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Error concealment algorithm using inter-view correlation for multi-view video

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Abstract

This paper proposes an error concealment algorithm for whole frame loss for multi-view video decoding. In our proposal, the relationship between motion vectors and disparity vectors is exploited first. Based on the parallelogram-like motion relationship, the motion vectors of error frames can be indirectly derived by projecting the disparity vectors from the counterpart view. In addition, to further improve the concealing results, a joint sum of the absolute difference (SAD) minimization approach is also proposed to find the block for the purpose of concealing the current error block by jointly considering motion vectors and disparity vectors. Experimental results show that our proposed algorithm provides better video quality than previous work and reduces error propagation.

Keywords: Error concealment; Multi-view; MVC; Motion vector; Disparity vector

1. Introduction

As multimedia technology has advanced in recent years, the applications of three-dimensional (3D) television and free viewpoint video (FVV) have become more attractive. To support multi-view video coding, the multi-view video coding standard has been proposed [1,2] based on the motion-compensated prediction (MCP) technology adopted in H.264/AVC [3,4] by incorporating the disparity-compensated prediction (DCP) technology as shown in Figure 1, to eliminate inter-view redundancy.

In the error-prone network environment, packet errors or packet loss may occur very frequently due to the unpredictable interruption of noise sources, which leads to the decline of the received video quality as shown in Figure 2. Therefore, error recovering mechanisms have become an important research issue. To deal with the problem in multi-view applications, many studies have been proposed. In general, error recovery can be undertaken by two approaches called error resilience [5-9] and error concealment [10-18]. For multi-view error concealment, study [17] uses the intra-view difference, inter-view correlation, and difference of the inter-view disparity vector projections on the neighboring views to conceal the error frames. However, this requires complex computations in terms of the temporal change detection, disparity estimation, and frame difference projection which results in difficulties for real-time applications. Study [18] compares the sum of the absolute difference (SAD) between the previous two frames and the SAD between adjacent views of the previous frame to achieve error concealment. However, useful information regarding disparity vectors has not been considered to help with the error concealment process. In [17], the authors prove that the disparity vectors could significantly improve the error concealment results.

To deal with error problem for multi-view video coding, we propose a whole frame error concealment algorithm which applies a predictive compensation approach as well as considering the inter-view correlation to conceal the error frame of the right view. By using the disparity vectors (DVs) in the previous frame as the reference prediction DVs, the motion vectors (MVs) inside the block, referred by the reference DVs, are collected to be the candidates for our error concealment process. Finally, the candidate MV with the smallest joint SAD is chosen as the best MV to conceal the error block, once the candidate MVs have been successfully collected.

The rest of this paper is organized as follows. In Section 2, the proposed algorithm is described in detail. Section 3 shows some simulation results to demonstrate

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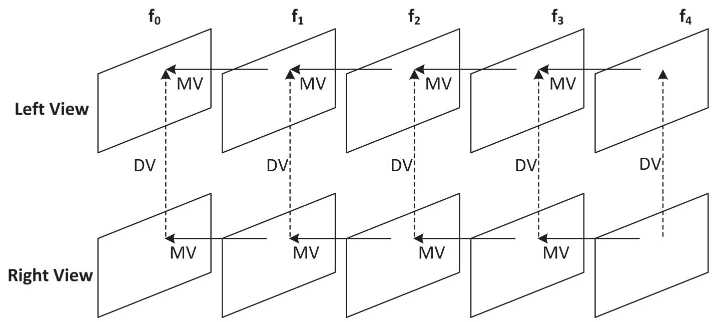

Figure 1 The prediction structure of two views.

the efficiency of our proposed error concealment algorithm. The conclusion is provided in Section 4.

2. Proposed algorithm

For the single-view error concealment approach, the error concealment algorithms are only considered using the information from the spatial and temporal domains. However, since we can have the information between coding views in the multi-view video coding, we can consider that the relationship between views achieves better error concealment results compared to the single-view error concealment. Therefore, we will first observe the relationship between views and propose our error concealment algorithm based on the observation.

2.1 Observation of multi-view characteristics

To create multi-view video sources, the cameras are usually placed along a horizontal line to capture the scene at the same time. In this case, the motion vectors between different views are very similar to each other due to the identical capturing target from the perspective of the time axis. However, when observing the target from the perspective of the view axis, we can observe that the distance between the placement of the cameras will cause the appearance of objects in the scene. Therefore, the inter-view disparity vectors are usually used to describe the object relationship between views. Figure 3 gives an example to illustrate the movement between frames and views.

If we discover the multi-view sequences, we can investigate the following properties. First, for the quiescent regions which have almost zero motion behavior, the relationship between frames in single view is higher than that between views. Second, for the high-motion regions, the relationship between views is much higher than that between frames. Based on the above observation, study [17] proposes a parallelogram-like motion relationship to describe the correlation between motion vectors and disparity vectors as shown in Figure 4. From this figure, we can find that if an object has been moved from frame (f-1) to frame (f) in one view, we can also observe the same movement in another view. Similarly, if we obtain certain disparity vectors from frame (f-1), we can obtain the similar disparity vectors from frame (f) as well.

