BACKWARD ERROR CONCEALMENT OF REDUNDANTLY CODED VIDEO

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ABSTRACT
Error concealment at the video decoder is to recover erroneous picture region based on correctly decoded region in the same frame or the neighboring frames. However, error concealment cannot give satisfactory result in some cases, e.g. when a whole frame is lost. In this paper, we propose a novel backward error concealment method. While the existing temporal error concealment methods recover an erroneous frame by using its reference frame, the proposed method uses a refreshed future frame to recover the previous corrupted reference frame. This is based on the observation that a future frame can be recovered before its reference frame when some error resilience tools such as intra refresh or redundant picture are used. The advantage of the proposed method is that it can recover most pixels in the corrupted reference frame by inverse motion compensation without any error, since typically the refreshed future frame has both MVs and the residues. In the experiments, the proposed method achieves up to 1.0dB gain over the state-of-the-art temporal error concealment method.

Index Terms— Video communication, Error concealment, Redundant picture, Backward decoding

1. INTRODUCTION
Video communications over the Internet and via mobile phones becomes more and more popular. However, most networks such as the Internet and wireless channels are not reliable enough to guarantee error-free transmission. As a result, video encoders and decoders should be equipped with appropriate error resilience and error concealment tools, to counteract the packet loss of video data.

Error concealment techniques at the decoder attempt to conceal erroneous picture areas based on the correctly decoded region and any other helpful information without modifying source and channel coding schemes [1]. In general, error concealment schemes can be divided into spatial approaches and temporal approaches[2].

The spatial error concealment approaches estimate or improve the reconstruction of erroneous region by exploiting the spatial correlation. This can be achieved by using weighted averages of the correct neighbor pixels or by edge based spatial interpolation[2], and can also be achieved by some sophisticated approaches such as projection on convex set (POCS)[3].

The temporal error concealment approaches, on the other hand, restore the missing area by exploiting temporal correlation between neighboring frames. For whole frame loss, typical temporal error concealment approaches include temporal replacement (TR) [2] and optical flow based estimation [4]. For the situation of partial MBs loss, the well-known boundary matching algorithm (BMA) in [5] chooses for each lost MB one motion vector among the candidates based on a spatial smoothness constraint, such that the concealed MB is smoothly connected to the surrounding pixels. Different from BMA, the decoder motion vector estimation (DMVE) method in [6] minimizes the temporal variation of the surrounding pixels.

The error resilience tools and error concealment tools can cooperate with each other for better performance. For example, the BMA desires to split one macroblock and its neighboring macroblocks in a picture into different slices. This can be fulfilled by a flexible slice organization format with the error resilience tool like flexible macroblock ordering (FMO) in H.264/AVC.

In this paper, we propose a novel backward error concealment algorithm which can efficiently cooperate with some error resilience tools such as intra refresh and redundant picture [7]. In [8], we have shown that enabling bidirectional decoding can significantly improve the error resilience performance. In this work we consider to apply backward decoding [9, 10] in the error concealment of H.264 bitstreams. In H.264, when intra refresh or redundant picture is used, a future frame can be decoded or concealed before the previous frames. Based on this observation, we propose to use a recovered future frame to refine the corrupted reference frame. The advantage of the proposed method is that it can recover most pixels in the corrupted reference frame by inverse motion compensation without any error, since typically the refreshed future frame has both the MVs and the residues.

The rest of this paper is organized as follows: In section 2 we propose the novel backward error concealment method. In section 3, we give the experimental results, and in section 4 we conclude the paper.

2. THE PROPOSED BACKWARD CONCEALMENT
2.1. Background and basic idea

In traditional temporal error concealment methods, erroneous frames are recovered in the decoding order. The decoder estimate the MVs of the corrupted frame based on available information, and then recover the corrupted frame by copying its reference frames. However, this may not give satisfactory concealment result especially when the corrupted frame is totally lost. This typically happens in low bit rate wireless video communication.

In this paper, we consider to use a future available frame to recover its reference frames. This is based on the observation that a future frame can be recovered before its reference frames when some error resilience tools such as intra refresh and redundant picture are used.

Fig.1 shows a typical example. In this example, frame 57 is corrupted and frames 57 ∼ 60 need to be recovered. Frame 61 has a redundant picture which can be correctly decoded, so it can be re-
constructed independently before its reference frame (the frame 60). After reconstructing frame 61, since the primary picture of the frame 61 including both the MVs and residues is available, we can subtract the residues from the reconstructions and then copy the results back to its reference frame (the frame 60) according to the MVs. By this, most pixels in the frame 60 can be reconstructed except those pixels not referenced by any pixels in frame 61. Those unreferenced pixels can be recovered by spatial or temporal error concealment methods. In this way, the reconstructed pixels in frame 60 should be very accurate because most of them are recovered by (backward) decoding rather than by error concealment. By repeating this process, we can recover frame 59, 58 and finally 57. The advantage of this method is that, it can recover the corrupted frame (frame 57) even if it is totally lost, because it only use the MVs and residues of the next frame (frame 58).

