

# Performance of Enhanced Error Concealment Techniques in Multi-view Video Coding Systems

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**Abstract**—Transmission of multi-view video encoded bit-streams over error-prone channels demands robust error concealment techniques. This paper studies the performance of solutions that exploit the neighbourhood spatial, temporal and inter-view information for this scope. Furthermore, different boundary distortion measurements, motion compensation refinement and temporal error concealment of Anchor frames were exploited to improve the results obtained by the basic error concealment techniques. Results show that a gain in performance is obtained with the implementation of each independent concealment technique. Furthermore, Peak Signal-to-Noise Ratio (PSNR) gains of about 4dB relative to the standard were achieved when adopting a hybrid error concealment approach.

**Keywords**—3DTV; BMA; Error concealment; Motion compensation concealment; MVC; OBMA and OBMC.

## I. INTRODUCTION

Improvements in capture and display technologies and the standardization of Multi-view Video Coding (MVC) have paved the way for a number of different video applications [1]. These include 3D television (3DTV) and free-viewpoint video (FVV), which offers the 3D depth impression and an interactive selection of viewpoint of the observed scenery. The common characteristic of these systems is to use multiple cameras to capture the same scene from different angles simultaneously, producing multi-view videos (MVVs). This suggests that efficient video compression is required to limit the bandwidth required to transmit these multiple views [1].

Transmission of compressed video bit-streams is very sensitive to channel errors [2]. Therefore, efficient error resilience and error concealment techniques are essential in limiting error propagation and to conceal the erroneously received video packets. Compressed MVV bit-streams are even more susceptible to transmission errors because each video has also inter-view dependencies [3]. The MVC standard has only been finalized in the last few years [4], and few studies in literature have investigated the performance of MVC in an error-prone environment. A study on the effect of transmission errors on MVC and the use of normative error resilience techniques to limit their degradation has already been presented in [3]. More error resilience coding and some basic error concealment techniques within the MVC structure can be

found in [5], but more advanced low complexity techniques are needed for better MVV reconstruction.

This paper studies an enhanced error concealment method where a larger selection of neighborhood Motion Vectors (MVs) and Disparity Vectors (DVs) are tested with the motion compensation (MC) error concealment technique, similar in approach to the single-view implementation in [6]. In this technique, the neighborhood spatial and temporal vectors, together with the collocated MVs from the Base view are tested. Two different boundary distortion measurements are used to distinguish the optimal compensated macroblock (MB) replacement and the selected MB is refined with the Overlapped Block Motion Compensation (OBMC) method [7]. Finally, a temporal concealment method is implemented for Anchor frames. The proposed method enhances the standard error concealment strategies studied in [5]. The novelty in this work resides in the adaptation of low complexity concealment strategies previously applied successfully to single-view video coding in [8] to the multi-view scenario. The performance of these techniques is investigated for different multi-view sequences with different characteristics and operating under different Packet Error Rates (PERs).

The rest of the paper is organized as follows: Section II describes the MVV encoding scheme and its sensitivity to transmission errors. Section III proposes advanced error concealment techniques that can be adopted for MVC. Section IV describes the implemented simulation environment while Section V presents the results obtained. Finally, Section VI provides the conclusion.

## II. BACKGROUND

The spatial and temporal redundancies in MVVs are removed using the Intra and Inter coding algorithms as specified in the standard [4]. In MVC, the similarities of the multi-view imagery are exploited by extending the motion compensation techniques to adjacent inter-view images to obtain the DVs and a combined temporal/inter-view prediction structure [1], as defined in Annex H of the H.264/AVC standard [4]. This gives significantly better results compared to using a simulcast solution [9]. In this prediction structure, frames that are encoded with only Intra algorithms or are disparity compensated from them, without any temporal correlation, are known as Anchor frames.

