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A Hybrid Error Concealment Technique for H.264/AVC Based on Boundary Distortion Estimation

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1. Introduction

Video compression technologies have been extensively studied in recent years. The basic concept of video compression is to reduce the amount of bits for video representation by exploiting spatial and temporal correlations in image sequences. In recent years, H.264/AVC (Advanced Video Coding) is the state-of-the-art video coding standard established by ITU-T Video Coding Experts Group and ISO/IEC Moving Pictures Experts Group. H.264/AVC provides a better compression efficiency and visual quality than prior standards, owing to it adopts some unique techniques to reduce the redundant information, such as multiple reference frames, variable block size, quarter-sample-accurate motion compensation, etc. In H.264/AVC encoder, integer DCT procedure transforms residual data into the frequency domain. Further through quantization will generate many continuous zero coefficients. Two excellent entropy coding schemes can reduce coding redundancy: context-adaptive variable length coding (CAVLC) (Bjontegarrd and Lillevold, 2002) and context-adaptive binary arithmetic coding (CABAC) (Marpe et al., 2003). Therefore, H.264/AVC has higher compression ratio than prior standards and is more appropriate to limited transmission channel. However, this highly compressed video bit stream is very fragile over transmission environments.

In the error-prone transmission channel, packet loss of the highly compressed video bit stream will cause the serious distortion. The distortion will propagate to its successive frames. This is because video coding standards utilize complex predictions to enhance the coding efficiency, especially as H.264/AVC. Thus, how to recover the lost video data in the decoder is critically essential. Since erroneous data would not only make seriously degrade in the current frame but also propagate to the following frames. For solving above-mentioned problems, the error resilience and the error concealment techniques have been proposed in many literatures.

The error resilience is a mechanism in the encoder for resisting packet loss. These preventative mechanisms are designed to improve the robustness of bit streams in noisy networks. On the other hand, the error concealment is an effective mechanism in the decoder. It applies to concealing corrupted regions by referencing previous decoded data. As a video sequence usually has strong spatial and temporal correlation, the corrupted macro-blocks (MBs) can be approximated from the information of the neighbouring MBs in spatial or temporal domain.

Temporal error concealment (TEC) approaches usually employ the dependence of continuous frames to estimate the lost motion vectors (MVs). Further corrupted MBs can be replaced with the corresponding MBs in reference frames. Corresponding MBs are judged by estimated MVs, obtained by boundary matching algorithms (BMA) (Lam et al., 1993). Spatial error concealment (SEC) approaches adopt neighbouring correct data in the current frame to restore the lost data. One of the remarkable SECs is bilinear interpolation (BI). Bilinear interpolation (BI) calculates weighted average pixel values from boundary pixels. Some SECs interpolate the lost pixels according to the estimated edge directions, such as directional interpolation (DI) mode, multi-directional interpolation (MDI) (Kwok and Sun, 1993) mode and selective directional interpolation (SDI) (Kung et al., 2006) mode.

This article proposes a hybrid error concealment technique which consists of both the proposed temporal and the proposed spatial error concealment approaches. If TEC approach is not appropriate for the corrupted MB, SEC approach will further be adopted. Simulation results show that the recovery performance could be enhanced by the proposed hybrid error concealment technique, even by the proposed temporal error concealment approach.

2. The proposed hybrid error concealment in H.264/AVC

The proposed hybrid error concealment technique is implemented in H.264/AVC decoder. It could make trade-off not only between TEC and SEC approaches but also between different error concealment schemes. The flowchart of the proposed technique is shown in Figure 1. In general, the recovery performance of TEC is better than SEC. However, SEC is better than TEC in some circumstances, such as scene-change frames or high motion regions. Therefore, while error occurs, the proposed technique will initially adopt the proposed TEC approach. If temporal information is unobtainable or inappropriate for restoring the corrupted data, the proposed technique will further switch to utilize the SEC approach according to the measure of temporal activity, T_{MSE}, and spatial activity, S_{Var}. The proposed SEC approach (Wang et al., 2010), adaptively integrating some interpolation schemes, will restore the corrupted data. Therefore, the proposed hybrid error concealment technique could enhance the recovery performance especially in scene-change frames and high motion regions. In other words, the recovery performance of the proposed TEC approach could be enhanced by adaptively utilizing the proposed SEC approach (Wang et al., 2010).

The switching mechanism in the proposed hybrid error concealment is based on temporal activity, T_{MSE}. While the temporal activity is greater than the spatial activity, S_{Var}, and a pre-determined threshold, the proposed SEC approach will further be adopted. T_{MSE} and S_{Var} are calculated by the Equation (1) and (2), respectively.

$$T_{MSE} = \frac{\sum (x_i - x_i')^2}{N} \tag{1}$$

$$S_{Var} = \frac{\sum (x_i - \mu)^2}{N} \tag{2}$$

where x_i and x_i' denote boundary pixel values around the corrupted MB in current frame and boundary pixel values around the replacement MB in reference frame, respectively. μ is the mean value of boundary pixel values around the corrupted MB.

