Temporal Error Concealment Algorithm Using Adaptive Multi-Side Boundary Matching Principle

Seung-Soo Jeong and Chae-Bong Sohn

VIA-Multimedia Center, Kwangwoon University, 447-1, Wolgye-Dong, Nowon-Gu, 139-701, Seoul, Korea

Summary
The environment of transmission via a wireless network is not always error-free. The loss of data or impairment caused by errors degrades the quality of image. The error concealment is the method that finds the best substitute information from the previous reference image with the boundary information around lost block. Therefore, This paper proposes an Adaptive Multi-Side Boundary Matching principle (AMSBM). AMSBM has two steps. First, the boundary matching degree examination on the boundary information is conducted. Second, AMSBM decides which data is the most reliable and conceals the lost block with the most reliable data. Experimental results show an improved performance of 0.36 dB on average compared to the previous method

Key words:
Adaptive Multi-Side Boundary Matching, Temporal Error Concealment Algorithm

1. Introduction

Compressed video bitstream under wireless transmission environment is strongly correlated. In some circumstances, data packets may suffer from network congestion or bit errors caused by defective physical network channels, including wire and wireless networks. The errors or lost data may result in unusable received data. A bit error that occurs in the bitstream will propagate through the bitstream.

Error concealment techniques conceal the corrupted blocks by exploiting high correlation among video frames. Based on the types of correlation used, we classify error concealment techniques into two classes. One is the concealment method in the spatial domain. Image or video coding involves a spatial correlation among adjacent pixels across a few macrobloks (MBs) which can be used to conceal the damaged MB from its neighboring information. This method utilizes the smoothness of adjacent pixels by exploiting the fact that human eyes are not highly sensitive to the high-frequency component. The other is the concealment method in the temporal domain. The temporal correlation between adjacent frames provides an estimate of error concealment. The repeated appearance of similar content and the consistency of motion over a certain period enable an approximate block in the temporal reference frame to be obtained as an estimate for the current error block[1].

Among the researches related to temporal domain, the temporal error concealment using multi-side boundary matching principle (MSBM) carried out improved performance. Because it conceals the lost block using more boundary data than the former researches. MSBM carried out block matching by selecting fixed position's data as reference data[2]. However, if the data that was incorrectly concealed is used as reference data of the following lost block, another error is generated. It causes not only subjective degradation of image quality, but also objective degradation of image quality.
In this paper, we propose AMSBM that carries out an examination of boundary matching degree and decides the position and size of the reference data block adaptively. It can reduce the degradation of performance that occurs by the error propagation.

2. Temporal error concealment algorithm using multi-side boundary block matching

MSBM is the temporal error concealment method. MSBM uses the boundary data of the lost block as a reference data and conducts block matching in the reference frame. The best matching data in reference frame has the smallest sum of absolute difference (SAD).

When there are MB errors caused by channel errors, MSBM method divides one lost MB into four sub-blocks. Four sub-blocks are concealed step by step. According to the available boundary data, the location of the reference boundary data can be different.

Chapter 2.1 illustrates the method when a single block error occurs. Chapter 2.2 illustrates the method when a single-slice error and a multi-slice error occur that come to the consecutive MB errors.

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2.1 Sub-block matching algorithm for a single block error

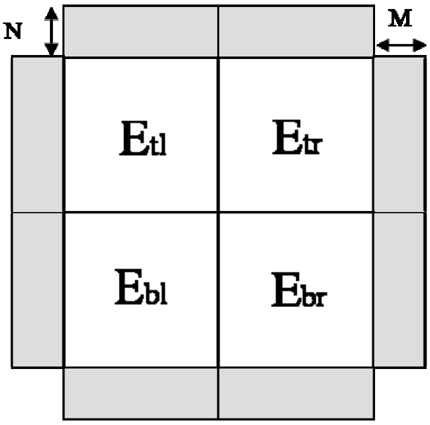


Fig.1. Rows and columns used in block matching principle

A corrupted MB is divided into four sub-blocks as shown in Fig. 1. E_{tl}, E_{tr}, E_{bl}, E_{br} are the divided sub-blocks at different location, respectively. The nearest adjacent N rows and M columns pixels of the MB are used to find the best block on the reference frame. In the case of a single block error, every boundary data is available. The search range is set to be 15 herein, and the full search (FS) is used to evaluate all possible candidate blocks within the search range.

