Error Concealment Using Intra-Mode Information Included in H.264/AVC-Coded Bitstream

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The H.264/AVC standard has adopted new coding tools such as intra-prediction, variable block size, motion estimation with quarter-pixel-accuracy, loop filter, and so on. The adoption of these tools enables an H.264/AVC-coded bitstream to have more information than was possible with previous standards. In this paper, we propose an effective spatial error concealment method with low complexity in H.264/AVC intra-frame. From information included in an H.264/AVC-coded bitstream, we use prediction modes of intra-blocks to recover a damaged block. This is because the prediction direction in each prediction mode is highly correlated to the edge direction. We first estimate the edge direction of a damaged block using the prediction modes of the intra-blocks adjacent to a damaged block and classify the area inside the damaged block into edge and flat areas. Our method then recovers pixel values in the edge area using edge-directed interpolation, and recovers pixel values in the flat area using weighted interpolation. Simulation results show that the proposed method yields better video quality than conventional approaches.

Keywords: H.264/AVC video coding, spatial error concealment, adaptive interpolation, intra-prediction mode.

I. Introduction

Channel noise or congestion often leads to packet loss when video streams are transmitted through noisy channels. To alleviate this problem, error concealment is very useful, since a decoded frame which has damaged blocks still includes spatial and temporal redundancy. When video data is corrupted, temporal error concealment methods [1]-[6] recover the damaged data using the information of previously decoded frames, and spatial error concealment methods recover the damaged area using spatially neighboring video data. In this paper, we focus on spatial error concealment with low complexity.

Several spatial error concealment algorithms to restore missing blocks of received video frames have been proposed [7]-[14]. Wang and others proposed the optimization algorithm in which the optimal DCT coefficients are estimated by imposing smoothness constraints between the intensity values of adjacent samples [7]. Lee and others proposed a spatial error concealment method based on spatial interpolation filtering and recovery of DCT coefficients employing fuzzy logic reasoning [8]. Sun and Kwok proposed a block recovery algorithm based on projection onto convex sets [9], Alkachouh and Bellanger reported a fast DCT-based spatial interpolation technique [10], and Park and others proposed an error concealment algorithm called recovery of image blocks using the method of alternating projections [11].

The H.264/AVC standard has adopted new coding tools such as intra-prediction, loop-filter, motion estimation, and compensation using variable block size. The adoption of these tools enables an H.264/AVC-coded bitstream to have more information than was possible with previous standards. From the information, the prediction mode (p-mode) of each intra-

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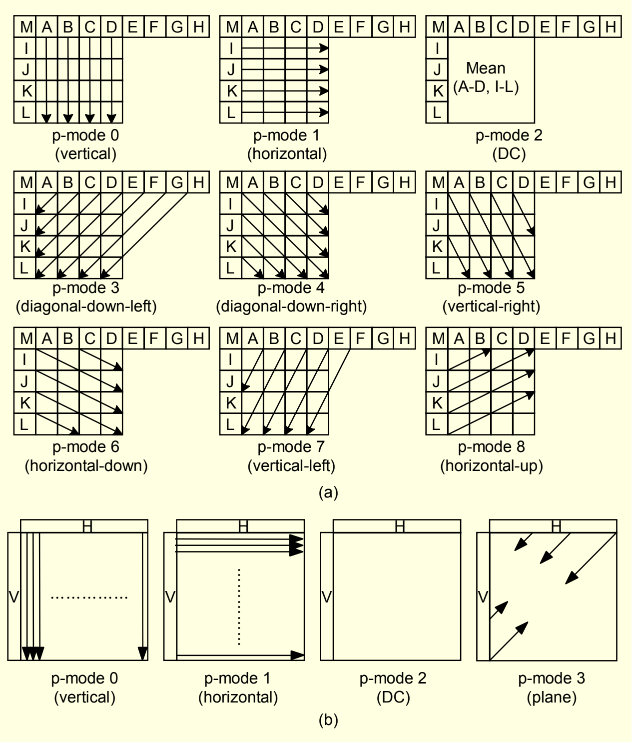


Fig. 1. Prediction modes of (a) intra 4×4 (or intra 8×8) and (b) intra 16×16.

block is very useful for spatial error concealment. This is because prediction direction in each p-mode is strongly related with the edge direction of the corresponding block.

