. 2. Updating the weight map

where $w_{i,j}$ denotes the weighting factor for pixel $f_{i,j}$ in a frame, ε is the weight for the pixels in the lost PU once it has been concealed, and $1 > \varepsilon > 0$. Here, we use $\varepsilon = 0.5$.

b) Calculating the total weight for a lost PU: In Fig 1, there are 10 lost PUs, outlined in red. For each lost PU, we calculate the total weight by summing up the weights that surround the lost PU as

$$\begin{aligned} Weight_{PU_k} = & \sum_{x=x_0}^{x_0+l_k-1} (w_{x,y_0-1} + w_{x,y_0+h_k}) \\ & + \sum_{y=y_0}^{y_0+h_k-1} (w_{x_0-1,y} + w_{x_0+l_k,y}), \end{aligned} \tag{2}$$

where (x_0, y_0) is the left-top position of the lost PU_k with the size $l_k \times h_k$.

c) Select the lost PU with the largest weight for concealment: We sort all the lost PUs by their total weights and pick the one with the largest weight to apply the weighted BMA (WBMA). If more than one PU has the largest weight, we will select one in a raster scan order. In the example of Fig. 2, the three largest PUs all have equal weights, and the weight is larger than any of the other 7 PUs. So the top left PU is selected to be concealed first. The WBMA cost function is defined as

$$\begin{aligned} Cost_{PU_k} = & \frac{1}{Weight_{PU_k}} \times \\ & [\sum_{x=x_0}^{x_0+l_k-1} w_{x,y_0-1} \times (\mid f_{x,y_0-1} - f'_{x,y_0-1} \mid) \\ & + \sum_{x=x_0}^{x_0+l_k-1} w_{x,y_0+h_k} \times (\mid f_{x,y_0+h_k} - f'_{x,y_0+h_k} \mid) \\ & + \sum_{y=y_0}^{y_0+h_k-1} w_{x_0-1,y} \times (\mid f_{x_0-1,y} - f'_{x_0-1,y} \mid) \\ & + \sum_{y=y_0}^{y_0+h_k-1} w_{x_0+l_k,y} \times (\mid f_{x_0+l_k,y} - f'_{x_0+l_k,y} \mid)], \end{aligned} \tag{3}$$

where $f'_{x,y} = f_{x+MVx,y+MVy}$, and (MVx, MVy) is the candidate motion vector of PU_k. The candidate motion vectors are collected from the PUs adjacent to and co-located with PU_k in the current and previous frames respectively.

After concealing the lost PU, the weighting map is updated according to (1), as shown in Fig. 2. Then, we repeat the steps $b)$ and $c)$ iteratively to conceal the rest of the lost PUs.

III. Experimental Results

In this section, both the objective results and the subjective visual quality are evaluated. We compare the PSNR performance and the visual quality of the proposed method using either the co-located PU partitions of the previous frame or the actual partitions of the lost LCUs with those of the conventional methods. Under real conditions, however, we are unable to use the actual partition decisions since those LCUs have been corrupted. Thus, we only apply the actual partitions of the lost LCUs in the proposed method for comparison and further discussion. There are three EC methods compared here:

1) Copy: directly copy pixels from the co-located LCUs from the previous frame.
2) LCU BMA: use BMA to find the best MV for a whole LCU.
3) WBMA: use BMA to find the best MV for each PU in a lost LCU.

Two video sequences, BQMall and Drill (832×480), are used. Each sequence consists of 60 frames and is encoded by HM11.0. The frame rate is 50 frames per second, and the quantization parameter is 28. For every 12 frames, only the first frame is an intra-coded frame (I-frame) and the remaining frames are inter-coded (P-frame). Two loss patterns of a sequence are tested, which are random dropping of LCUs or slices. Each slice has a fixed 8 LCUs.

The locations of erroneous LCUs or slices are randomly generated in P-frames according to the LCU error rate (LER) or the slice error rate (SER) as

$$\begin{aligned} LER &= \frac{\textit{\# of corrupted LCUs}}{\textit{\# of total LCUs}}, \\ SER &= \frac{\textit{\# of corrupted slices}}{\textit{\# of total slices}}. \end{aligned} \tag{4}$$

LER and SER values of 1%, 5%, 10%, 15%, 20%, and 30% are tested. For each error rate, 100 error bitstreams are generated and decoded.

Fig. 3 depicts PSNR performances averaged over all frames in 100 realizations with different LERs and SERs. The WBMA using the previous partitions achieves PSNR gains up to 2.97

dB and 0.89 dB for Drill and 2.05 dB and 1.07 dB for BQMall, compared to the copy method and the LCU BMA respectively. It also demonstrates we can still obtain comparable PSNR results for the WBMA between using the previous partitions and the actual partitions.