The best sub-block to conceal a lost one is determined by the minimum SAD. For the four sub-blocks, their SADs are calculated by the following equations:

$$\mathrm{SAD}(E_{tl}) = \sum_{j=-N}^{-1}\sum_{i=0}^{7}\left| E_{tl}(x+i, y+j) - E_{tl}'(x+dx+i, y+dy+j)\right| + \sum_{j=0}^{7}\sum_{i=-M}^{-1}\left| E_{tl}(x+i, y+j) - E_{tl}'(x+dx+i, y+dy+j)\right| \tag{1}$$

$$\mathrm{SAD}(E_{tr}) = \sum_{j=-N}^{-1}\sum_{i=0}^{7}\left| E_{tr}(x+i, y+j) - E_{tr}'(x+dx+i, y+dy+j)\right| + \sum_{j=0}^{7}\sum_{i=8}^{7+M}\left| E_{tr}(x+i, y+j) - E_{tr}'(x+dx+i, y+dy+j)\right| \tag{2}$$

$$\mathrm{SAD}(E_{bl}) = \sum_{j=8}^{7+N}\sum_{i=0}^{7}\left| E_{bl}(x+i, y+j) - E_{bl}'(x+dx+i, y+dy+j)\right| + \sum_{j=0}^{7}\sum_{i=-M}^{-1}\left| E_{bl}(x+i, y+j) - E_{bl}'(x+dx+i, y+dy+j)\right| \tag{3}$$

$$\mathrm{SAD}(E_{br}) = \sum_{j=8}^{7+N}\sum_{i=0}^{7}\left| E_{br}(x+i, y+j) - E_{br}'(x+dx+i, y+dy+j)\right| + \sum_{j=0}^{7}\sum_{i=8}^{7+M}\left| E_{br}(x+i, y+j) - E_{br}'(x+dx+i, y+dy+j)\right| \tag{4}$$

where x and y are the most top and most left position of the lost sub-block in the current frame, dx and dy are the displacement between the lost sub-block in current frame and the candidate sub-block in the reference frame. N and M are fixed to 3 in MSBM[2]. The sub-block E_{tl}, E_{tr}, E_{bl}, E_{br} are concealed by the sub-block with the minimum SAD from Eq. (1),(2),(3),(4), respectively. E is the corrupted frame and E' is the reference frame.

2.2 Sub-block matching algorithm for slice errors

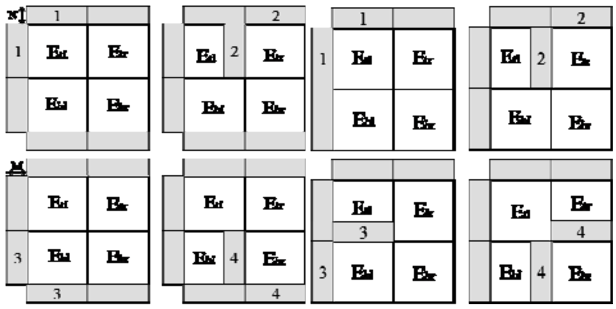


Fig.2 MSBM error concealment algorithm for single-slice (left) and for multi-slice (right)

In the case of a single slice error and a multi-slice error, every boundary data cannot be available such like the case of a single block error. Fig. 2 depicts the error concealment methods according to each error pattern.

In the case of a single slice error, E_{tl} and E_{tr} are concealed in a row. MSBM conducts multi-side block matching using N rows and M columns. The best sub-block to conceal a lost sub-block is determined by the minimum SAD using Eq. (1). Then, E_{bl} and E_{br} are concealed using the down and left boundary data of lost sub-block instead of up and left boundary data. The best sub-block to conceal a lost sub-block by the minimum SAD using Eq. (3).

In the case of multi-slice error, E_{tl}, E_{tr}, E_{bl} and E_{br} are concealed in a row. In this step, to find best sub-block, MSBM uses the up and left boundary data of a lost sub-block. It conducts block matching using Eq. (1).

3. Proposed method

The type of a single slice error has sequential MB error. When a single slice error occurs, MSBM conceals lost blocks by the unit of a MB sequentially. In the case of concealing two upper sub-blocks, MSBM uses up and left boundary data, regularly. In the case of concealing two below sub-blocks, it uses down and left boundary data regularly.