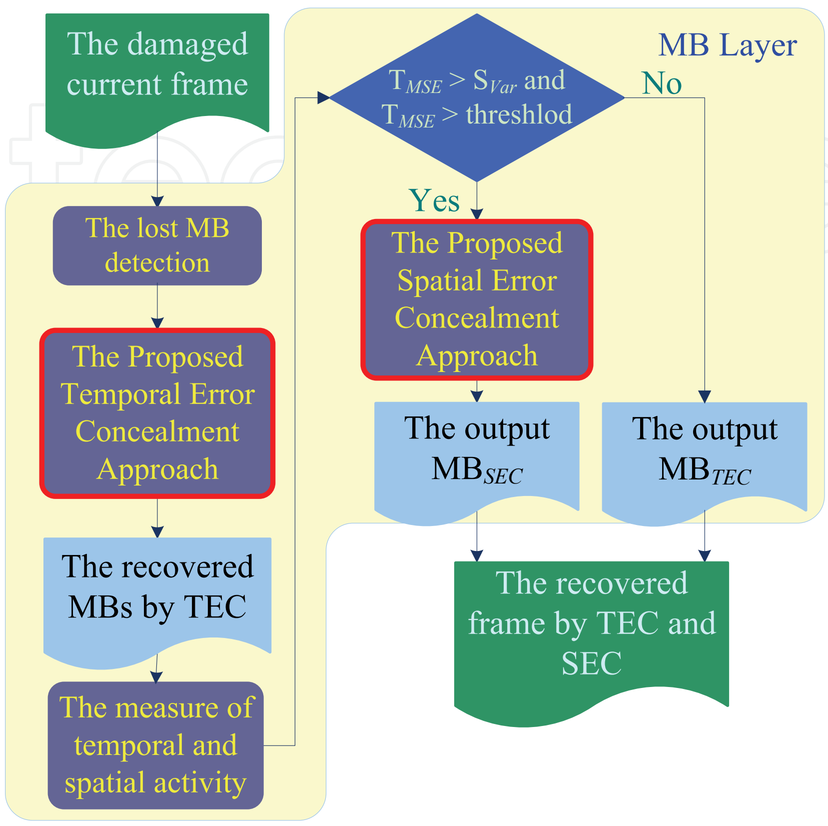


Fig. 1. The flowchart of the proposed hybrid error concealment technique

In the temporal domain, the proposed TEC approach determines an optimal result to restore the corrupted MB according to the internal boundary distortion estimation. This optimal result can be determined from one of the following two restored candidate MBs. One candidate is obtained by adopting mean absolute difference (MAD) of external boundary pixels to search for the most similar MB. The other is obtained by adaptively integrating the above-mentioned MB's data and an enhanced data with the proposed texture-based selective calibration. Inspired by bi-linearity interpolation filter (BIF) (Cui et al., 2009), this enhanced data is measured by the proposed estimated boundary residuals. In the spatial domain, the proposed SEC approach determines an integrated method to optimize recovery performance. The determination is based on a unique measure, the proposed external boundary distortion estimation. One of the integrated methods combines results of selective directional interpolation (SDI) (Yi et al., 2009) and bilinear interpolation (BI) with the adaptive weight. The other integrates results of multi-directional interpolation (MDI) (Zhan and Zhu, 2009) and BI with the adaptive weight. The details of the proposed TEC and SEC approaches will be briefly described in the following sub-sections.

2.1 The proposed temporal error concealment approach

The proposed temporal error concealment approach could find out the optimal restored data for concealment. Its flowchart is shown in Figure 2. First, the similar MB is estimated by a conventional temporal method to replace the corrupted MB. Secondly, the enhanced MB is calculated by appending enhanced residuals to the replaced MB. Then the proposed temporal adaptive weight-based switching (TAWS) algorithm adaptively integrates above two estimated data into the integrated MB. Finally, the proposed texture-based selective calibration (TSC) algorithm will find out the most appropriate restored data for corrupted MBs based on boundary distortion estimation. These exhaustive steps are described in the following sub-sections.

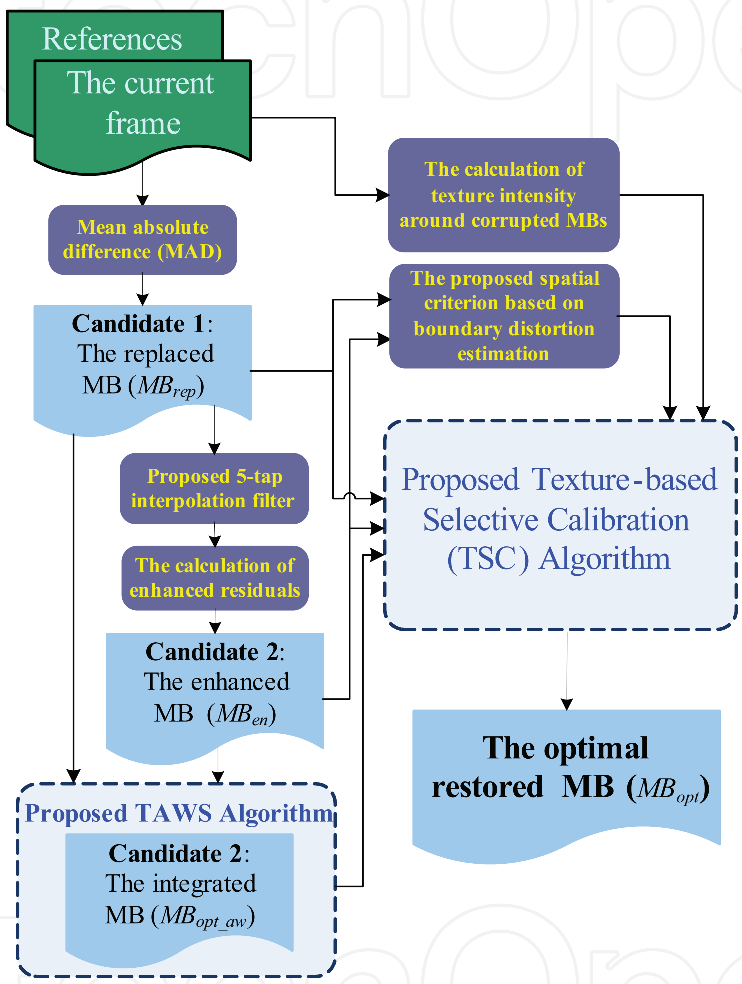


Fig. 2. The flowchart of the proposed temporal error concealment approach

2.1.1 Searching for the most similar MB by mean absolute difference

The most similar MB for corrupted MB is estimated in the first step. Like the restoring component of AECOD (Qian et al., 2009), the mean absolute difference (MAD) of external boundary pixels is adopted to search for the most similar MB. Then the corrupted MB is replaced with the most similar MB, namely replaced MB (MB_{rep}). If certain boundary of the corrupted MB is not available, the corresponding coefficient is set to be 0.

2.1.2 Calculation of boundary residuals for generating enhanced macro-blocks

This step utilizes boundary residuals to perform the proposed 5-tap interpolation filter in order to enhance the recovery performance. Firstly, boundary residuals are obtained by subtracting the boundary pixels around corrupted MB from the boundary pixels around the most similar MB in the previous frame. These are calculated by Equation (3), where *BR*, *CBP*, and *RBP* denote the boundary residual, the boundary pixels of the current frame and the boundary pixels of the reference frame, respectively.

