Motion Estimation with Optical Flow-based Adaptive Search Region

Kyoung-Kyoo Kim, Seong-Won Ban, Won-Sik Cheong, and Kuhn-Il Lee

School of Electronic and Electrical Engineering, Kyungpook National University, Korea
Phone: +82-53-950-5512, Fax.: +82-53-950-5505
E-mail: ktriple@palgong.knu.ac.kr

Abstract An optical flow-based motion estimation algorithm is proposed for video coding. The algorithm uses block-matching motion estimation with an adaptive search region. The search region is computed from motion fields that are estimated based on the optical flow. The algorithm is based on the fact that true block-motion vectors have similar characteristics to optical flow vectors. Thereafter, the search region is computed using these optical flow vectors that include spatial relationships. In conventional block matching, the search region is fixed. In contrast, in the new method, the appropriate size and location of the search region are both decided by the proposed algorithm. The results obtained using test images show that the proposed algorithm can produce a significant improvement compared with previous block-matching algorithms.

I. Introduction

The efficient reduction of temporal redundancies in a video signal produces high performance image sequence coding. Accordingly, various motion estimation and compensation techniques have been successfully applied to video coding. Motion estimation can provide a good temporal prediction and has a simultaneous requirement of low complexity and overhead information [1],[2].

Block matching algorithms [3] are widely used as a motion estimation technique for video coding since they only require simple hardware and can produce a good quality motion compensated image. In a full search algorithm, block matching is performed for every search point in a fixed search region. As the search region is increased, the accuracy of the motion estimation is also increased. However, it is difficult to determine the proper size and location of the search region using this algorithm.

The proposed algorithm uses block matching and an optical flow technique. As a result, the algorithm includes block matching motion estimation with an adaptive search region. The search region is computed from motion fields that are estimated based on an optical flow technique. The use of an optical flow technique is expected to overcome the drawbacks of traditional block matching, thereby producing more accurate predictions and eliminating any annoying block artifacts [4]-[9].

The algorithm is based on the assumption that true block-motion vectors have similar characteristics to optical-flow vectors. The optical flow is estimated from the frames of a video sequence using the least square algorithm [5]-[7]. These optical flow vectors are divided block by block, where each block is $N \times N$. Thereafter, the search region is computed using these vectors that have spatial relationships. The center point of the search region is the mean of the optical flow vectors in the block, whereas, the size of the search region is computed based on the variance of the optical flow vectors in the block. A full search is then performed based on the computed search region. As a result, the appropriate size and location of the search region are both determined by the proposed algorithm.

Simulations using the proposed algorithm with a variety of video sequences produced significant improve

-ments over a full search algorithm. In particular, the proposed algorithm showed a good quality performance with fast and complex motion sequences, like the FOOTBALL sequence.

II. Optical flow estimation

Optical flow techniques assume that image intensity does not change over a small time interval. The optical flow constraint equation is

$$E_x u + E_y v + E_t = 0, \quad (1)$$

where E_x, E_y, and E_t denote the spatial temporal derivatives of image intensity E, and the velocity of an image point in the x and y directions by u and v [4].

The optical flow equation (1) can not be solved where components u and v of the optical flow vector are both unknown. The global approach [5] imposes a correlation among velocities that does not exist across motion boundaries. As a result, an unlikely flatness in a velocity field outcome appears on the boarders of objects that have different motions. Local techniques [6],[7] are then required for smoothness in order to maintain the pixels within a restricted neighborhood. Consequently, an over-constrained set of linear equations is built to solve the optical flow problem.

If an M-pixel square window sliding over the image is considered, this solves the over-constrained set of linear equations generated by applying the optical flow equation (1) to each pixel lying within a window. By assuming that all the pixels inside a window have the same velocity and applying the least square technique $\vec{v} = (u, v)$ is obtained as the best estimate.

$$\vec{v} = (A^T A)^{-1} A^T b, \quad (2)$$

where the coefficient matrix is

$$A = \begin{pmatrix} E_{x1} & E_{y1} \\ \dots & \dots \\ E_{xn} & E_{yn} \end{pmatrix} \text{ and } b = -(E_{t1}, \dots, E_{tn})^T.$$

The results of the least square algorithm can be degraded in a noisy image. The usual technique is to apply pre-processing to the input image or post-processing spatial smoothing to the output vector field to suppress the noise. However, the proposed method does not require the search region to compute accurate vectors but instead only rough vectors [7].