Fig. 4 demonstrates the visual comparisons among different EC methods, where the WBMA outperforms the conventional methods. In Fig. 4, the WBMA, using either the co-located partitions or the actual partitions, recovers the body parts of the players, whereas the Copy method and the LCU BMA show blocking artifacts and boundary misalignments.

IV. Conclusion

In this paper, we have presented a weighted boundary matching EC method for HEVC, adopting the block partition decisions to improve the conventional block matching algorithm. The experimental results show that the proposed method outperforms the conventional EC methods. Furthermore, we apply either the co-located partitions in the previous frame or the actual partitions in the proposed method to demonstrate that using only the co-located partitions can still achieve similar objective results and visual quality compared to using the actual partitions for various LCU and slice error rates.

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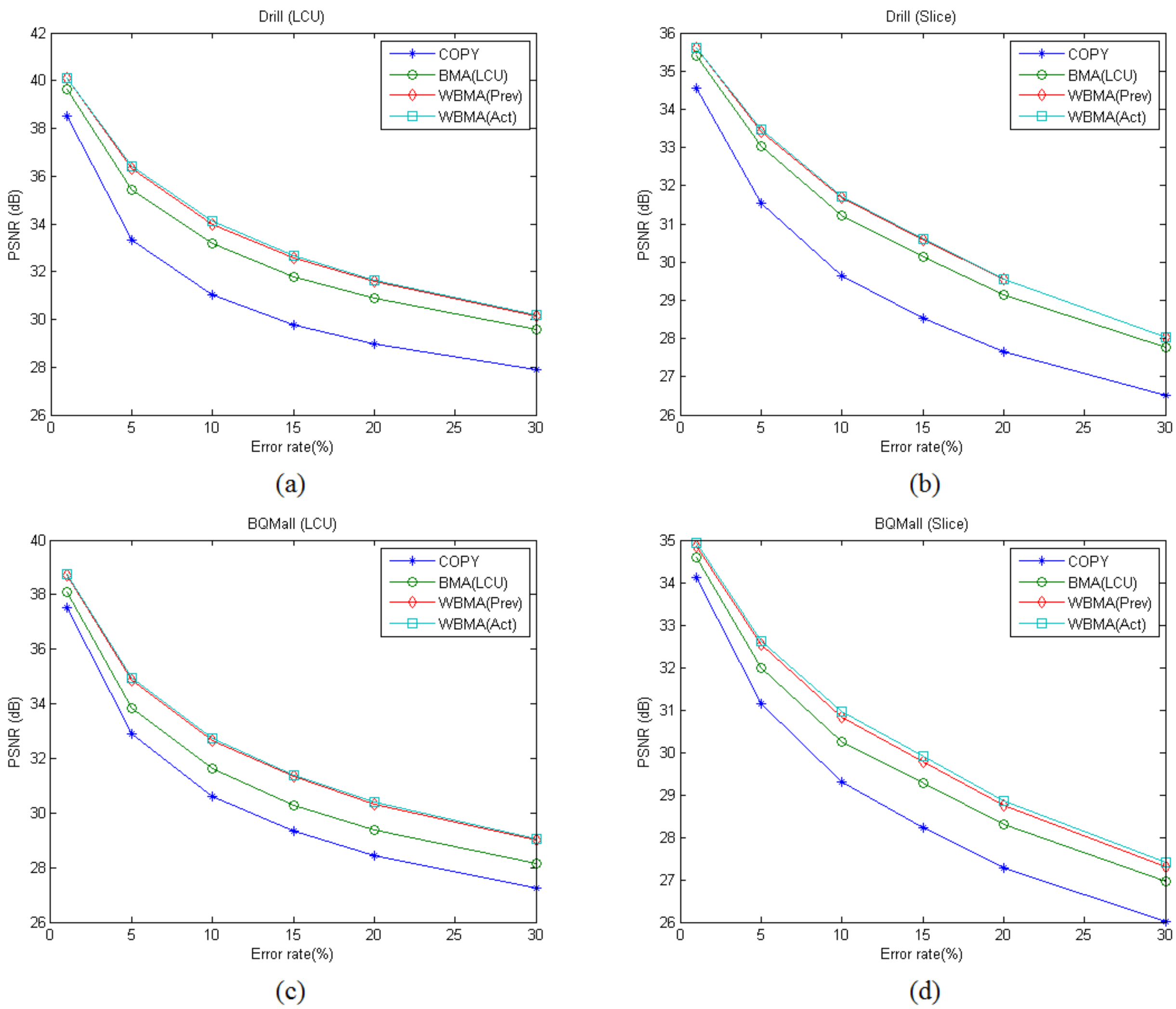

Fig. 3. PSNR Comparison for dropping LCUs or slices: (a) Drill (LCU), (b) Drill (Slice), (c) BQMall (LCU), (d) BQMall (Slice).