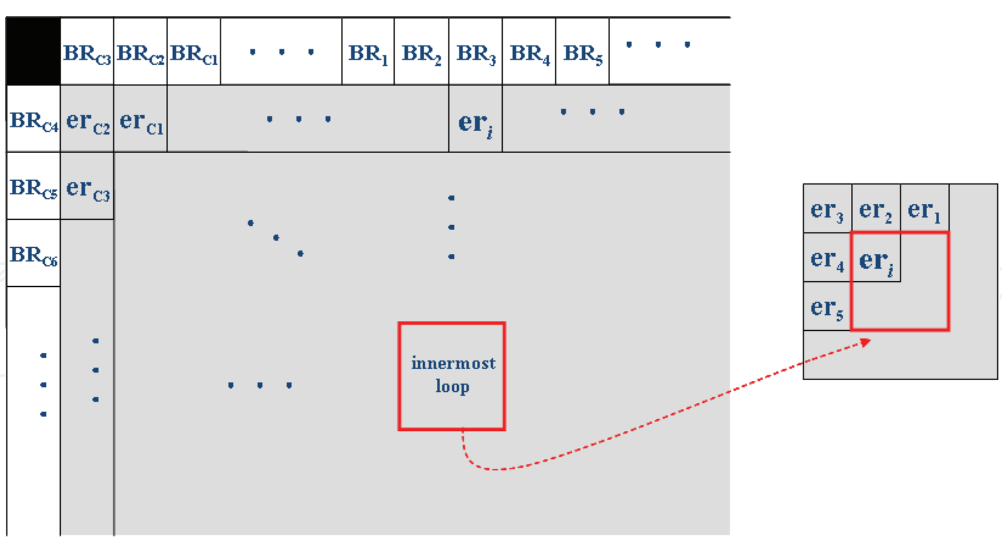
$$MB_{BR}(x,y,n) = MB_{CBP}(x,y,n) - MB_{RBP}(x,y,n-1) \tag{3}$$

Secondly, inspired by (Zhan and Zhu, 2009), enhanced residuals for the replaced MB are estimated. The improved 5-tap filter is developed to interpolate the enhanced residuals. Its equations are expressed as Equation (4) and (5),

$$er_i = \frac{\sum_{n=0}^{4} x_n y_n}{\sum_{n=0}^{4} x_n}, \quad \text{where} \begin{cases} \text{for general cases} \\ \quad (x_n, y_n) = (\,[1,3,1],\ [BR_{c1}, BR_{c2}, BR_{c3}]\,) \\ \text{for boundary conditions} \\ \quad (x_n, y_n) = (\,[1,3,6,3,1],\ [BR_1, BR_2, BR_3, BR_4, BR_5]\,) \end{cases} \tag{4}$$

$$er_{c2} = \frac{[BR_{c3} + BR_{c4} + er_{c1} + er_{c3}]}{4}, \quad \text{four corner points only} \tag{5}$$

and its corresponding figure is shown in Figure 3. Then, the estimated residuals will be appended to the replaced MB. In the beginning, the proposed interpolation filter estimates the enhanced residual of the outermost loop by Equation (4), except for the four corner points. Next, the enhanced residual of corner point is calculated by adopting Equation (5) to average the four neighbouring values, where BR_{c3}, BR_{c4}, er_{c1} and er_{c3} are shown in Figure 3(a).



(a) (b)

Fig. 3. The proposed 5-tap interpolation filter (a) The filter in the outer loop of the replaced MB; (b) The filter in the innermost loop of the replaced MB.

Similarly, enhanced residuals of the second-outer loop are interpolated by adopting enhanced residuals of the first-outer loop. The filter can estimate enhanced residuals for the replaced MB sequentially from the outermost loop to inner loops. Then, enhanced residuals of the innermost loop are calculated by averaging the partially five surrounding values, such as er_1, er_2, er_3, er_4 and er_5 in Figure 3(b). Therefore, 256 enhanced residuals can be estimated by above-mentioned procedures.

Finally, the estimated residuals are appended to the enhanced MB. The appended data is the enhanced MB, MB_{en}.

2.1.3 The proposed boundary distortion estimation

This step calculates the standard deviation and the proposed boundary distortion estimation for two following sub-sections. The standard deviation, σ, of correctly received 4-pixels wide neighbouring boundary pixels is calculated to represent the texture intensity of corrupted MB. Its equations are shown as Equation (6) and Equation (7).

$$\sigma = \sqrt{\frac{1}{N \times M - 1} \sum_{i=1}^{N} \sum_{j=1}^{M} \left(P(i,j) - \mu \right)^2} \tag{6}$$

$$\mu = \frac{1}{N \times M} \sum_{i=1}^{N} \sum_{j=1}^{M} P(i,j) \tag{7}$$

In Equation (6) and Equation (7), $P(i, j)$ and μ denote the pixel value of correctly received neighbouring boundary region and the mean value of boundary pixels, respectively. $N \times M$ denotes the amount of all boundary pixels.

The proposed boundary distortion estimation is estimated from two values, the replaced MB and enhanced MB. It is illustrated in Figure 4 and its equation is expressed as

$$BD_n = \sum_{i=1}^{64} \left| EB(i) - IB(i) \right| \tag{8}$$

In Equation (8), BD_n, $EB(i)$ and $IB(i)$, respectively, denote the boundary distortion value of the replaced MB or enhanced MB (MB_n), the external boundary pixels around MB_n and the internal boundary pixels of MB_n.

