Adaptive Block Distance Interpolation for MDC Frame Recovery

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Abstract—**Temporal Multiple Description Coding (T-MDC) is more robust to transmission errors in delivering video quality over networks than the conventional single description (streaming) coding (SDC). In general, T-MDC becomes more error resilient when the number of its descriptions increases, with a cost of higher bit rate overhead. Such an overhead should be constrained in a low bandwidth networking environment, where 2-description T-MDC is preferred. To compensate for the weaker error resilience due to bit rate saving, several conventional error concealment algorithms have been proposed for frame recovery of 2-description T-MDC. In the same context, this paper presents a novel error concealment algorithm called ABDI (Adaptive Block Distance Interpolation). The novelty of ABDI is two-folded: (1) ABDI provides an *adaptation* mechanism to dynamically select a smaller *block-based SAD* (*Sum of Absolute Difference*) from its two component algorithms called BDI (Block Distance Interpolation) and BPA (Bidirectional Pixel Average); (2) BDI can non-linearly reconstruct the motion vector of any missing block in the lost frame so that every lost frame can be recovered by using all its reconstructed motion vectors to grab frame recovery materials bi-directionally from the preceding and succeeding reference frames which belong to the video description successfully received. Our results show that ABDI outperforms all the conventional algorithms.**

Keywords-adaptive block distance interpolation; frame recovery; nonlinear motion vector reconstruction; temporal multiple description coding

I. Introduction

In recent years, advanced multimedia coding technologies have made feasible Internet-based real-time communications and generated a wide range of applications for daily life. However, since the Internet was not designed for quality of service and its available bandwidth is highly time-varying, the target video traffic can only be transferred with best effort when network congestion occurs. Network congestion can induce packet delay, jitter, and even loss, which result in video quality impairment. Thus, stable and high quality video over the Internet is still a challenging issue.

Video streaming is the major form of video over the Internet. In general, the source of video at the sender is first encoded into a *single* bit-stream, and then packetized to transfer over the Internet, and finally decoded at the receiver. To avoid or minimize video quality impairment from network congestion, the design goal of a video coder usually aims for a better Rate-Distortion (R-D), which means a better video quality given a bit-rate budget, or a lower bit-rate compression capability given a minimum requirement on video quality. However, better R-D is usually accompanied by weaker error resilience. In other words, R-D is a trade-off of error resilience. This is a common problem that *single description* (*streaming*) *coding* (SDC) has to face.

As the other extreme, the design goal of *multiple description* (*streaming*) *coding* (MDC) aims for better error resilience at the cost of bit-rate overhead, i.e. with R-D as a trade-off [1]. MDC can segment the video source into multiple descriptions from the *temporal*, *spatial*, and/or *frequency domains*, where the former two emphasize more on error resilience, and the latter more on R-D [2]-[4]. *Hybrid-domains* based MDC methods [5], [6] aiming for balancing between error resilience and R-D also exist. In particular, increasing the number of video descriptions of *temporal-domain* MDC (T-MDC) can strengthen its error resilience while damaging its R-D. To achieve a good R-D in the scenario of T-MDC, the number of video descriptions should be as small as possible. In this context, weak *error resilience* should be compensated by robust *error concealment*. In terms of the communication model, *error resilience* is a design issue of the encoder at the sender, while *error concealment* is a matter of the decoder at the receiver. In other words, *error concealment* can be viewed as the final line of defense for video quality due to transmission loss.

This paper discusses the error concealment techniques for lost-frame recovery in the literature, in particular for the scenario of *2-description* T-MDC, and proposes a novel algorithm called Adaptive Block Distance Interpolation (ABDI). To achieve a better understanding of the conventional algorithms and their roots from the SDC based frame recovery algorithms will also be briefly summarized.

The rest of this paper is organized as follows. Section II overviews the related works and gives the details of our proposed ABDI algorithm. Section III details the experimental setup and parameters. Analyses and discussions of the results are given in Section VI. Section V concludes the paper and outlooks the future work.

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978-981-08-9085-8/11 ©2011 IACSIT

II. Related Works and the Proposed

This section overviews the conventional algorithms for the frame recovery techniques in the context of *2-description* T-MDC, and details the proposed ABDI algorithm.

A. Conventional algorithms

The conventional frame recovery algorithms for *2-description* T-MDC were discussed and compared in [9], including Frame Copy (FC), Motion Vector Extrapolation (MVE), and Bidirectional Weighted Motion Vector Extrapolation (BW-MVE). This paper overviews in essence the similarities and differences between these convectional algorithms and those for SDC.