III. Optical flow based-adaptive search region

The proposed algorithm uses block matching and an optical flow technique. The algorithm includes block-matching motion estimation with an adaptive search region. The search region is computed from optical flow vectors that are estimated based on an optical flow technique.

Conventional least square optical flow techniques consist of two steps. The spatial and temporal derivatives are first estimated by means of prefilter-derivative filter pairs. The optical flow vectors are then computed using the least-square technique [4]-[9].

This study uses Simoncelli's three-tap filter pairs [8]. However, only two frames are used in the temporal direction, the same as in a conventional block-matching algorithm. The use of these filter pairs produces a good performance [9].

The least square technique was adopted with a 3×3 window size. As the window size is increased the accuracy of the flow vectors also increases. However, a large window size results in a substantial increase in computational complexity. In contrast to the conventional least square technique, the current study sought to reduce the computational complexity, therefore, instead of using all the pixels in a block only 12.5% pixels were used.

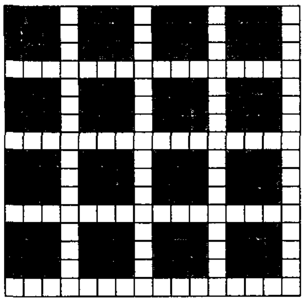


Figure 1. Pixels computed using least-square technique (colored pixel points).

Figure 1 shows the points in the block that were computed using the least square technique. Thereafter, the search region is computed using these vectors that include spatial relationships.

The center point of the search region is the mean of the optical flow vectors in the block. As a result, the i th block center point of search region, c_i, is

$$c_i = \frac{1}{n}\sum_{k=0}^{n-1} \vec{v}_{ik} , \tag{3}$$

where $\vec{v}_{ik}$ denotes the optical-flow vector and n denotes the number of optical-flow vectors in the block. The center point of the search region is the nearest integer value of c_i. And the size of the search region is computed based on the variance of the optical flow vectors in the block. The i th block size of search region, r_i is

$$r_i = \frac{s}{n}\sum_{k=0}^{n-1} | \vec{v}_{ik} - c_i |^2 , \tag{4}$$

where s denotes the scale factor. The scale factor, s is obtained experimentally. Thereafter, a full search is performed for these computed search regions.

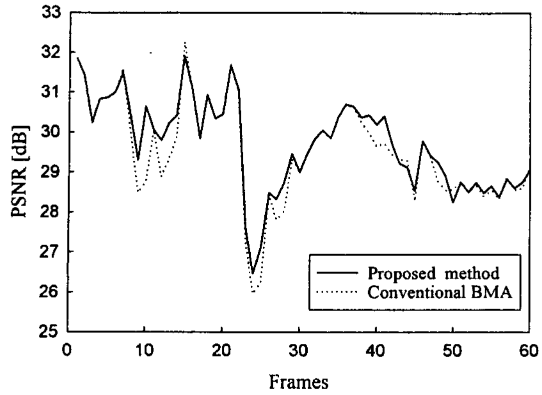
In conventional block matching, the search region is fixed. However, in this new method, the size and location of the search region are both decided by the proposed algorithm. Accordingly, the proposed algorithm is a significant improvement over previous block-matching algorithms.

IV. Experimental results

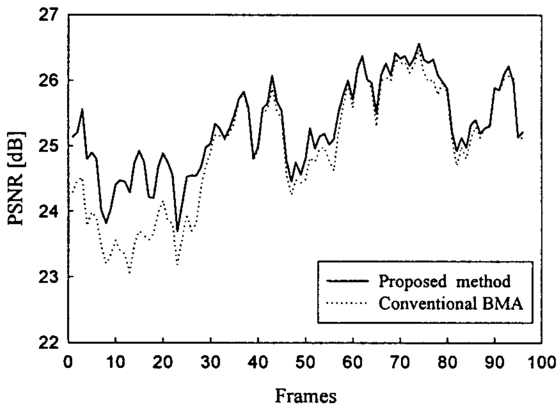
The performance of the proposed algorithm was assessed using various test images. In particular, sequences with fast and complex motion were chosen, since the search regions of the proposed algorithm in small motion sequences are included in those of conventional block-matching algorithms. To evaluate the performance of the proposed algorithm, it was applied to the TABLE TENNIS and FOOTBALL sequences in the format of SIF.