Since this kind of error has the sequential MB error, lost blocks should be correctly concealed successively. When MSBM conceals a MB, the lost data is concealed by using conducting block matching in the reference frame. The concealed data is not original image data. That data is artificial for the high visual quality about human visual system. However, if this data is not concealed correctly, the effect of this incorrect data can propagate error to the following MB concealment process. The reason why video coding involves temporal correlation between adjacent video frames which is used to achieve high compression efficiency by removing temporal redundancy.

The AMSBM decides if it uses the boundary data as the reference data after examining a boundary matching degree between the previous concealed block and its upper original data. According to the result of the examination, AMSBM makes the lost block concealed without error propagation at maximum by changing the size of reference boundary data.

The chapter 3.1 explains the examination of the matching degree of boundary data. The chapter 3.2 explains how to decide the position and size of variable reference block data by the result of the boundary matching degree.

3.1 Examination of the matching degree of boundary data

There is the former method related to the analysis of boundary data. It determines the edge direction at the boundary of the lost block and then decides which boundary data is relatively efficient to be the reference data for concealing the lost block[3]. However, it doesn't offer an adaptive threshold value and cannot be applied to each boundary, independently. We propose the advanced the boundary matching degree examination.

Fig.3 and Fig.4 show AMSBM in concealing E_{tl} with error. Fig.3 shows the matching degree examination step 1 of boundary data. Here, since AMSBM considers a single slice error type, the available data is upper and left boundary data of E_{tl}. The left boundary data was concealed in the process of previous MB concealment and the left upper data of sub-block E_{tl} is error free data in a single slice error type. Before concealing the sub-block E_{tl}, AMSBM conducts the matching degree examination of boundary data.

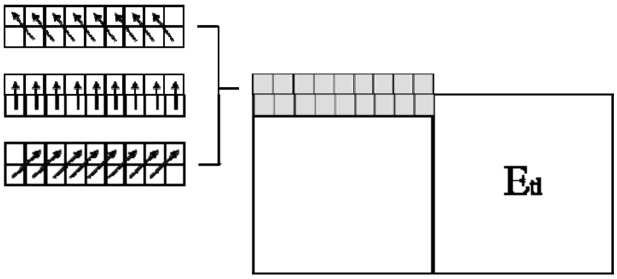


Fig.3 Boundary matching degree examination step 1 for single slice

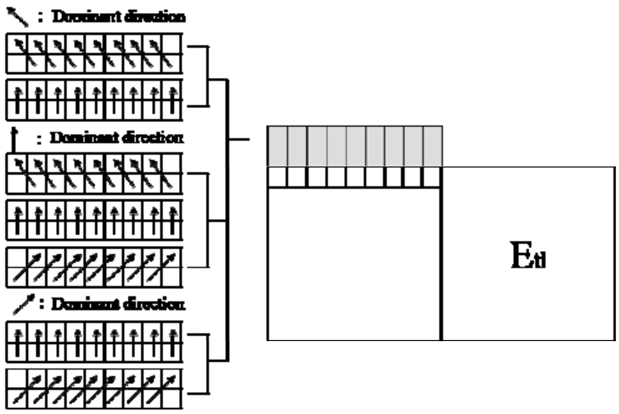


Fig.4 Boundary matching degree examination step 2 for single slice

First, AMSBM conducts the matching degree examination of error free 8x2 pixels which are located on left upper data of sub-block E_{tl} as shown in Fig. 3. The examination cost functions of matching degree according to each direction are Eq. (5),(6),(7), respectively.

$$D_o = \frac{1}{N-1}\sum_{i=0}^{N-2} \left| P(x+i, y) - P(x+i+1, y-1) \right| \tag{5}$$

$$D_v = \frac{1}{N}\sum_{i=0}^{N-1} \left| P(x+i, y) - P(x+i, y-1) \right| \tag{6}$$

$$D_i = \frac{1}{N-1}\sum_{i=1}^{N-1} \left| P(x+i, y) - P(x+i-1, y-1) \right| \tag{7}$$

D_o is the cost function that is applied to the oblique edge direction. D_V and D_i are the cost functions for each vertical and inverse oblique line edge direction. Also, x and y mean the positions of the bottom line's first pixel among 8x2 pixels. In this step 1, x and y are the most bottom line's first pixel of left upper sub-block of sub-block E_{tl} as shown in Fig. 3.