In this paper, using these characteristics of H.264/AVC, an effective error concealment algorithm with low complexity is presented for intra-frames in H.264/AVC. We assume that all spatial errors are detected using detection methods such as that presented in [15]. Using the p-modes of intra-blocks adjacent to a damaged macroblock, the proposed method estimates the edge direction of a damaged macroblock and classifies the damaged area into an edge and a flat region in the pre-processing stage. Afterward, the pixel values in the edge region are recovered by edge-directed interpolation in advance. Then, those in the flat region are recovered by weighted interpolation, which is embedded in the reference software of H.264/AVC.

II. Spatial Error Concealment in H.264/AVC

1. Prediction Modes in H.264/AVC

For encoding intra-blocks, H.264/AVC uses three intra-modes: 4×4, 8×8, and 16×16. An intra 8×8 mode is only supported by H.264/AVC fidelity range extension (FRExt). As shown in Fig. 1, there are nine p-modes in intra 4×4 and intra 8×8 and four p-modes in intra 16×16 [16]-[18].

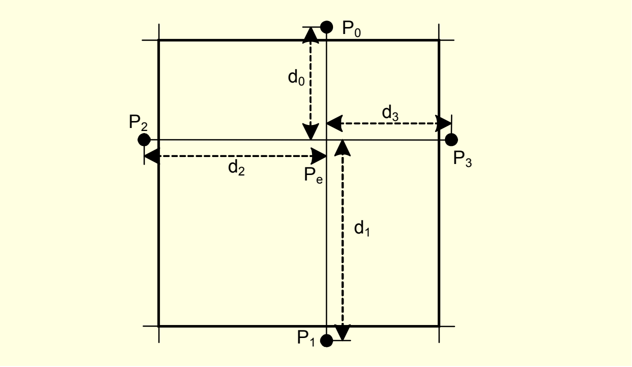


Fig. 2. Spatial error concealment method in the reference software of H.264/AVC.

2. Spatial Error Concealment in the Reference Software

For spatial error concealment, the reference software (JVT Model) of H.264/AVC uses weighted averaging interpolation of four pixel values located at vertically and horizontally neighboring boundaries of a damaged macroblock [19], [20]. As shown in Fig. 2, a pixel value in a damaged macroblock, P_e is replaced with the weighted average of the four boundary pixel values located at the top, bottom, left, and right sides, where P_e indicates a pixel value in a damaged macroblock, P_0 to P_3 are vertically and horizontally neighboring boundary pixels, and d_i indicates the distance between P_e and P_i.

Therefore, the reconstructed pixel value using weighted average interpolation can be formulated as

$$p_e = \frac{d_1 \cdot p_0 + d_0 \cdot p_1 + d_3 \cdot p_2 + d_2 \cdot p_3}{d_0 + d_1 + d_2 + d_3}. \tag{1}$$

A spatial error concealment method for intra-frames in the reference software takes only the weighted average of vertically and horizontally neighboring boundary pixel values regardless of the edge characteristics of a video frame. 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.

III. Proposed Spatial Error Concealment

The proposed algorithm for spatial error concealment in intra-frames during the H.264/AVC decoding process consists of pre-processing and adaptive interpolation, and each process has two steps as shown in Fig. 3.

The pre-processing part first chooses the dominant prediction mode (DPM) from p-modes around a damaged macroblock, and estimates the edge direction of a damaged macroblock by the DPM. By using the DPM, the algorithm identifies parts of

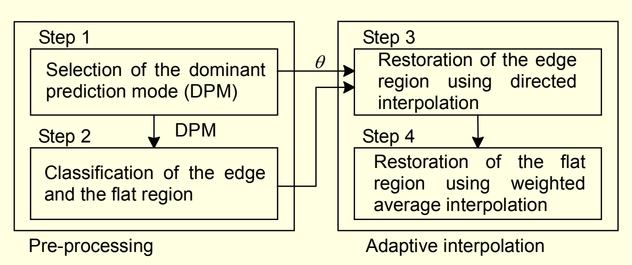


Fig. 3. Architecture of the proposed method for spatial error concealment in intra-frames during the decoding process.

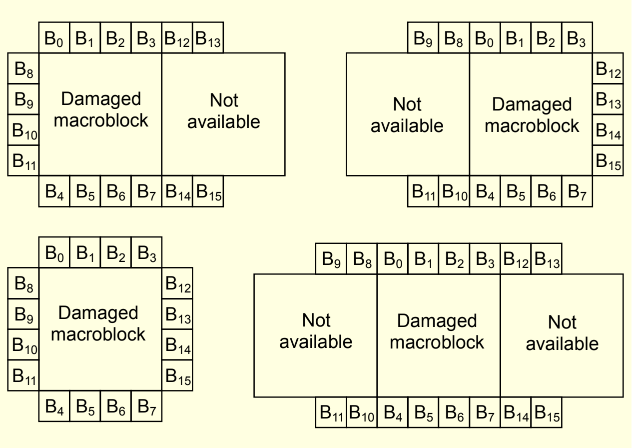


Fig. 4. The sixteen p-modes used in pre-processing according to availability of neighboring macroblocks.

the damaged area as the edge region and the flat region.

