Joint Space-Time-View Error Concealment Algorithms for 3D Multi-View Video

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ABSTRACT

Efficiently compressing 3D multi-view video, while maintaining a high quality of received 3D video, is very challenging. Error Concealment (EC) algorithms have the advantage of improving the received video quality without modifications in the transmission rate or in the encoder hardware or software. To improve the quality of reconstructed 3D multi-view video, we propose different algorithms to conceal the erroneous and lost blocks of intra-coded and inter-coded frames by exploiting the spatial, temporal and inter-view correlations between frames and views. A hybrid of Space Domain Error Concealment (SDEC) and Time Domain Error Concealment (TDEC) is introduced for concealment of intra-frames errors. Three EC modes are introduced for inter-frames, which are Time Domain Error Concealment (TDEC), Inter-view Domain Error Concealment (IVDEC) and joint Time and Inter-view Domain Error Concealment (TIVDEC). Our simulation results show that the proposed algorithms can significantly improve the objective and subjective quality of reconstructed 3D multi-view video sequences.

Index Terms**—** 3D multi-view video; error concealment; multi-media communications; intra-frames; inter-frames; video coding; inter-view coding.

1. INTRODUCTION

3D multi-view video has received wide attention lately and is expected to quickly replace traditional 2D video in many applications. In multi-view video coding (MVC), video sequences are generated by capturing the same scene simultaneously with multiple cameras located at different view-point angles. A multi-view video sequence exhibits high inter-view correlations, in addition to spatio-temporal correlations within each view. Error Concealment (EC) exploits this advantage of inter-view and intra-view correlations to conceal lost packets or frames [1].

3D Video transmitted over wireless networks is always subject to packet losses including both random and burst errors. Due to the predictive coding structure of MVC compressed video, which utilizes intra and inter coded frames, errors could propagate to the subsequent frames and to the adjacent views and result in poor video quality [2, 3]. It is not possible to retransmit all erroneous or lost packets due to delay constraints on real-time video transmission. Therefore there is a need for post-processing Error concealment methods at decoder. EC algorithms are attractive since they have the advantage of reducing the visual artifacts caused by channel errors or erasures without increasing the bit rate or transmission delay or requiring any difficult modifications in the encoder. EC algorithms were proposed to protect mono-view videos or stereo videos against transmission errors [5, 6]. These EC algorithms can be adopted to conceal erroneous frames in 3D multi-view video sequences. However, they are very efficient in concealing errors in multi-view video sequences as they take the advantage of the inter-view correlations.

In this paper, we focus on pre-compressed MVC sequences generated by Joint MVC (JMVC) reference software, based on H.264/AVC [4]. We propose different hybrid EC algorithms which exploit the inter-view and intra-view spatio-temporal correlations to conceal lost blocks in intra-frames and inter-frames. Our goal is to reconstruct the 3D multi-view video sequences with high quality and low complexity. The rest of this paper is organized as follows: Section 2 presents the proposed error concealment algorithms for intra-frames and inter-frames, Section 3 presents our experimental simulation results and Section 4 concludes the paper.

2. PROPOSED MVC ERROR CONCEALMENT ALGORITHMS

In this section, we present our proposed error concealment algorithms for 3D MVC intra-frames and inter-frames. In the following we detail our proposed EC algorithms: Space Domain EC (SDEC), Time Domain EC (TDEC), joint Space and Time Domain EC (STDEC), Inter-view Domain EC (IVDEC), and joint Time and Inter-view Domain EC (TIVDEC) algorithms. A high-level flow chart diagram of our proposed joint intra-frames and inter-frames EC algorithms at the decoder showing when each algorithm is applicable is presented in Fig. 1.

