

Adaptive Vector Length Interpolation for Whole-Frame Error Concealment of Temporal MDC

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Abstract— The video quality of the conventional single description (streaming) coding (SDC) is vulnerable to transmission errors. Once a video frame is lost, it is likely to cause error propagation to the subsequent received frames, and this increases the difficulty of whole-frame error concealment by its preceding and/or succeeding reference frames. The temporal Multiple Description Coding (T-MDC) is more error resilient than SDC by distributing the risks of transmission at a cost of higher coding bit rate overhead which increases with the number of video descriptions. This cost limits the error resilience of T-MDC in a low bandwidth environment, and a small number of descriptions is preferred, where error concealment is still highly demanded to serve as the final line of defense for video quality. In the literature there have been some algorithms developed for the whole-frame error concealment of SDC and T-MDC. This paper proposes a novel algorithm called AVLI (Adaptive Vector Length Interpolation) for the whole-frame error concealment of 2-description T-MDC. AVLI consists of two component algorithms, and can adaptively select one of them with a smaller sum of absolute difference, leading to a higher video quality of Y-PSNR. One component algorithm adopts *non-linear interpolation* for the 4 x 4 block based motion vector reconstruction in the lost frame which is bi-directionally weighted by the inverse square of the reference motion vector lengths. The other adopts *linear interpolation* for the pixel based block reconstruction. Our results show that the proposed outperforms the conventional algorithms by 0.5 to 5 dB for the test cases.

Keywords— Multiple Description Coding, Error Concealment, Adaptive Vector Length Interpolation, Non-linear Motion Vector Reconstruction, Bi-directional Pixel Average

I. INTRODUCTION

With the fast advancement of video coding and networking technologies, video transfer over networks has been widely used and covers a broad range of applications. However, high quality video transfer over the Internet is still a main challenge to video coding because the current Internet lacks of quality of service (QoS), and can only transfer video to its *best effort* (BE) when network congestion occurs. Network congestion can cause packet delay, jitter, and even loss, and these effects may lead to great damage to the received video quality.

On the other hand, to achieve a high compression and low bit rate while maintaining satisfying video quality, namely good rate-distortion (R-D), modern video coders usually adopt highly complicated prediction techniques in time, space, and/or frequency domains. However, the design goal of a good R-D

usually contradicts with its capability of error resilience to network transfer. To tackle this problem, error concealment is thus important to the video coder design in the sense that error resilience is a matter of the encoder at the sender side, while error concealment is a matter of the decoder at the receiver side. Since good R-D is usually accompanied by weak error resilience, an efficient error concealment technique is a highly demanded tool.

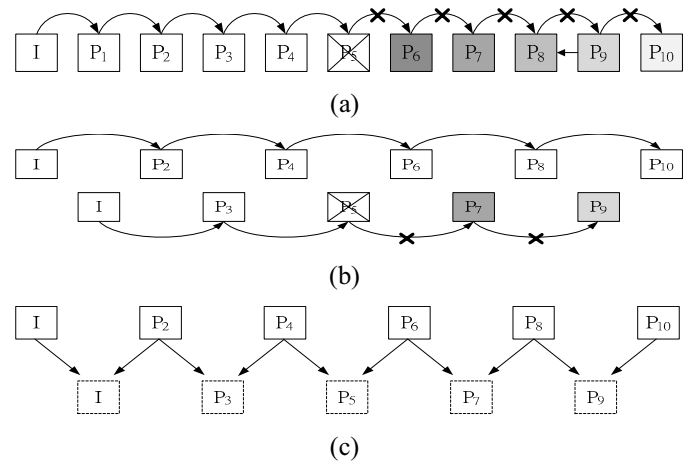


Figure 1. Various ways of video coding and error concealment: (a) SDC and its error propagation, (b) a random loss in one description of MDC and its error propagation, (c) a bursty or full loss in one description of MDC and its error propagation.

When using a low bit rate, a single video packet loss may cause serious error propagation spatially or temporally [1]. The error propagation effects, as demonstrated in Figure 1(a), are the main challenge to the error concealment task, especially for the conventional video streaming, which is based on single description (stream) coding (SDC). On the other hand, multiple description coding (MDC) [2], [3] is designed for error resilience at the cost of bit rate overhead which impairs the R-D. In recent years, there have been many MDC techniques developed for different purposes. For instance, spatial-domain MDC (S-MDC) and temporal-domain MDC (T-MDC) are designed for high error resilience, while frequency-domain MDC for good R-D; hybrid methods aiming at balancing both also exist. A special classification scheme according to the types of MDC predictor was proposed by [4]. In principle, increasing the number of video

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descriptions in MDC can enhance its error resilience while damaging its R-D. Thus, to keep a good R-D, a robust error concealment technique is still demanded for MDC which has only few video descriptions.