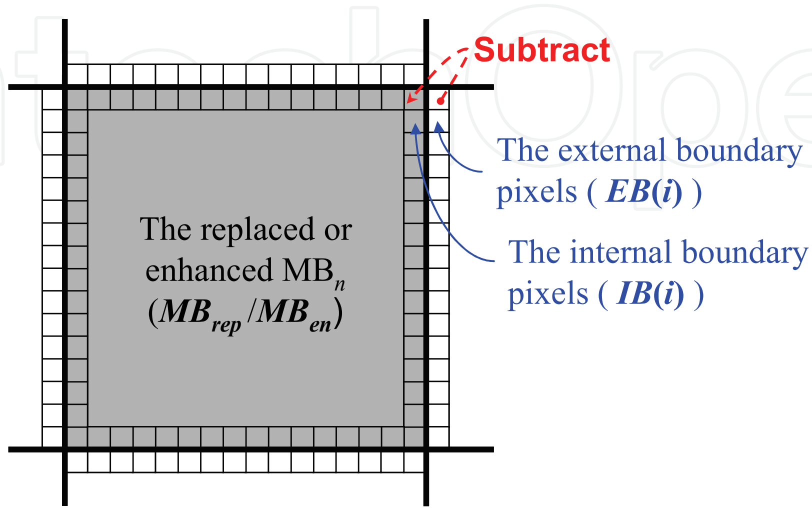


Fig. 4. The proposed boundary distortion estimation

2.1.4 Applying the temporal adaptive weight-based switching algorithm

The proposed temporal adaptive weight-based switching algorithm (TAWS) is adopted to determine a weight, ω, and calculating the optimal integrated MB, MB_{opt_aw}, for the last step. The optimal integrated MB is calculated by adaptively integrating the replaced MB, MB_{rep}, and enhanced MB, MB_{en}, with the adaptive weight. This algorithm is described as follows:

```
ω = 1
for (i = 1; i < 10; i++)
{
    MB_aw(i) = ω × MB_rep + (1 - ω) × MB_en
    ω = ω - 0.125
}
MB_opt_aw = MinBD( MB_aw(i) )
```

In above algorithm, MB_{aw} is the integrated MB with the temporal adaptive weight-based switching algorithm. The function **MinBD( )** is utilized to find the optimal integrated MB, MB_{opt_aw}, with minimal boundary distortion.

2.1.5 Applying the texture-based selective calibration algorithm

In the last step of the proposed temporal error concealment technique, the texture-based selective calibration algorithm (TSC) is proposed to determine the optimal restored MB, MB_{opt}. The determination is based on many criteria, such as boundary distortions and standard deviation, σ. The proposed TSC algorithm is described as follows:

```
Set initial thresholds (SD_up = 100; SD_low = 75; BD_th = 1)
for (i = 0; i < 4; i++)
{
  if (i = 0)
    if (σ > SD_low)
      if (BD_rep > BD_en & |BD_rep – BD_en| > BD_th)
        MB_opt = 0.5 × MB_rep + 0.5 × MB_en
      else
        MB_opt = MB_rep
    else
      if (σ > SD_low & σ < SD_up)
        if (BD_rep > BD_en & |BD_rep – BD_en| > BD_th)
          MB_opt = MB_opt_aw
        else
          MB_opt = MB_rep
  SD_up = SD_up – 25
  SD_low = SD_low – 25
  BD_th = BD_th + 2
}
```

In the above algorithm, the standard deviation is normalized form 0 to 100 firstly. SD_{up} and SD_{low} are the dynamic upper-bound and dynamic lower-bound of the standard deviation, respectively. They could determine four intervals of standard deviation to represent different texture intensity: high, medium-high, medium-low and low texture. The threshold, BDth, is utilized to determine the magnitude of boundary distortion. It is calculated by BD_{rep} and BD_{en}, the boundary distortion of the replaced MB, MB_{rep}, and the enhanced MB, MB_{en}, respectively. SD_{up} and SD_{low} decrease 25 and BD_{th} increases 2 after each iteration. In other words, the interval with higher texture corresponds to smaller threshold for boundary distortion, BD_{th}. In our observations, the optimal restored MB is generally the replaced MB. As to the interval with higher texture, it will be obtained by averaging MB_r and MB_e. Therefore, this proposed TSC algorithm could optimize the recovery performance for damaged MBs by many above-mentioned criteria.

2.2 The proposed spatial error concealment approach

The proposed spatial error concealment approach is based on adaptive weight-based switching directional interpolation, namely AWSDI (Wang et al., 2010). It utilizes a spatial adaptive weight-based switching algorithm (SAWS) to adaptively switch two integrated modes in order to optimize recovery performance. This approach adopts a unique spatial evaluation criterion, judged by boundary distortion estimation. One of the integrated modes combines SDI (Kung et al., 2006) and BI with the adaptive weight. The other integrates MDI and BI with the adaptive weight. Flowchart of the proposed spatial error concealment is shown in Figure 5. The steps of the proposed spatial error concealment are addressed in the following sub-sections.