2.2 Proposed error concealment algorithm

From the above sub-section, we observe that the motion vectors between views and disparity vectors between frames have a high degree of similarity and a close relationship. The proposed error concealment algorithm is based on this observation. Figure 5 shows the flowchart of the proposed algorithm. First, a DV set is reconstructed

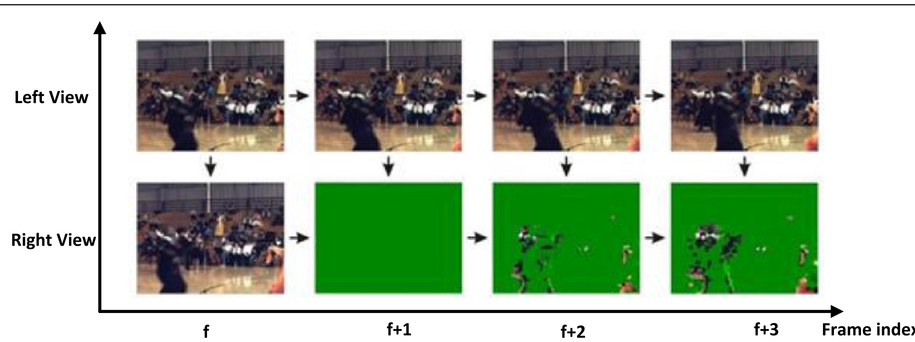

Figure 2 **Illustration of error propagation in a multi-view application.**

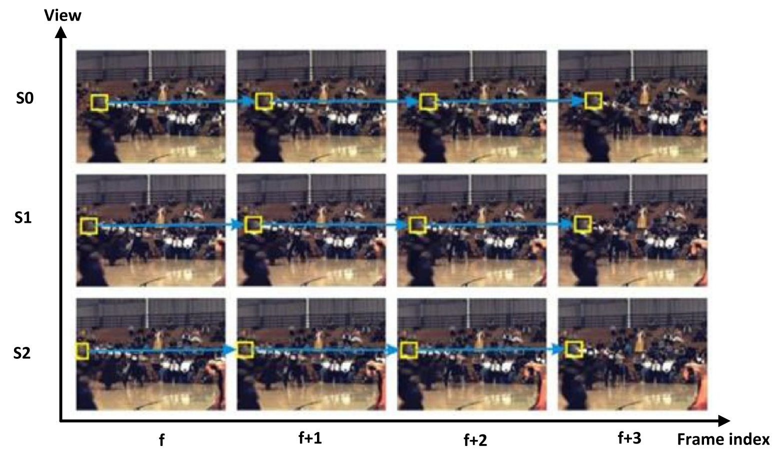

Figure 3 Illustration of real sequence with multi-views.

according to the extended window (EW). Once the EW has been decided, we check if there is any disparity vector within EW. If there is, the proposed DV-based error concealment algorithm will be applied for dealing with the error recover problem. Otherwise, the proposed MV-based error concealment algorithm will be used. The details of the proposed algorithm are described as follows:

1. EW construction
   In the proposed algorithm, the block size of B is adopted to conceal the erroneous frames. However, using 16 or 8 for B will obtain better concealment results since selecting 4 for B would result in a broken frame. After deciding on the block size, we extend B pixels all around the corresponding block in the previous frame to form a $3B \times 3B$-size EW as shown in Figure 6. The derivation process of EW can be expressed as follows:

$$\mathrm{EW} = \left\{ \mathrm{DV}^{i}_{\mathrm{R,f\text{-}1}} \middle| 0 \le i < N;\ \mathrm{DV}^{i}_{\mathrm{R,f\text{-}1}} \text{ covered by } 3B \times 3B \right\} \tag{1}$$

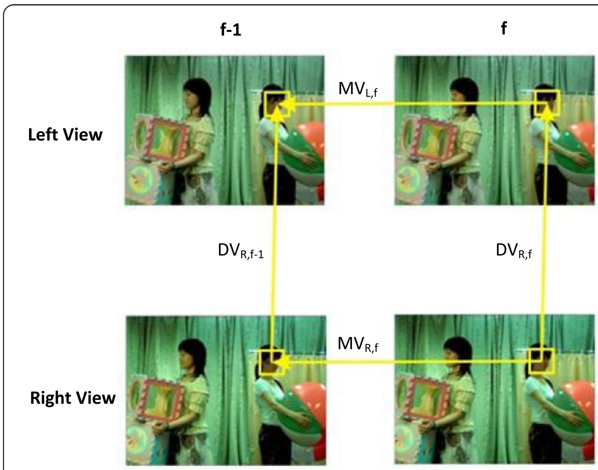

Figure 4 The in-view and cross-view parallelogram-like motion relationship ($DV_{R,f-1} \approx DV_{R,f}$, $MV_{R,f} \approx MV_{L,f}$).

2. DV-based error concealment
   If the EW contains any DV, we will calculate the area covered by each disparity vector in the EW and check whether any covered area has exceeded a predefined threshold. In our proposed algorithm, the default of the threshold is set to half of the EW area. If all of the covered areas pointed to by DVs in the EW are less than a predefined threshold TH, the error concealment algorithm will switch to the MV-based error concealment. Otherwise, the covered area of each DV inside the EW will be calculated and the DV with the biggest area size in the EW will be selected to conceal the error block.
3. MV-based error concealment
   (a) Reconstruction of new extended window
   The proposed MV-based error concealment algorithm will be executed by two conditions. The first condition is the switching from DV-based error concealment while the second condition is the empty EW. Therefore, based on the condition, a new extended window (NEW) will be reconstructed as follows:

$$\mathrm{NEW} = \begin{cases} \left\{ \mathrm{DV}^{i}_{\mathrm{R,f\text{-}1}} \middle| 0 \le i < N;\ \mathrm{DV}^{i}_{\mathrm{R,f\text{-}1}} \text{ covered by } W \times H \right\}, \\ \qquad \text{if EW is empty} \\ \mathrm{EW}, \text{ if switched from DV-based EC} \end{cases} \tag{2}$$

where W and H mean the width and height, respectively, of the entire frame. In other words, if the MV-based