This paper explores the whole-frame error concealment techniques in the literature in particular for the 2-description T-MDC, and proposes a novel error concealment algorithm called AVLI (Adaptive Vector Length Interpolation). To address this issue, let us start with the whole-frame error concealment techniques for SDC. When a video frame is lost during transmission, the simplest way of whole-frame recovery is to copy from its preceding frame, and such a method is called FC (Frame Copy) [5]. FC can perform quite well in case of random frame losses. However, in case of burst frame losses, the visual *freezing* effect can be very serious.

MVE (Motion Vector Extrapolation) [6] can avoid the *freezing* effect by exploiting block based reconstruction for the lost frame. MVE first compares all the macro blocks (MBs are in units of 16 x 16 pixel) in the preceding frame with the 8 x 8 missing block in the current lost frame by extrapolating all the MBs to the current lost frame to find the best MB which has a *maximum overlap* area with the missing block; once the best MB is found, its motion vector will be used as the motion vector of the missing block to extrapolate an 8 x 8 substitute block from the preceding frame to compensate for the missing block. MVE is better than FC to some extent. However, the spatial precision of 8 x 8 blocking in MVE limits its performance.

PMVE (Pixel based MVE) [7] extends the motion vector extrapolation to the pixel level. The missing pixels of the lost frame are classified into two types: (1) for a missing pixel covered by any extrapolated MB, its reconstructed motion vector is a mean of the motion vectors of all the overlapped MBs; (2) for a missing pixel not covered by any extrapolated MB, its reconstructed motion vector is copied from that of the same pixel in the preceding frame. PMVE outperforms MVE in large motion scenes.

As a hybrid method of MVE and PMVE, HMVE [8], [9] performs the pixel based motion vector reconstruction in units of 4 x 4 block both in the current lost frame and the preceding reference frame, where the missing pixels of the lost frame are classified into three types for reconstruction based on the *overlap* between the missing pixel or the 4 x 4 block which the missing pixel belongs to in the current lost frame and all the 4 x 4 blocks in the preceding reference frame. HMVE outperforms the forementioned algorithms for SDC. However, all these SDC based error concealment methods suffer from temporal error propagation if a long GOP (Group of Pictures) is adopted for coding.

Unlike SDC, T-MDC can alleviate the effect of error propagation. Figure 1(b) demonstrates a typical case of the 2-description T-MDC, where the odd frames forms one description, and the even frames forms the other. Assume these two descriptions are transmitted and forwarded via different routing paths, and one of them has some lost frames, and the other description is perfectly received. Since each description is encoded and decoded independently, the error

propagation in the partially lost description will not affect the decoding of the successfully received description at all. Equivalently, no continual error propagation exists after combining all the decoded frames from these two descriptions. Figure 1(c) illustrates another similar but worse case for the 2-description T-MDC where one description is totally lost and the other is perfectly received. As a consequence, every lost frame is surrounded by two received frames temporally. Both of these two cases show that T-MDC is more error resilient than SDC, and this paves a good foundation for the error concealment of T-MDC.

The rest of this paper is organized as follows. Section II describes the related works and details the proposed algorithm. A brief description of the experimental setup is given in Section III. Section IV analyzes and discusses the results. Section V concludes this paper and outlooks the future works.

II. RELATED WORKS AND THE PROPOSED ALGORITHM

This section discusses the related works for the error concealment issue of 2-description T-MDC, including FC, MVE, and BW-MVE, and all these works were conducted and compared in [10]. In addition, this section also details our proposed AVLI algorithm and explains its novelty.

A. Frame copy

The basic mechanism of FC for T-MDC [10] is identical as that of FC for SDC, as described in Section I. However, the quality of FC for T-MDC is better since T-MDC is more error resilient than SDC. Notably, even in the worst case that one description has a long error propagation or is completely lost, the *freezing* effect of FC for T-MDC does not last for more than two frames. Due to the nature of direct pixel copy from the preceding reference frame, FC fails to perform well for those lost frames with fast motions.

