RECOVERY OF MOTION VECTORS FOR ERROR CONCEALMENT

Jae-Won Suh and Yo-Sung Ho

Kwangju Institute of Science and Technology (K-JIST)
1 Oryong-Dong Puk-Gu, Kwangju, 500-712, Korea
E-mail: won@gogh.kjist.ac.kr, hoyo@kjist.ac.kr

Abstract

A compressed bitstream generated by an MPEG-2 video coder is sensitive to channel errors. Due to the coding structure of the MPEG-2 video compression algorithm, a bit error can affect not only the current picture frame but also succeeding frames. In this paper, we propose a temporal domain error concealment algorithm to recover lost or erroneously received motion vectors. In order to estimate the motion vector of the erroneous macroblock at the decoder, we examine neighboring luminance intensity values of the lost macroblock. Simulation results show that the proposed algorithm produces reconstructed pictures of acceptable quality.

I. INTRODUCTION

Digital TV requires transmission of an enormous amount of visual information over a band-limited channel. The bandwidth constraint necessitates the use of an efficient coding scheme to compress the video data. In recent days, MPEG-2 becomes a popular video coding standard where motion compensation is employed to reduce temporal redundancies among successive picture frames.

If all the coded bitstream of a video sequence is received correctly, the receiver can reconstruct image frames of desired picture quality. However, due to the nature of broadcasting, it is nearly impossible to design a system to be totally error free. Therefore, if some coded bits are lost or corrupted during transmission, an appropriate data recovering process is needed to obtain reconstructed pictures of acceptable visual quality.

Several methods, including automatic retransmission request (ARQ), forward error correction coding, and interleaving techniques, have been proposed to solve the above problem. However, they are often ineffective. ARQ may aggravate the channel congestion and cause the system to drop more data. Forward error correction coding usually requires too many additional parity bits for error detection and error correction. Interleaving techniques may require considerable time delay.

An alternative approach is error concealment, where we intend to reduce bit error effects at the receiver. In error concealment schemes, we exploit both redundancies in the correctly received data and limitations of the human visual system without requiring additional information. Therefore, we can avoid channel congestion and the time delay problem.

There are mainly two different approaches for error concealment: spatial-domain error concealment and temporal-domain error concealment. They exploit the spatial and temporal correlation in the video sequence.

Spatial-domain error concealment techniques utilize adjacent luminance intensity values of the lost macroblocks (MBs) to restore the corrupted data in the spatial domain. Some examples include averaging or linear interpolation [1] and directional interpolation [2]. This approach assumes the existence of statistical correlation between neighboring image blocks. Therefore, if the corrupted block and its surrounding neighbors belong to homogeneous regions, they can reproduce a good approximation for the lost MBs.

Temporal-domain error concealment techniques make use of adjacent motion vectors (MVs) of the lost MBs and previously reconstructed reference frames in the temporal domain. A simple and yet quite effective method is to replace the corrupted MB with its corresponding MB in the previously decoded reference frame. Although this method generally works well in stationary parts of the picture, it cannot produce satisfactory results in fast moving areas, lighting condition changes, or sudden scene changes [3]. Other schemes for reconstructing the MV of the lost MB attempt to use a linear combination of MVs of surrounding MBs [4, 5].

In this paper, we address the problem of error concealment in packet-based transmission of MPEG-2 coded video bitstream over a lossy channel. We especially focus on the case where MVs of MB slices in the video frame are corrupted. We propose a new technique for restoring the corrupted MBs by estimating the lost MVs, exploiting the fact that adjacent pixels of the lost MB tend to have similar movement as the lost MB.

II. MODIFIED MPEG-2 VIDEO CODEC

A hierarchical structure of MPEG-2 video coding is shown in Figure 1. The input sequence is divided into a series of group of pictures (GOP). Each GOP may include three different picture types: intra-coded picture (I-picture), predictive-coded picture (P-picture), and bidirectionally predictive-coded picture (B-picture). I-picture is coded by itself, not using any previous or future information. The reconstructed I-picture is used as an anchor for forward and backward prediction of neighboring pictures. P-picture is coded using forward motion compensated prediction from the past I-picture or P-picture. B-picture is coded using bidirectional motion compensated prediction from the past and the future I-picture and P-picture. A

0-7803-5739-6/99/$10.00©1999 IEEE.

picture is divided into MB slices, while each MB slice consists of several MBs. A MB contains 16 x 16 luminance pixels and corresponding two chrominance blocks. A block contains 8 x 8 pixels.

