An Error Concealment Scheme for MPEG-2 Coded Video Sequences

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Abstract— **The problem of errors occurring in MPEG-2 coded video sequences, caused by signal loss during transmission, is examined in this paper and an attempt is made to reconstruct the lost parts at each frame. The proposed error concealment scheme exploits reconstructed temporal information from previously decoded frames in order to conceal bitstream errors in all types of frames: I, P, or B, as long as temporal information is available. Since no such information is available for the first frame (I-frame) of an MPEG-2 coded sequence, another concealment technique is added to the proposed scheme, which uses spatial information from neighbouring macroblocks (MBs). The simulation results compared with other methods prove to be better judging from both *PSNR* values and the perceived visual quality of the reconstructed sequence. Its quality ameliorates with time.**

I. Introduction

The MPEG-2 compression algorithm allows compressed bitstreams at bitrates close to 20 Mbits/s. These are transmitted through physical communication channels of limited bandwidth, where signal loss is inevitable. Since resynchronisation points are placed at the header of the next slice by the MPEG-2 codec, unless otherwise specified, partial or total loss of a compressed bitstream leads to the loss of all information from that point until the next resynchronisation point. This results in the severe degradation of the current frame quality after decoding, as well as of the quality of the subsequent decoded frames in a group of pictures (GOP) due to temporal error propagation. While the locations of bitstream errors are sensed by the decoder in the way described in [1], the locations of propagation errors have to be estimated, when either the concealment method is performed after the decoding of the entire sequence or postprocessing of imperfect concealment errors is desirable. A simple method of locating partially or entirely damaged MBs due to error propagation is described.

Since no temporal information is available for the first frame in the coding order of a video sequence, a different concealment method is presented for that frame. This technique utilises spatial information from existing top and bottom MBs aiming at concealing the lost MBs in such a way so that the transition between existing and reconstructed lost regions in a frame is smoothly performed. The concealment method that is proposed for the reconstruction of lost parts in the rest frames of the sequence exploits reconstructed temporal information from previously decoded frames. The proposed methods are embedded in the decoder model. In this way, only bitstream error concealment is required. The results obtained indicate satisfactory performance of both methods. The improved visual quality of the video sequence justifies the previous remark especially as time passes, i.e., the frame index number increases.

II. Error Detection

Sometimes, information loss occurs in communication channels. In the case of transmission of highly compressed MPEG-2 video sequences, this leads to significant errors observed at the receiver. These errors are either:

(a) **Bitstream errors**, which are caused by direct loss of part of or the entire compressed bitstream of a coded MB, and result in the loss of the following slice information, if default resynchronisation has been adopted, and

(b) **Propagation errors**, which corrupt P- and B-frames only, due to the additional use of motion-compensated information during their decoding.

Bitstream error detection is performed in the way proposed in [1]. Consequently, the locations of bitstream errors are available at the decoder. Their knowledge in the reference frames enables the detection of propagation errors in the current frame. At the locations of propagation errors all information is available at the decoder (i.e. motion vectors, MB coding modes, prediction errors). If the motion vector and coding mode of a MB in the current frame are such that, for the decoding of this MB, information is obtained from a damaged MB in the reference frame, then the current MB is most probably partially or entirely corrupted due to propagation of the reference frame errors. The knowledge of propagation error locations can prove useful in estimating the propagation of errors due to imperfect concealment from previously reconstructed frames.

III. Split-Match Error Concealment Method

The proposed method is used to conceal bitstream errors in the first I-frame of a video sequence. The reason for proposing a different technique for concealing the errors in this frame is that, in this case, no temporal information is available and, consequently, only spatial information can be used. The best possible reconstruction of an I-frame is most desirable because imperfect reconstruction results in the propagation of imperfect concealment errors to all frames in the respective GOP and finally in the degradation of the video sequence visual quality.

Given the location of a lost MB in a certain slice, the algorithm first examines if the neighbouring MBs at the top and bottom slices are available. If the immediate top or bottom neighbours of the current MB are missing, the algorithm searches for the next available ones. In such a case, it is understandable that the region to be concealed becomes larger in the vertical direction. For this reason the search region defined by the algorithm in one of each steps is enlarged, aiming at attempting to fully reconstruct lines or edges in almost all directions. The algorithm consists of four steps, as shown in Figure 1. It performs

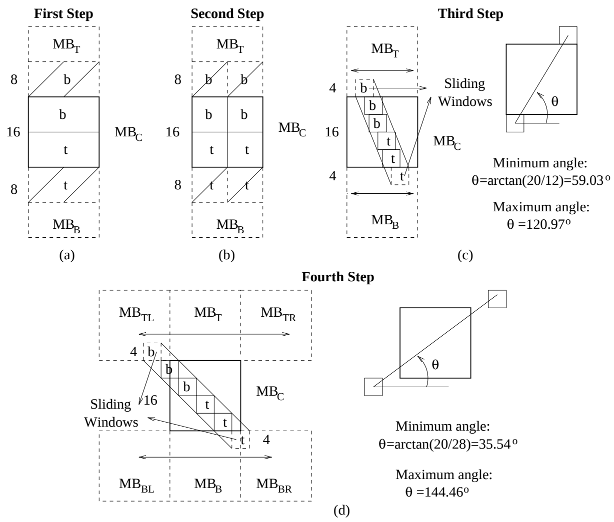

Fig. 1. Graphical presentation of the Split-Match Error Concealment algorithm. The edge or line directions that can be reconstructed are indicated. MB_T, MB_B, MB_{TL}, MB_{TR}, MB_{BL}, MB_{BR} are the surrounding 16×16 MBs to the current lost MB_C, located in the top (T) and bottom (B) slice, respectively.