After pre-processing is finished, the adaptive interpolation part restores pixel values with different interpolation methods according to the classified region. The pixel values in the edge region are restored using an edge-directed interpolation method in advance. After that, a weighted interpolation method which is embedded in the reference software recovers the pixel values in the flat region using previously interpolated pixel values in the edge region as well as the boundary pixel values of the damaged macroblock.

1. Pre-processing

The proposed method uses p-modes of sixteen 4×4 blocks located around a damaged macroblock. Figure 4 illustrates the use of sixteen p-modes in pre-processing according to the availability of neighboring macroblocks.

If one neighboring macroblock is coded as intra 16×16 or intra 8×8, the proposed method considers that the p-mode of a 4×4 block is repeated. For example, if a macroblock is coded as intra 16×16 using p-mode 1 (horizontal prediction), the proposed method regards all 4×4 blocks in the macroblock as p-mode 1 because the prediction directions of p-mode 0 to p-mode 3 in intra 16×16 are similar to those in intra 4×4 [16]. Using these p-modes in the pre-processing stage, the proposed method estimates the edge direction of the damaged macroblock and classifies the edge and the flat regions.

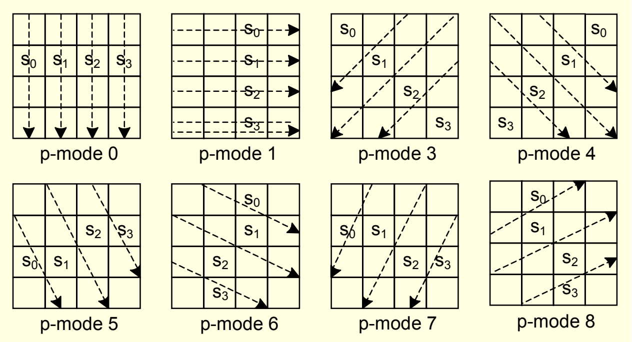


Fig. 5. Four pixel values located perpendicular to the prediction direction in each p-mode for calculating the edge magnitudes of sixteen 4×4 blocks.

A. Estimation of the Edge Direction

Sixteen p-modes located around a damaged macroblock can be exploited efficiently to estimate the edge direction of a damaged macroblock because each p-mode represents the edge direction of the corresponding block. However, these p-modes do not provide any information about the edge magnitude and simply indicate the edge directions. Therefore, to estimate the edge direction of a damaged macroblock, the edge magnitude of each block as well as the p-modes of neighboring blocks must be considered.

The edge magnitudes (M_{edge}) of sixteen neighboring 4×4 blocks are calculated as follows.

Step 1. Choose four pixels located at the perpendicular direction of the prediction direction in the p-mode of each neighboring 4×4 block.
Step 2. Obtain the difference between maximum and minimum pixel values.

The process of edge magnitude calculation is shown in Fig. 5 and is formulated in (2). As shown in (2), for p-mode 2, namely DC prediction, the proposed method assumes that there is no edge, and the edge magnitude is set to zero.

$$M_{edge} = \begin{cases} 0, & \text{for p-mode 2,} \\ \max(\bar{s}) - \min(\bar{s}), & \text{otherwise,} \end{cases} \tag{2}$$

where $\bar{s} = [s_0, s_1, s_2, s_3]$.

Once the edge magnitudes of the sixteen neighboring 4×4 blocks are obtained, a DPM is chosen with a p-mode which maximizes the sum of the edge magnitude at each p-mode. The prediction direction of the DPM is chosen as the edge direction

Table 1. Edge direction of a damaged macroblock when each p-mode (except p-mode 2) is chosen as a DPM.

p-modes	p-mode 0	p-mode 1	p-mode 3	p-mode 4
Edge direction	90°	0°	45°	135°
p-modes	p-mode 5	p-mode 6	p-mode 7	p-mode 8
Edge direction	112.5°	157.5°	67.5°	22.5°

of the damaged macroblock. Thus, the proposed algorithm can consider the eight edge directions identical to the prediction directions of the p-modes except p-mode 2. However, if both left and right neighboring macroblocks are unavailable, the proposed method does not consider p-mode 6 and p-mode 8. Table 1 shows the edge direction of a damaged macroblock when each p-mode is chosen as a DPM. If all the prediction modes have similar edge magnitude, this indicates that the damaged macroblock is nearly flat. That is, there is no edge in the macroblock. Nevertheless, we choose a DPM that has a maximum edge magnitude, since the performance of directional interpolation for the edge region is similar to that of weighted interpolation for the flat region if the damaged macroblock is really flat.