FC is the simplest way to conceal a lost frame, and better than doing nothing. FC directly copies the preceding frame to conceal the current lost frame. The fundamental problem with FC is the *visual freezing effect*. In the scenario of SDC, FC may still perform fairly well in case of random frame losses, whereas the *visual freezing effect* can be very serious in case of burst frame losses [7]. The mechanism of FC for *temporal-domain* MDC is identical as that of FC for SDC. However, the quality of FC for T-MDC is better [9]. In particular, even if one video description of T-MDC may have a long error propagation effect due to single frame loss or be completely lost, the *visual freezing effect* of FC for T-MDC does not last for more than two frames as long as the other video description via a different transmission channel is successfully received. Another problem with FC is that it does not work well for a fast-motion video sequence.

Peng et al. proposed the MVE algorithm [8] for block-based temporal error concealment of SDC, and Lu et al. applied MVE for T-MDC [9]. The mechanisms of MVE in both cases are the same. MVE is better than FC and can avoid the *visual freezing effect*. MVE conceals a lost frame in units of 8 x 8 block. For each missing block in the current lost frame, MVE first extrapolates all the macro blocks (MBs are in units of 16 x 16 pixel) in the preceding frame onto the current lost frame according to their motion vectors; the best MB which has a maximum overlap area with the missing block is then found, and its motion vector is used as the motion vector of the missing block to extrapolate an 8 x 8 substitute block from the preceding frame to conceal the missing block. For instance, as illustrated in (1), after finding the best MB in the preceding frame (say frame *n*-1), its motion vector MV_{n-1} is used as the motion vector MV_n of the missing block in the current lost frame (i.e. frame *n*) to extrapolate every pixel $P_{n-1}(x+MV_{n,x}, y+MV_{n,y})$ of the substitute block to compensate the corresponding pixel $P_n(\mathrm{x},y)$ of the missing block. The major problem with MVE lies in the fact that its spatial precision of 8 x 8 blocking is too rough and this limit its video quality performance.

$$P_n(\mathrm{x},y) = P_{n-1}(x+MV_{n,x}, y+MV_{n,y}) \tag{1}$$

BW-MVE [9] was proposed by Lu et al. to enhance the error concealment capability of 2-description T-MDC. It adopts *non-linear interpolation* by extending the unidirectional MVE algorithm into a bi-directional one, namely the motion vector based extrapolations are conducted from the preceding and succeeding frames. For each direction, the mechanism of finding the optimal substitute block is similar to that of MVE, with the key difference in that BW-MVE is in units of 4 x 4 block. For instance, as illustrated in (2), every pixel $P_n(x,y)$ of each 4 x 4 missing block in frame *n* can be *non-linearly interpolated* by the pixels $P_{n,n-1}(x,y)$ and $P_{n,n+1}(x,y)$ of the bi-directional 4 x 4 substitute blocks and the corrected pixel $P_{DMC}(x,y)$:

$$P_n = \frac{w_1 P_{n,n-1}(x,y) + w_2 P_{n,n+1}(x,y) + w_3 P_{DMC}(x,y)}{w_1 + w_2 + w_3} \tag{2}$$

where the first two weighting factors w_1 and w_2 are the numbers of *overlapped* pixels between the missing block in frame *n* and its bi-directional substitute blocks; the third weighted term $P_{DMC}(x,y)$, named as *Direct Motion Compensation*, is introduced as a corrected term only when w_1 and w_2 are too small simultaneously, taking the pixels by directly applying the motion vector of the same block position from the preceding frame; the corresponding weighting factor w_3 is defined by (3).

$$w_3 = ma\,x(0, W - ma\,x(w_1, w_2)) \tag{3}$$

where W is a threshold value (=12).

Along the track of frame recovery algorithms for SDC, PMVE [10] and HMVE [11], [12] are two major variants from MVE with improved performances. Instead of being block-based, PMVE is pixel-based, and HMVE is a hybrid of MVE and PMVE. Since both have not been applied to T-MDC, more discussions on them are out of the scope of this paper.

B. Adaptive Block Distance Interpolation (The Proposed)

Similar to BW-MVE, the proposed ABDI algorithm is also specifically designed for the whole-frame error concealment of 2-description T-MDC. The principle of *non-linear interpolation via weighted average* is adopted in our proposed ABDI (Adaptive Block Distance Interpolation) algorithm and the blocking is also based on 4 x 4, whereas the novelty of ABDI lies with the following:

1) Adaptation: ABDI is adaptive between the two proposed component algorithms in this paper for error concealment, i.e. BDI (Block Distance Interpolation) and BPA (Bi-direction Pixel Average), as detailed below.

