Efficient Partial Distortion Algorithms with Sorting Order of Calculation for Motion Estimation

Ming-Te Wu
Information Technology Department, Kao Yuan University, Kaohsiung City, 82151 Taiwan
E-mail: t90078@cc.kyu.edu.tw

***Abstract*—In order to accelerate the motion estimation process, the normalized partial distortion search algorithm calculates the partial distortion by constantly selecting specific pixels from every sub-macroblock to early reject the incorrect motion vector. However, these selected pixels are supposed that the pixels' values of sub-macroblock are uniform distribution. This paper proposes a partial distortion search algorithm that joints the motion correlation of neighbored macroblocks and the sorting order of calculation with non-uniform distortion. The proposed algorithm first finds the coarse motion vector using the motion correlation of neighbored macroblocks to accelerate the motion estimation process and then calculates the partial distortion by replacing the order of calculation of normalized partial distortion search algorithm with the sorting order of calculation we proposed to early reject the impossible motion vectors. In addition to increase the probability of rejecting the impossible motion vectors without extra computations, the proposed method has a significantly lower computation and better objective quality than traditional algorithms.**

***Index Terms*—normalized partial distortion search, motion estimation, motion correlation, uniform distribution, the order of calculation.**

I. Introduction

For promoting the coding speed, most compression schemes [1]-[5] employ block motion estimation (BME) to lower the temporal redundancy of interframe. Through comparing the reference with current frame, BME [6] algorithm try to search the optimal motion vector (MV). BME algorithm calculates the distortions between all candidate MBs within a well-defined region in the reference and the current MB in the current frame to search the optimum macroblock (MB) which has the minimum block-matching distortion (BMD). BMD is defined as sum of absolute difference (SAD) of two MBs, from the reference and current frame, respectively. The most straightforward BMD algorithm is the full search (FS). However, the FS algorithm matches all MBs within specified range from the reference frame with each MB from current frame, lead to the massive calculation of BMD. Thus the fast motion estimation algorithm is pressingly exploited for motion compensation.

In fact, it has little discrepancy between the current and the reference frame, especially for sequences with slow-motion content. Therefore, to remove the redundancy for motion estimation becomes considerably essential. The motion estimation algorithms try to find out the correlation hidden in interframes and acquire the high compression ratio with fine restored performance. For accelerating the process of motion estimation, several motion estimation algorithms [7]-[11] are exploited to reduce the huge calculations of BMD. One of the most famous method is the Diamond search (DS) algorithm [13]. The DS algorithm employs a nine-point and a five-point diamond pattern to calculate the BMD for decreasing the matching points within a search window [9]. Like the DS algorithm, other pattern-based motion estimation algorithm [7], [12] and [13] are suggested to reduce the massive computation. As the BMD methods exclude the global minimum by using the search points, these algorithms indeed reduce the computation of motion estimation. Nevertheless, the minimum distorted points with multi-local attributes often emerge when the image sequences especially have the characteristic of fast moving content, result in the test point often acquiring local minimum distortion and getting more mistake than the FS algorithm.

Another popular BMD approach different from the pattern-based algorithms on reducing search points is the calculation reduction of SAD. Because the SAD means the summation of absolute difference of all pixels' value in a macroblock (MB) between current and reference frame, the partial SAD is certainly less calculation than entire SAD between two MBs. Bei *et al*. extended this opinion to develop, a partial distortion search (PDS) algorithm [14] to decrease the calculation for vector quantization. Montrucchio *et al*. combined the PDS algorithm and the distortion analysis [15] to propose a rapid and lossless PDS algorithm. For advancing the process of motion estimation, Cheung *et al*. [16] and [17] released the normalized partial distortion search (NPDS) algorithm in

Manuscript received September 15, 2012; revised December 28, 2012.
This work was supported by the National Science Council, Taiwan, for financially supporting this research under Contracts No. NSC 101-2221-E-244 -018.

doi: 10.12720/joams.1.1.1-5

2000. The NPDS algorithm first normalized the distortions of current minimum and partial accumulation, and then compared them to remove the impossible candidate MVs for reducing the computations. Since then, several approaches [18] and [19] regarding calculation-reduced motion estimation are proposed successively. The calculation-reduced algorithms can indeed achieve fine visual performance; but it is still a consumptive calculation problem. This problem drives us to develop the approach with the advantage of less calculation and fine visual performance.

This paper proposes a partial distortion search algorithm, considers the pixels in sub-MB being non-uniform distribution, with the sorting order of calculation of each pixel for motion estimation. In order to reduce the extra computation of each pixel's sorting calculation, the proposed algorithm first utilizes the motion correlation of adjacent MBs to acquire the coarse MV. The partial distortion are then calculated by employing the sorting order of calculation we proposed instead of the fixed ordering of NPDS to early remove the invalid MVs. Experimental results demonstrated that the proposed approach has fewer computations and better PSNR than other existing schemes such as TSS, DS and NPDS algorithms.

The remainder of this study is introduced as follows. Section II depicts the NPDS algorithm and the proposed method. Experimental results are illustrated in Section III. Conclusions are provided in Section IV.