B. Identification of Edge and Flat Regions

The damaged region can be divided into the edge region, where there are edge components, and the flat region, where there are no edge components. In order to divide a damaged macroblock into edge and flat regions, the proposed method utilizes the DPM defined in the previous step.

The process of identifying the edge and flat regions is performed as follows.

Step 1. Among sixteen neighboring 4×4 blocks, the block with a p-mode identical to the DPM is chosen as a reference block.

Step 2. The area on the prediction direction of the DPM from the reference blocks is classified as the edge region. In this process, the width of the edge region is expanded with some margin because the smoothness of edges in a natural image differs from that of ideal edges.

Step 3. The other area which is not chosen as the edge region is designated as the flat region.

Figure 6 shows the identification of the edge and flat regions when p-mode 4 is chosen as the DPM and all macroblocks located at vertically and horizontally neighboring positions are available. Figure 6 shows the identification of the edge and flat regions when p-mode 4 is chosen as the DPM. If B_1, B_5, and B_{10} blocks have a p-mode 4 identical with the DPM, then the area located on the p-mode 4 direction (135°) from those three reference blocks is chosen as the edge region. In this process, we extend the edge region with some margin.

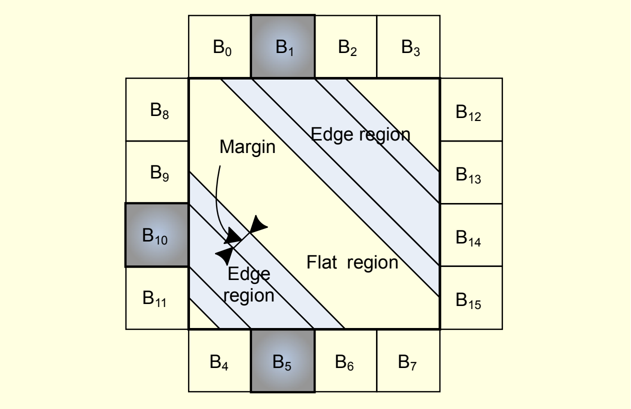


Fig. 6. Identification of edge and flat regions when the DPM is p-mode 4 and B_1, B_5, and B_{10} blocks have a p-mode 4 identical to the DPM.

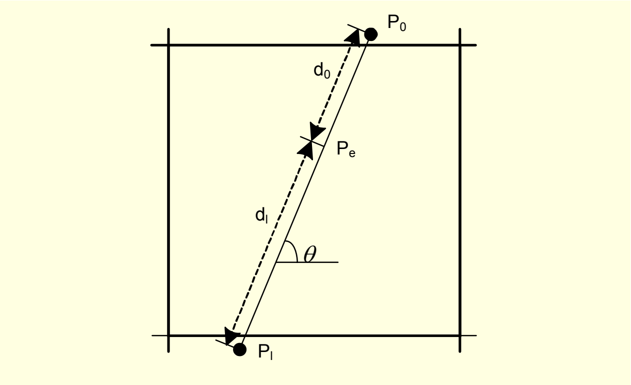


Fig. 7. Edge-directed interpolation method using first-order linear interpolation with two boundary pixel values.

2. Adaptive Interpolation

After the estimation of the edge direction and the identification of the edge and flat regions in the pre-processing stage, the damaged macroblock is restored by using different interpolation methods for each region. The proposed method restores the pixel values in the edge region in advance. Afterward, the pixel values in the flat region are interpolated.

A. Restoration of the Edge Region

The pixel values in the edge region are restored by an edge-directed interpolation method using the estimated edge direction, as shown in Fig. 7, where θ is the prediction direction of the DPM, that is, the estimated direction of a damaged macroblock. As shown in Fig. 7, the proposed method uses first-order linear interpolation with low complexity as an edge-