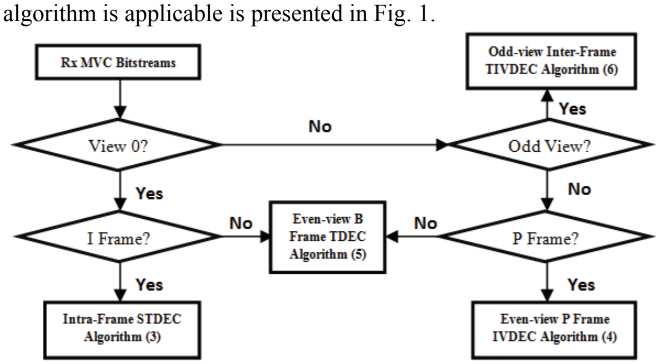


Fig.1. Flow chart of the proposed MVC error concealment algorithms.

2.1 Proposed Hybrid Space-Time Domain Error Concealment for 3D Multi-View Video Intra-Frames

Intra-frames error concealment is not only essential for improving the video quality of reconstructed intra-frames but also for improving the video quality of reconstructed inter-frames in the subsequent frames and views. We present below the proposed error concealment algorithms for intra-frames to improve the subjective and objective quality of reconstructed 3D MVC video.

Consider an intra-frame with a missing macro-block (MB) as shown in Fig. 2. The vectors $\mathbf{P}_{U1}$, $\mathbf{P}_{U2}$, $\mathbf{P}_{R1}$, $\mathbf{P}_{R2}$, $\mathbf{P}_{B1}$, $\mathbf{P}_{B2}$, $\mathbf{P}_{L1}$, and $\mathbf{P}_{L2}$ consist of the outside boundary pixels of the upper, right, bottom and left sides of the missing MB, respectively. The upper, right, bottom and left inner boundary pixels of the candidate MB are represented by the vectors $\mathbf{X}_{U1}$, $\mathbf{X}_{U2}$, $\mathbf{X}_{R1}$, $\mathbf{X}_{R2}$, $\mathbf{X}_{B1}$, $\mathbf{X}_{B2}$, $\mathbf{X}_{L1}$ and $\mathbf{X}_{L2}$ respectively [5].

$$\hat{\mathbf{X}} = \arg_{X_{U1}, X_{U2}, \ldots, X_{L2}} \min \varepsilon^2 \quad (1), \qquad \varepsilon^2 = \varepsilon_U^2 + \varepsilon_R^2 + \varepsilon_B^2 + \varepsilon_L^2 \quad (2)$$

$$\varepsilon_U^2 = \sum_{i=1,2} \|(X_{U_i} - P_{U_i})\|^2 \quad (3), \qquad \varepsilon_R^2 = \sum_{i=1,2} \|(X_{R_i} - P_{R_i})\|^2 \quad (4)$$

$$\varepsilon_B^2 = \sum_{i=1,2} \|(X_{B_i} - P_{B_i})\|^2 \quad (5), \qquad \varepsilon_L^2 = \sum_{i=1,2} \|(X_{L_i} - P_{L_i})\|^2 \quad (6)$$

Algorithm 1: Intra-Frame Time Domain EC (TDEC) Algorithm

1. Find the 8x8 adjacent sub-blocks to the lost MB, i.e., $\mathbf{U}_1$, $\mathbf{U}_2$, $\mathbf{R}_1$, $\mathbf{R}_2$, $\mathbf{B}_1$, $\mathbf{B}_2$, $\mathbf{L}_1$ and $\mathbf{L}_2$ and their matching blocks **U1', U2', R1', R2', B1', B2', L1'** and **L2'** in the previous Group Of 8 Frames as shown in Fig.2, and Fig.3 .
2. Calculate the Motion Vectors (MVs) between the adjacent sub-blocks and their matching blocks by using equations (3-6).
3. Select the block that gives the smallest Sum of Absolute Differences (SAD) given by equation (2).
4. Replace the lost MB with the selected MB.