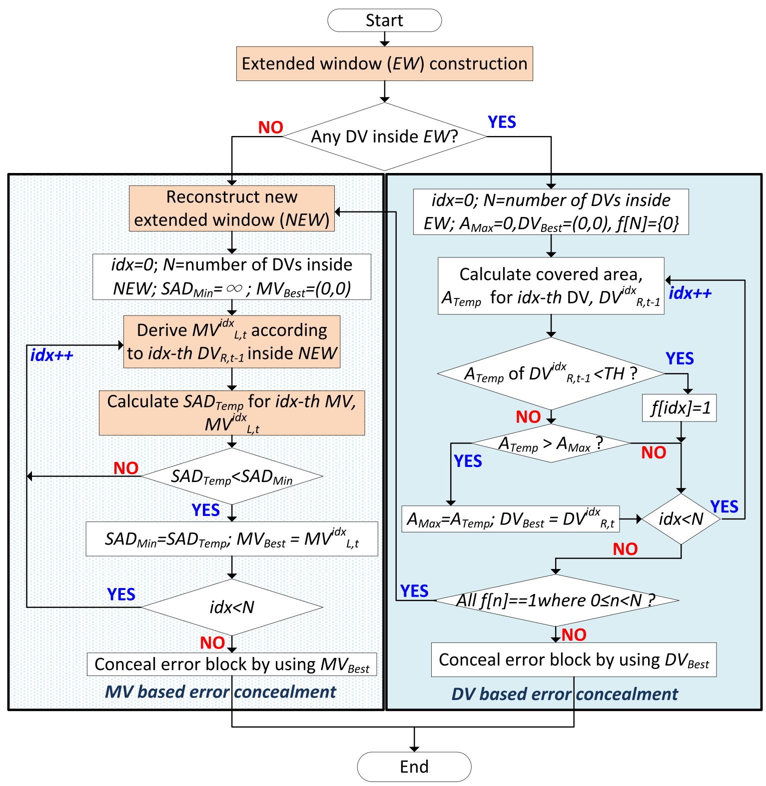

Figure 5 Flowchart of the proposed error concealment algorithm.

error concealment process is trigged by the empty EW, the NEW will be constructed by all DVs in the entire frame. Otherwise, the NEW will be the same as the EW.

(b)MV derivation process

Once the NEW has been constructed successfully, the DVs inside NEW will be considered to select the motion vectors from the left view. To derive the motion vectors corresponding to all DVs in NEW, the DVs inside NEW will be used to be projected onto the left view with a $B \times B$ window called a covered

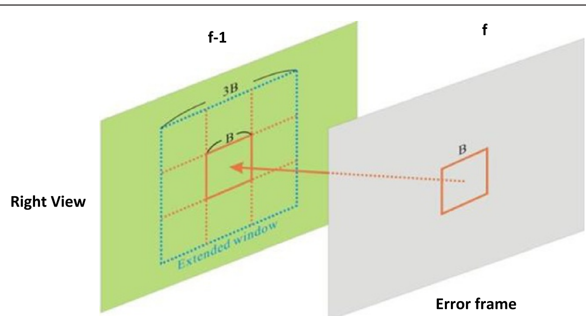

Figure 6 Schematic diagram of the extended window.

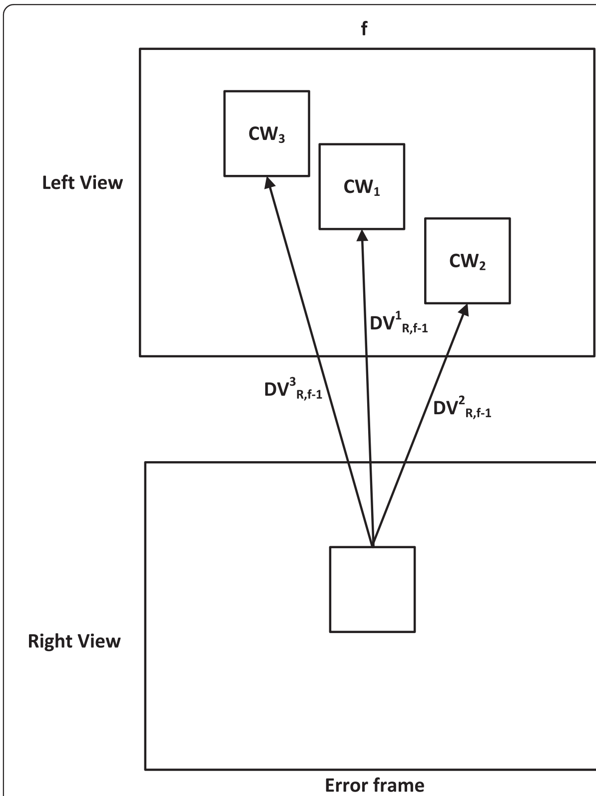

Figure 7 Relationship between DVs and CWs.