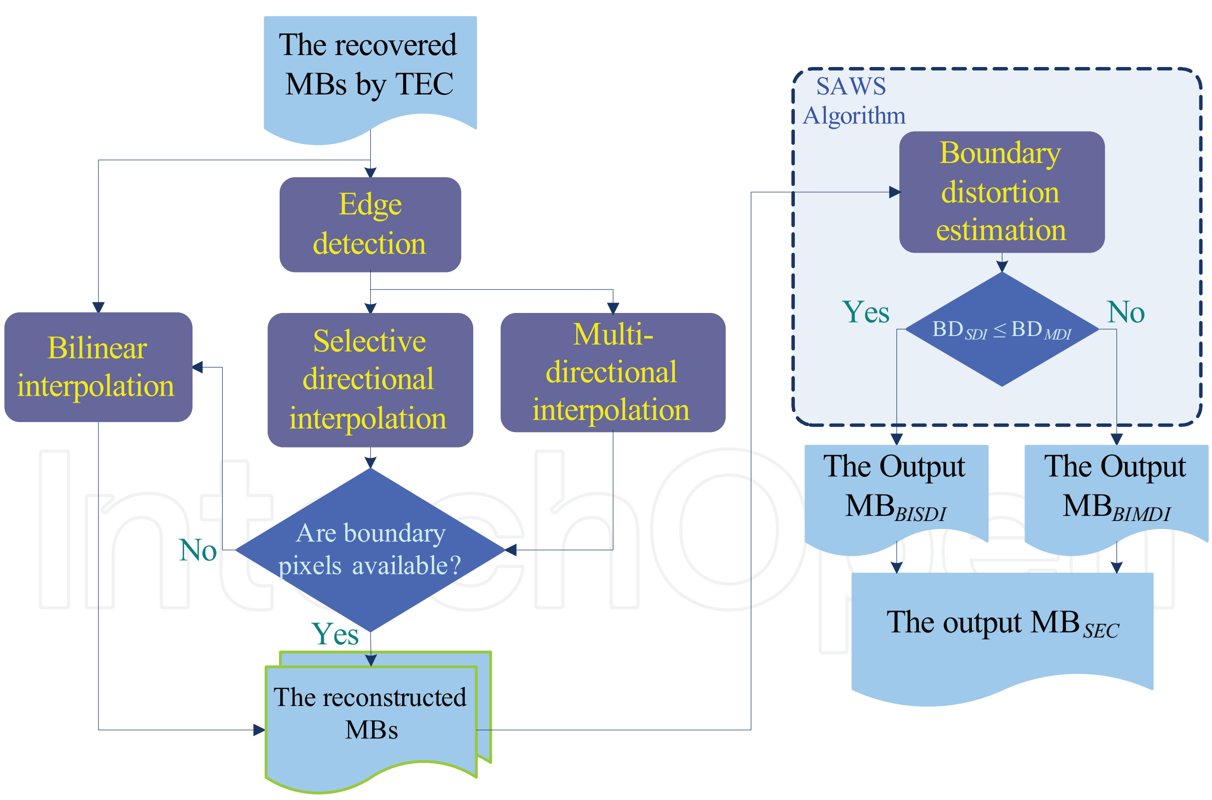


Fig. 5. Flowchart of the proposed spatial error concealment approach

2.2.1 Determining the dominant edge points by edge detection

Firstly, the edges of boundary regions around a corrupted MB are detected. Then, estimated edges would be refined according to the detected edges. In spatial error concealment approaches, directional interpolation algorithms recover the corrupted MB by interpolating lost pixels along estimated edge directions. The estimated edge directions of the corrupted MB are corresponding to detected edges in boundary regions due to spatial dependency. Therefore, the proposed spatial error concealment approach adopts Sobel gradient filter with 4-pixel wide boundary regions. Then the dominant edge points, $P_{\text{edge}}(i,\ j)$, are determined for the following directional interpolations. The determination is expressed as

$$P_{\text{edge}}(i,j) = \begin{cases} P(i,j), & G(i,j) \geq \max(G(i,j))/2 \\ 0 & , G(i,j) < \max(G(i,j))/2 \end{cases} \tag{9}$$

Equation (9) means that if the gradient magnitude $G(i,\ j)$ of the pixel $P(i,\ j)$ is greater than or equal to one-half of the maximum magnitude, the pixel will be determined as the dominant edge point. The maximum magnitude, $\max(G(i,j))$, denotes the maximum gradient magnitude of all the boundary pixels.

2.2.2 Integration of three interpolation modes

In this step, the proposed technique integrates pre-recovery results of three interpolation modes (BI, SDI and MDI) with an adaptive weight, w. The weight will be determined in the last step. Each corrupted macro-block has to be recovered by BI, SDI and MDI initially. Then three pre-recovery results, MB_{BI}, MB_{SDI} and MB_{MDI}, are integrated into two results, MB_{BISDI} and MB_{BIMDI}, with an adaptive weight w, respectively. In addition, the main difference between our integration and recent literatures (Kung et al., 2006; Zhan and Zhu, 2009) is that other methods adopted fixed weight to integrate or switch pre-recovery results. Conversely, the proposed integrated results are generated with an adaptive weight, which will be determined by the evaluation criterion.
The main reason of above-mentioned integrations is that SDI and MDI could not restore well in some cases, such as the smooth MB, too complex texture MB. Conversely, BI could not restore well in the slant directions texture MB. Therefore, it is essential to adaptively integrate various interpolation modes. These two integrated results will be applied to enhancing the recovery performance.

2.2.3 Calculation for the proposed spatial evaluation criterion

This step calculates the boundary distortion for the last step. The last step will select the best integrated result with minimal boundary distortion for one corrupted macro-block. By subtracting the correctly received boundary from pseudo-recovered boundary as shown in Figure 6, the boundary distortion is calculated. The pseudo-recovered boundary is generated as the following.
Firstly, the first-loop external boundary is assumed to be lost. Then, the second-loop external boundary is utilized to restore the first-loop external boundary. The recovered first-loop external boundary is the pseudo-recovered boundary. In this process, the recovery method is the same as the integrated macro-block, MB_{BISDI} or MB_{BIMDI}. It is worth pointing that the criterion is based on the similarity between original external boundary and pseudo-recovered boundary. This is because if the pseudo-recovered boundary using certain integrated mode is more similar with original boundary, this integrated mode is more adequate to the corrupted macro-block.

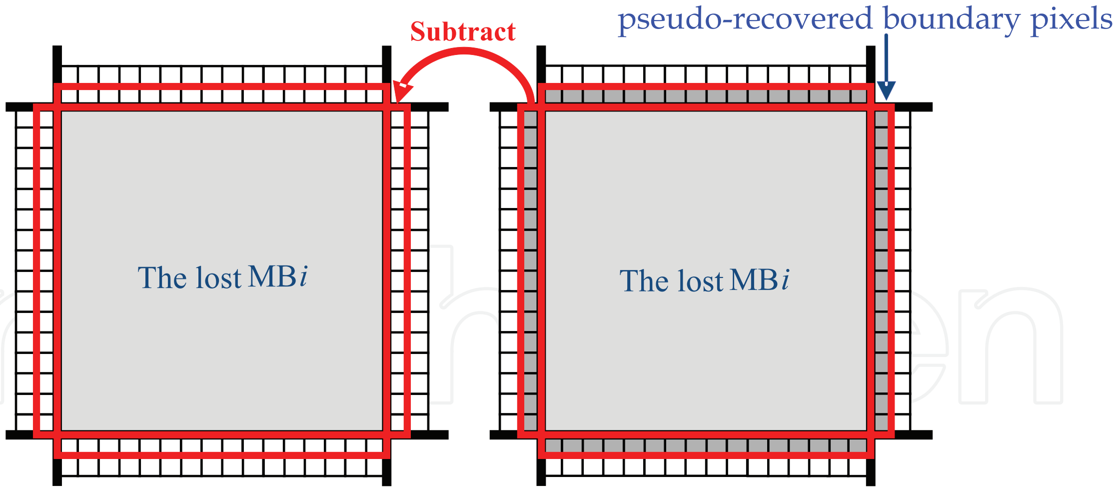


Fig. 6. The proposed evaluation criterion based on boundary distortion estimation

