Motion Vector Recovery Using Optical Flow Fields

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@kjist.ac.kr, hoyo@kjist.ac.kr

ABSTRACT: If channel errors are introduced during video transmission over error-prone communication channels, we can repair damaged portions of the corrupted image by exploiting the spatial and temporal redundancy in the video sequence. Motion compensation with the estimated motion vector (MV) plays an important role in concealing the damaged image region. In this paper, we propose a new MV recovery algorithm for error concealment based on optical flow fields. Because optical flow fields are very similar to the true object motion, we can estimate MV of the lost macroblock with them and conceal the lost macroblock by compensating with the estimated MV. We demonstrate that the proposed algorithm provides improved performance over other error concealment schemes based on the boundary matching algorithm.

1 Introduction

The fast growing digital communication technology enables us to send digital video sequences over band-limited transmission channels. The bandwidth constraint necessitates the use of efficient coding schemes, such as MPEG-2, to compress the digitized video data. However, extensive use of predictive and variable length coding algorithms in video compression systems makes them very sensitive to transmission errors. If some coded bits are lost or corrupted by channel errors during transmission, we need to apply an appropriate data recovering process to obtain an acceptable visual quality.

In order to make the compressed bitstream resilient to transmission errors, we must add redundancy to the bitstream to detect and correct bit errors. Typically, this is done at the channel coding by forward error correction (FEC) [1]. However, FEC usually requires too many additional parity bits for error detection and error correction. Therefore, if we consider a limited channel bandwidth, FEC may not always be the best solution.

An alternative approach is error concealment, where we reconstruct the lost data by exploiting spatial and temporal redundancies existing in the video sequence. There are two kinds of error concealment techniques: spatial-domain and temporal-domain error concealment techniques. For spatial-domain error concealment, we use various interpolation methods to recover the lost data [2,3]. MV recovery and compensation with the estimated MV is one of the critical issues to conceal the corrupted macroblocks (MBs) in the temporal-domain error concealment [4]-[6]. A number of MV recovery algorithms based on boundary matching algorithm (BMA) have been developed. This paper proposes a new MV recovery algorithm based on optical flow to improve video quality.

2 Error Concealment Techniques

An estimate for the MV of the lost MB can be obtained by taking the average value of MVs of vertically adjacent MBs (AVG) [4] of the lost MB. In this scheme, if vertically neighboring MBs have MVs, we can obtain reasonably good reconstruction quality for the lost MB. If only one or none of the vertical neighbors has a valid MV, however, quality of the reconstructed image is not satisfactory.

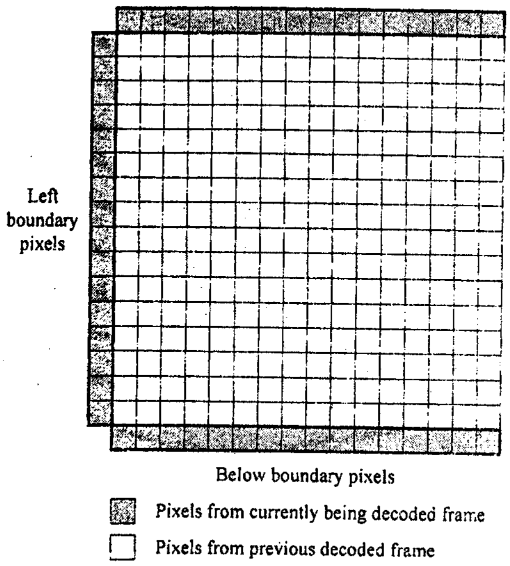


Fig. 1: Boundary Matching Algorithm

Other conventional MV recovery algorithms use boundary pixels of the lost MB and pixel values of previously decoded reference frame to estimate the lost MV. The BMA [5] uses adjacent above, below, and left boundary pixels of the lost MB to recover MV as shown in Fig. 1. In the beginning, we calculate the squared sum of differences between boundary pixels of currently being decoded frame and pixels of previous decoded frame. The BMA chooses the MV, which produces the smallest total squared sum of differences. Decoder motion vector estimation algorithm (DMVE) [6] exploits several pixel boundary lines (two to eight) of above, below, and left, and corner pixels of the lost MB. Although the implementation methods of these algorithms are slightly different, they contain almost the same idea. Furthermore, they have significant limitations that left boundary pixels of the lost MB are not available for the MV estimation. Even if left boundary pixels are used for MV recovery, they already include error concealment mismatch from the second position of the MV estimation.