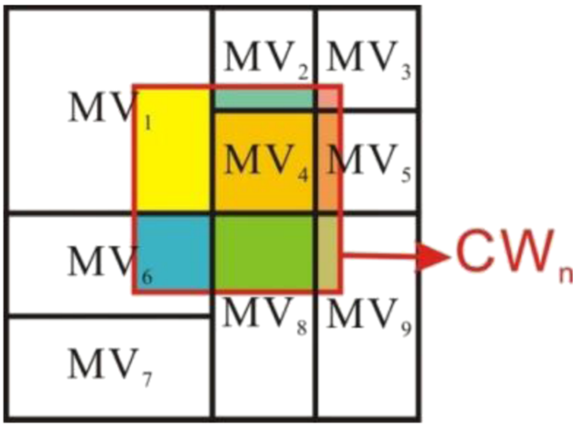

Figure 8 Illustration of motion vectors covered by CW.

window (CW) as shown in Figure 7. After the DV projection, we will face the problem that the CW would cover more than one motion vector as shown in Figure 8. Therefore, a simple mechanism that the motion vector with the largest covered area by CW will be selected as the final motion vector in the motion vector derivation process. The motion vectors can be selected as follows:

$$\mathrm{MV}_{\mathrm{L,f}}^{i} = \mathrm{argmax}_{0 \le k < N}\{\mathrm{Area}(\mathrm{MV}_k)\}, \tag{3}$$

where Area(.) is the function of the area calculation according to the specific target.

(c) SAD calculation according to selected MV

Based on the parallelogram-like motion relationship between inter-frame and inter-view correlation as shown in Figure 4, we can observe that the $\mathrm{DV}_{\mathrm{R,f-1}}^{n}$ will be very similar to the $\mathrm{DV}_{\mathrm{R,f}}^{n}$ and the $\mathrm{MV}_{\mathrm{L,f}}^{n}$ will be very similar to the $\mathrm{MV}_{\mathrm{R,f}}^{n}$ also. Therefore, when the *f*th frame of the right view has an error occurring, the MV obtained from the corresponding block in the left view shifted by the DV will be very similar to the original MV of the error frame if the corresponding DV in the previous frame is correct. Therefore, the SADs between B_1 and B_2 as shown in Figure 9 are calculated for all MVs covered by CW to determine the block for concealing the current erroneous block. However, the situation might be faced when the block has been shifted from the wrong DV and the luminance component difference between blocks pointed to by the wrong MVs is unnoticeable. To solve this problem, we further consider SADs between the left and right views in the previous frame ($F_{\mathrm{L,f-1}}$). The step-by-step block selecting procedure for computing SADs is described below.

Step 1: The disparity vector $\mathrm{DV}_{\mathrm{R,f-1}}^{n}$ of erroneous block B_c has been selected and projected onto the left view to obtain the block B_1 pointed to by $\mathrm{DV}_{\mathrm{R,f-1}}^{n}$.

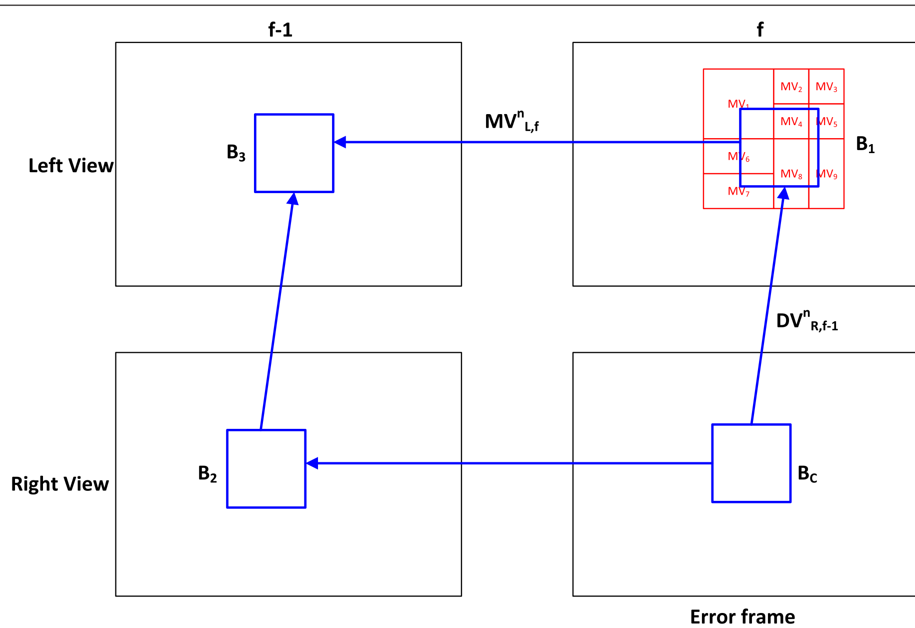

Figure 9 Illustration of block relationship for computing SAD.

Table 1 Simulation parameters

Parameter	Value
View	2
Reference software	JMVC8.5
Processor	Intel Core i7 870 2.93 GHz
GOP structure	IPPP…
Intra-refresh	Only the first frame
Frame rate	25
Frame number	100
Reference frame number	2
Coding order	0 → 1
QP	32
PLR	5%, 10%, 15%, 20%

Step 2: The motion vector $MV^n_{L,f}$ with the largest area coverage by B_1 will be selected and projected onto the previous frame of the right view to obtain B_2.

Step 3: The corresponding block B_3 pointed by $DV^n_{R,f\text{-}1}$ from B_2 will be used to calculate the SAD between B_2 and B_3.