Thus, MVC adopts a coding structure which is similar to H.264/AVC producing bit-streams that are very sensitive to transmission errors. In such a spatial-temporal-view dependent block based structure even a single corrupted bit will desynchronize the entropy decoder [10], leading to spatial, temporal and inter-view propagation of visual distortions. This generally results in a significant degradation in visual quality of the reconstructed MVV sequences [3].

The network layer generally drops the erroneously received video packets and presents the decoder with only intact ones [2]. Thus, error resilience and error concealment techniques become vital in providing a good Quality of Experience (QoE). A study of the performance of the normative error resilience techniques on MVC is found in [3] and [5]. Some concealment techniques for MVVs can be found in literature, but few of them consider error concealment techniques for MVC. Some basic methods are also found in [5], however, better techniques are still necessary.

Techniques that do not increase the bandwidth requirements or the CODEC's complexity are desirable, since the bit-stream must be concealed while it is being decoded. One of these techniques is the Boundary Matching Algorithm (BMA) [11] which is a basic motion compensation error concealment technique recommended as a non-normative part of the H.264/AVC standard for temporal concealment [6]. This is modified to utilize also the DVs for inter-view concealment and is applied to MVC in [5], providing a fair performance. Moreover, the authors in [12] consider the Decoder Motion Vector Estimation [13] within MVC obtaining better results than the BMA for high PERs. However, this comes at the expense of more than twice the computational complexity of the latter [13]. Nevertheless, enhanced techniques like those in [8] that do not increase the CODEC's complexity and enhance the BMA to obtain better concealment results, can still be applied to MVC.

### III. ERROR CONCEALMENT FOR MVC

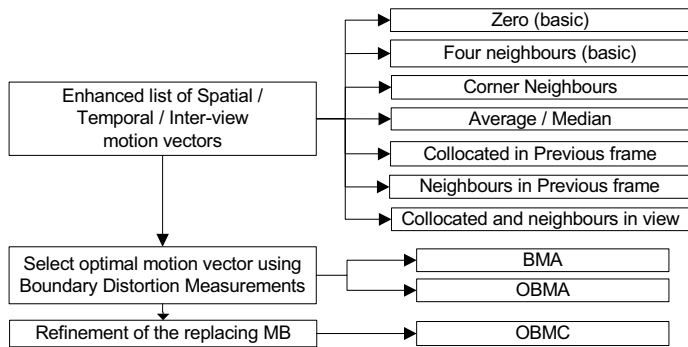


Figure 1. Enhanced Temporal Error Concealment.

A block diagram of the proposed MVC concealment technique is illustrated in Fig. 1. This method is designed to enhance the system adopted in [5]. Apart from having the zero MV and the four nearest neighbor MBs' vector in the motion/disparity compensation candidate list [5], the other four neighbor corner vectors (top left, top right, bottom left and

bottom right), their average and their median, together with the collocated vector from the temporal frame and its eight neighbourhood vectors, were included as candidate compensation vectors. These are considered because a large correlation exists between vectors that are spatially and temporally neighbours to the corrupted MB. Together with these vectors, the collocated MVs from the Base view and their eight neighbourhood MVs, were also investigated for inter-view predicted videos. Since in MVVs the same scene is being captured from different angles, some of the MVs in different views are correlated. In the replacement vector selection process, the selection of the motion/disparity compensated MB is based on the smallest matching distortion measurement which can be found by using the BMA [11] or the Outer BMA (OBMA) [14]. The BMA gives the Sum of Absolute Difference (SAD) between the pixels on the inner boundary of the replacing MB and the outer boundary of the corrupted MB. The OBMA is a variant of the BMA which gives the SAD between the two pixel wide outer boundary of the replacing MB and the same external boundary of the corrupted MB. This offers significantly better concealment performance than BMA while maintaining the same low level of complexity [14]. The selected compensated MB can be further enhanced by using the Overlapped Block Motion Compensation (OBMC) technique. This divides the damaged MB into four 8x8 sub-blocks, where for each sub-block, the winning vector and the three nearest 8x8 vectors are used to form four motion/disparity compensated sub-blocks which are weighted to give the replacing sub-block [7]. In addition to [7], our method uses also the 8x8 corner vector together with appropriate weights that promote more the corner motion compensation MB. Since both DVs and MVs are used in these techniques, they become temporal/inter-view error concealment techniques where the best MV or DV is used to conceal the missing MB.