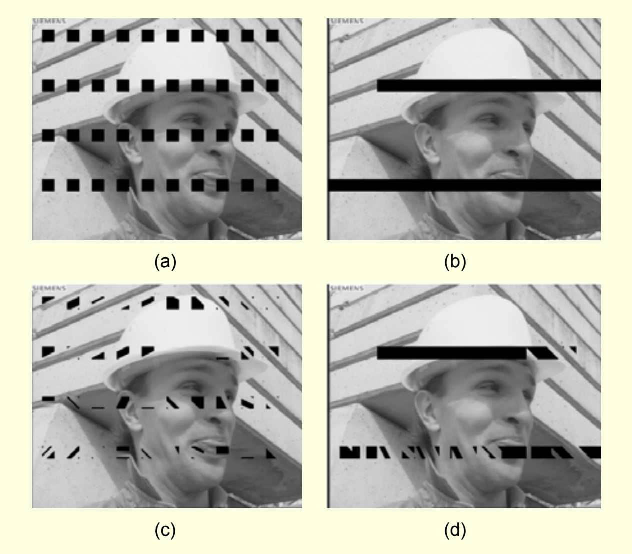


Fig. 8. Damaged frames with (a) isolated block error, (b) consecutive block error, and (c) and (d) the reconstructed frames of (a) and (b), respectively, when only the pixel values in the edge region are restored using the edge-directed interpolation method.

directed interpolation.

As in Fig. 7, the pixel value in the edge region, P_e, is restored by first-order linear interpolation with two boundary pixel values which are on a straight line from the location of P_e in the direction of the estimated edge direction:

$$p_e = \frac{d_1 \cdot p_0 + d_0 \cdot p_1}{d_0 + d_1}. \qquad (3)$$

When the DPM is a mode from p-mode 5 to p-mode 8, either P_0 or P_1 in Fig. 7 is a pixel value at a half-pixel position. In this case, the pixel value at a half-pixel position is replaced with the average of two pixel values at neighboring integer positions.

Figure 8 shows an intermediate result of the Foreman sequence with CIF (352×288) format, where only pixel values in the edge region are restored in cases of isolated and consecutive block error, respectively. As these intermediate results demonstrate, most of the area including edges is identified as the edge region and restored by edge-directed interpolation, especially in the case of isolated error.

B. Restoration of the Flat Region

The values of the pixels in the flat region are restored using the weighted interpolation scheme which is embedded in the reference software of H.264/AVC. However, there is a slight difference between the proposed method for restoration of the flat region and that in the reference software. When the weighted interpolation method is applied, the proposed method uses the previously restored pixel values in the edge region in addition to the boundary pixel values.

3. Complexity Analysis

A. Complexity of Pre-processing

In pre-processing, the complexity of estimating the edge direction depends upon the neighboring p-modes, because there is no operation to calculate the edge magnitude in the case of p-mode 2. Let us consider the worst case, in which no neighboring 4×4 block is encoded using p-mode 2. In this case, the total number of operation for selecting the DPM is as follows:

Step 1. To calculate edge magnitudes of sixteen neighboring 4×4 blocks, 96 (6×16) comparisons and 16 (1×16) subtractions per damaged macroblock are required.

Step 2. To calculate the sum of the edge magnitude for each p-mode, 16 additions are required.

Step 3. To select the DPM, 8 comparisons are needed. Selecting a DPM is equal to estimating the edge direction of a damaged macroblock.

After selection of the DPM, identification of the edge and flat regions requires only 16 comparisons to choose the blocks with p-modes which are identical to the DPM. Consequently, during the pre-processing, 16 additions, 16 subtractions, and 120 comparisons are needed. Neither multiplication nor division is included in pre-processing since the proposed algorithm uses p-modes that are already known.

B. Complexity of Adaptive Interpolation

Since a different interpolation method is used in each region, the complexity of adaptive interpolation varies with the size of

Table 2. Comparison of the number of operations to restore 256 pixel values when no neighboring block is encoded using p-mode 2 and half of a damaged macroblock is the edge region.

Operations	Reference software	Alkachouh's method	Proposed method	
			Pre-processing	Interpolation
Addition	768	17,408	16	1,024 or 1,152*
Subtraction	-	-	16	-
Multiplication	1,024	17,408	-	768
Division	256	-	-	256
Comparison	-	512	120	-
Shift	-	-	-	0 or 128*

* In case that one of p-mode 5 to p-mode 8 is selected as the DPM.