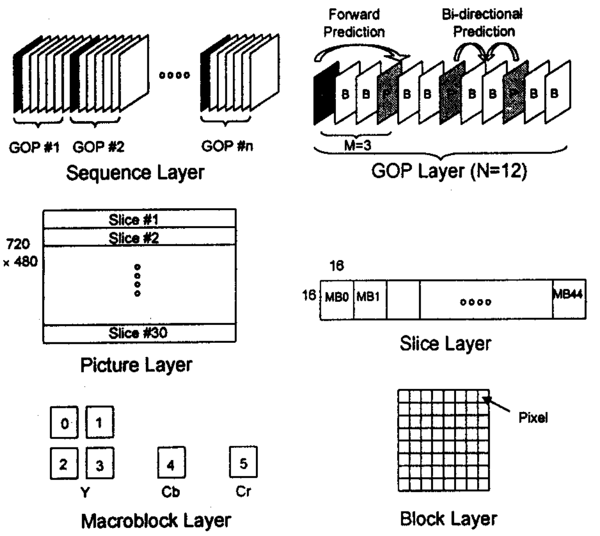


Figure 1: Hierarchical Layers of MPEG-2 Video Coding

The GOP structure implies that if some error occurs within I-picture data, it can propagate through all other pictures in the same GOP. Similarly, an error in the P-picture may affect the neighboring P-picture and B-picture, while errors in the B-picture can be isolated. Therefore, it is desirable to develop an error stopping mechanism to prevent error propagation within the GOP, and consequently, to improve reconstructed picture quality.

The MPEG-2 video coding standard is a hybrid algorithm of motion estimation (ME) and motion compensation (MC), discrete cosine transform (DCT), difference pulse coded modulation (DPCM), and variable length coding (VLC) [6]. Figure 2 shows a functional block diagram of the MPEG-2 video encoder.

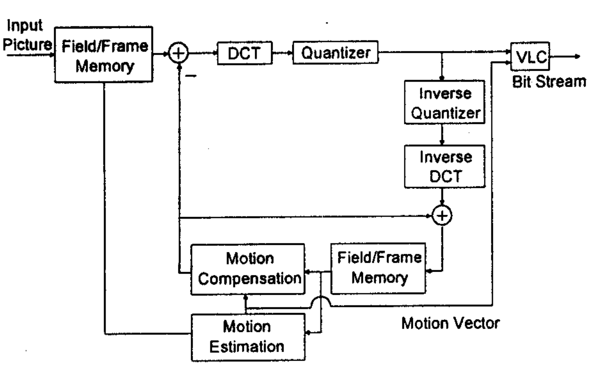


Figure 2: MPEG-2 Video Encoder

To code a video sequence, the first I-picture is DCT transformed. The DCT coefficients are quantized and entropy coded using Huffman tables. The I-picture appears periodically to eliminate error propagation. In succeeding picture frames, temporal redundancies are removed by ME and MC. Motion compensated residual errors are DCT transformed and quantized. Each MV is coded differentially with respect to that of previous MB.

During transmission over a band-limited channel, the coded bitstream can be corrupted by channel noise. If a packet is damaged by uncorrectable bit errors, it is difficult to tell which part of the data within the packet is usable. Therefore, for a practical purpose, the damaged packet is thrown out and treated as a lost packet. The packet size of the MPEG-2 transport stream (TS) is 188 bytes, including four bytes header information.

Figure 3 shows a functional block diagram of a modified MPEG-2 video decoder. Except for the error concealment block, the configuration is the same as the MPEG-2 decoder. In this paper, we propose an error concealment algorithm for estimating lost motion vectors.

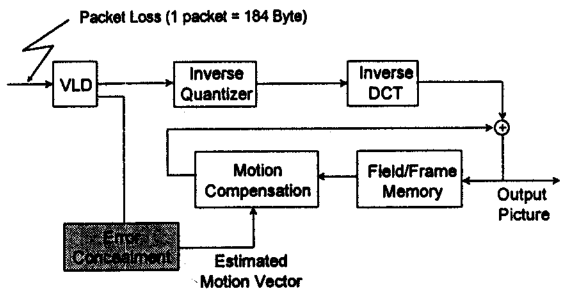


Figure 3: Modified MPEG-2 Video Decoder

The MPEG-2 video bitstream has a hierarchical structure. Several startcodes are inserted at various locations according to the video bitstream syntax. With these startcodes, we can follow the decoding state systematically, such as sequence, GOP, picture, and MB slice. Among them, we should pay a special attention to the MB slice. The MB slice is the smallest unit of synchronization and it can be used for preventing error propagation within the picture. When we receive a corrupted packet, all successively received packets become useless until synchronization is re-established. Consequently, we may lose a horizontal stripe of MBs until the next slice header. Therefore, we assume that only the upper and the lower luminance intensity values and the MVs of the lost MB are available.