Usually, Intra coded Anchor frames are concealed with spatial concealment algorithms [6]. However a temporal concealment method can be adopted [8]. This can also be used for the disparity compensated Anchor frames to form a temporal/inter-view concealment method. Thus, apart from the spatially collocated disparity vectors, the collocated vectors from the temporal frame, together with its eight neighborhood vectors and the temporal referenced zero MV become candidates for motion/disparity compensation replacement.

### IV. SIMULATION

The Joint Multi-view Video Coding (JMVC ver 5.0.5) reference software [15] was used to replicate the MVC standard. The Flexible Macroblock Ordering (FMO) and slice encoding, together with the basic spatial and temporal error concealment techniques as described in [3] and [5], were implemented in the JMVC software. To demonstrate the performance of the advanced concealment methods in the multi-view scenario, the decoder was further updated to test more neighborhood candidate spatial/temporal/inter-view MVs and DVs with the two different boundary distortion measurements. The replacing MB is then refined with the OBMC technique. The decoder was further modified to conceal Anchor frames from the temporal frame, using the collocated temporal compensation vectors.

To study the performance of these concealment algorithms, the *Exit* and the *Vassar* (8 views, VGA, YUV 4:2:0, 25Hz) [16] test sequences were utilized. A Group of Pictures (GOP) value of 1 was selected to get the encoding sequence of I-P-P-P. The inter-view prediction structure is defined as I-B-P [9]. The CAVLC was used as the entropy encoder, to obtain low delay characteristics. To limit the temporal propagation, an Intra-coded frame was inserted every 12 frames (0.5 seconds) [17]. A fixed QP of 31 was utilized for all the frames including Anchor frames, for MVC with a slice size of 120 bytes and without FMO. The dispersed type FMO with 4 slice groups was then used to aid concealment. All the sequences were encoded with a fixed bit-rate obtained by adjusting the QP to the lowest quantizer possible to approximate the bit-rates to those of 120 bytes without FMO. It is believed that the QoE comparison is still fair since the remaining small excess in bit-rate contains more errors to achieve the same PERs. These parameters provide low complexity and are suitable for low delay real-time applications [18]. The used PERs are 0%, 1%, 2%, 5%, 10% and 20%. The first 3 views with a total of 250 frames each were used. The results of two fixed slice sizes equal to 120 and 150 bytes (low probability of being in error [2]) with five different error patterns were averaged.

## V. RESULTS AND ANALYSIS

Table 1 gives the performance obtained from the basic concealment method with FMO when the enhanced list of candidate vectors is added to the basic list of vectors, with the BMA. From the results it can be observed that the collocated inter-view MVs do improve the reconstruction of the MVV by 0.15dB at high PERs. A higher gain of 0.29dB is obtained when all the spatial, temporal and inter-view collocated vectors are added to the candidate list, with the collocated temporal vectors giving the most significant contribution, due to their higher correlation with the missing MB. The gains obtained without FMO are comparable. View 0 was not tested with the collocated multi-view MVs, thus, for the first set of results, it is unaffected. The average and median vectors did not provide any contribution.

Fig. 2 illustrates the performance obtained when the advanced error concealment techniques are added one after the other to enhance the basic temporal/inter-view concealment method. The first results show the performance attained with an enhanced list of all the neighborhood vectors. The distortion measurement was then changed to utilize the OBMA. The results show that better MVV reconstruction is obtained when using the OBMA, with some sequences having gains of up to 0.8dB in PSNR at high PERs. The OBMC technique was then used to refine the motion compensated MB. The objective results indicate gains of up to 0.5dB when multiple neighborhood motion or disparity vectors or both are used to conceal the MB. Finally, Anchor frames are concealed using also the motion compensated concealment techniques with the temporal references. Significant gains of around 3dB on the video sequences and up to 4dB on their Anchor frames are obtained at high PERs, with respect to the spatial or disparity compensated techniques. This shows that even though Anchor

frames are encoded with only the spatial and inter-view correlation, there is still a high correlation with temporal frames that can be exploited for better concealment.