Step 4: Finally, the motion vector with minimum joint SADs will be derived by the following equations to conceal the error block B_c:

$$\begin{aligned} MV_{L,f}(i,j) = \arg\min_{MV^n_{L,f}\in MV_{L,f}} \sum_{a=0}^{B-1}\sum_{b=0}^{B-1} \Big| & F_{R,f\text{-}1}\left(B\times i + MV^n_{L,f,x} + a, B\times j + MV^n_{Lf,y} + b\right) \\ & - F_{L,f}\left(B\times i + DV^n_{R,f\text{-}1,x} + a, B\times j + DV^n_{R,f\text{-}1,y} + b\right)\Big| \\ & + \Big| F_{R,f\text{-}1}\left(B\times i + MV^n_{L,f,x} + a, B\times j + MV^n_{L,f,y} + b\right) \\ & - F_{L,f\text{-}1}\left(B\times i + MV^n_{L,f,x} + DV^n_{R,f\text{-}1,x} + a, B\times j \right. \\ & \left. + MV^n_{L,f,y} + DV^n_{R,f\text{-}1,y} + b\right)\Big| \end{aligned} \tag{4}$$

The notations of Equation 4 are listed as follows:

- i and j, the horizontal and vertical indexes of the $B \times B$ block in a frame
- a and b, the horizontal and vertical indexes of the pixel inside the block
- $F_{R,f}$, the lost frame of the right view
- $F_{R,f\text{-}1}$, the previous frame of the lost frame in the right view
- $F_{L,f}$, the current frame of the left view

Table 2 PSNR comparison of our proposed algorithm with other methods for entire frames ($B = 8$)

		Sequences						
		Ballroom	Vassar	Race1	Exit	AkkoKayo	Flamenco	Average
Error free		35.499	34.957	35.820	37.214	36.930	38.448	36.478
5%	FC	29.077	34.396	22.635	33.617	28.069	29.673	29.578
	MC	29.323	34.494	23.885	33.721	29.610	29.818	30.142
	[18]	29.292	34.388	22.780	33.614	28.184	29.743	29.667
	Proposed	30.241	34.541	26.926	33.608	31.232	30.239	31.131
	ΔPSNR	0.949	0.153	4.146	−0.006	3.048	0.496	1.464
10%	FC	25.463	33.525	19.551	30.748	23.431	26.445	26.527
	MC	25.445	33.579	21.189	31.083	26.098	26.325	27.287
	[18]	25.470	33.583	20.040	30.970	23.688	26.524	26.713
	Proposed	26.063	33.721	23.877	30.972	26.293	26.608	27.922
	ΔPSNR	0.593	0.138	3.837	0.002	2.6050	0.084	1.210
15%	FC	23.466	32.394	17.479	29.056	20.595	24.308	24.550
	MC	23.481	32.634	19.937	29.506	22.249	24.447	25.376
	[18]	23.666	32.480	18.336	29.114	20.762	24.557	24.819
	Proposed	24.399	33.114	21.557	28.902	23.547	24.917	26.073
	ΔPSNR	0.733	0.634	3.221	−0.212	2.785	0.360	1.254
20%	FC	22.117	31.900	16.568	27.301	19.939	22.948	23.462
	MC	22.220	31.747	19.048	28.247	22.089	23.095	24.408
	[18]	22.334	31.964	17.693	27.213	20.726	22.858	23.798
	Proposed	23.439	32.726	20.698	27.811	22.921	23.446	25.174
	ΔPSNR	1.105	0.762	3.005	0.598	2.195	0.588	1.376

Table 3 PSNR comparison of our proposed algorithm with [18] for error frames only ($B = 8$)

		Sequences						
		Ballroom	Vassar	Race1	Exit	AkkoKayo	Flamenco	Average
5%	Error free	35.520	34.991	35.792	37.275	36.906	38.505	36.498
	[18]	22.114	33.049	16.732	30.809	21.823	25.485	25.002
	Proposed	22.659	33.325	21.309	30.585	25.286	26.378	26.590
	ΔPSNR	0.545	0.276	4.577	−0.224	3.463	0.893	1.588
10%	Error free	35.519	34.970	35.772	37.225	36.953	38.480	36.487
	[18]	21.479	32.296	16.590	29.216	20.429	24.088	24.016
	Proposed	22.185	32.582	20.847	29.131	23.299	24.456	25.417
	ΔPSNR	0.706	0.286	4.257	−0.085	2.870	0.368	1.400
15%	Error free	35.513	34.973	35.762	37.224	36.972	38.439	36.481
	[18]	20.854	31.360	16.261	27.885	18.848	22.928	23.023
	Proposed	21.593	32.327	19.747	27.674	21.785	23.449	24.429
	ΔPSNR	0.739	0.967	3.486	−0.211	2.937	0.521	1.407
20%	Error free	35.513	34.965	35.790	37.219	36.950	38.462	36.483
	[18]	20.134	32.120	15.894	26.341	19.026	21.567	22.514
	Proposed	21.143	31.973	19.151	26.897	21.427	22.235	23.804
	ΔPSNR	1.009	−0.147	3.257	0.556	2.401	0.668	1.291

Table 4 PSNR comparison of our proposed algorithm with other methods for entire frames ($B = 16$)