matching of existing top and bottom neighbouring blocks. The mean absolute difference (MAD) between top and bottom neighbouring blocks, located in a search region, is estimated. That combination of blocks (referred to as the "best match") that leads to the minimum MAD can be used to recover the image content of the lost image part between them. The matching procedure initially tries to match large neighbouring blocks, proceeds by splitting the initial blocks into smaller ones and performs matching between the new ones, if $MAD_i < T_i$, $i = 1, .., 4$, is not satisfied, where T_i are predefined thresholds, or until a minimum block size has been reached, e.g. 4×4. The initialisation of the algorithm with large block matching ensures that big homogeneous or textured regions will be reconstructed directly, thus avoiding processing delays or computational complexity. On the other hand the satisfactory reconstruction of smaller homogeneous or textured regions, regions with small details, lines and edges, requires the matching of smaller blocks. As soon as a best match has been found, concealment is performed by copying the image content of the best matched blocks into the lost region between them in the direction of the match. The first two steps are performed once, whereas the other two are performed iteratively until the concealment of the entire MB. The processing time is kept small because the introduction of several steps prevents useless computations.

Due to the copying technique, blocking artifacts in the concealed areas are unavoidable. In order to smooth this blocking effect, the postprocessing technique of [2] is used. This method performs only on the concealed areas leaving the already existing ones untouched.

IV. Forward-Backward Temporal Block Matching Error Concealment Method

The proposed concealment scheme is implemented as a part of the MPEG-2 decoder. The decoder receives the compressed bitstreams, performs the decoding and then the error concealment processor steps in to process the possibly damaged decoded frame. If this frame is an I- or P-frame, it is stored, after processing, in the past or future decoder frame buffer. Thus, propagation errors are prevented leaving only the bitstream errors to be dealt with. The modified decoder model can be seen in Figure 2. The concealment of bitstream errors in frames for which temporal information is available is performed by the *Forward-Backward Temporal Block Matching error concealment method*.

The proposed method exploits the temporal redundancy of an image sequence. The assumption of a smooth and uniform motion for adjacent blocks is

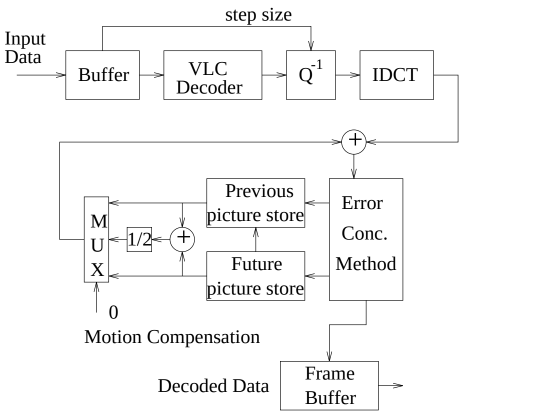

Fig. 2. Introduction of the proposed Error Concealment scheme in the MPEG-2 decoder model.

adopted. Temporal block matching is performed between the available top and/or bottom MBs adjacent to the current lost MB and equally sized blocks located in a predefined search region of size $N \times M$ in the reference frame/frames, its centre being the lost MB. The search region is bigger if the matching is performed between far distant frames and decreases if the frames in question are closer in time. The purpose of this procedure is to avoid useless computations and reduce the time delay. Special attention is paid so that the matched MBs are vertically aligned with vertical distance equal to 16 pixels. In this way, when the best match is found based on the MAD minimization, the 16×16 region between the equally sized blocks of the best match is copied to the current lost MB. The matching process is illustrated in Figure 3. For I- and P-frames, the match-

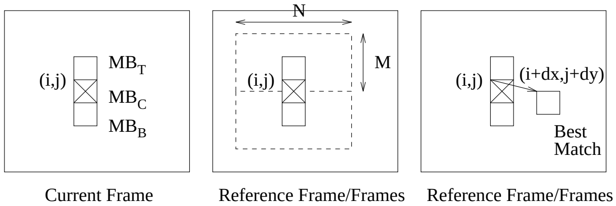

Fig. 3. Temporal Matching of the available top and/or bottom MBs (MB_T, MB_B) between current and reference frame/frames. The in-between 16×16 region is copied to the currently considered lost MB.

ing is performed between the current and the past reference frames, while for B-frames, the matching is performed between the current and the past as well as the future reference frames. No additional memory requirements are introduced because the reference frames used are previously reconstructed and stored in the past or future frame buffers of the decoder. Even for I-frames, the previously concealed P-frame already exists in the past frame buffer to be used for the decoding of the next in line B-frames.