2) Block Distance Interpolation: In order to reconstruct a lost frame, it is the motion vector of the missing block that is *non-linearly interpolated via weighted average*, not the missing pixel.

ABDI is adaptive in the sense that it provides a perception based selection mechanism in units of 4 x 4 block to switch between its component algorithms (BDI and BPA) based on SAD (Sum of Absolute Difference). In other words, for each missing block in a lost frame, the component algorithm with a smaller SAD is selected, and thus the entire lost frame can be optimally concealed.

Fig. 1 illustrates the adaptive control algorithm of ABDI, where the double for loops are conducted for each frame of the lost video description in the context of 2-description T-MDC, and for each missing block (say block i) in the lost frame (say frame n in units of the combined frame number of two video descriptions). The first two statements in the inner loop make function calls to *BDI*() and *BPA*(), which stand for the BDI and BPA algorithms respectively, and each function call returns two values: SAD and the concealed block. The *if-else* will choose a better concealed block from either $B^i_{n,\mathrm{BDI}}$ or $B^i_{n,\mathrm{BPA}}$ and assign it to $B^i_{n,R}$ depending on $SAD^i_{n,\mathrm{BDI}}$ and $SAD^i_{n,\mathrm{BPA}}$, which are defined by (4) and (5) respectively.

```
$for(each\ frame\ of\ the\ lost\ video\ description)$
{
  $for(each\ missing\ block\ i\ in\ lost\ frame\ n)$
  {
      $[SAD^i_{n,\mathrm{BDI}}, B^i_{n,\mathrm{BDI}}] = BDI()$
      $[SAD^i_{n,\mathrm{BPA}}, B^i_{n,\mathrm{BPA}}] = BPA()$
        $if(SAD^i_{n,\mathrm{BDI}} \le SAD^i_{n,\mathrm{BPA}})$
            $B^i_{n,R} = B^i_{n,\mathrm{BDI}}$
        $else$
            $B^i_{n,R} = B^i_{n,\mathrm{BPA}}$
  }
}
```

Figure 1. The proposed ABDI algorithm.

$$SAD^i_{\mathrm{BDI}} = \sum_{x=1}^{4}\sum_{y=1}^{4} \left|P^i_{n,bmv}(x,y) - P^i_{n,fmv}(x,y)\right| \qquad (4)$$

where $P^i_{n,bmv}(x,y)$ and $P^i_{n,fmv}(x,y)$, obtained from the BDI component algorithm and defined by (8) and (9), are the pixel values of the 4 x 4 extrapolated substitute blocks $B^i_{n,bmv}$ and $B^i_{n,fmv}$ respectively from the preceding and succeeding frames using the *non-linearly interpolated* motion vector for the missing block B^i_n in the current lost frame.

$$SAD^i_{\mathrm{BPA}} = \sum_{x=1}^{4}\sum_{y=1}^{4} \left|P^i_{n,bpx}(x,y) - P^i_{n,fpx}(x,y)\right| \qquad (5)$$

where $P^i_{n,bpx}(x,y)$ and $P^i_{n,fpx}(x,y)$, obtained from the BPA component algorithm, are the pixel values of the 4 x 4 substitute blocks $B^i_{n,bpx}$ and $B^i_{n,fpx}$ respectively from the preceding and succeeding frames at the same block position as the missing block, as defined by (11) and (12).

- Block Distance Interpolation (BDI)

BDI is one of the two component algorithms of ABDI for conducting error concealment, and it is called by ABDI when $SAD^i_{\mathrm{BDI}} \le SAD^i_{\mathrm{BPA}}$. BDI adopts *non-linear interpolation* and can efficiently handle those missing blocks with rapid motion where *linear interpolation* does not work well for error concealment.

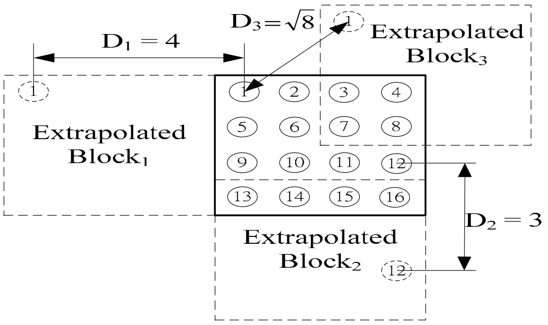

Figure 2. Block distance for some extrapolated blocks.