B. Motion Vector Extrapolation

The mechanism of MVE for T-MDC [10] is the same as that of MVE for SDC, as mentioned in Section I. As illustrated in (1), after finding a best MB in the preceding reference frame which has the maximum *overlap* area with the 8 x 8 missing block in the current lost frame, the motion vector MV_{n-1} of the best MB in reference frame $n-1$ is used as the motion vector MV_n of the missing block in lost frame n to extrapolate every pixel $P_{n-1}(x + MV_{n,x}, y + MV_{n,y})$ of the substitute block to compensate for the corresponding pixel $P_n(x, y)$ of the missing block.

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

C. Bi-directional Weighted MVE

BW-MVE was specifically proposed in [10] to further improve the performance of error concealment for the 2-description T-MDC. Here the temporal *Bi-directional Extrapolations* are actually equivalent to a temporal *Interpolation*; the mechanism of finding the best substitute block for the missing block in the lost frame for each direction is similar to that of MVE with the difference in that BW-MVE performs bi-directional MVE all in units of 4 x 4 block. As illustrated in (2), every pixel $P_n(x, y)$ of the 4 x 4 missing

block 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 $P_{DMC}(x,y)$, with the weighting factors w_1 , w_2 , and w_3 respectively:

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

where w_1 and w_2 are the numbers of *overlapped* pixels between the missing block in the current lost frame and the bi-directional substitute blocks; $P_{DMC}(x,y)$ is a corrected term introduced only when w_1 and w_2 are both too small, 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 determined according to (3)

$$w_3 = \max(0, W - \max(w_1, w_2)) \quad (3)$$

where W is a threshold value (=12).

D. Adaptive Vector Length Interpolation (The Proposed)

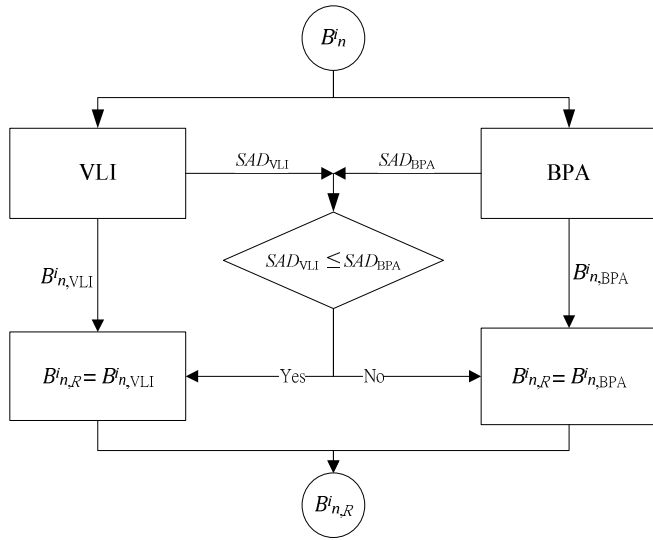


Figure 2. Flowchart of AVL I

The essence of the proposed AVL I algorithm is also based on the principle of *non-linear Interpolation*, whereas the novelty of AVL I lies with the following:

1) Adaptation: AVL I is adaptive between the two component algorithms: VLI and BPA, as detailed below.

2) Vector Length Interpolation: For reconstructing a lost frame, it is the motion vector of the missing block that is *non-linearly weighted* and *interpolated*, not the missing pixel. Besides, the weighting factors used in VLI are vector length based, as defined by (8).

AVL I is *adaptive* in the sense it consists of three parts:

- SAD based Adaptation (SADA),
- Vector Length Interpolation (VLI),
- Bi-directional Pixel Average (BPA),

where SADA is the control mechanism providing an *adaptive* control to switch between the two component algorithms we propose in this paper for error concealment, called VLI and BPA.

As shown in Figure 2, SADA consists of several steps for concealing all the missing 4 x 4 blocks in a given lost frame:

Step 1: For missing block i of lost frame n (denoted as B_n^i), SADA firstly performs both VLI and BPA, and calculate each individual *SAD* (*Sum of Absolute Difference*).

Step 2: SADA then adaptively selects the minimum *SAD* between SAD_{VLI} and SAD_{BPA} . Namely, if $SAD_{VLI} \leq SAD_{BPA}$, go to Step 3; otherwise, go to Step 4.

Step 3: Assign the concealed block $B_{n,VLI}^i$ as the reconstructed block $B_{n,R}^i$.