V. Simulation Results and Conclusions

The first 125 frames of the Flower Garden sequence have been used to test the performance of the proposed scheme. Objective comparison is performed by estimating $PSNR$ values, whereas subjective one is achieved through the perception of the visual quality of the processed frames.

The spatial split-match concealment method (S/M EC) is compared with the method proposed in [1] (SVI EC). Results are presented in Table 1, for all three color components Y, U and V. While the proposed technique is slightly better than the one in [1] concerning $PSNR$, the visual quality of the processed image proves to be significantly better than that achieved by the latter method. Edges or lines

Fig. 4. Frame 0: Error Free, $PSNR = 32.2193$ (top-left), Erroneous, $PSNR = 15.7172$ (top-right), processed by method [1], $PSNR = 26.1087$, (bottom-left) and by Sp. B S/M EC method, $PSNR = 26.3157$ (bottom-right).

other than vertical ones are better reconstructed and the texture continuation is smoother. The proposed method fails only in regions whose reconstruction is hardly possible if only spatial information is used, as it is the case in similar methods ([1]). One disadvantage of the proposed method are the blocking artifacts caused by block copying into the lost areas. The processing time remains small, because processing is performed only to the lost parts and because each of the algorithm's four steps is executed only when considered necessary. A drawback of the spatial technique is its dependence on thresholds.

The performance of the proposed forward-backward temporal block matching concealment method (F/B BM EC) is compared with that achieved by the adaptive EC of [3] and by the temporal ECs of [1] referred to as motion compensated temporal EC and zero motion EC. The average values of $PSNR$ measured on the first 125 frames of the

TABLE 1

$PSNR$ MEASURED ON Y,U,V COMPONENTS OF FRAME 0 PROCESSED BY THE S/M EC AND THE SVI EC OF [1].

Method	$PSNR$		
	Y	U	V
Error Fr	32.2193	34.3306	36.0781
S/M EC	26.3157	33.0859	35.2774
SVI EC	26.1087	33.1572	35.1536
Erroneous	15.7172	30.1665	32.9893

test sequence are given in Table 2. The observation

TABLE 2

AVERAGE $PSNR$ MEASURED ON THE 125 FRAMES PROCESSED BY THE F/B BM EC, THE ADAPTIVE EC OF [3] AND THE ZERO MOTION AND MOTION COMPENSATED TEMPORAL ECs OF [1].

Method	Comp.	Average $PSNR$
Error Free Seq.	Y	28.155256
F/B BM EC	Y	26.499157
Adaptive EC	Y	25.296177
Motion Comp. EC	Y	25.090319
Zero Motion EC	Y	23.962755
Erroneous Seq.	Y	15.949784

of these results leads to the conclusion that the proposed method performs significantly better than the others. The visual quality of the entire sequence also proves to be satisfactorily improved with respect to that achieved by the other methods. Figure 5 shows the achieved visual quality of a B-frame. This sig-

Fig. 5. Frame 92: Error Free, $PSNR$ = 27.1917 (top-left), Erroneous, $PSNR$ = 11.0338 (top-right), processed by method [3], $PSNR$ = 21.1499 (bottom-left) and by F/B T BM EC method, $PSNR$ = 24.5583 (bottom-right).

nificant visual and $PSNR$ improvement results from the fact that concealment in I-frames is much better performed when taking into account temporal information. Their best possible reconstruction results in a remarkable improvement of the visual quality of the decoded sequence. The MPEG-2 standard has, of course, the possibility to transmit concealment motion vectors for I-frames in the bitstream. However, bitstream errors might lead to their loss as well.

Although the concealed decoded video sequence is of satisfactory visual quality, some defects and propagated concealment errors cannot be avoided. Such kind of reconstruction errors are caused in occluded regions, where mere past time information proves rather useless. Defects might appear in the borders of the reconstructed frame, where new image content enters. Furthermore, in cases where the assumption of uniform motion does not apply, the method will not perform satisfactorily. However, the visual artifacts caused in such cases are not easily perceived, considering that, e.g. for PAL quality, 25 frames are displayed per second. Another drawback might prove to be the processing time. This is true when a great number of MBs in a frame are lost. In order to reduce the processing time, the search region in the reference frame may be chosen smaller if the frames are nearer in time and larger when they are far apart.

In conclusion, the Spatial Split-Match EC method achieves line, edge and smooth texture continuation in most cases. Its processing time is kept as small as possible. The method fails only in regions which cannot be reconstructed by mere spatial information. A drawback of the algorithm is its dependence on thresholds. The Forward-Backward Temporal Block Matching EC method achieves significant improvement of both $PSNR$ and visual quality of the concealed video sequence. Its processing time depends on the loss percentage. Defects due to occlusions or new image content entering from the frame borders as well as propagated imperfect concealment errors cannot be prevented. However, these visual artifacts are hardly obvious in most cases.

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