A NOVEL ERROR CONCEALMENT METHOD FOR STEREOSCOPIC VIDEO CODING

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ABSTRACT

A novel error concealment method is proposed for two-view based stereoscopic video coding to address the challenging problem of adaptively combining inter-view correlation and temporal correlation. First, the disparity vectors of the lost macroblocks' neighboring macroblocks are used to recover the lost or erroneously received motion or disparity vectors. Then we propose a novel error concealment method based on overlapped block motion and disparity compensation, whose weights are determined by the side match criterion and viewpoints. Simulation results show that the subjective and objective performances of the proposed technique are both superior to those of conventional temporal error concealment methods for stereoscopic video coding.

***Index Terms*—**Stereoscopic video coding, error concealment, inter-view correlation, motion and disparity compensation

1. INTRODUCTION

Stereoscopic video, which consists of video sequences of the same scene captured from different perspectives, is an important form of 3-D video. With proper rendering techniques the stereoscopic video can provide viewers the 3-D sensation. It will be the most practical and dominant manner for 3-D video applications.

Nowadays, how to efficiently compress stereoscopic videos has been a hot topic. The main conclusion is that the inter-view correlation should be used to improve the prediction efficiency. So the popular stereoscopic or multi-view video coding systems adopt both the disparity compensation prediction (DCP) [1] in the inter-view direction and motion compensation prediction (MCP) in the temporal direction of a single view. The basic prediction structure of the two-view based stereoscopic video coding is shown in Fig. 1, where DCP is the key technique that is different from the traditional DCT-based hybrid coding in single view compression. In this paper, we put emphasis on the two-view based stereoscopic video. The discussion can be easily extended to the case of more than two views.

Robust video delivery via error-prone networks is an important application. Error concealment is a major kind of technique that effectively deals with this task. It is executed at the decoder side to fill up the lost video contents. Error concealment techniques in the traditional single view coding have been widely exploited. The simplest way is temporal replacement (TR) [2], which utilizes the zero motion vector (MV) to reconstruct a lost macroblock (MB). Then the block matching algorithm (BMA) is proposed to select an optimal MV to substitute for the lost one [3] [4]. In [5], a technique which combines the overlapped motion compensation and the side match criterion makes the effect of lost motion vectors subjectively imperceptible. Chen *et al*. [6] proposed a refined boundary matching algorithm (RBMA). These techniques are designed for the single-view video coding, only considering the temporal or spatial correlations. So there will be inefficiency if they are directly applied in stereoscopic video coding, as the inter-view correlation is not considered at all.

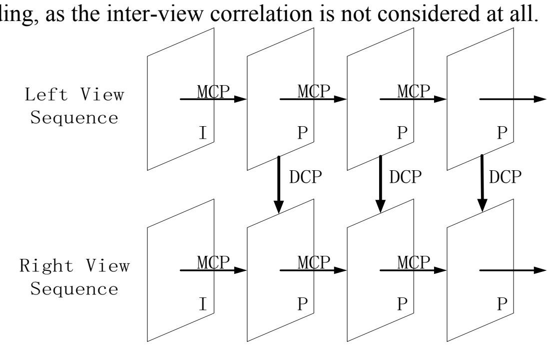

Fig. 1 Basic prediction structure of two-view based stereoscopic video coding

To our knowledge, few works [7] have been reported on the error concealment of stereoscopic video coding. How to effectively take error concealment in a DCP-based stereoscopic video coding system is still an unanswered question. This paper aims at this problem. First, we utilize the neighboring available disparity vectors as well as the motion vectors to reconstruct the lost MBs. Then, a novel error concealment method is proposed based on overlapped block motion and disparity compensation (OBMDC), whose weights are determined by the side match criterion and viewpoints. Also we point out that the concealed blocks of the left view should be utilized to improve the performance of the right view.