Using these cost functions, AMSBM can gain the cost function's result value for each direction. It decides a direction with the minimum value into the dominant direction of the boundary and fixes that result value of the dominant direction as a result value R. The result value R is used as a standard value that is compared with result values under a pixel.

If the dominant direction is decided, a cost functions are applied to the similar directions under a pixel according to the dominant direction. If an oblique direction is decided into the dominant direction, cost functions are applied to an oblique and a vertical direction under a line as shown in Fig. 4. If an inverse oblique direction is decided into the dominant direction, cost functions are applied to a vertical and an inverse direction. If a vertical direction is decided into the dominant direction, cost functions are applied to an oblique, vertical and inverse oblique direction under a pixel.

According to the dominant direction, it gains the difference value group between result value R and the result values of cost functions under a pixel. For example, if the dominant direction is decided to the oblique direction at the upper pixel lines, the cost function is applied to the oblique direction and vertical direction at the below pixel lines. And then, we can gain the group of two difference values. One is the difference value between the result value R and the result value of the oblique direction. The other is the difference value between the result value R and the result value of the vertical direction.

Among the difference values of the group, if there is a smaller value than predefined threshold T, the boundary of these sub-blocks is determined to be natural and be well concealed. If there isn't a smaller value than predefined threshold T, the boundary of this sub-block is not determined to be natural and be well concealed. The predefined threshold T is fixed as the most suitable value 4 by an experiment. We experimented by fixing threshold T as 4 in this paper.

Also, for sub-block E_{bl} below E_{tl}, AMSBM examines the boundary matching degree with the same method. Then, instead of examining boundary matching degree about upper pixels of the left sub-block of E_{tl}, it examines boundary matching degree about lower pixels of the left sub-block. In the case of a single slice error type, the lower data of the left sub-block can be used to decide if the left sub-block was correctly concealed through the comparison with pixel data concealed in the process of previous MB concealment. Since the lower data is error free, it can be used as an efficient value to gain the result value R. For concealing the sub-block E_{bl}, AMSBM examines boundary matching degree with the same method that carried out on the upper pixel lines before concealing sub-block E_{bl}. For concealing the sub-block E_{tr} and E_{br}, AMSBM applies the same examination of the boundary matching degree such as E_{tl} and E_{bl}, respectively.

3.2 Decision method of variable block position and size by examination boundary match

In the process of chapter 3.1, we can examine reliability about the pixels on the left boundary of the sub-block that will be concealed. This method decides which position's boundary data is used to conceal the lost sub-block according to the result of examination.

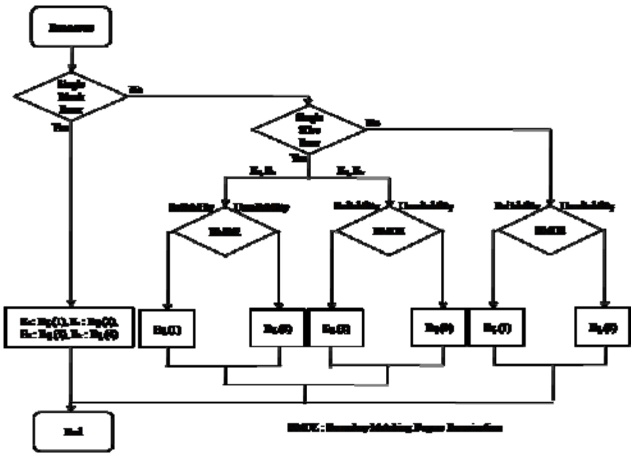


Fig.5 Flowchart of proposed method

If AMSBM determines the left boundary data has reliability in the process of chapter 3.1, it conceals the lost sub-block with existing method. However, if it is determined that the left boundary data has no reliability, we refer only the upper boundary data of the sub-block that will be concealed. The reason is why the data is error free. We solve the lacking guarantee matter related to amount of the reliable reference data by referring more pixel data located on the upper sub-block using Eq. (8),(9). K value is 6. We can check through block diagram of the total method in Fig. 5.