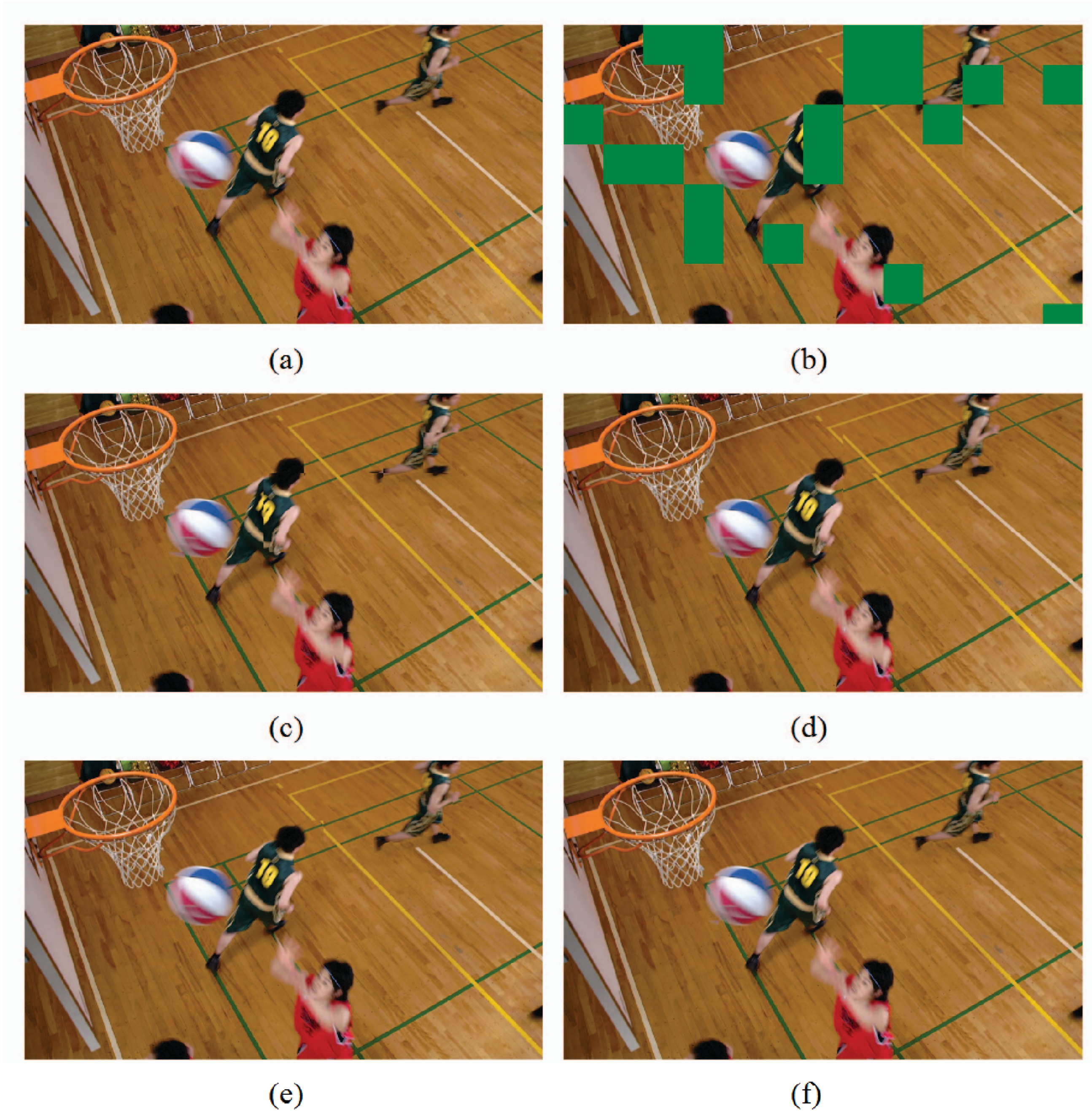

Fig. 4. (a) Original 11th frame of the *Drill* sequence, (b) LCU loss pattern from $LER = 15\%$. The frame concealed by: (c) copy, (d) LCU BMA, (e) WBMA using the co-located partitions, (f) WBMA using the actual partitions.