As defined by (6), BDI first reconstructs a *non-linearly interpolated* motion vector $MV(B^i_n)$ for missing block i of lost frame n, and $MV(B^i_n)$ is then used to grab the substitute blocks $B^i_{n,bmv}$ and $B^i_{n,fmv}$ bi-directionally from the preceding and succeeding frames, and the reconstructed block $B^i_{n,\mathrm{BDI}}$ is simply an arithmetic mean (i.e. *linear interpolation*) of $B^i_{n,bmv}$ and $B^i_{n,fmv}$, as defined in (7). The further details of (6) and (7) are given as follow.

$MV(B^i_n)$ is *non-linearly interpolated* in the sense that it is a weighted mean of both $MV(B^{opt}_{n-1})$ and $MV(B^{opt}_{n+1})$, which are the motion vectors of the *optimal blocks* B^{opt}_{n-1} and B^{opt}_{n+1} respectively chosen from the preceding and succeeding frames. The backward weighting factor $w(B^{opt}_{n-1})$ is defined as the shortest one among those distances of the missing block B^i_n in the lost frame and the motion-vector-extrapolated candidate blocks from the preceding frame, which are the 5 x 5 neighbouring blocks centered at block B^i_{n-1} and extracted on to the lost frame using their corresponding motion vector. In other words, B^{opt}_{n-1} is the shortest-distance candidate block. For instance, Fig. 2 demonstrates three candidate extracted blocks (denoted as EB_i with i = 1, 2, 3) from the preceding frame on to the lost frame, and the other candidate *EBs* with longer distances are omitted for simplicity; EB_3 is obviously the optimal block B^{opt}_{n-1} because its distance from B^i_n is the shortest. Likewise, the forward weighting factor $w(B^i_{n+1})$ is defined similarly except that the optimal block B^{opt}_{n+1} is chosen and extracted from the succeeding frame. In addition, the coefficient D (= 1/2) in (6) is introduced as a length correction term, considering the fact that both $MV(B^{opt}_{n-1})$ and $MV(B^{opt}_{n+1})$ belong to the same video description of 2-description T-MDC.

$$MV(B^i_n) = D\left\{\frac{w(B^{opt}_{n-1})\times MV(B^{opt}_{n-1}) + w(B^{opt}_{n+1})\times MV(B^{opt}_{n+1})}{w(B^{opt}_{n-1}) + w(B^{opt}_{n+1})}\right\} \qquad (6)$$

$$B^i_{n,\mathrm{BDI}} = \tfrac{1}{2}B^i_{n,bmv} + \tfrac{1}{2}B^i_{n,fmv} \qquad (7)$$

In (7), $B^i_{n,bmv}$ and $B^i_{n,fmv}$ are the *backward* and *forward* substitute blocks respectively grabbed from the preceding and succeeding frames using $MV(B^i_n)$. Numerically speaking, however, the grabbing procedures involve sub-pel precision since $MV(B^i_n)$ is a weighted mean of two *integral* motion vectors $MV(B^{opt}_{n-1})$ and $MV(B^{opt}_{n+1})$ and its vector components $MV_x(B^i_n)$ and $MV_y(B^i_n)$ could thus be *non-integral*. (8) and (9) respectively describe the pixel-by-pixel *backward* and *forward* grabbing mechanisms using both $MV_x(B^i_n)$ and $MV_y(B^i_n)$, where $P^{\,i}_{bmv}(x,y)$ represents each pixel of $B^i_{n,bmv}$ obtained from the *backward* grabbed pixel $P^i_{n-1}\left(x + MV_x(B^i_n),\ y + MV_y(B^i_n)\right)$ with the $\frac{1}{4}$-pel location search (i.e. $f_{1/4}$) in the preceding frame while $P^{\,i}_{fmv}(x,y)$ is defined in a similar way except that it is for *forward* grabbing.

$$P^{\,i}_{bmv}(x,y) = f_{1/4}\left\{P^i_{n-1}\left(x + MV_x(B^i_n),\ y + MV_y(B^i_n)\right)\right\} \quad (8)$$

$$P^{i}_{fmv}(x,y) = f_{1/4}\left\{P^i_{n+1}\left(x - MV_x(B^i_n),\ y - MV_y(B^i_n)\right)\right\} \quad (9)$$