$$\mathrm{SAD}(E_{tl}) = \sum_{j=-K}^{-1}\sum_{i=0}^{7} \left| E_{tl}(x+i, y+j) - E_{tl}'(x+dx+i, y+dy+j) \right| \quad (8)$$

$$\mathrm{SAD}(E_{bl}) = \sum_{j=8}^{7+K}\sum_{i=0}^{7} \left| E_{bl}(x+i, y+j) - E_{bl}'(x+dx+i, y+dy+j) \right| \quad (9)$$

4. Experimental Results

Four test sequences were used to compare objective quality of MSBM method with the proposed method. Four sequences are Football, Foreman, Stefan and Silent. We applied to H.264 reference software (JM 10.2) and used 100 frames that coded with IPPP structure. GOP size is 3. We inserted the block loss to P frame.

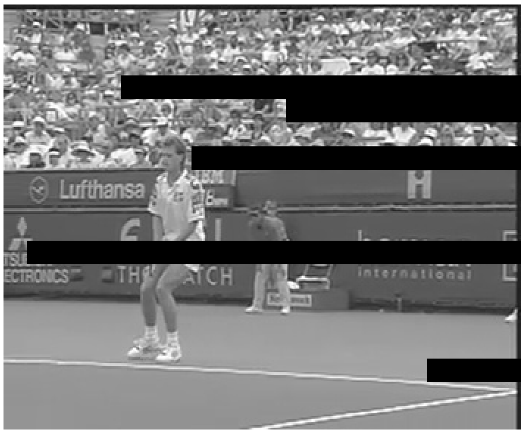
Table 1 shows each different MB ratio, test sequences and the average PSNR of each frame in concealing error with each method after losing MB randomly to 5%, 10%, 15% and 20% on frame except for the first frame of each test sequences. Therefore, it has a structure that uses by referring concealed image of the former page in the following frame.

AMSBM has higher performance than MSBM in every test sequence. It means AMSBM shows higher performance in terms of not only subjective image quality, but also objective image quality.

Table 1: Simulation results for different MB loss ratios

Test Sequence	PSNR (dB)	MB Loss Ratio			
		5%	10%	15%	20%
Football	**MSBM**	**34.809**	**30.484**	**27.868**	**25.959**
	AMSBM	**35.470**	**31.134**	**28.447**	**26.185**
Foreman	**MSBM**	**41.638**	**35.992**	**32.021**	**29.078**
	AMSBM	**42.250**	**36.378**	**32.364**	**29.114**
Stefan	**MSBM**	**36.600**	**32.069**	**29.162**	**27.024**
	AMSBM	**37.178**	**32.565**	**29.506**	**27.160**
Silent	**MSBM**	**48.071**	**40.692**	**35.163**	**31.188**
	AMSBM	**48.073**	**41.036**	**35.321**	**31.281**

(a) Errorfree



(b) Erroneous

(c) MSBM

(d) Proposed

Fig. 6 Frame #56 of the Stefan : (a) Error free, (b) Erroneous(20% MB loss), (c) MSBM, (d) Proposed

5. Conclusion

In this paper, AMSBM that uses examination of the boundary matching degree brings better performance by using adapted image reference pixels considering edge direction between boundaries. AMSBM can prevent error propagation that causes in the process of error concealment and it brings largely improved performance in terms of subjective image quality and also better performance on every test sequence in the PSNR part that means objective image quality. Experimental results show an improved performance of 0.36 dB on average compared to the previous method.

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Seung-Soo Jeong was born in Seoul, South Korea, in 1981. He received the B.S. degree in electronics engineering from Kwangwoon University, Seoul, Korea in 2007. He is currently working toward the M.S. degree in electronics engineering from Kwangwoon University, Seoul, Korea. His research interests include video coding and error concealment.

Chae-Bong Sohn received the B.S., M.S., and Ph.D. degree in electronics engineering from Kwangwoon University, Seoul, Korea in 1993, 1995, and 2006, respectively. From 2000 to 2005, he worked in Hanyang Women’s College as a full-time lecturer. He is currently an assistant professor in department of Electronics and Communications Engineering, Kwangwoon University. His research interests include image compression, transcoding, digital broadcasting systems.