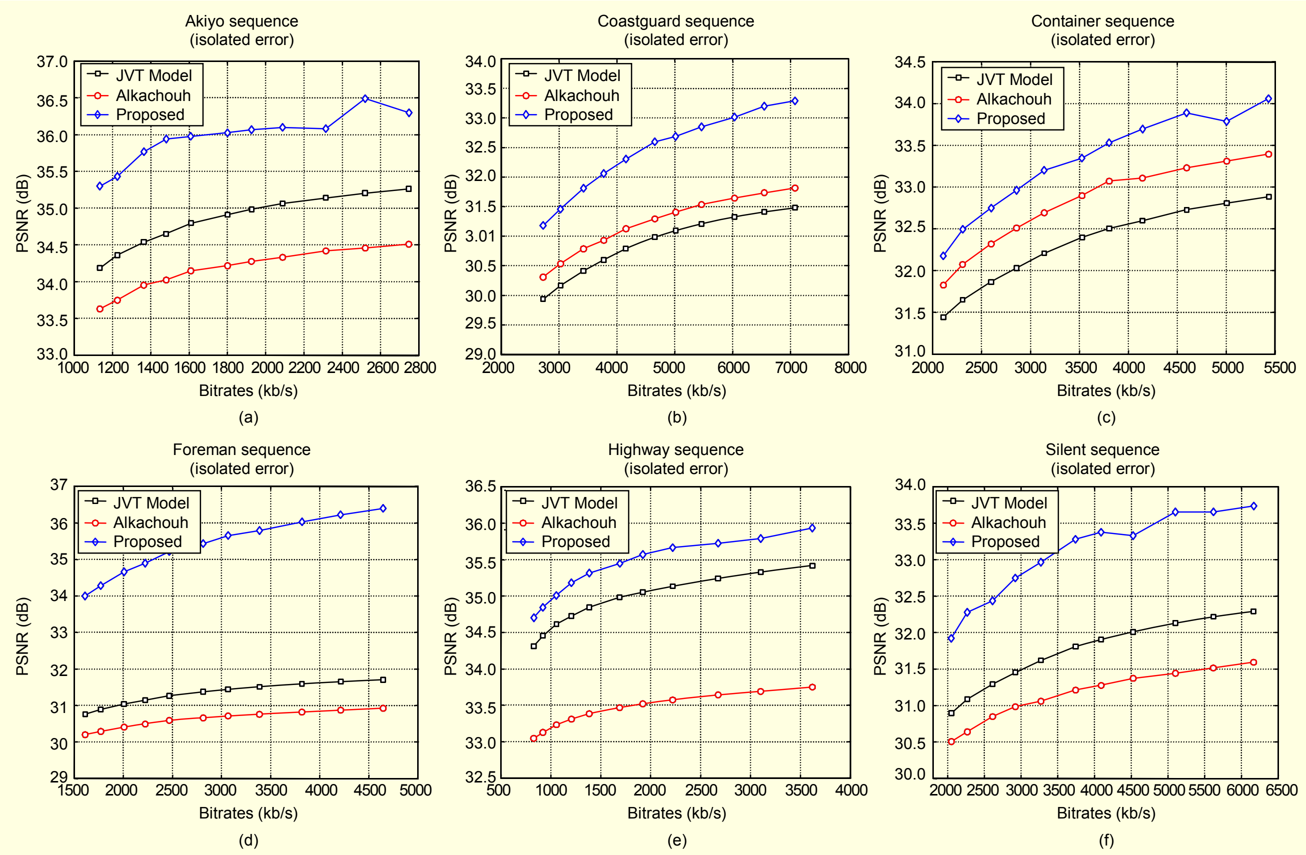


Fig. 9. Comparison of objective qualities of (a) Akiyo, (b) Coastguard, (c) Container, (d) Foreman, (e) Highway, and (f) Silent sequences at various bitrates with isolated block error.

each region. The pixel values in the flat region are recovered by using the same method as that embedded in the reference software, as given in (1). However, there are fewer additions in the reference software than in the proposed method in the flat region because the reference software identifies all the damaged area as belonging to the flat region (in terms of the proposed algorithm) and fixes the denominator of (1) as 36. Thus, it can save 3 addition operations. In the proposed method, 6 additions, 4 multiplications, and 1 division are required in order to restore a pixel value in the flat region.

The pixel values in the edge region are recovered by using edge-directed interpolation as shown in (3); thus, 2 additions, 2 multiplications, and 1 division are required for restoring a pixel value in the edge region. However, when a DPM is a p-mode from p-mode 5 to p-mode 8, 1 addition and 1 shift operation are also needed because one of the boundary pixels in (3) is located at a half pixel position.

C. Comparison of Complexity

As previously described, the complexity of the proposed algorithm depends upon the p-modes of neighboring blocks, the chosen DPM, and the size of each region. For cases when vertically and horizontally neighboring macroblocks are available, Table 2 compares the complexity of the proposed algorithm with a method in the reference software of H.264/AVC and Alkachouh's fast DCT-based method when no neighboring block is encoded using p-mode 2, and the edge region occupies half of a damaged region. In Table 2, the number of operations in Alkachouh's method is derived from a case in which an interpolation mask ((20) in [10]) is calculated and saved in advance.