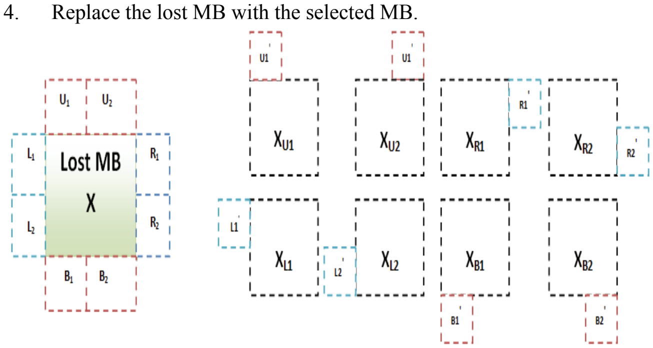


Fig.2. 8 sub-blocks adjacent to the lost MB and the corresponding sub-blocks in the previous frame with the candidate MB connected to them.

Algorithm 2: Intra-Frame Space Domain EC (SDEC) Algorithm

1. Apply Weighted Pixel Averaging Algorithm [7] to find the matching pixels surrounding the lost MB's pixels.
   a. Calculate Disparity Vectors (DVs) between pixels inside the lost MB and pixels surrounding the lost MB.
2. Find the summation of the calculated pixels values of the DVs found in Step 2.
3. Replace the lost MB with that calculated in the last step.

Algorithm 3: Intra-Frame Space-Time Domain EC Algorithm

1- Find the temporal candidate MB using TDEC Algorithm (1).
2- Find the spatial candidate MB using SDEC Algorithm (2).
3- Calculate the summation of the MV and DV values of the candidate MBs.
4- Replace the lost MB with that calculated in the last step.

2.2 Proposed Hybrid Time and Inter-view Domain Error Concealment for 3D Multi-view Video Inter-Frames

The assumed prediction structure for MVC is shown in Fig. 3 [6]. Thus we propose that EC techniques for inter-view frames (P and B-frames) should be different across views: In even views (e.g. S_2, S_4 and S_6), the first frame is concealed using left inter-view frames as reference frames (IVDEC) whereas other frames are concealed using the previous and following frames in the same view as reference frames (TDEC). In odd views (e.g. S_1, S_3 and S_5), EC is done using the previous and following frames in the same view as well as the left and right frames in the adjacent views as the reference frames (TIVDEC). Thus, except the first frames, there are two candidate blocks for EC of lost MBs of inter-frames in even views, and four candidates for EC of lost MBs of inter-frames in odd views. This is also demonstrated in the flow chart of Fig.1, and also in Fig.3.

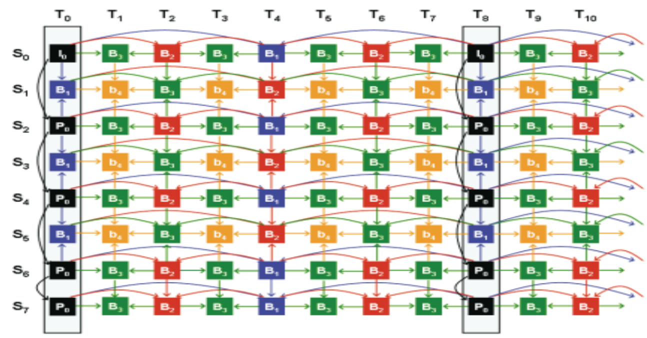


Fig.3. Efficient prediction structure for MVC proposed in [6].

Decoder Motion Vector Estimation (DVME) techniques can estimate the motion vectors of the lost blocks by using a full search in the reference frames, as proposed in [7], and are useful in identifying the replacing MBs that minimize the boundary distortion error. Since the 3D video should often be decoded in real-time, the process of searching for MBs that replace erroneous ones using TDEC or TIVDEC must be fast. Thus, we propose using the method of Outer Block Boundary Matching Algorithm (OBBMA) [1] instead, where the decoder determines the motion vectors for error-free neighboring pixels in the reference frame which are adjacent to the lost MB. So, it only checks the highly correlated neighborhood motion vectors and the neighborhood MBs can be predicted using disparity vectors values.

Our proposed algorithm for inter-frame EC has three modes as described below:

Algorithm 4: Even-view P Frame IVDEC Algorithm

1. Find the locations of the lost MBs inside P frame.
2. Apply Weighted Pixel Averaging algorithm [7] to find the matching pixels inside the left frame.
   a. Calculate the most correlated candidates DVs to lost MB within left frame.
3. Average DV values of the candidates MBs.
4. Replace the lost MBs with the candidates MBs by using the averaged calculated value.