The rest of this paper is organized as follows. Section 2 describes the proposed algorithm in detail. Section 3 reports the experimental results including both the subjective and objective comparisons. Finally the conclusion is drawn in section 4.

2. THE PROPOSED ERROR CONCEALMENT METHOD FOR STEREOSCOPIC VIDEO CODING

Both the left and right view sequence images of a stereoscopic video might be erroneously received via error-prone networks. Since the left view is predicted independently while the right view is predicted with both MCP and DCP, the error concealment techniques for the two views are different. For convenience, the error concealment problem is studied from two aspects. Firstly, we assume the left view is delivered correctly and the right view is delivered erroneously. Under this assumption, we only need to find an effective error concealment algorithm for the right view. Secondly, we assume the right view is transmitted correctly and the left view is transmitted erroneously. Based on this assumption, we need to determine whether utilizing the concealed blocks of the left view for decoding the right view. Finally, we synthesize the two conditions and propose our error concealment algorithm for the stereoscopic video coding with both the left and right view being delivered erroneously, as is shown in Fig. 2.

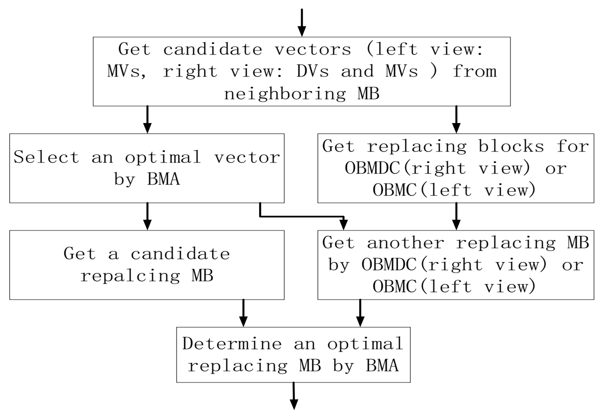

Fig. 2 Flowchart of the proposed error concealment algorithm with utilizing inter-view correlation and OBMDC

2.1. Error concealment on the right view

The error concealment process on the right view is performed in two stages. Firstly, we utilize inter-view correlation as well as temporal correlation to get candidate motion and disparity vectors for reconstructing the lost MB, and determine a suitable replacing MB by the BMA criterion. Secondly, we utilize our proposed OBMDC method to produce a new replacing MB, and then an optimal replacing MB is determined by the BMA criterion again.

2.1.1. Selection of the replacing MB

In stereoscopic video coding, blocks in the right view may be predicted from the left view with disparity vectors by utilizing the inter-view correlation between the left and right images. Furthermore, the inter-view correlation can be used for error concealment. Utilizing a correct disparity vector to reconstruct a lost MB can get better effect of error concealment than utilizing an incorrect MV or sometimes even a correct MV. Therefore we should utilize not only the motion vectors but also the disparity vectors of the lost MB's neighboring MBs to reconstruct the lost MB.

Fig. 3 shows the positions of the lost MB and the neighboring MBs. First, we get some candidate motion vectors or disparity vectors from neighboring available motion or disparity vectors. In H.264, a 16×16 MB can be divided into sub-blocks with different size for motion estimation, among which the minimum size is 4×4. Hence a neighboring MB can provide at most four nearest motion vectors or disparity vectors. Then we can get the candidate motion vectors MV_i^{T}, MV_i^{TL}, MV_i^{TR}, MV_i^{B}, MV_i^{BL} and MV_i^{BR} (i=1,2,3,4), which denote the motion vectors of the top, top-left, top-right, bottom, bottom-left and bottom-right blocks respectively if the blocks are temporally predicted with available motion vectors. Similarly we can get the candidate disparity vectors DV_i^{T}, DV_i^{TL}, DV_i^{TR}, DV_i^{B}, DV_i^{BL} and DV_i^{BR} (i=1,2,3,4), which denote the disparity vectors of the top, top-left, top-right, bottom, bottom-left and bottom-right blocks respectively if the blocks are predicted from the left view with available disparity vectors. Each candidate vector provides a candidate replacing MB from the reference frame for error concealment.