2.2.4 Applying the spatial adaptive weight-based switching algorithm

In the last step, the proposed spatial error concealment adopts the spatial adaptive weight-based switching (SAWS) algorithm to determine the optimal recovered MB, MB_{opt}. The determination is based on boundary distortion estimation calculated by Step 3. It is defined as the following algorithm:

$\omega = 1$
For ($i = 1$; $i < 10$; i++)
{
$MB_{BISDI}(i) = \omega \ . \ MB_{BI} + (1 - \omega) \ . \ MB_{SDI}$
$MB_{BIMDI}(i) = \omega \ . \ MB_{BI} + (1 - \omega) \ . \ MB_{MDI}$
$\omega = \omega - 0.125$
}
MB_{opt} = **MinBD(MinBD(** $MB_{BISDI}(i)$ **), MinBD(** $MB_{BIMDI}(i)$ **))**

MB_{BISDI} and MB_{BIMDI} are the integrated results obtained by section 2.2.2. In this algorithm, the interval of each adaptive weight is 0.125. The most adequate weight will be found out by the function **MinBD( )**, utilized to select the optimal recovered macro-block with minimal boundary distortion. Therefore, the spatial adaptive weight-based switching algorithm could optimize the recovery performance of corrupted macro-blocks.

3. Simulation results

The proposed hybrid error concealment technique is implemented in the decoder of H.264/AVC Reference Software Joint Model 16.2 (JM 16.2). Three benchmark sequences, such as *carphone*, *Stefan* and *foreman* are employed in our simulations. These sequences are encoded by the H.264/AVC standard. The frame size is both at QCIF (176×144) and CIF (352×288) resolution, and the frame rate is 30 fps. The period of I frame reset is 15 and the number of reference frames is 1. A constant quantization parameter (QP) of 28 is maintained for all frames and the slice type is set to be dispersed FMO. The packets are randomly selected and dropped according to the predefined packet loss rate (PLR). The PLR is set to be 5%, 10% and 15%. Table 1 lists the comparison of the proposed temporal error concealment approach and the proposed hybrid error concealment technique with JM 16.2. And the comparisons of subjective quality are shown in Figures 7~9.

The performance of the proposed hybrid error concealment technique is impressive. This is because the proposed technique not only adaptively switches TEC approach to SEC approach but also enhances each approach. The proposed TEC approach improves the BIF and adaptively integrates BIF with a conventional scheme, using MAD criterion. In cases of scene-change frames or high motion regions, the performance of the proposed TEC approach may be not good enough. Then the proposed SEC approach will further be adopted. It adaptively combines several interpolation modes to two integrated methods. Finally, the unique evaluation criterion, based on external boundary distortion estimation, is utilized to measure out the best integrated method. Thus, the proposed hybrid error concealment technique has excellent performance.

Sequence		PLR (%)	JM 16.2	Proposed TEC	Proposed HEC
QCIF	*carphone*	5	32.53	34.52	**34.64**
		10	30.98	32.35	**32.44**
		15	28.96	30.70	**30.78**
	Stefan	5	29.15	29.34	**29.53**
		10	26.12	26.34	**26.47**
		15	23.97	23.99	**24.20**
	foreman	5	31.86	32.63	**32.93**
		10	28.78	29.46	**29.56**
		15	26.39	26.94	**27.28**
CIF	*carphone*	5	33.51	35.37	**35.37**
		10	31.50	32.93	**32.93**
		15	29.76	31.10	**31.19**
	Stefan	5	31.02	31.22	**31.38**
		10	27.58	27.36	**27.56**
		15	25.38	24.92	**25.20**
	foreman	5	32.84	33.75	**34.13**
		10	29.69	30.77	**30.94**
		15	27.30	28.15	**28.35**