Algorithm 5: Even-view B Frame TDEC Algorithm

1. Find the locations of the lost MBs inside B frame.
2. Apply OBBMA algorithm [1] to find the matching pixels inside the previous and subsequent frames.
   a. Calculate the most matched candidates MVs to the lost MB within previous and subsequent frames.
3. Average MV values of the candidates MBs.
4. Replace the lost MBs with the candidates MBs by using the averaged calculated value.

Algorithm 6: Odd-view Inter-Frame TIVDEC Algorithm

1. Find the locations of the lost MBs inside B frame.
2. Check if Temporal information > Spatial information or vice versa.
3. Apply Weighted Pixel Averaging Algorithm [7] and OBBMA Algorithm [1].
   a. Calculate the most matched candidates MVs and DVs to the lost MB within previous, subsequent, left and right frames.
4. Average DV and MV values of the candidates MBs.
5. Set appropriate coefficient values to averaged values of MVs and DVs (avg (MVs) and avg (DVs), respectively) depending on Scene Change Detection Algorithm [7] by selecting between the following two cases:
   - Candidate MB = 1/3 avg (MVs) + 2/3 avg (DVs).
   - Candidate MB = 2/3 avg (MVs) + 1/3 avg (DVs).

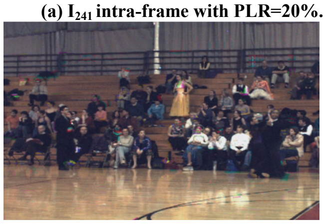
   This depending on "Is the Temporal information > Spatial information or vice versa?", as known in step (2).
6. Replace the lost MBs with candidates MBs by using the weighted average calculated value of MVs and DVs in last step.

Sequence	Frame Size (Resolution)	Features	Camera Specification		
			No. of cameras	Spacing distance	Property of camera array
Ballroom	640×480	Great disparity and violent motion	8	20 cm	1D/parallel
Exit	640×480	Great disparity	8	20 cm	1D/parallel

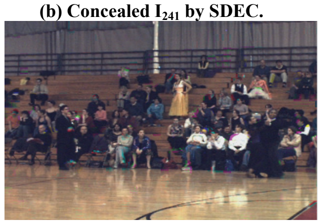
Table (1): Properties of the test sequences

(a) I_{241} intra-frame with PLR=20%.

(b) Concealed I_{241} by SDEC.

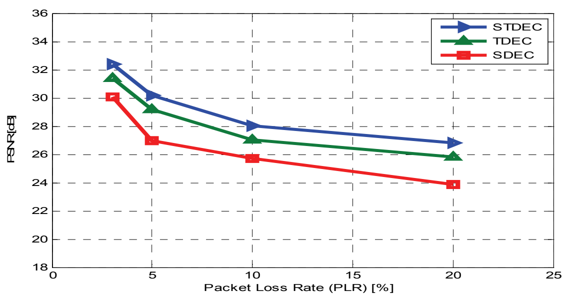


(c) Concealed I_{241} by TDEC.

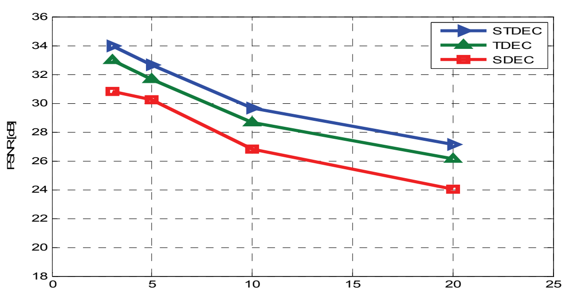


(d) Concealed I_{241} by STDEC.

Fig.4. Subjective simulation results for the selected 241th intra-frame within the first view S_o within the "Ballroom" sequence with PLR=20%.



[1]"Ballroom" Sequence.