TABLE I. RESULTS FOR CONCEALMENT WITH DIFFERENT LISTS OF MVs

PER	0%	1%	2%	5%	10%	20%
<b>Seq. (view)</b>	<b>List of basic vectors (Original)</b>					
Exit(0)	37.16	36.48	35.84	34.37	32.48	29.68
Exit(1)	37.20	36.46	35.81	33.88	31.69	28.63
Exit(2)	37.15	36.08	35.28	33.67	31.45	28.53
Vassar(0)	34.83	34.44	34.15	33.16	31.80	29.53
Vassar(1)	35.13	34.64	34.22	33.00	31.39	29.07
Vassar(2)	35.02	34.51	34.06	32.83	31.32	28.84
	<b>List of basic and collocated Base view motion vectors</b>					
Exit(0)	37.16	36.48	35.84	34.37	32.48	29.68
Exit(1)	37.20	36.46	35.82	33.98	31.80	28.75
Exit(2)	37.15	36.08	35.33	33.76	31.61	28.62
Vassar(0)	34.83	34.44	34.15	33.16	31.80	29.53
Vassar(1)	35.13	34.64	34.22	33.02	31.45	29.14
Vassar(2)	35.02	34.51	34.06	32.86	31.36	28.91
	<b>An enhanced list of all the vectors</b>					
Exit(0)	37.16	36.50	35.88	34.50	32.70	29.97
Exit(1)	37.20	36.44	35.82	34.02	31.83	28.82
Exit(2)	37.15	36.18	35.39	33.82	31.70	28.64
Vassar(0)	34.83	34.45	34.14	33.21	31.90	29.67
Vassar(1)	35.13	34.63	34.21	33.04	31.50	29.19
Vassar(2)	35.02	34.50	34.03	32.89	31.37	29.00

The results also illustrate that an overall gain of up to 4dB, with respect to the basic concealment techniques is obtained when multiple solutions are applied. Furthermore, videos encoded with FMO still provide the best QoE. The gains obtained from the advanced concealment techniques with FMO are smaller than those obtained without it. This occurs because FMO provides better intact candidate neighborhood vectors to the basic set leaving little space for further improvements.

Since the MVC utilizes the temporal/inter-view prediction structure, when an error occurs in one view, this propagates in time and to the other views causing significant loss in multi-view reconstruction quality [3]. The gains obtained from these concealment techniques on the base view that does not contain any inter-view correlations, are all comparable to those found in [8] and [14]. Moreover, gains obtained with the advanced concealment techniques, on the reconstructed inter-view predicted sequence are also very high and comparable to those obtained on the base view, even though they are inter-view predicted with the inter-view distortions. These good concealment results are obtained because a type of temporal/inter-view concealment technique is adopted with this prediction structure such that when both temporal and inter-view compensated replacements exist, both are tested and the best reconstructed MB is chosen. A combination of the temporal/inter-view replacement is also used in the OBMC technique. The selected techniques are preferred since they are low in decoder complexity and offer good gains without the need of any further error resilience or change in video bit-rates or in the encoder.