Table 1. Comparison of the proposed hybrid error concealment technique with JM

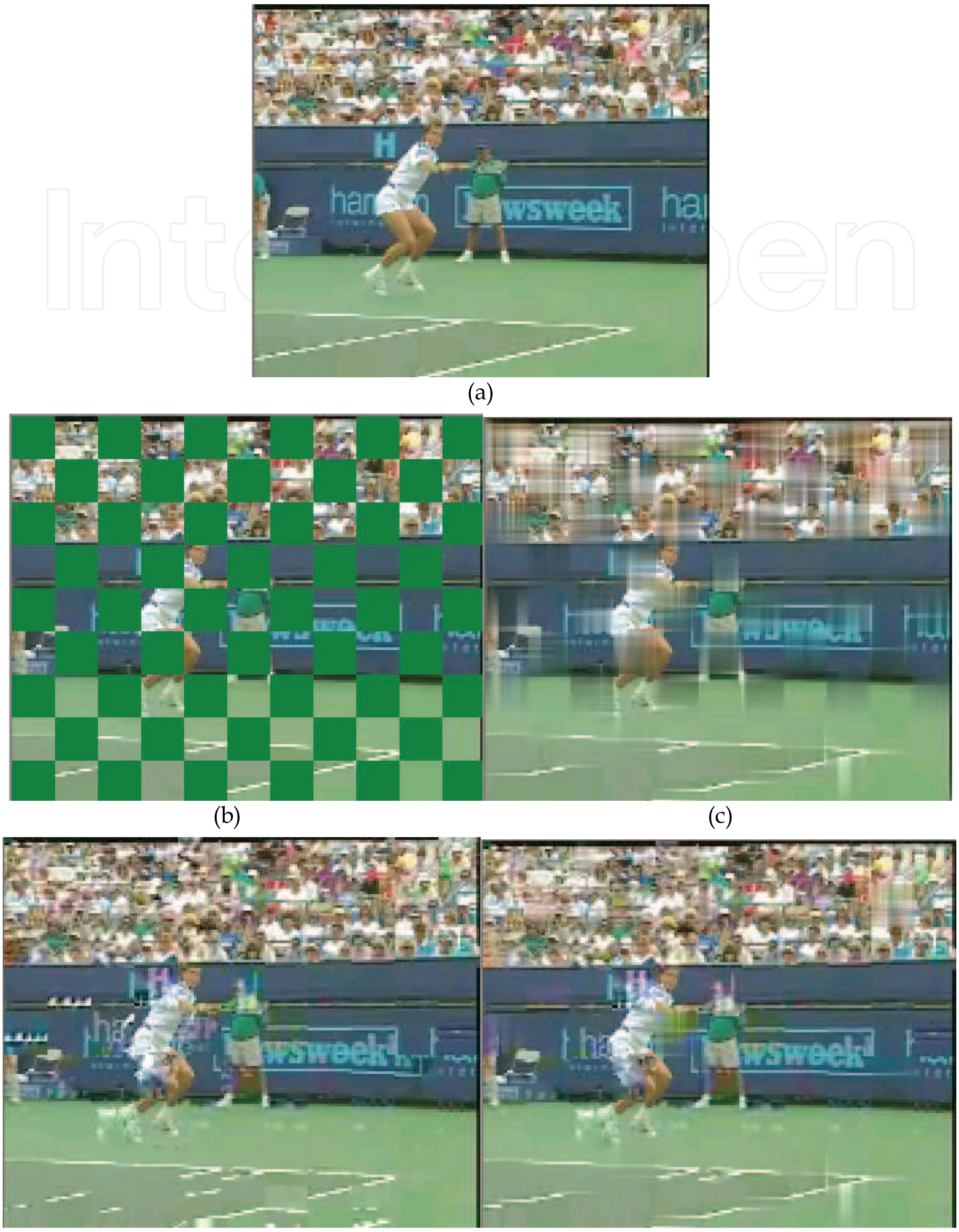


Fig. 7. Recovery performance for the 190th frame of *Stefan* (QCIF, GOP=10) (a) The error-free frame; (b)The corrupted frame; (c)JM (21.7594 dB); (d)Proposed TEC (20.9881 dB); (e) Proposed HEC (22.1987 dB)

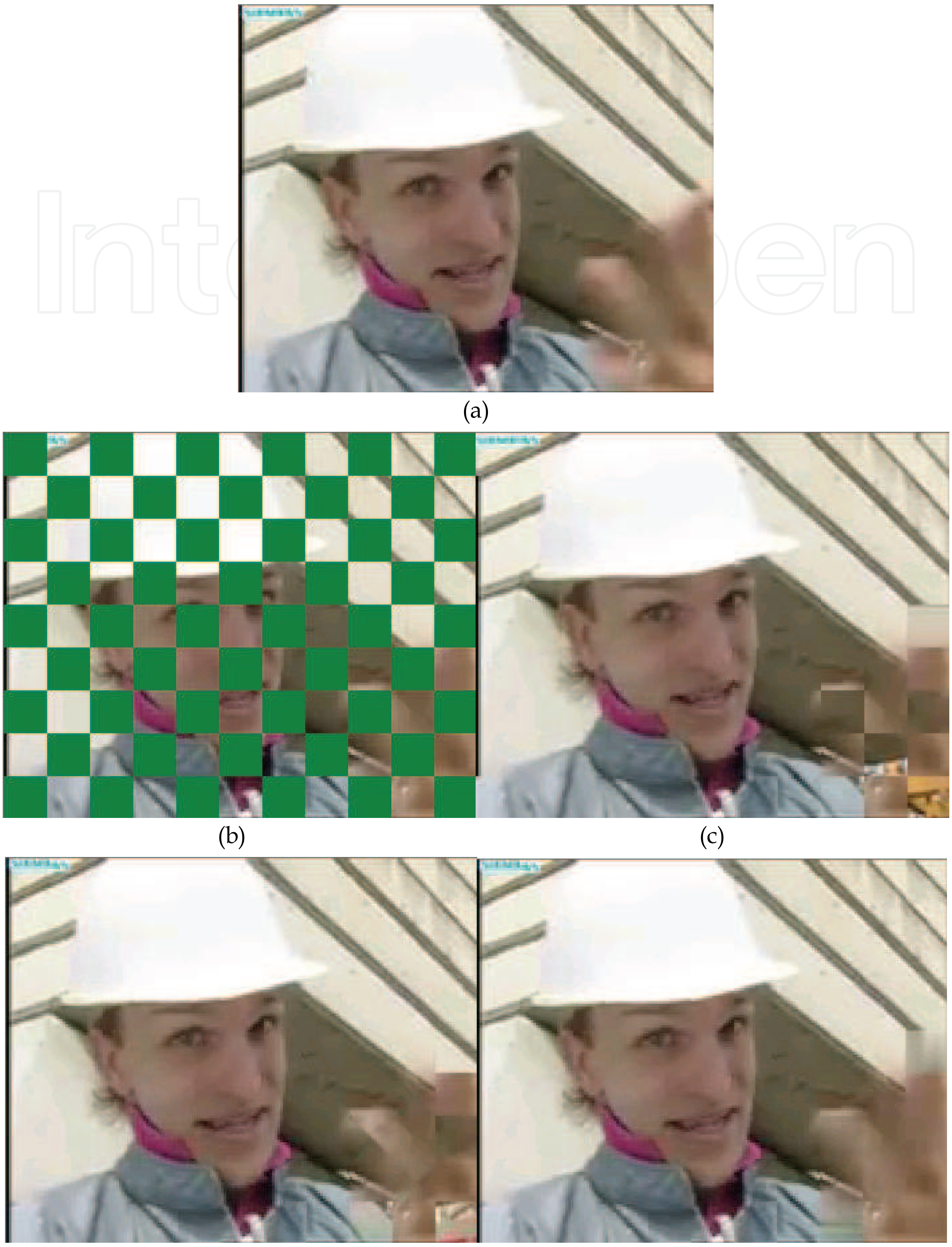


Fig. 8. Recovery performance for the 152th frame of *foreman* (QCIF, GOP=10) (a) The error-free frame; (b)The corrupted frame; (c)JM (26.7743 dB); (d) Proposed TEC (28.9247 dB); (e) Proposed HEC (30.3790 dB)