2.2. Backward decoding for referenced pixels

Let $\hat{f}_n(x)$ be the original reconstruction value at location $x$ in the $n^{th}$ frame (in error free case). $MV_n(x)$ is the motion vector of the block which the pixel $x$ belongs to. $f_{n-1}(x + MV_n(x))$ is the value of motion compensated prediction. $\hat{r}_n(x)$ is the (reconstructed) residue value at location $x$. In H.264 and most other hybrid video coding schemes, the reconstruction is the summation of the prediction and the residue:

$$\hat{f}_n(x) = f_{n-1}(x + MV_n(x)) + \hat{r}_n(x) \quad (1)$$

Suppose the $n^{th}$ frame has been recovered by backward error concealment. Let $\hat{f}_n^{(bc)}(x)$ be the concealed result at location $x$. In the case that $x + MV_n(x)$ is integer pixel location, we recover the pixel $x + MV_n(x)$ in the $(n-1)^{th}$ frame by backward decoding:

$$\hat{f}_n^{(bc)}(x + MV_n(x)) = \hat{f}_n^{(bc)}(x) - \hat{r}_n(x) \quad (2)$$

In the case that $x + MV_n(x)$ is non-integer pixel location, we recover the most nearest pixel around $x + MV_n(x)$ in the $(n-1)^{th}$ frame. Denote $\hat{MV}_n(x)$ as the nearest integer motion vector to $MV_n(x)$.

We recover the pixel $x + \hat{MV}_n(x)$ by:

$$\hat{f}_{n-1}^{(bc)}(x + \hat{MV}_n(x)) = \hat{f}_n^{(bc)}(x + \hat{MV}_n(x) - MV_n(x))$$

$$-\hat{r}_n(x + \hat{MV}_n(x) - MV_n(x)) \quad (3)$$

where the sub-pixel value of $\hat{f}_n^{(bc)}(\cdot)$ and $\hat{r}_n(\cdot)$ are obtained by applying the sub-pixel interpolation filter of H.264.

2.3. MV based concealment of unreferenced pixels

With Eq.(2) and Eq.(3), there are still a small amount of pixels in the $(n-1)^{th}$ frame which cannot be recovered. Those pixels are not referenced by any pixel in the $n^{th}$ frame. Since the percentage of those unreferenced pixels is small, we propose to recover those pixels by the following simple but efficient MV-based concealment method.

Initially, each referenced pixel in the $(n-1)^{th}$ frame has a motion vector pointed from a pixel in the $n^{th}$ frame. The inverse of those motion vectors form a motion field pointing from the $(n-1)^{th}$ frame to the $n^{th}$ frame. We interpolate this motion field such that each unreferenced pixel in the $(n-1)^{th}$ frame also get a motion vector pointing to a corresponding pixel in the $n^{th}$ frame. Then similar to the referenced pixels, each unreferenced pixel in the $(n-1)^{th}$ is also recovered by backward decoding, i.e. by subtracting the reconstruction and the residue of the corresponding pixel in the $n^{th}$ frame. Since that corresponding pixel has already a reference pixel in the $(n-1)^{th}$ frame, the unreferenced pixel can also be considered as recovered by copying that referenced pixel.

Fig.2 is a illustration of the proposed backward error concealment method. The proposed method first recover most pixels (the referenced pixels) by backward decoding (inverse motion compensation), then recover the rest pixels (the unreferenced pixels) by concealment.

3. EXPERIMENTS

In the experiments, we compare following three methods: the first is the temporal replacement (TR), i.e. each damaged region is directly replaced by the co-located region in the temporally previous
picture with zero motion [2]; the second is the state-of-the-art error concealment method for whole frame loss based on the optical flow constraint (OptFlow) [4]; the third is the proposed backward concealment method (BC).

The test is based on H.264 (JM 14.2) baseline profile. The GOP structure is ‘IPPPP...’. Redundant pictures (RP) are periodically inserted, such that frame 1, 11, 21, ... has both primary picture and redundant picture. Similar to [4], the experiments focus on the situation of whole frame loss, i.e. each picture is one transmission packet.

Fig. 3 gives a frame by frame PSNR comparison between the proposed method and the other two methods. The test sequence is ‘foreman’ of QCIF size at 15Hz. The bit rate of primary pictures is 108.40kb/s. The bit rate of redundant picture is 30.92kb/s. The total bit rate is 139.32kb/s. The frames 6, 20, 24, 26, 28, 30, 47, 55, 64 are lost during transmission. According to this figure, the proposed BC can significantly improve the reconstruction PSNR in some cases. For example, when the 6th frame is lost and the 11th frame is refreshed by the corresponding redundant picture, BC yields much better reconstruction than both TR and OptFlow for the frames 6 ~ 10.

Fig. 4 shows the intermediate result during the backward error concealment process. (a) is the reconstruction of the frame 61 which is recovered by using redundant picture. By applying backward decoding on (a), we recover most pixels in frame 60 and get partial image (b). At last we recover the remaining pixels (the black holes in (b)) by MV-based concealment and get final backward concealment result (c).

Fig. 4 also shows the visual quality of the frame 60 by OptFlow.
By comparing (c) and (d), we can see that the proposed BC significantly outperforms OptFlow in frame 60 in both PSNR and visual quality.

Fig. 5 is the comparison of the rate distortion performance at loss rate 10%. For each bit rate, we simulate 100 different loss patterns obtained from [11]. In the tests the proposed BC performs the best. It gains up to 2dB over TR and up to 1dB over the OptFlow method.

4. CONCLUSION

In this paper, we propose a novel backward error concealment method. Different from existing methods, the proposed method uses a refreshed future frame to recover its corrupted reference frame. The advantage of the proposed method is that most pixels in the corrupted reference frame can be recovered by backward decoding without any error. Experiments suggest that the proposed method can achieve considerable gain over the state-of-the-art temporal error concealment method in both objective and subjective quality.

5. REFERENCES