The proposed algorithm estimates the edge direction of a damaged macroblock and identifies the edge and flat regions inside a damaged macroblock with a small number of operations by using neighboring p-modes which are already known. Moreover, when the edge region covers more than 50% of the damaged area, the propose algorithm has fewer multiplication than those of the reference software and Alkachouh's method. Since the time delay of 8-bit-by-8-bit multiplication is about three times of that of 8-bit-by-8-bit addition in common conditions of ASIC design, the operation time of the proposed method is only 89% or 92% compared to that of the reference software. Considering various edge directions in a video sequence, it is possible for the proposed

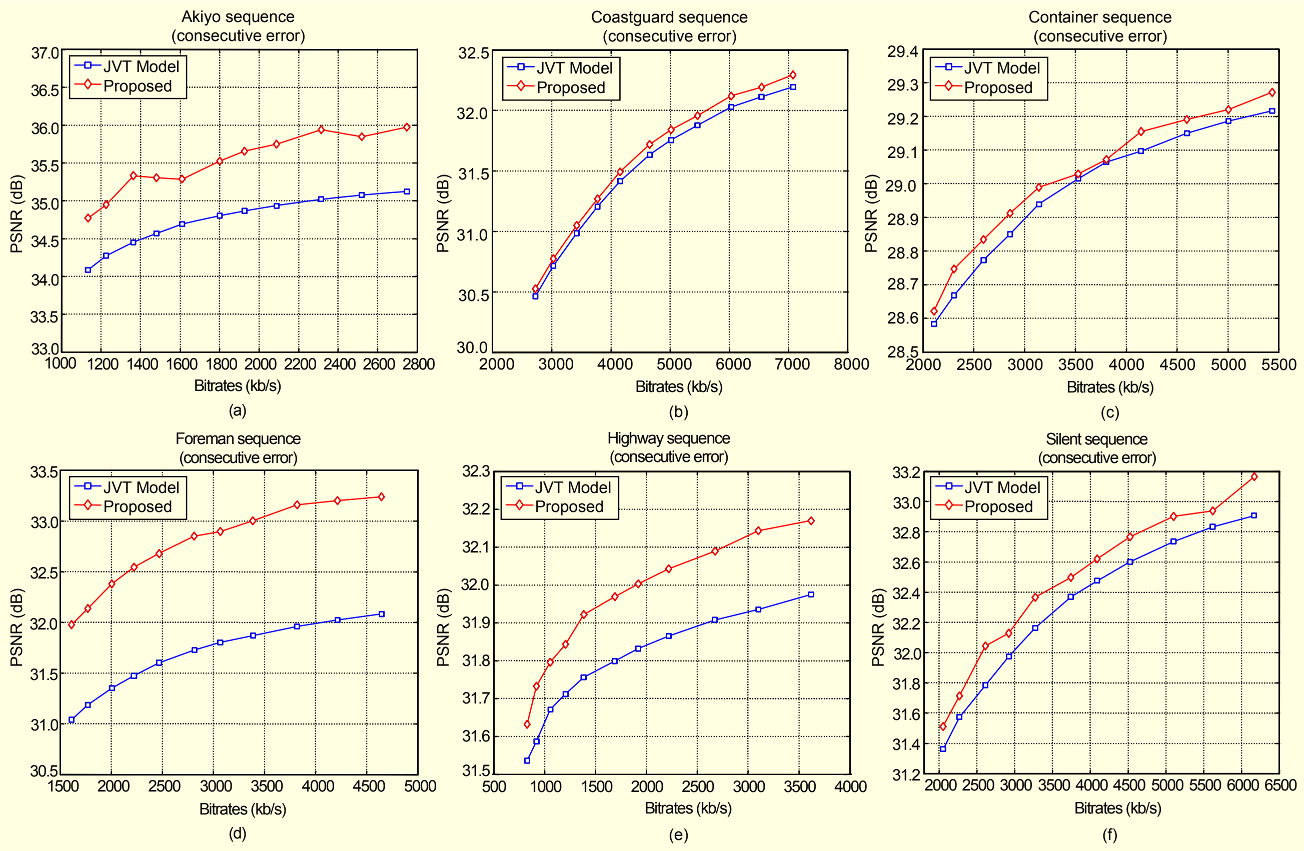


Fig. 10. Comparison of objective qualities of (a) Akiyo, (b) Coastguard, (c) Container, (d) Foreman, (e) Highway, and (f) Silent sequences at various bitrates with consecutive block error.

algorithm to alleviate the complexity further.