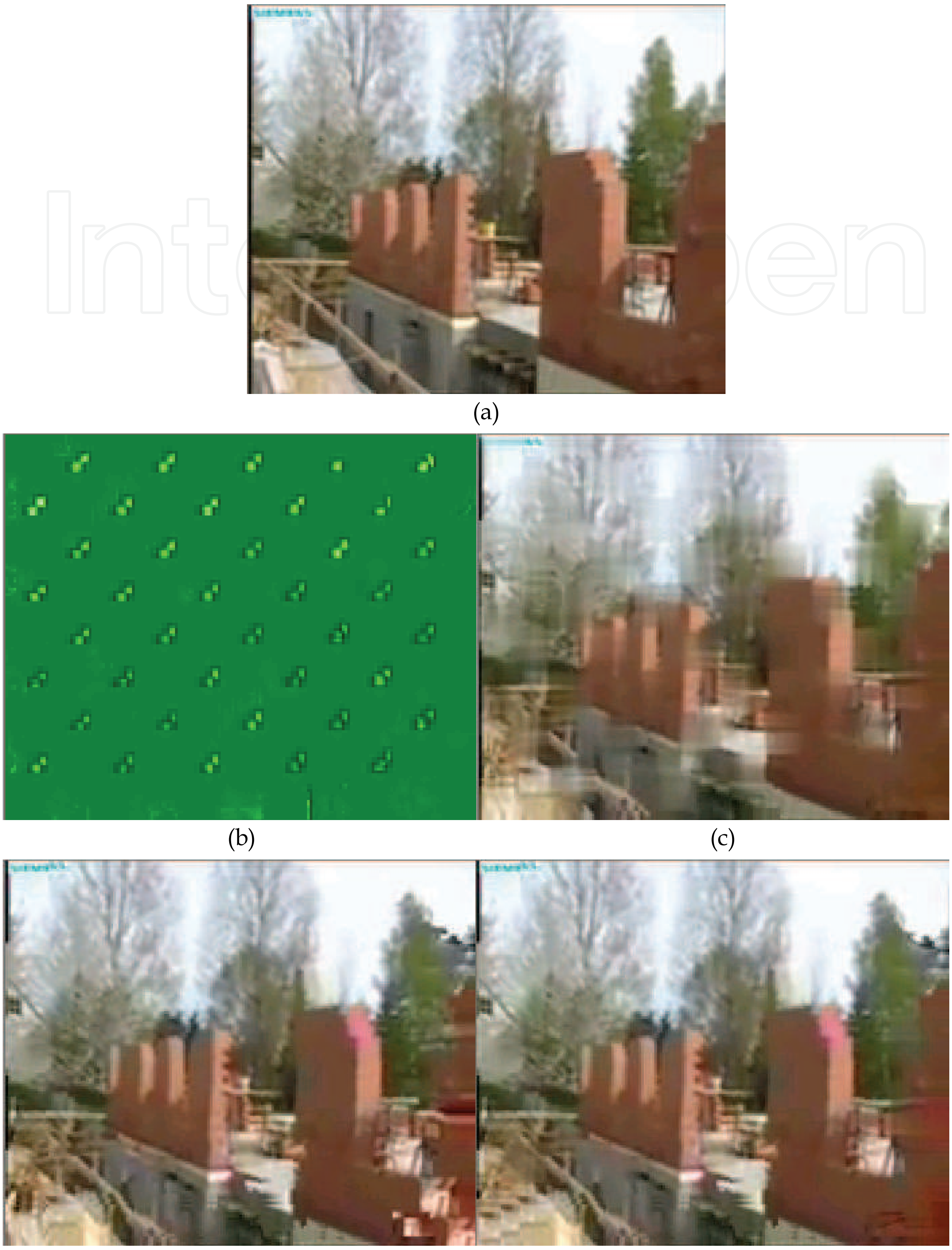


Fig. 9. Recovery performance for the 225 th frame of *foreman* (QCIF, GOP=10) (a) The error-free frame; (b)The corrupted frame; (c)JM (23.1123 dB); (d) Proposed TEC (21.6732 dB); (e) Proposed HEC (23.4388 dB)

4. Conclusion

In this article, a hybrid error concealment technique in H.264/AVC decoder has been proposed. It could effectively restore the corrupted data by adaptively switching temporal error concealment approach to spatial error concealment approach. The hybrid error concealment technique performs a temporal error concealment approach initially. If the performance is not good enough, especially in scene-change frames or high motion regions, the spatial error concealment approach is employed. Both temporal and spatial error concealment approaches adopt the proposed temporal or spatial adaptive weight-based switching algorithm to optimize the performance of each integrated macro-block. Then the boundary distortion estimation is utilized to determine the best integrated method for a corrupted macro-block. Simulation results show that the proposed hybrid error concealment technique performs excellent gains of up to 2 dB compared to that of the Joint Model (JM) decoder for a wide range of benchmark sequences.

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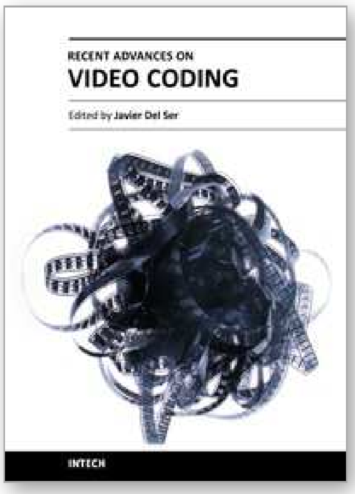

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This book is intended to attract the attention of practitioners and researchers from industry and academia interested in challenging paradigms of multimedia video coding, with an emphasis on recent technical developments, cross-disciplinary tools and implementations. Given its instructional purpose, the book also overviews recently published video coding standards such as H.264/AVC and SVC from a simulational standpoint. Novel rate control schemes and cross-disciplinary tools for the optimization of diverse aspects related to video coding are also addressed in detail, along with implementation architectures specially tailored for video processing and encoding. The book concludes by exposing new advances in semantic video coding. In summary: this book serves as a technically sounding start point for early-stage researchers and developers willing to join leading-edge research on video coding, processing and multimedia transmission.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

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