III. TEMPORAL-DOMAIN TECHNIQUES FOR ERROR CONCEALMENT

3.1 Temporal Replacement

We may regard a lost MV to be zero, assuming that no motion has occurred between the previous and the current pictures [1]. When a MB is lost in the current picture, we can copy the MB that corresponds to the same location in the previous anchor picture. A temporal replacement would produce a reasonably good approximation of the lost MB in the stationary area. However, this technique is not satisfactory in areas of significant movement.

In general, neighboring MBs of the picture often move in the similar fashion. Therefore, we can exploit spatial correlation to improve the performance of temporal replacement.

3.2 Average of MVs of Vertically Adjacent MBs

As shown in Figure 4, an estimate for the lost MV can be found by taking the average value of MVs of the vertically adjacent MBs [4,5].

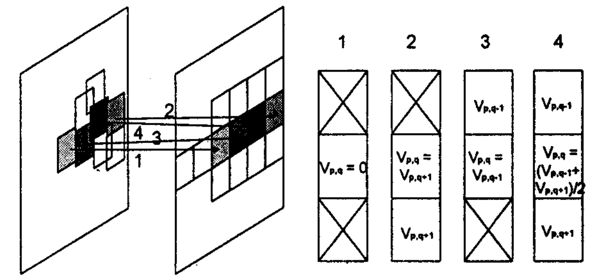


Figure 4: Average Method

In Figure 4, $V_{p,q}$ represents a MV of a MB at the p-th column and the q-th row. If the upper and the lower MBs have MVs, the MV of the lost MB is replaced by the average of the two MVs. If only one of the vertical neighbors has a valid MV, we substitute that MV for the lost MV. Unfortunately, if no valid MV of the vertical neighbors is available, we use the simple temporal replacement with a zero MV for the lost MB recovery.

When vertically neighboring MBs have valid MVs, the picture quality of the reconstructed image is very good. However, if only one or none of the vertical neighbors has a valid MV, the quality of the reconstructed image is not sufficient. For this reason, we devise the following schemes for recovering the lost MV.

3.3 Weighted Sum of Neighboring Motion Vectors

As shown in Figure 5(a), we consider 16 x 8 target blocks (TBs), TB1 and TB2, above and below the lost MB. The MV of each TB is computed by the block matching algorithm (BMA) at the decoder. We substitute the lost MV by the average of the MVs of the two TBs.

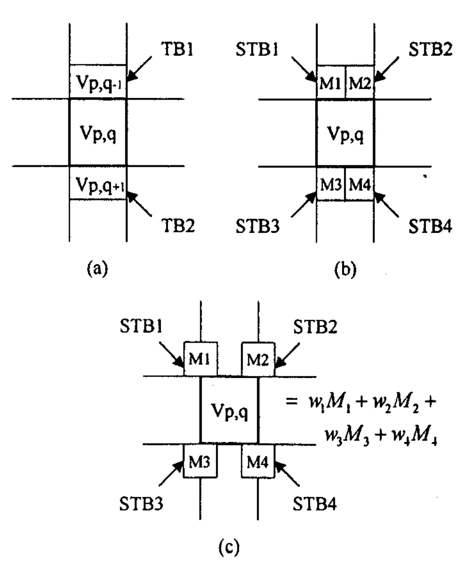


Figure 5: Weighted Sum Method

In order to obtain more accurate MVs, we separate each 16 x 8 TB into two 8 x 8 smaller target blocks (STBs), as shown in Figure 5(b). We can take average of the MVs of the four STBs for the lost MV. This approach, however, entails a considerable amount of processing complexity at the decoder.