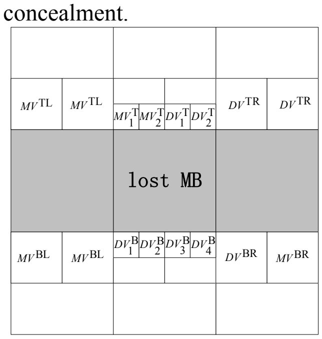

Fig. 3 Positions of the lost MB and the neighboring MBs with available motion or disparity vectors.

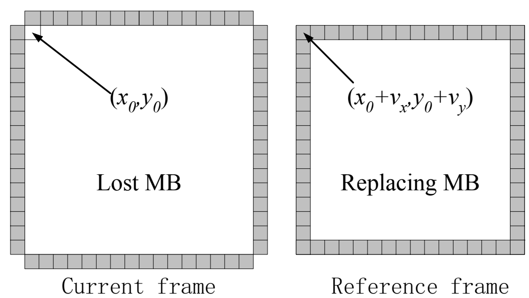

Fig. 4 Illustration of the block matching algorithm (BMA)

In order to choose an appropriate motion or disparity vector which is used as the motion or disparity vector of the lost MB from these candidates, we utilize the BMA criterion. The cost function of BMA is defined as the absolute difference between the external boundary of the lost macroblock in the current frame and the internal boundary of the replacing macroblock in the reference frame, and it is formulated as follows:

$$Cost_{BM} = \sum_{x=x_0}^{x=x_0+15} [|P(x,y_0-1)-P^r(x+v_x,y_0+v_y)|+|P(x,y_0+16)-P^r(x+v_x,y_0+15+v_y)|] + \sum_{y=y_0}^{y=y_0+15} [|P(x_0-1,y)-P^r(x_0+v_x,y+v_y)|+|P(x_0+16,y)-P^r(x_0+15+v_x,y+v_y)|] \quad (1)$$

where (x_0, y_0) denotes the coordinate of the top-left pixel in the lost MB, and (v_x, v_y) denotes the candidate vector. P and P^r denote the pixels of the current and reference frames, respectively. Fig. 4 shows the illustration of BMA. The motion or disparity vector which results in the smallest cost is selected. And the corresponding MB from the reference frame determined by the vector can be used to replace the lost MB.

2.1.2. Error concealment based on OBMDC

In order to disentomb inter-view correlation more and promote the effect of error concealment, we propose a novel error concealment method based on OBMDC. We use both motion compensation and disparity compensation for overlapped block compensation.

It is not enough to replace the lost MB by just one motion or disparity vector which is determined by BMA. Assigning each lost MB a vector is under the assumption that each pixel of the MB undergoes uniform translational movement. However, the pixels are unstructured and the movements are irregular in some regions, where we cannot get good effect of error concealment. Fortunately we find that overlapped block compensation is very suit to resolve the problem. Furthermore, we find that both disparity compensation and motion compensation can be utilized for overlapped block compensation because of inter-view correlation and temporal correlation. Thus, we utilize the candidate replacing MBs to produce a new replacing MB, and each pixel in the new replacing MB is determined by a weighted average of several corresponding pixels from the candidate replacing MBs.

The selected MB in the last subsection should get the largest weight because it has the best block side matching. Then the corresponding motion or disparity vector can decide which view is better for getting replacing MBs, and we believe that the lost MB may be predicted from that determined view. Thus, the replacing MBs which are compensated from the determined view have a lager weight than the other replacing MBs come from the other view. Therefore, we get a new replacing MB in which each pixel is decided by the following equation:

$$P_{lost}(i,j) = \frac{w_1 \times P_{best}(i,j) + w_2 \times \sum_{view1} P_{replacing}(i,j) + w_3 \times \sum_{view2} P_{replacing}(i,j)}{w_1 + \sum_{view1} w_2 + \sum_{view2} w_3} \tag{2}$$