3 Optical Flow Fields

Optical flow is the distribution of apparent velocities of movement of brightness patterns in an image. Optical flow arises from relative motion of objects and the viewer. Consequently, optical flow can be corresponded to the 2D-motion. To find optical flow is to minimize the error in the optical flow constraint equation and the measure of departure from smoothness as Eq. (1) [7].

$$e^2 = \iint [(E_x u + E_y v + E_t)^2 + \alpha^2 (u_x^2 + u_y^2 + v_x^2 + v_y^2)] dxdy \qquad (1)$$

where u and v are the x and y components of the optical flow, E_x, E_y, and E_t means partial derivatives of image brightness with respect to x, y and t, respectively. The minimization is to be accomplished by finding suitable values for the optical flow velocity (u, v). Using the calculus of variation and the approximation of Laplacian, Eq. (1) can be written as

$$(\alpha^2 + E_x^2 + E_y^2)(u - \bar{u}) = -E_x(E_x \bar{u} + E_y \bar{v} + E_t),$$
$$(\alpha^2 + E_x^2 + E_y^2)(v - \bar{v}) = -E_y(E_x \bar{u} + E_y \bar{v} + E_t). \qquad (2)$$

α^2 plays a significant role only for areas where the brightness gradient is small and prevents haphazard adjustments to the estimated flow velocity occasioned by noise in the estimated derivatives. This parameter should be roughly equal to the expected noise in the estimated of $E_x^2 + E_y^2$. Optical flow can be computed by a new set of velocity estimates (u^{n+1}, v^{n+1}) using the estimated derivatives and the average of the previous velocity estimates (u^n, v^n) as Eq. (3)

$$u^{n+1} = \bar{u}^n - E_x \frac{E_x \bar{u}^n + E_y \bar{v}^n + E_t}{\alpha^2 + E_x^2 + E_y^2},$$
$$v^{n+1} = \bar{v}^n - E_y \frac{E_x \bar{u}^n + E_y \bar{v}^n + E_t}{\alpha^2 + E_x^2 + E_y^2} \qquad (3)$$

where n is iteration number, and $\bar{u}$ and $\bar{v}$ are local average of velocity. We can obtain the derivatives of brightness and local averages of velocity from the discrete set of image intensities [7].

4 The New Concealment Algorithm

The proposed MV recovery algorithm uses the optical flows of correctly decoded neighboring data as shown in Fig. 2. As a beginning, we obtain optical flows of the optical flow region (OFR) with the current frame and the previously decoded reference frame using Eq. (3). In the second place, we take average of optical flows within the MV estimate block (MVEB) that come in touch with the lost MB. The average value is used as the MV for the lost MB. In this algorithm, how to define the OFR and the MVEB is very important. If the OFR is increased, the computation time is increased. The MVEB is closely related to the accuracy of estimated MV for the lost MB.

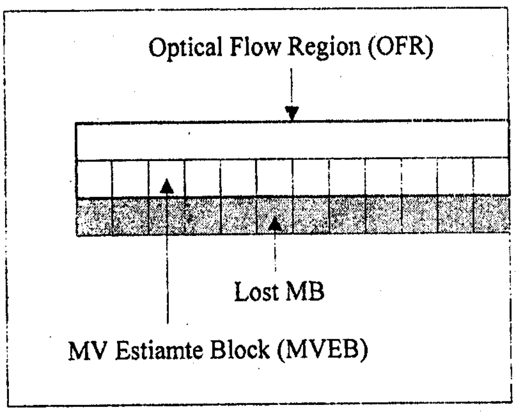
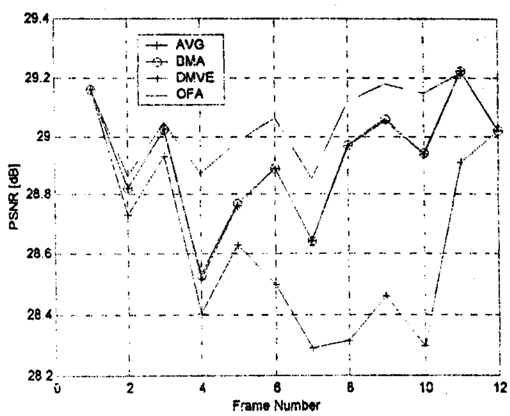