D. Simulation Results

To evaluate the proposed algorithm, a public reference encoder (JVT Model [20]) was used. Six standard video sequences in CIF (352×288) format were analyzed. These included the Akiyo, Coastguard, Container, Foreman, Highway, and Silent sequences. In this evaluation, the first 30 frames of each sequence which were encoded as I-frames only were used, and the simulation results of the proposed method were compared with those of other conventional methods for two different block error types. The proposed algorithm used the value 2 as the margin (see Fig. 6) of the edge region. The best margin value was found through experimental analysis for various test sequences.

Figures 9 and 10 illustrate the objective quality for each sequence with isolated block error and consecutive block error, respectively. As these figures demonstrate, the proposed algorithm outperforms other methods in terms of objective quality at all bitrates for all sequences. Especially for the Foreman sequence, the proposed algorithm improves the objective quality by about 4 dB for isolated block error and 1 dB for consecutive block error. This is because there are a lot of edge components in the Foreman sequence which cannot be considered in those methods.

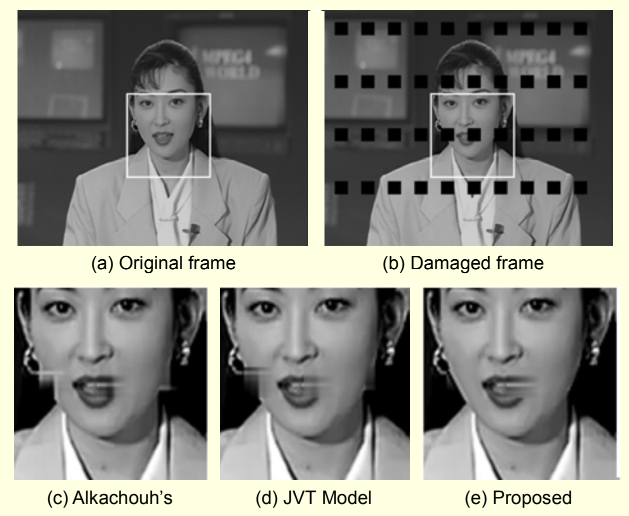
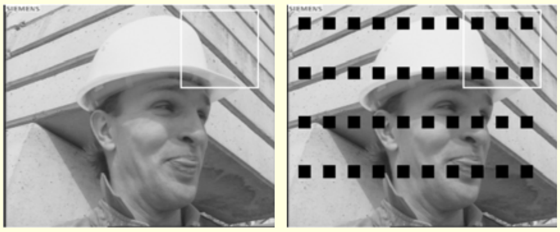


Fig. 11. Comparison of subjective video qualities of the 18th frame of Akiyo sequence for isolated block error.

Figures 11 to 16 show subjective qualities for the Akiyo,



(a) Original frame (b) Damaged frame

(c) Alkachouh's (d) JVT Model (e) Proposed

Fig. 12. Comparison of subjective video qualities of the 7th frame of Foreman sequence for isolated block error.

(a) Original frame (b) Damaged frame

(c) Alkachouh's (d) JVT Model (e) Proposed

Fig. 13. Comparison of subjective video qualities of the 17th frame of Highway sequence for isolated block error.

(a) Original frame (b) Damaged frame

(c) Original block (d) JVT Model (e) Proposed

Fig. 14. Comparison of subjective video qualities of the 21st frame of Akiyo sequence for isolated block error.

(a) Original frame (b) Damaged frame

(c) Original block (d) JVT Model (e) Proposed

Fig. 15. Comparison of subjective video qualities of the 27th frame of Foreman sequence for isolated block error.

(a) Original frame (b) Damaged frame

(c) Original block (d) JVT Model (e) Proposed

Fig. 16. Comparison of subjective video qualities of the 24th frame of Highway sequence for isolated block error.

Foreman, and Highway sequences with two different block error types. As these results demonstrate, the proposed algorithm also outperforms the other two methods in terms of subjective quality, especially for the region which includes edge components.

IV. Conclusion

In this paper, a spatial error concealment technique for H.264/AVC was proposed. It exploits the information included in an H.264/AVC-coded bitstream. The proposed algorithm conducts the pre-processing which estimates the edge direction of a damaged macroblock using p-modes of intra-blocks around the damaged macroblock. It also differentiates parts of the area inside the macroblock into edge or flat regions.

For each of the two region types, different interpolation techniques are applied to restore pixel values. The simulation results show that the proposed algorithm outperforms two other existing techniques for intra-frames in terms of both the subjective and the objective video qualities. It improves the image quality by about 4 dB for isolated block error and by about 1 dB for consecutive block error in which there are many directions of edge components as in the Foreman sequence.

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