- Bidirectional Pixel Average (BPA)

BPA is one of the two component algorithms of ABDI for error concealment, and it is called by ABDI when $SAD_{\text{BPA}} < SAD_{\text{BDI}}$. As defined in (10), BPA adopts a *linear interpolation* principle, where the reconstructed block $B^i_{n,\text{BPA}}$ is simply the arithmetic mean of $B^i_{n,bpx}$ and $B^i_{n,fpx}$which represent the two subtitute blocks at the same block position *i* of the preceding and succeeding frames respectively.

$$B^i_{n,\text{BPA}} = \frac{1}{2}\left(B^i_{n,fpx} + B^i_{n,bpx}\right) \quad (10)$$

where the corresponding pixel values $P_{n,fpx}(x,y)$ and $P_{n,\text{bpx}}(x,y)$ of blocks $B^i_{n,fpx}$ and $B^i_{n,bpx}$ are defined by (11) and (12).

$$P_{n,fpx}(x,y) = P_{n+1}(x,y) \quad (11)$$

$$P_{n,\text{bpx}}(x,y) = P_{n-1}(x,y) \quad (12)$$

III. Simulation Setup

To evaluate the performance of the proposed ABDI algorithm, two standard test video sequences of different spatial resolution— *Paris* CIF and *Foreman* QCIF are both analysed for their first 240 frames in the scenario of 2-description T-MDC. Hence, each video sequence was first separated into two video descriptions via a video splitter; each video description was then encoded, transmitted, decoded independently; eventually the two decoded video descriptions were merged together via a video merger.

H.264 [11] was adopted for the encoding and decoding of each video description, where the coding pattern is (I, P...P). The combined frame rate of each video sequence was set to be 30 fps, and a quantization parameter of 28 was adopted uniformly for all the frames. To enhance the motion estimation of H.264, all the seven block sizes (16 x16, 16 x 8, 8 x16, 8 x 8, 8 x 4, 4 x 8, and 4 x 4) were used.

The simulation scenario is totally based on 2-descrisption T-MDC, and it was assumed that all the odd frames, i.e. description 1, were completely lost; and all the even frames, i.e. description 2, were successfully received. Finally, the results of the proposed ABDI are compared with those of the conventional algorithms: FC, MVE, and BW-MVE.

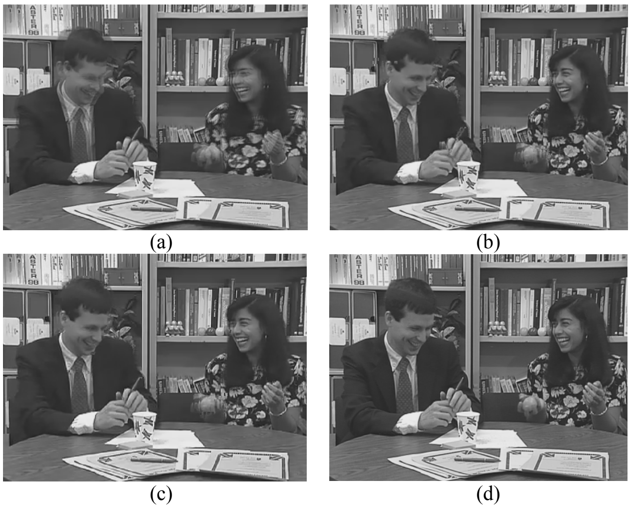

Figure 3. The visual results in the 45th frame of *Paris* CIF : (a) concealed only with BPA (27.57 dB), (b) concealed only with BDI (30.69 dB), (c) concealed with ABDI (31.77 dB), and (d) the original frame.

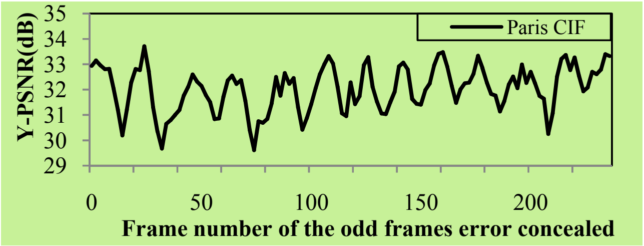

Figure 4. The error concealment performance of ABDI for the lost odd frames of *Paris* QCIF.