We also modify the previous algorithm to reduce the processing complexity. As shown in Figure 5(c), we define different STBs. With this modification, we can reduce the computational complexity by half. After calculating the four MVs of the STBs, a weighted sum of the MVs of STBs is computed by

$$V_{p,q} = w_1M_1 + w_2M_2 + w_3M_3 + w_4M_4 \qquad (1)$$

where M_1, M_2, M_3 and M_4 are the MVs of the STBs, and w_1, w_2, w_3 and w_4 are weighting factors. The weighting factors are assigned inversely proportional to the squared sum of pixel differences between the original STB and the estimated STB.

IV. SIMULATION RESULTS

In order to evaluate the performance of the error concealment algorithms, we perform computer simulations on test video sequences: FOOTBALL, BUS, BALLET, and BICYCLE. They have the 4:2:0 format of 720 x 480 pixels, and they are coded at the rate of 5 Mbits/sec. Each GOP consists of 12 pictures (N=12, M=3). A MB slice is composed of 45 MBs.

Assuming that we have lost a TS packet in the first P-picture, we compare performances of different error concealment algorithms: simple temporal replacement (TR), average of the MVs of the vertically adjacent MBs (AVG), and weighted sum of neighboring motion vectors (WG). Table 1 shows PSNR values of the reconstructed P-picture with error concealment and average PSNR values of all picture frames in the GOP that includes the erroneous P-picture. We calculate average PSNR values of one GOP to examine the effect of error propagation.

Table 1: PSNR Values for Test Sequences

Test Sequence	Concealed P-picture			Average PSNR of GOP		
	TR	AVG	WG	TR	AVG	WG
FOOTBALL	27.18	30.58	31.53	30.11	31.28	31.43
BUS	25.13	25.22	25.10	23.94	23.94	23.89
BALLET	28.53	28.57	28.65	28.83	28.87	28.93
BICYCLE	24.65	25.15	24.41	24.62	24.79	24.5

Figure 6 shows the corrupted FOOTBALL image and concealed images by estimating the lost MV by various MV recovery algorithms. Figure 6(b) is obtained by replacing the damaged MB by the MB at the same position in the previous anchor picture. In this reconstructed picture, we can observe abrupt changes of luminance values along the MB slice boundaries, which are quite annoying to human vision. Figure 6(c) is obtained by the average of the MVs of the vertically adjacent MBs. Figure 6(c) provides better picture quality than Figure 6(b), but it has some blocky spots. Since object movement is not homogeneous in the motion area, there is a possibility of different movement in the vertically neighboring MBs. Figure 6(d) is obtained by the weighted sum of the neighboring MVs. From Figure 6, we observe that the weighted sum algorithm of neighboring MVs produces better subjective picture quality than the other algorithms.

V. CONCLUSIONS

In this paper, we have described the problem of packet loss and various error concealment algorithms for MPEG video coding systems. In temporal-domain error concealment methods, we replace the lost MB by an MB in the previous reference picture. This simple temporal replacement algorithm provides good results in stationary areas; however, we observe significant degradations in areas of fast movement. We improve picture quality of the reconstructed images by taking the average of vertically adjacent MVs for the lost MV. Simulation results demonstrate that the proposed weighted sum algorithm is very effective in recovering good picture quality at the video decoder. However, it adds computational complexity.

ACKNOWLEDGMENT

This work was supported in part by LG Electronics Inc. and in part by the Korea Science and Engineering Foundation (KOSEF) through the Ultra-Fast Fiber-Optic Networks (UFON) Research Center at Kwangju Institute of Science and Technology (K-JIST).

REFERENCES

[1] S. Aign and K. Fazel, "Temporal and Spatial Error Concealment Techniques for Hierarchical MPEG-2 Video Codec," *IEEE International Conference on Communication*, Vol. 3, pp. 1778-1783, 1995.

[2] J.W. Suh and Y.S. Ho, "Error Concealment Based on Directional Interpolation," *IEEE Transactions on Consumer Electronics*, Vol. 43, No. 3, pp. 295-302, Aug. 1997.

[3] M. Ghanbari and V. Seferidis, "Cell loss concealment in ATM video codecs," *IEEE Transactions on Circuit and System for Video Technology*, Vol. 3, pp. 238-247, June 1993.

[4] H. Sun, K. Challapali, and J. Zdepski, "Error Concealment in Digital Simulcast AD-HDTV Decoder", *IEEE Transactions on Consumer Electronics*, Vol. 38, No. 3, pp. 108-116, Aug. 1992.