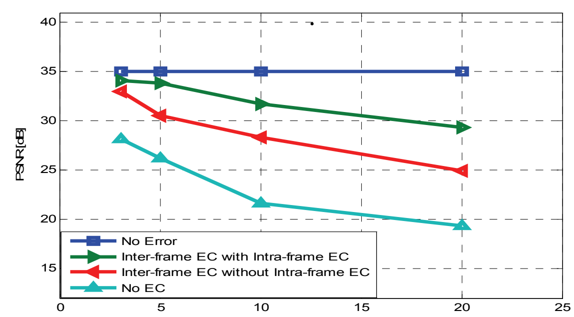
[2] "Exit" Sequence.

Fig.5. PSNR performance for "Ballroom" and Exit" test sequences with different PLRs for the selected 241th intra-frame.

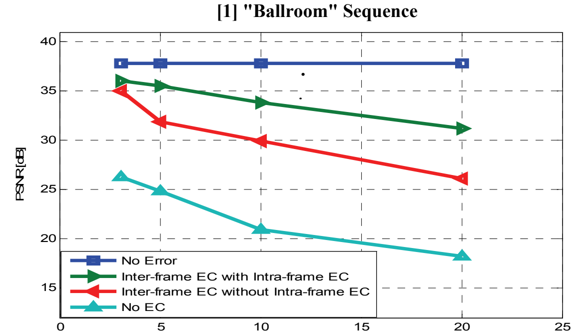
3. SIMULATION RESULTS

In order to evaluate the performance of the proposed EC algorithms, we run some experiments on the well-known test sequences given by table (1). JMVC [4] reference software is employed as the platform for our proposed simulation work. All encoding parameters are set according to the JVT common test condition [8]. For each sequence, the bitstreams are produced and then transmitted over a communication channel with various random packet loss rates (PLRs) (3%, 5%, 10% and 20%) and then decoded by the proposed algorithms. We assume that the decoder is able to know the locations of the lost MBs. Fig.4. shows the subjective simulation results for the "Ballroom" sequence. We select the 241th intra-coded frame with PLR=20%. We concealed the 241th intra-frame with the three proposed algorithms SDEC, TDEC and STDEC. We can declare that the proposed STDEC algorithm gives the highest subjective and objective results compared to SDEC and TDEC algorithms, where there is a lot of redundant information in space and time domains that can be exploited in EC. This is also demonstrated by the objective results given in Fig.5. Our simulation results show that the proposed STDEC algorithm is always better, in case of 3D MVC sequences containing significant movement, such as "Ballroom" sequence, as well as sequences with smooth motion, such as "Exit" sequence, and at high loss rate.

To demonstrate the effectiveness of the proposed EC algorithms for P and B inter-frames, "Ballroom" and "Exit" sequences were used with low complexity parameters at the decoder which makes the EC process more realistic with small delay to be suitable for real-time transmission in wireless mobile systems. In the simulation tests, the inter-view frames in views S_1 and S_2 are corrupted, with random packet loss rates (3%, 5%, 10% and 20%). Fig.6. and Fig.7, present the objective results of the proposed EC algorithms for inter-frames in odd views and in even views, respectively. Fig.8. and Fig. 9, show the subjective simulation results of the even and odd views of the "Exit" sequence. In Fig. 8, it is noted that the 241th inter B frame in view S_1 is concealed by using of the proposed hybrid TIVDEC algorithm in (b) without taking into account intra-frame EC and in (c) with taking into account intra-frame EC. In Fig.9, the 241th inter P frame in view S_2 is concealed by using of the proposed IVDEC algorithm in (b) without using intra-frame EC and in (c) with using intra-frame EC. We note that the performance of EC of inter-frames is improved by taking advantage of EC algorithms for both intra-frames and inter-frames and thus achieving a higher objective and subjective quality for the overall 3D video transmitted sequence.