		Sequences						
		Ballroom	Vassar	Race1	Exit	AkkoKayo	Flamenco	Average
Error free		35.499	34.957	35.820	37.214	36.930	38.448	36.478
5%	FC	29.077	34.396	22.635	33.617	28.069	29.673	29.578
	MC	29.323	34.494	23.885	33.721	29.610	29.818	30.142
	[18]	29.604	34.382	22.765	33.686	28.022	29.705	29.694
	Proposed	30.441	34.460	26.631	33.558	31.159	30.607	31.143
	ΔPSNR	0.837	0.078	3.866	−0.128	3.137	0.902	1.449
10%	FC	25.463	33.525	19.551	30.748	23.431	26.445	26.527
	MC	25.445	33.579	21.189	31.083	26.098	26.325	27.287
	[18]	25.782	33.509	20.141	30.769	23.870	26.468	26.757
	Proposed	26.668	33.831	23.684	31.445	25.872	26.509	28.002
	ΔPSNR	0.886	0.323	3.543	0.676	2.002	0.041	1.245
15%	FC	23.466	32.394	17.479	29.056	20.595	24.308	24.550
	MC	23.481	32.634	19.937	29.506	22.249	24.447	25.376
	[18]	23.933	32.458	18.515	28.960	20.719	24.541	24.854
	Proposed	25.131	33.075	21.264	29.478	22.781	25.209	26.156
	ΔPSNR	1.198	0.617	2.749	0.518	2.062	0.668	1.302
20%	FC	22.117	31.900	16.568	27.301	19.939	22.948	23.462
	MC	22.220	31.747	19.048	28.247	22.089	23.095	24.408
	[18]	22.506	31.942	17.867	27.220	20.881	23.016	23.905
	Proposed	24.040	32.996	20.741	28.031	22.787	23.167	25.294
	ΔPSNR	1.534	1.054	2.874	0.811	1.906	0.151	1.389

Table 5 PSNR comparison of our proposed algorithm with [18] for error frames only (*B* = 16)

		Sequences						
		Ballroom	Vassar	Race1	Exit	AkkoKayo	Flamenco	Average
5%	Error free	35.520	34.991	35.792	37.275	36.906	38.505	36.498
	[18]	22.229	33.039	16.674	31.007	21.862	25.495	25.051
	Proposed	23.965	33.759	21.246	31.382	26.274	26.474	27.183
	ΔPSNR	1.736	0.720	4.572	0.375	4.412	0.979	2.132
10%	Error free	35.519	34.970	35.772	37.225	36.953	38.480	36.487
	[18]	21.701	32.113	16.656	29.200	20.596	24.054	24.053
	Proposed	23.291	32.948	20.843	30.043	23.349	24.305	25.797
	ΔPSNR	1.590	0.835	4.187	0.843	2.753	0.251	1.743
15%	Error free	35.513	34.973	35.762	37.224	36.972	38.439	36.481
	[18]	20.993	31.330	16.401	27.757	18.831	22.916	23.038
	Proposed	22.603	32.306	19.633	28.399	21.351	23.715	24.668
	ΔPSNR	1.610	0.976	3.232	0.642	2.520	0.799	1.630
20%	Error free	35.513	34.965	35.790	37.219	36.950	38.462	36.483
	[18]	20.295	31.080	16.020	26.373	19.191	21.705	22.444
	Proposed	22.105	32.398	19.234	27.279	21.488	21.946	24.075
	ΔPSNR	1.810	1.318	3.214	0.906	2.297	0.241	1.631

- $F_{L,f\text{-}1}$, the previous frame of the lost frame in the left view
- $DV^{n}_{R,f\text{-}1,x}$, the horizontal component of the *n*th DV in the block of the previous frame of the right view
- $DV^{n}_{R,f\text{-}1,y}$, the vertical component of the *n*th DV in the block of the previous frame of the right view
- $MV^{n}_{L,f,x}$, the horizontal component of the *n*th MV in the block of the current frame of the left view
- $MV^{n}_{L,f,y}$, the vertical component of the *n*th MV in the block of the current frame of the left view

By jointly considering the SADs between views and frames, the concealing results can be further improved.

3. Simulation results

In this section, several simulation results are given to demonstrate the efficiency of our proposed MVC error concealment algorithm. The test sequences we used for simulation are Ballroom (640 × 480), Exit (640 × 480), Flamenco (640 × 480), Race1 (640 × 480), AkkoKayo (640 × 480), and Vassar (640 × 480). In our simulation, we assume that only the right view has the whole frame error while the left view has not. Study [18] is adopted for comparison in this paper, but we have made some modifications for [18] in order to allow the algorithm of [18] to be able to support whole frame loss error concealment. The simulation settings are summarized in Table 1, in which the packet loss rate (PLR) is simulated by randomly dropping a certain number of frames. For example, the 5% PLR is simulated by randomly dropping 5 frames out of 100 frames.

Tables 2 and 3 tabulate the peak signal-to-noise ratio (PSNR) comparison for our proposed algorithm with other methods under different packet error rate conditions for entire frame and error frame only cases, respectively. Frame Copy (FC), Motion Copy (MC), and the algorithm of [18] are compared. In these tables, the ΔPSNR is calculated by the PSNR values of our proposal minus the PSNR values of [18] while *B* is set to 8, which means that the basic error concealing block size is 8. From these tables, we can observe that our proposed algorithm outperforms other methods. Quantitatively, our proposed algorithm can achieve about 4-dB PSNR improvement compared to [18] for the high-motion sequence Race1 under the 5% packet error rate condition. However, for other sequences such as Exit and Vassar, the PSNR improvement is less significant. This situation can be explained as follows. From [18], it can be found that the MB pixels at the same spatial position from the

Table 6 Average decoding time comparison of our proposed algorithm (Ballroom sequence) (ms/frame)

Packet loss rate	Error free	Proposed	Overhead (%)
5%	112.98	165.53	46.5
10%	112.98	231.22	104.7
15%	112.98	316.06	179.7
20%	112.98	362.59	220.9