Step 4: Assign the concealed block $B_{n,BPA}^i$ as the reconstructed block $B_{n,R}^i$.

The definition of SAD_{VLI} and SAD_{BPA} are given by (4) and (5) respectively:

$$SAD_{VLI} = \sum_{All P_n(x,y) \in B_n^i} |P_{n,fmv}(x,y) - P_{n,bmv}(x,y)| \quad (4)$$

where $P_{n,fmv}(x,y)$ and $P_{n,bmv}(x,y)$ are defined in (10) and (11) respectively;

$$SAD_{BPA} = \sum_{All P_n(x,y) \in B_n^i} |P_{n,fpv}(x,y) - P_{n,bpv}(x,y)| \quad (5)$$

where $P_{n,fpv}(x,y)$ and $P_{n,bpv}(x,y)$ are defined in (13) and (14) respectively.

Both VLI and BPA are conducted in units of 4 x 4 block, and their details are given as follow.

• Vector Length Interpolation (VLI)

The VLI algorithm is one of the two component algorithms of AVL I for error concealment, and it is called by AVL I when $SAD_{VLI} \leq SAD_{BPA}$. As defined in (6), VLI uses a *non-linearly interpolated* motion vector $MV(B_n^i)$ for missing block i of lost frame n to grab its substitute blocks $B_{n,bmv}^i$ and $B_{n,fmv}^i$ bi-directionally from the preceding and succeeding reference frames, and the reconstructed block $B_{n,VLI}^i$ is the average of these two substitutes.

$$B_{n,VLI}^i = \frac{1}{2} B_{n,fmv}^i + \frac{1}{2} B_{n,bmv}^i \quad (6)$$

As defined in (7), $MV(B_n^i)$ is *non-linearly interpolated* in the sense that $MV(B_n^i)$ is a weighted mean of $MV(B_{n-1}^i)$ and $MV(B_{n+1}^i)$, which are the motion vectors of the i^{th} blocks of the preceding and succeeding frames, where a length correction coefficient $D (= 1/2)$ is introduced considering the fact that, in the case of 2-description T-MDC, both $MV(B_{n-1}^i)$ and $MV(B_{n+1}^i)$ belong to the same description. In other words, they are equivalently calculated every other frame when viewed from the whole combined video sequence.

$$MV(B_n^i) = D \left\{ \frac{w(B_{n-1}^i) \times MV(B_{n-1}^i) + w(B_{n+1}^i) \times MV(B_{n+1}^i)}{w(B_{n-1}^i) + w(B_{n+1}^i)} \right\} \quad (7)$$

As defined by (8), the weighting factors $w(B_{n-1}^i)$ and $w(B_{n+1}^i)$ are inversely proportional to the square of their corresponding reference motion vector lengths $L_{mv}(B_{n-1}^i)$ and $L_{mv}(B_{n+1}^i)$. Such a definition is based on the assumption that the larger $MV(B_{n-1}^i)$ or $MV(B_{n+1}^i)$ is, the less similar to $MV(B_n^i)$ it is.

$$\begin{cases} w(B_{n-1}^i) = (L_{mv}(B_{n-1}^i))^{-2} \\ w(B_{n+1}^i) = (L_{mv}(B_{n+1}^i))^{-2} \end{cases} \quad (8)$$

Note that $L_{mv}(B_{n-1}^i)$ and $L_{mv}(B_{n+1}^i)$ can be respectively written in terms of the x and y components of $MV(B_{n-1}^i)$ and those of $MV(B_{n+1}^i)$, as shown in (9).

$$\begin{cases} L_{mv}(B_{n-1}^i) = D \sqrt{(MV_x(B_{n-1}^i))^2 + (MV_y(B_{n-1}^i))^2} \\ L_{mv}(B_{n+1}^i) = D \sqrt{(MV_x(B_{n+1}^i))^2 + (MV_y(B_{n+1}^i))^2} \end{cases} \quad (9)$$

where the length correction coefficient $D (= 1/2)$ is needed again as explained previously for (7).