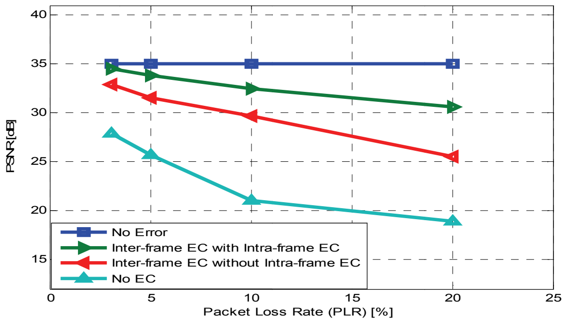


[1] "Ballroom" Sequence

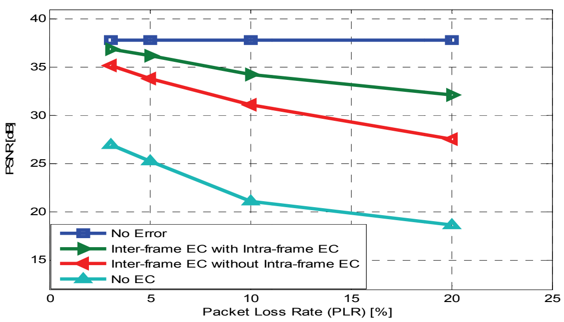


[2] "Exit" Sequence.

Fig.6. PSNR performance for "Ballroom" and "Exit" test sequences with different PLRs for inter-frames within odd views.



[1] "Ballroom" Sequence.



[2] "Exit" Sequence

Fig.7. PSNR performance for "Ballroom" and "Exit" test sequences with different PLRs for inter-frames within even views

4. CONCLUSIONS

In this paper, we have proposed different error concealment algorithms with low complexity for 3D multi-view video sequences corrupted by errors due to transmission over communication channels. The main idea of our work is that spatial, temporal and inter-view correlations in multi-view video are jointly utilized for EC of both intra-frames and inter-frames. Our simulation results show that our joint error concealment algorithms, STDEC, TDEC, IVDEC and TIVDEC, are significantly superior to conventional algorithms that exploit error concealment in either space domain only or time domain only. Our results show that the proposed EC algorithms can conceal lost blocks of intra-frames and inter-frames efficiently with low complexity. Our results also show that EC of intra-frames improves the performance of EC of subsequent inter-frames. The proposed joint EC algorithm picks the appropriate domains for error concealment for each frame and we demonstrated that it can recover 3D multi-view video sequences with high video quality.

ACKNOWLEDGEMENT

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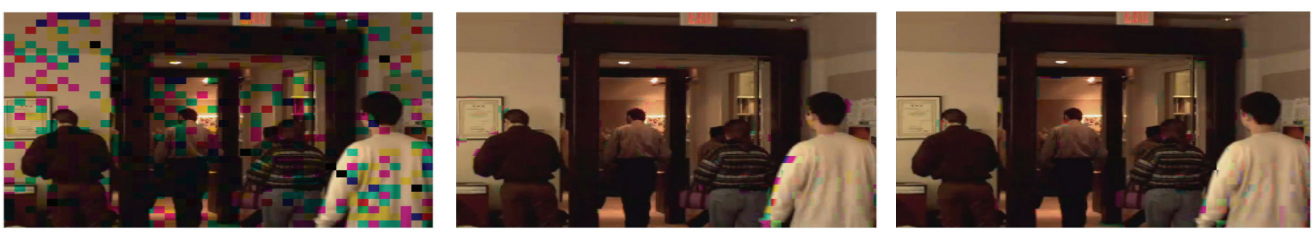

(a) I_{241} intra-frame with PLR=20%. **(b) Inter-frame EC without Intra-frame EC** **(c) Inter-frame EC with Intra-frame EC**

Fig.8. Subjective simulation results for 241[th] inter B frames within the odd view S_1 of "Exit" sequence with PLR=20%.

(a) I_{241} intra-frame with PLR=20%. **(b) Inter-frame EC without Intra-frame EC** **(c) Inter-frame EC with Intra-frame EC**

Fig.9. Subjective simulation results for 241[th] inter P frames within the even view S_2 of "Exit" sequence with PLR=20%.