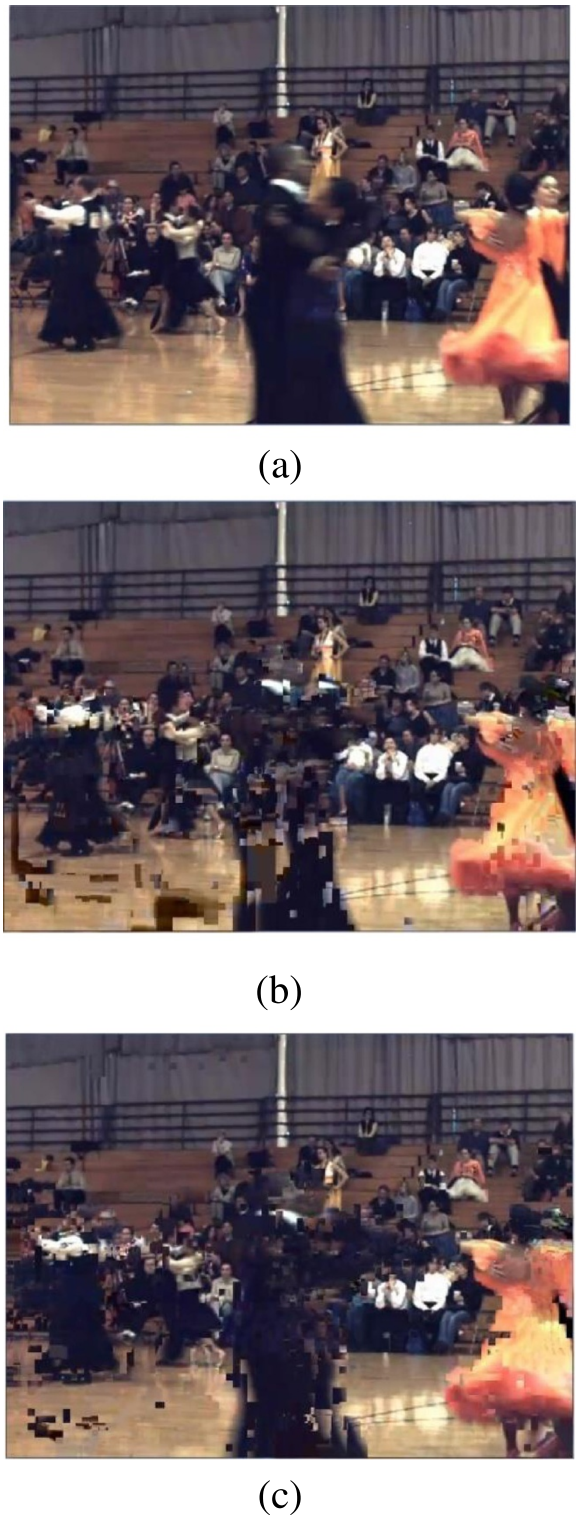

Figure 10 Subjective comparison of Ballroom sequence at the 30th frame (*B* = 8). (a) Error free (35.444 dB). **(b)** Concealed frame by [18] (19.093 dB). **(c)** Concealed frame by the proposed algorithm (20.134 dB).

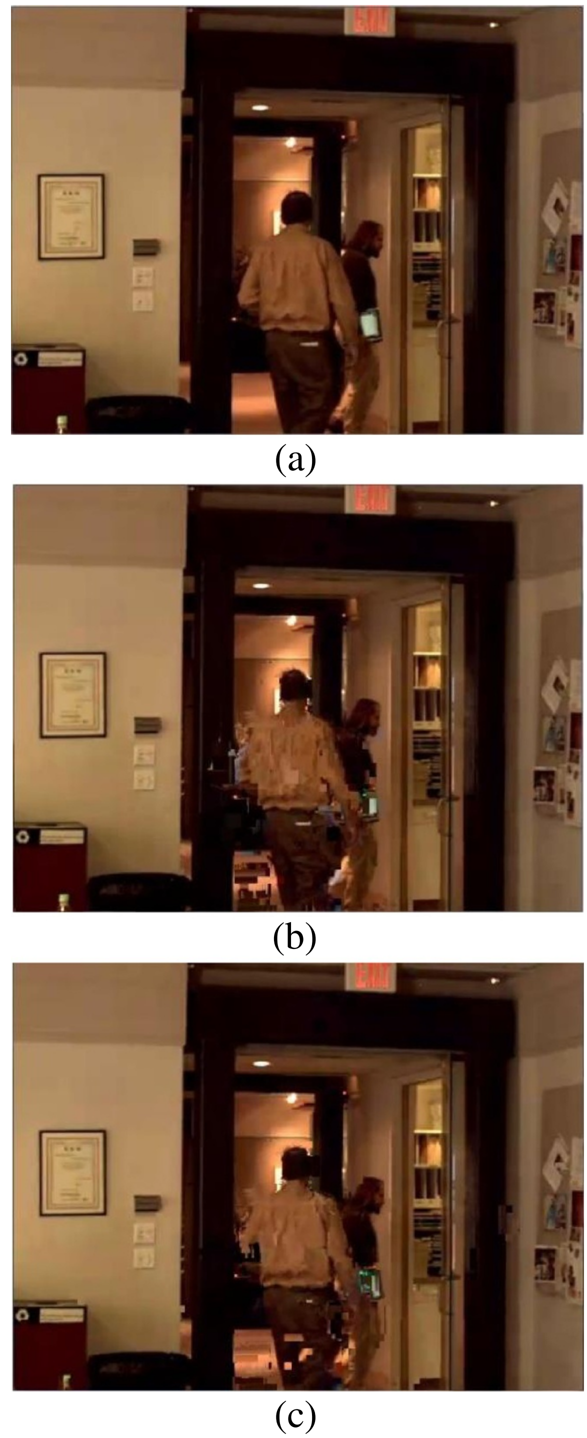

Figure 11 Subjective comparison of Exit sequence at the 20th frame (*B* = 8). (a) Error free (37.142 dB). **(b)** Concealed frame by [18] (27.040 dB). **(c)** Concealed frame by the proposed algorithm (28.534 dB).

temporal and inter-view directions are evaluated. In other words, [18] does not take the motion of the frame into account. This mechanism could be able to obtain good concealment results for low-motion sequences.