where $w_1 > w_2 > w_3$, and they denote the weights for OBMDC. P_{lost}, P_{best} and $P_{replacing}$, denote the pixel of the new replacing MB, the formerly selected best replacing MB by BMA and the other replacing MBs, respectively. And (i, j) shows the position of the pixel in these MBs. And *view1* denotes the determined view whereas *view2* denotes the other view. The weights w_1, w_2, and w_3 are set to 5, 4, and 3 respectively, since these values can lead to satisfying performance in experiments.

Finally, we utilize the BMA criterion again to select an optimal replacing MB to reconstruct the lost MB between the new replacing MB which is produced by OBMDC and the original best replacing MB which is determined by just one motion or disparity vector.

2.2. The effect of erroneously received left view on correctly received right view

When the left view video is erroneously delivered, we cannot get the original encoded right view images even if they are delivered correctly. Because some blocks of the right view images are predicted from the left view images, and it will lead to error propagation if they are predicted from erroneous blocks of the left view.

There are two intuitive methods to resolve the problem. The first one is to perform error concealment process on the left view, and then decode the right view normally utilizing the concealed blocks of the left view. The other one is to perform error concealment in the right view blocks which are predicted from the erroneous blocks within the left view, and the concealed blocks of the left view images will not be used as reference blocks.

We believe that the first method is better than the second one. For a block which is predicted from erroneous blocks of the left view, we can get a correct disparity vector and correct residual data. Besides, we need to get a block which is similar to the original block of the left view. Obviously, performing effective error concealment on the left view usually can provide the best similar block. However, with regard to performing error concealment on the right view, we need to find a new motion or disparity vector and an original block, which often does not make the best use of the correct residual data. Thus, the first method can achieve a better effect of error concealment than the second one. Simulation results in section 3 will sustain our conclusions.

3. SIMULATION RESULTS

We utilize the H.264 reference software JM 10.0 to simulate a two-view based stereoscopic video coding system. The left view sequence is coded independently with MCP, and the right view sequence is predicted with both MCP and DCP. Then they are transmitted to the decoder respectively.

Three different error concealment algorithms are simulated on the stereoscopic video coding system. They are temporal replacement (TR), the error concealment method of JM (JM) which only performs error concealment process in the temporal direction of a single view, and the proposed approach (PR). The sequences *Ballroom* and *Race1* are encoded using the IPPP GOP structure for 225 frames. The packet loss rates (PLR) at 5%, 10%, 20% are tested in experiments.

In order to verify the proposed method's validity for the right view, we assume that the left view sequence is transmitted correctly and the right view sequence is transmitted with packet losing. Table 1 gives the performance results of the right view under the given condition. We can see that the proposed method can obtain an average gain in PSNR up to 2 dB compared with JM with PLR=20%. Fig.5 shows the error concealment results of sequence *Race1*, where the proposed method can get better subjective quality than other methods. The results indicate that the proposed error concealment utilizing inter-view correlation is indeed valid.

In order to verify our conclusion in section 2.2, we assume that the right view sequence is transmitted correctly and the left view sequence is transmitted with packet losing. We first perform error concealment process on the left view then decode the right view in two methods. One is normally decoding, the other is performing error concealment process without utilizing the concealed blocks of the left view. In Table 2, we can see that the former strategy can obtain an average gain in PSNR up to 0.5 dB compared with the latter one. Thus the concealed blocks of the left view should be utilized for the right view since effective error concealment on the left view can improve the performance of the right view.

In Table3, we can see the comparison among the three methods when both the left and right view sequences are transmitted with packet losing. When PLR=20%, we can get an average gain about 1 dB in PSNR compared with JM in the stereoscopic pairs of sequences, especially the average gain is about 1.4 dB in the right view sequence.