Recall (4) and (6), the corresponding pixel values $P_{n, fmv}(x, y)$ and $P_{n, bmv}(x, y)$ of the substitute blocks $B_{n, fmv}^i$ and $B_{n, bmv}^i$ using the *non-linearly interpolated* motion vector $MV(B_n^i)$ are defined by (10) and (11).

$$P_{n, fmv}(x, y) = P_{n+1}(x - MV_x(B_n^i), y - MV_y(B_n^i)) \quad (10)$$

$$P_{n, bmv}(x, y) = P_{n-1}(x + MV_x(B_n^i), y + MV_y(B_n^i)) \quad (11)$$

● Bi-directional Pixel Average (BPA)

The BPA algorithm is one of the two component algorithms of AVLI for error concealment, and it is called by AVLI when $SAD_{BPA} < SAD_{VLI}$. As defined in (12), BPA adopts a *linear interpolation* principle, where the reconstructed block $B_{n, BPA}^i$ is the average of the two substitute blocks $B_{n, bpx}^i$ and $B_{n, fpx}^i$ at the same block position i of the preceding and succeeding reference frames respectively.

$$B_{n, BPA}^i = \frac{1}{2} (B_{n, fpx}^i + B_{n, bpx}^i) \quad (12)$$

In other words, the pixel values of $B_{n, BPA}^i$ are the averages of the pixel values $P_{n, fpx}(x, y)$ and $P_{n, bpx}(x, y)$ of blocks $B_{n, fpx}^i$ and $B_{n, bpx}^i$ respectively, where $P_{n, fpx}(x, y)$ and $P_{n, bpx}(x, y)$ are defined by (13) and (14).

$$P_{n, fpx}(x, y) = P_{n+1}(x, y) \quad (13)$$

$$P_{n, bpx}(x, y) = P_{n-1}(x, y) \quad (14)$$

III. EXPERIMENT SETUP

To evaluate the performance of the proposed AVLI algorithm and compare it with FC, MVE, BW-MVE for the scenario of 2-description T-MDC, two video sequences *Foreman* and *Carphone* both in the format of QCIF are analyzed for the first 240 frames. Each video sequence was first separated into two video descriptions via a video splitter, and each video description was then encoded, transmitted, and decoded independently. The H.264 codec [11] was used for the encoding and decoding of each video description. For each description, only the first frame is encoded as an I-frame, and all the others are encoded as P-frames. The combined frame rate of each video sequence was set to be 30 fps and a quantization parameter of 28 was applied for all the I-frames and P-frames uniformly. The motion estimation of H.264

adopted all the seven block sizes, namely 16 x 16, 16 x 8, 8 x 16, 8 x 8, 8 x 4, 4 x 8, and 4 x 4.

In order to conduct the comparison of the proposed algorithm with the forementioned algorithms for 2-description T-MDC, the same assumption was applied that all the odd frames, i.e. description 1, were completely lost, and all the even frames, i.e. description 2, were successfully received.

IV. RESULTS

To visualize the effects of AVLI and its component algorithms VLI and BPA, the 237th frame of *Foreman* is demonstrated for comparison in Fig. 3, where Fig. 3(a) is the error concealed frame using BPA with a Y-PSNR of 30.96 dB, and the major failures of this lost frame's reconstruction are concentrated around the neighborhoods of the mouth, nose, and ear, which look quite blur; Fig. 3(b) is the error-concealed frame using VLI with a better improvement of 32.16 dB, and the neighborhoods of the mouth, nose, and ear are much clearer whereas some miss-reconstructed blocks are scattered around the rim of the cap; Fig. 3(c) is the error concealed frame using the complete AVLI algorithm with a further improvement up to 33.28 dB, which demonstrates that the adaptive control mechanism does play its role in compensating for the shortcomings of BPA and VLI; and finally the original frame is placed for visual comparison in Fig. 3(d).



Figure 3. The visual results in the 237th frame of *Foreman* QCIF : (a) concealed only with BPA (30.96 dB), (b) concealed only with VLI (32.16 dB), (c) concealed with the complete AVLI (33.28 dB), and (d) the original frame.

Fig. 4 illustrates the Y-PSNR of error concealed frames using the proposed AVLI algorithm, where the horizontal axis specifies the frame number of the odd frames which are lost. The importance of adaptive control of AVLI is shown in Fig. 5, where the vertical axis are the Y-PSNR gains of AVLI over VLI and BPA. Notably, the adaptive control can effectively compensate for the individual shortcomings of VLI and BPA. Besides, it is also seen that VLI outperforms BPA in general.