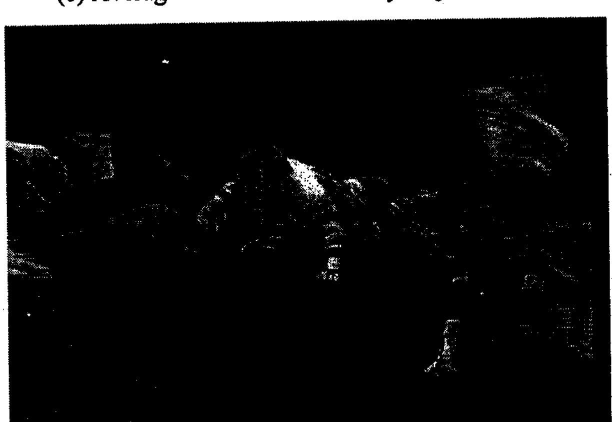
[5] A. Narula and J. Lim, "Error Concealment Techniques for an All-Digital High-Definition Television System," *SPIE Visual Communication and Image Processing*, pp. 304-315, Nov. 1993.

[6] ISO/IEC IS 13818-2 (MPEG-2 Video): Information Technology - Generic Coding of Moving Pictures and Associated Audio Information, April 1996.

(a) Corrupted Image

(b) Temporal Replacement

(c) Average of MVs of Vertically Adjacent MBs



(d) Weighted Sum of Neighboring MVs

Figure 6: Subjective Quality Evaluation

Results

Algorithm was tried on gray images and color images, using ADSP 2100 Simulator

Results of two images are given in table.

Image	Codebook	Codebook size	bits/ pixel
Mman1	Fixed	256 vectors	0.50
Mman2	Adaptive	256+64 vectors	0.56
Mman3	Adaptive	256+89 vectors	0.56
Fruits1	Fixed	256 vectors	0.50
Fruits2	Adaptive	256+ 32 vectors	0.56

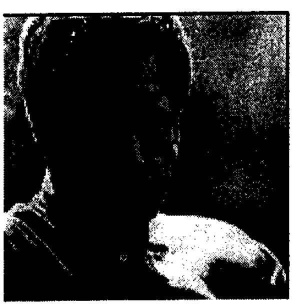
Conclusion

1. Quality of the image was found to be improved using adaptive codebook.
2. Addition of few code vectors selectively from image itself results better quality compared to fixed codebook with small increase in compression time and slightly lower compression ratio.

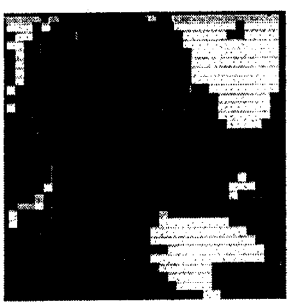
References

1. Robert M. Gray "Vector Quantization" IEEE ASSP Magazine, April 1984
2. Woods R.E. and Gonzalez R.C. " Digital Image Processing" Addison Weskey Publishing Company.(1992)
3. Gregory A. Baxes "Digital Image Processing Principals & Applications" John Willey &sons(1994)
4. Paul Michael & Farrete Springverlag ' Recursive Block coding for Image Compression"
5. Y. Linde Buzo " An Algorithm for vector quantizer design" IEEE Transactions on Image Processor, March1997
6. Michale Lightstone , S.K. Mitra " Image Adaptive Vector Quantization"IEEE Transactions on Image Processor, March 1997

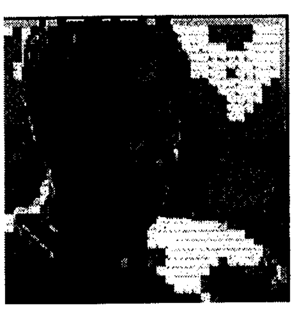
MMAN



MMAN



MMAN1

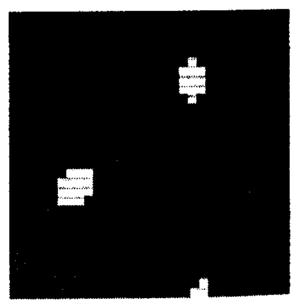


MMAN2

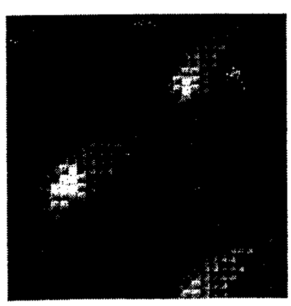
MMAN3

FRUITS

FRUITS



FRUITS1



FRUITS2