The proposed algorithm and the block matching algorithm were compared on the basis of 60 and 100 frames. The full-search block matching algorithm used 16×16 blocks and a 32×32 search region. The proposed algorithm determined four-step search regions, 4×4, 8×8, 16×16, and 32×32 using threshold values.

The PSNR's are compared in Figure 2. In Figure 2(a), the average PSNR for the proposed algorithm and block matching algorithm was 29.7 and 29.5, respectively. And in Figure 2(b), the average PSNR was 25.3dB and 25.0dB, respectively. This figure also shows the results for the first 30 frames in Figure 2(b), where the average PSNR for the proposed algorithm and block matching algorithm was 25.4dB and 24.6dB, respectively. Based on these results, the proposed method improved the image quality by 0.3dB compared with the conventional method. Whereas, for the first 30 frames, proposed method improved the image quality by 0.8dB compared with the conventional method. Accordingly, the proposed method produced a remarkable performance with fast and complex motion sequences. In addition, the search regions of the proposed method and the conventional method were almost similar for sequences with small motion, like the CLAIRE sequence.



(a)



(b)

Figure 2. PSNR of conventional full search algorithm and proposed algorithm for (a) TABLE TENNIS and (b) FOOTBALL sequences.

V. Conclusion

The proposed algorithm uses block matching and an optical flow technique. The algorithm includes block matching motion estimation along with an adaptive search region. The search region is computed from optical-flow vectors that are estimated based on an optical flow technique.

In conventional block matching, the search region is fixed. However, in this new method, the appropriate size and location of the search region are both decided by the proposed algorithm. As a result, the proposed algorithm is a distinct improvement on previous block matching algorithms.

Simulations using the proposed algorithm with a variety of video sequences produced significant improvements over a full-search algorithm. In particular, the proposed algorithm showed an excellent performance with fast and complex motion sequences, like the FOOTBALL sequence.

References

[1] A. M. Tekalp, *Digital Video Processing*, Englewood Cliffs, NJ: Prentice-Hall, 1995.

[2] A. N. Netravali and B. G. Haskell, *Digital Pictures*, 2nd Ed., Plenum Press, 1995.

[3] ISO/IEC 11172-2, "Coding of Moving Pictures and Associated Audio for Digital Storage Media at up to about 1.5Mbits/s: Video."

[4] B. K. P. Horn and B. G. Schunck, "Determining Optical flow," *AI 17*, pp. 185-204, 1981.

[5] H. H. Nagel, "An investigation of smoothness constraints for the estimation of displacement vector fields from image sequences," *IEEE Trans. Patt. Anal. Mach. Intel.*, vol. 8, pp. 565-593, 1986.

[6] J. K. Kearney, W. B. Tompson, and D. L. Boley, "Optical Flow Estimation: An Error Analysis of Gradient-based Methods with Local Optimization," *IEEE Trans. PAMI.*, vol. 9, no. 2, pp. 229-244, 1987.

[7] C. H. Chu and E. J. Delp, "Estimating Displacement Vectors from an image sequence," *J. Pot. Soc. Am. A*, vol. 6, no. 6, pp. 871-878, 1989.

[8] E. Simoncelli, "Distributed representation and analysis of visual motion," Ph.D. dissertation, Dept. Electr. Eng. Comput. Sci., MIT, Cambridge, 1993.

[9] P. Moulin, R. Krishnamurthy, and J. W. Woods, "Multiscale modeling and estimation of motion fields for video coding," *IEEE Ttans. Image Processing*, vol. 6, no. 12, pp. 1606-1620, 1997.