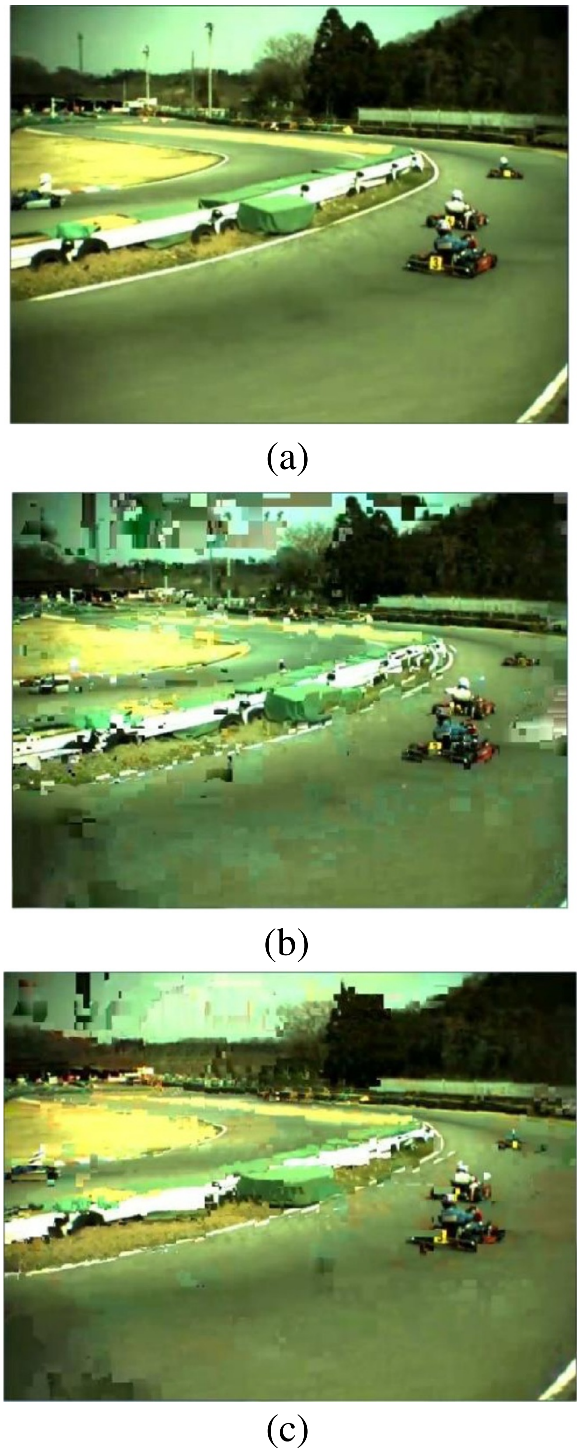

Figure 12 Subjective comparison of Race1 sequence at the 55th frame ($B = 8$). (a) Error free (36.016 dB). **(b)** Concealed frame by [18] (14.985 dB). **(c)** Concealed frame by the proposed algorithm (19.021 dB).

However, since our proposal takes both motion vector and disparity motion into account, the proposal can obtain better concealment results for high-motion sequences. On average, our proposed algorithm can receive 1.326- and 1.421-dB PSNR improvement compared to [18] for entire frame and error frame only cases, respectively.

Tables 4 and 5 list the PSNR comparison for the case that B is 16. From these tables, we can observe that even though the basic error concealing block size has been extended to 16, our proposed algorithm can still achieve PSNR improvement when compared to [18]. On average, our proposed algorithm can receive 1.346- and 1.784-dB PSNR improvement compared to [18] for entire frame and error frame only cases, respectively. From Tables 2, 3, 4, and 5, we can observe that the PSNR improvement of smaller B is better than that of larger B. This situation can be explained as follows. In general, the larger B will contain more objects within a single block. Intuitively, it will not be easy to find a matching block from the temporal or inter-view directions which contains multiple objects. For smaller B, multiple objects can be possibly divided into multiple blocks and thus leads to the ease of finding matching blocks. Table 6 tabulates the decoding time of our proposed algorithm when compared to the error frame decoding.

Figures 10, 11, and 12 exhibit the subjective quality comparisons for our proposed algorithm with [18]. From these figures, it is very obvious that our proposed algorithm can significantly improve the subjective quality results. In general, our proposed algorithm can efficiently reduce the broken image effects.

4. Conclusions

To deal with entire frame loss problem in multi-view video decoding, this paper proposes an error concealment algorithm by considering the relationship between motion vectors and disparity vectors. Based on the parallelogram-like motion relationship, a joint SAD minimization approach is proposed to find the best block for concealing the current error block. Through the help of the proposal, the error propagation problem can thus be reduced. Simulation results demonstrate that our proposed algorithm outperforms previous work in terms of subject and objective quality measurements.

Competing interests

The authors declare that they have no competing interests.

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