4. CONCLUSIONS

In stereoscopic video coding, there are inter-view correlation between the stereo images pair which is very useful for the inter-view error concealment. In this paper, an effective hybrid temporal and inter-view error concealment method is proposed for stereoscopic video coding. We utilize the neighboring available disparity vectors to reconstruct the lost MB as well as the neighboring available motion vectors. Further, a novel error concealment method is proposed based on overlapped block motion and disparity compensation, whose weights are determined by the side match criterion and viewpoints. Also we point out that the concealed blocks of the left view should be utilized for the right view and effective error concealment on the left view can improve the performance of the right view. Simulation results show that the proposed algorithm can improve both subjective and objective performances of reconstructed stereo video sequences.

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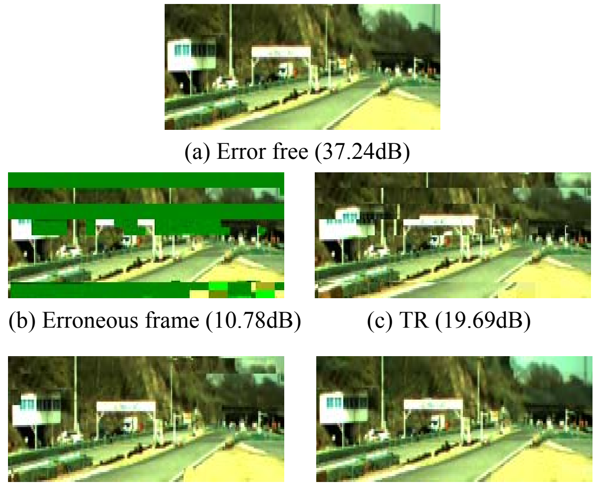
Table 1 Average PSNR performance comparison of the three error concealment methods for right view sequence

Video sequence	Original PSNR(dB)	PSNR (dB)	Packet loss rate 5%	10%	20%
Ballroom	36.95	TR	30.61	27.71	24.83
		JM	32.93	30.26	27.61
		PR	34.11	32.33	29.95
Race1	38.17	TR	28.96	26.36	24.15
		JM	33.48	31.35	28.98
		PR	34.67	32.58	30.76



(a) Error free (37.24dB)

(b) Erroneous frame (10.78dB) (c) TR (19.69dB)

(d) JM (24.65dB) (e) Proposed (31.43dB)

Fig. 5 Subjective quality comparison for frame 34 (right view image) of the sequence *Race1* with PLR=20%.

Table 2 Average PSNR performance comparison (utilizing the concealed blocks of the left view or not for right view sequence)

Video sequence	Original PSNR(dB)	Utilizing concealed blocks	Packet loss rate 5%	10%	20%
Ballroom	36.95	No	33.36	31.60	29.21
		Yes	33.89	32.27	29.94
Race1	38.17	No	34.97	33.13	31.83
		Yes	35.59	33.43	32.18

Table 3 Average PSNR performance comparison of the three error concealments (Both the left and right view sequences are transmitted with packet losing.)

Video sequence	View point	Original	PSNR (dB)	Packet loss rate 5%	10%	20%
Ballroom	Whole	37.04	TR	29.05	25.96	23.39
			JM	31.80	28.75	26.31
			PR	32.57	29.54	27.40
	Left	37.07	TR	29.84	26.18	23.74
			JM	32.44	28.99	26.79
			PR	32.87	29.43	27.49
	Right	37.01	TR	28.26	25.75	23.05
			JM	31.16	28.52	25.83
			PR	32.27	29.65	27.30
Race1	Whole	37.94	TR	26.42	23.43	21.36
			JM	32.24	29.06	26.44
			PR	32.72	29.85	27.33
	Left	37.81	TR	26.64	23.31	21.37
			JM	32.70	29.28	26.71
			PR	32.96	29.77	27.23
	right	38.07	TR	26.20	23.54	21.35
			JM	31.77	28.84	26.17
			PR	32.47	29.94	27.43