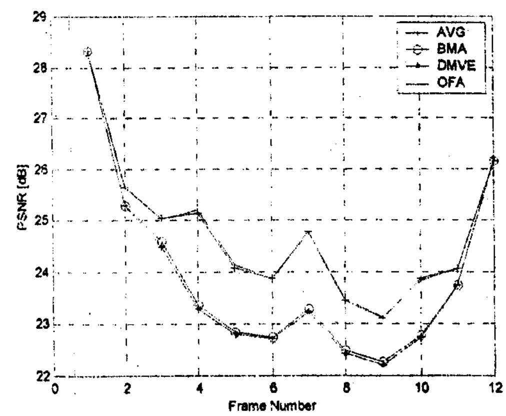
Fig. 2: Error Concealment with Optical Flow

5 Simulation Results

In order to evaluate the performance of the error concealment algorithms, we perform computer simulations on test video sequences: BALLET and BICYCLE sequences. They have the 4:2:0 format of 720 × 480 pixels. These are encoded using the pattern of IBBPBBPBBPBB at 30 frames/sec (NTSC). We consider MPEG-2 TS packet system for considering noisy channels and assume that the first P-frame has lost one TS packet. Performance comparison has been done on four algorithms: AVG [1], BMA [2] which has [-25, 25] search range and 1 pixel boundary line, DMVE [3] which has [-25, 25] search range and 2 pixel boundary lines, and proposed optical flow algorithm (OFA). The width of the OFR is 32 pixels and the size of the MVEB is the same as that of a MB. Therefore, we need 32 iterations to obtain optical flow of the OFR.



(a) BALLET



(b) BICYCLE

Fig. 3: Performance Comparison

Fig. 3 shows the peak signal-to-noise ratio (PSNR) for the two test video sequences. It is founded from the results that BMA and DMVE produce very similar performance and proposed OFA produces the best PSNR over all the other methods. As shown in Fig. 4, we can get better subjective video quality using the proposed OFA for the test video sequences.

6 Conclusions

We have briefly introduced and compared several error concealment algorithms for MPEG–2 video transmission system. Temporal-domain error concealment algorithms can recover the lost MB data by compensating with the estimated the MV. The simulation results indicate that the proposed OFA produces a higher PSNR value compared with conventional algorithms. While conventional methods have a big computation burden due to the process of motion estimation in the decoder, OFA requires several iterations to estimate the MV of the lost MB. These results lead us to the conclusion that the proposed OFA is one of the best solutions for error concealment.

Acknowledgement

This work was supported in part by KOSEF through UFON and in part by MOE through BK21.

References

[1] E. Ayanoglu, P. Pancha, A.R. Reibman, and S. Talwar, "Forward error control for MPEG-2 video transport in a wireless ATM LAN," Proc. of ICIP1996, vol. 2, pp. 833-836, 1996.

[2] S. Aign and K. Fazel, "Temporal and Spatial Error Concealment Techniques for Hierarchical MPEG-2 Video Codec," Proc. of ICC, vol. 3, pp. 1778-1783, 1995.

[3] J.W. Suh and Y.S. Ho, "Error Concealment Based on Directional Interpolation," IEEE Trans. on Consumer Electronics, vol. 43, no. 3, pp. 295-302, Aug. 1997.

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

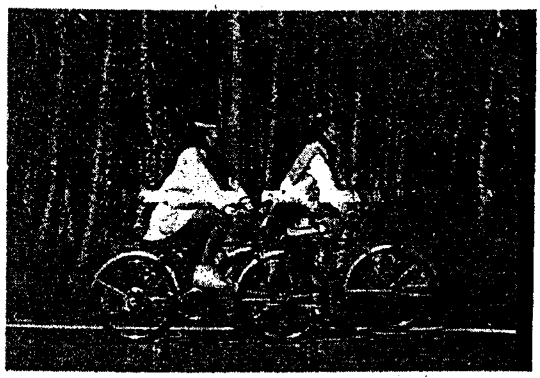
[5] W.M. Lam, A.R. Reibman, and B. Liu, "Recovery of Lost or Erroneously Received Motion Vectors," Proc. of ICASSP, vol. 5, pp. 417-420, 1993.

[6] J. Zhang, J.F. Arnold, and M.R. Frater, "A Cell-Loss Concealment Technique for MPEG-2 Coded Video," IEEE Trans. on Circuits and Systems for Video Technology, vol. 10, no. 4, pp. 659-665, June 2000.

[7] B.K.P. Horn and B.G. Schunck, "Determining Optical Flow," Artificial Intelligence, vol. 17, pp. 185-203, 1981.

(a) BALLET by BMA

(b) BALLET by OFA



(c) BICYCLE by BMA

(d) BICYCLE by OFA

Fig. 4: Subjective Quality Comparison