Table 1 presents the clear comparison of the average Y-PSNR performances of error concealment among FC, MVE, BW-MVE, and the proposed AVLI algorithm for 2-description of T-MDC using the two test video sequences: *Foreman* and *Carphone*, both in the format of QCIF. The performance gains of the proposed AVLI algorithm over FC, MVE, BW-MVE are summarized in Table 2 as *Gain-1*, *Gain-2*, and *Gain-3* respectively. Notably, AVLI outperforms FC by up to 5.34 dB in *Foreman*, and 1.90 dB in *Carphone*. In addition, AVLI also performs better than BW-MVE by 0.46 dB in *Foreman*, and by 1.04 dB in *Carphone*.

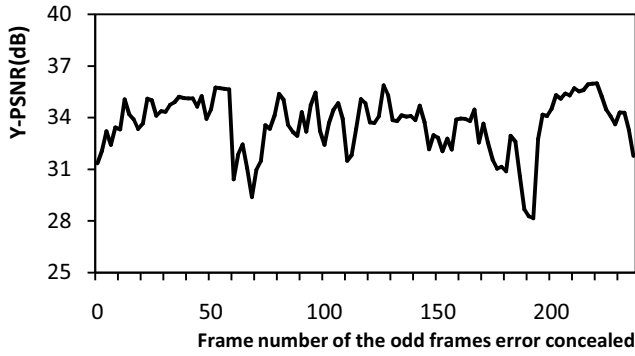


Figure 4. The error concealment performance of AVLI on the lost odd frames in *Foreman* QCIF.

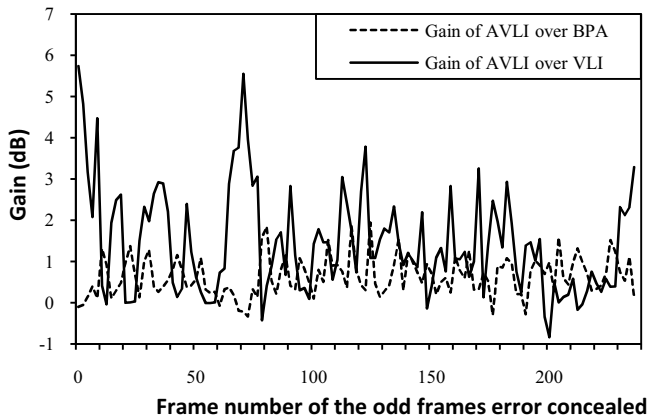


Figure 5. The average Y-PSNR gains of AVLI over VLI and BPA on the lost odd frames in *Foreman* QCIF.

TABLE 1. PERFORMANCE COMPARISON OF THE PROPOSED (AVLI) AND THE CONVENTIONAL ALGORITHMS (FC, MVE, BW-MVE).

Sequence	Y-PSNR(dB)			
	FC	MVE	BW-MVE	The Proposed
<i>Foreman</i> QCIF	28.29	30.34	33.17	33.63
<i>Carphone</i> QCIF	29.78	28.47	30.64	31.68

TABLE 2. PERFORMANCE GAINS OF THE PROPOSED OVER FC, MVE, AND BW-MVE.

Sequence	Gain(dB)		
	Gain-1	Gain-2	Gain-3
<i>Foreman</i> QCIF	5.34	3.29	0.46
<i>Carphone</i> QCIF	1.90	3.21	1.04

V. CONCLUSIONS

A novel error concealment algorithm called AVLI has been proposed in this paper. AVLI is designed for the scenario of 2-description T-MDC. It consists of two component algorithms called VLI and BPA and an adaptive control mechanism to switch between VLI and BPA depending on which one has a smaller *SAD* (*Sum of Absolute Difference*). A *bi-directional motion vector reconstruction* mechanism based on *nonlinear interpolation* is adopted for the missing blocks' reconstruction of VLI, where the *nonlinear interpolation* is achieved via the weighting based on the *inverse square* of the motion vector lengths of the corresponding blocks in the preceding and succeeding reference frames; whereas the pixel average based on *linear interpolation* is adopted for the missing blocks' reconstruction of BPA. Our results have shown that the adaptive control mechanism does play its role in achieving an average Y-PSNR as high as 33.63 dB in *Foreman* QCIF and 31.68 dB in *Carphone* QCIF. In comparison to other conventional algorithms, the proposed AVLI algorithm outperforms FC, MVE, and BW-MVE for 2-description T-MDC.

For the future works, more component algorithms are under development to be included for the adaptive selection so that the lowest *SAD* among the component algorithms can be chosen and a further video quality improvement of whole-frame error concealment can be achieved by compensating for the shortcomings of each component algorithm.

ACKNOWLEDGMENT

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

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