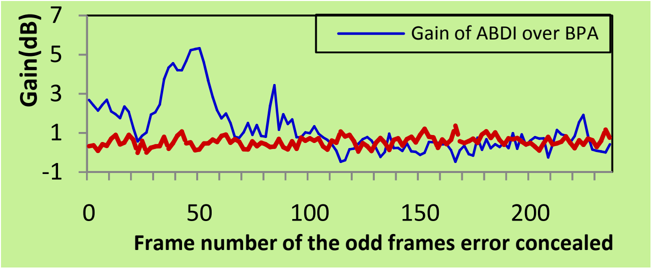

Figure 5. The Y-PSNR gains of ABDI over BDI and BPA for the lost odd frames for *Paris* CIF.

IV. Simulation Setup

To visualize the effects of ABDI and its component algorithms BDI and BPA, the 45th frame of *Paris* CIF is demonstrated for comparison in Fig. 3 (recall the assumption that all the odd frames of the merged video sequence were lost), where Fig. 3(a) is the error concealed frame using BPA with a Y-PSNR of 27.57 dB, and the major reconstruction failures of this lost frame are the shaking-and-doubly-imaged areas around the male's head and his necktie, as well as the blur areas around the female's head and her hands; Fig. 3(b) adopts BDI to obtain the concealed frame with a much better quality up to 30.69 dB, where both persons' heads are much clearer and the male's necktie is no more shaking or doubly-imaged except one bad news that the single pen on the male's left hand seems to split into two; Fig. 3(c) is the error concealed frame using the complete ABDI algorithm with a further improvement up to 31.77 dB, which demonstrates that the adaptive control mechanism of ABDI does play its role in compensating for the shortcomings of BPA and BDI; finally, Fig. 3(d) shows the original frame for visual comparison.

Fig. 4 depicts the Y-PSNR of every error concealed frame of *Paris* CIF using the proposed ABDI algorithm, where the horizontal axis specifies the frame number of the lost odd frames. To further understand the role of adaptive control of ABDI, Table 1 summarizes the average Y-PSNR performances of ABDI and its component algorithms – BPA and BDI, and Fig. 5 details the Y-PSNR gains of ABDI over BDI and BPA. In general, the adaptive control of ABDI can effectively compensate for the individual shortcomings of BDI and BPA.

TABLE I. AVERAGE Y-PSNR PERFORMANCE COMPARISON OF ABDI AND ITS COMPONENT ALGORITHMS (BDI AND BPA).

Sequence	**Average Y-PSNR (dB)**		
	BDI	***BPA***	***ABDI***
Paris CIF	31.48	30.81	32.03
Foreman QCIF	33.32	32.18	33.76

TABLE II. PERFORMANCE COMPARISON OF THE PROPOSED AND THE CONVENTION ALGORITHMS (FC, MVE, BW-MVE).

Sequence	**Average Y-PSNR (dB)**			
	FC	***MVE***	***BW-MVE***	***ABDI***
Paris CIF	28.38	29.46	31.52	32.03
Foreman QCIF	28.29	30.34	33.17	33.76

TABLE III. PERFORMANCE GAINS OF THE PROPOSED OVER FC, MVE, AND BW-MVE.

Sequence	**Gain (dB)**		
	Gain-1	***Gain-2***	***Gain-3***
Paris CIF	3.65	2.57	0.51
Foreman QCIF	5.47	3.42	0.59

V. CONCLUSION

A novel error concealment algorithm called ABDI has been proposed in this paper for frame recovery of 2-description T-MDC to combat transmission loss. The novelty is two-folded. First, ABDI provides an *adaptation* mechanism to dynamically select a smaller *block-based SAD* (*Sum of Absolute Difference*) from its two component algorithms called BDI and BPA. Furthermore, based on the so-called *block distance interpolation*, BDI can non-linearly reconstruct the motion vector of any missing block in the lost frame so that every lost frame can be recovered by using all its reconstructed motion vectors to grab frame recovery materials bi-directionally from the preceding and succeeding reference frames which belong to the video description successfully received. Our results show that ABDI can achieve an average *Y-PSNR* as high as 32.03 dB in *Paris* CIF and 33.76 dB in *Foreman* QCIF. In comparison to the conventional algorithms, ABDI outperforms FC, MVE, and BW-MVE.

This research is based on the assumption that a smaller *block-based SAD* can achieve a better *frame-based* Y-PSNR. In order to further enhance the video quality of error concealment, it should be useful to study the correlation between *block-SAD* and *frame*-Y-PSNR. This will be left as a future work.

ACKNOWLEDGMENT

This work was supported in part by Taiwan National Science Council under grants NSC 98-2221-E-155-043 and 99-2219-E-155-005.

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