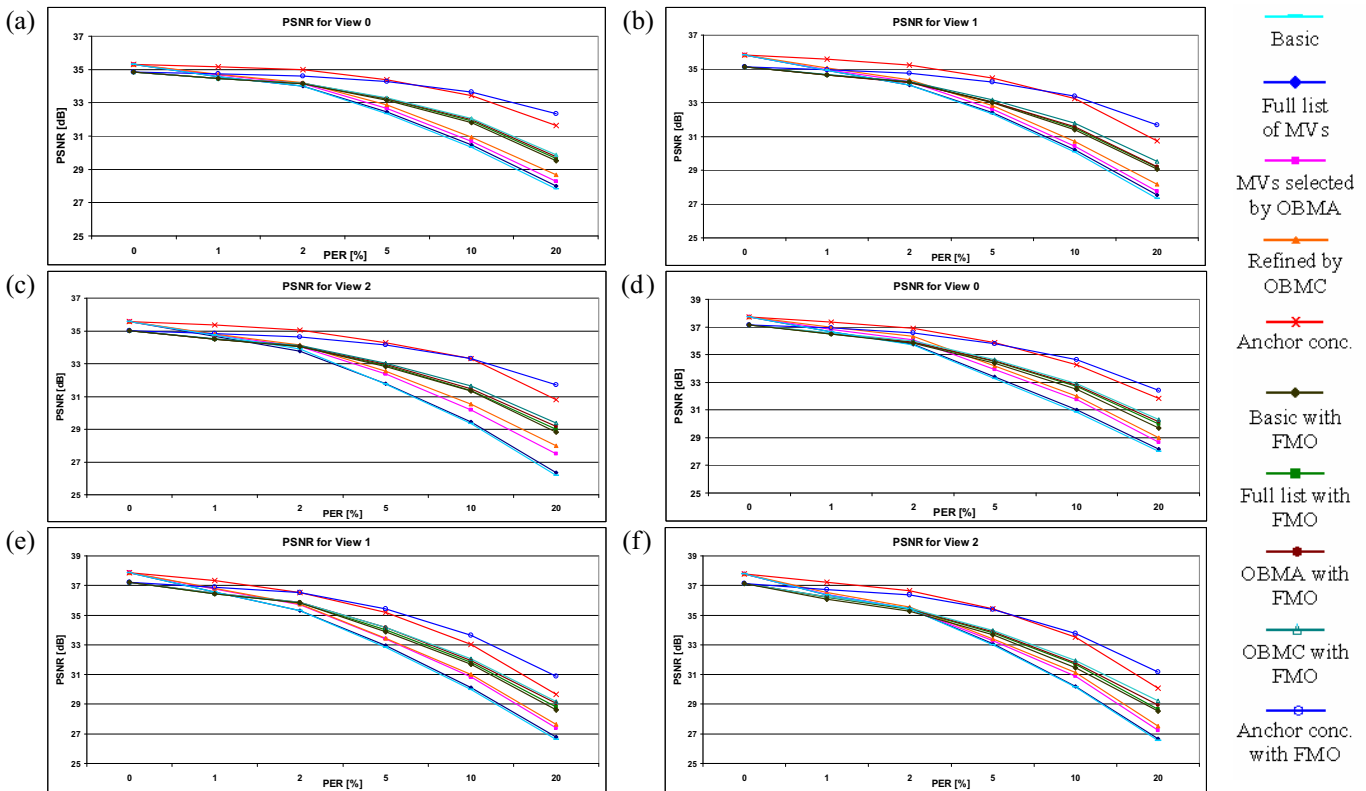


Figure 2. Objective results for (a) view 0, (b) view 1 and (c) view 2 of the Vassar sequence and (d) view 0, (e) view 1 and (f) view 2 of the Exit sequence.

## VI. CONCLUSION

In this paper, advanced temporal/inter-view concealment techniques were adopted for H.264-MVC. Simulation results have shown that with the use of such methods, better multi-view video reconstruction can be obtained at the decoder even when transmitting over error-prone channels. A gain of up to 4dB in PSNR is registered over the standard error concealment techniques and this gain is obtained without changing the encoded video bit-streams or through more complicated error resilience coding that could demand an increase in the video bit-rate. The adopted error concealment techniques were chosen to be low in complexity, thus, more adequate for real-time applications.

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