II. Proposed Partial Distortion Search Algorithm

A. *Summary of NPDS*

The NPDS algorithm tried to midway end pending the comparison process if the candidate MV is wrong. Each partial distortion in NPDS includes the distortion of 16 pixels which own the same space within neighboring pixels and the *m*-th partial distortion is expressed as

$$d_m = \sum_{i=0}^{3} \sum_{j=0}^{3} \Big| I_f(x + 4i + p_m, y + 4j + q_m) - If-1+4i+pm+u,y+4j+qm+v, \quad (1)$$

where (p_m, q_m) is the location of the upper left corner point of the *m*-th partial distortion from the upper left corner point of a candidate MB; indices *i* and *j* mean the sub-MB at the vertical and horizontal situations, respectively, and $I_f(x, y)$ is the pixel's value of position (x, y) in the current frame *f*. (u, v) indicates the site of candidate MB from the upper left corner of reference frame. The partial distortion of the *m*-th accumulation is defined as

$$D_m = \sum_{m=1} d_m, \quad (2)$$

where $m \leqq 16$.

The NPDS first tests all check points within restricted search window just like the FS algorithm. The search process initiates at the beginning point of MB and shifts outside by applying a spiral moving path. In each MB matching, the NPDS algorithms compare each accumulative partial distortion D_m with the normalized minimum distortion. The process starts from m=1 to m=16 and the comparison is finished when the accumulative partial distortion of candidate MV is greater than the current normalized minimum distortion, which is indicated as

$$D_m > \frac{m}{16} D_{min} \quad (3)$$

where D_{min} is the current minimum distortion.

B. *Proposed Partial Distortion Search Algorithm with Sorting Order of Calculation*

In this section, the proposed algorithm is present as follow. As the motion connection of neighboring MBs to predict the motion vector is significant for spatial domain, the proposed algorithm adopted the directly left, above, above-left and above-right adjacent the current MB[18]. The proposed approach first calculates the mean of the difference between current pixel and adjacent 8 pixels to determine the sorting order of calculation for each pixel in each sub-MB. After deciding the prior order for each pixel of sub-MB, the order of calculation of NPDS algorithm is substituted with the sorting order of the proposed method. Through the NPDS algorithm with the sorting order, the proposed algorithm can obtain the MVs of the upmost row and leftmost column MBs. The MVs of these MBs are utilized to forecast the possible area of the entire minimum distortion situation for other MBs. The average algorithm is then employed to forecast the coarse central point (α_c, β_c) of the current MB for motion estimation process. The vector $\vec{m}$ of the current MB is the average of the MVs of its three neighboring MBs defined as

$$\vec{a} = \frac{1}{3} \sum_{i=1}^{3} \overrightarrow{MV_n}, \quad (4)$$

where $\vec{a} = (\alpha_c, \beta_c)$ is the minimum distortion point of the current MB; $\overrightarrow{MV_n}$, n = 1, 2, 3 are the MVs of the left, above-left and above MB relevant to the current MB, respectively.

After determining the coarse central point of the current MB, the seeking area of each MB can be decided from the MV situations of its adjacent MBs. The seeking area is defined as

$$\begin{cases} S_a(\alpha,\beta) = \{(\alpha,\beta) | \alpha_c - (a + o_s) \le \alpha \le \alpha_c - (a + o_s), \beta_c - (a + o_s) \le \beta \le \beta_c - (a + o_s)\} \\ a = [\max(MV_n(x)) - \min(MV_n(x))] + [\max(MV_n(y)) - \min(MV_n(y))], \text{for } n = 1,2,3 \end{cases} \quad (5)$$

where $S_a(\alpha, \beta)$ is the place in the possible seeking area and o_s means the offset which dominates the dimension of the seeking area S_a. The NPDS algorithm with sorting order is then implemented on this seeking area to achieve the optimal MV.

Based on the purpose of soon discarding the invalid candidate MVs, the NPDS algorithm picks out 16 pixels from each MB and estimates their partial distortion value. But if the pixels within a MB are not regular distribution, the candidate MV may acquire the point of local minimum distortion and the outcome is obtaining the wrong MV. In order to reduce the possibility of achieving the wrong MV, the distribution of pixels in each group is desired to know in advance. For finding the minimum distortion between interframes, the deviation of each pixel is critical on forecasting the MV of current MB. Consequently, the sorting order of calculation of each pixel is employed in the proposed approach. The order of each pixel is determined by the value of pixel. In other words, the larger the value of pixel is, the higher the order of calculation is. Based on this opinion, the proposed algorithms calculate the value of each pixel in each step to find the order of calculation for early discarding invalid MV. After deciding the order of calculation of each pixel from each sub-MB, the first partial distortion is first measured in this study. Because of (2), the first accumulated partial distortion D_1 is sure to equal to the first partial distortion d_1. However, if the first partial distortion of candidate vectors is greater than the current normalized minimum distortion, the matching procedure will execute from *m*-th to (*m*+1)-th group and the optimal MV is then acquired.

If the matching is not success, the second partial distortion relying on the second prior order of calculation is then accumulated with the first partial distortion. If the accumulated partial distortion is still less than the current normalized minimum distortion, then the next order-of-calculation distortion are accumulated as the current partial distortion. Each distortion of group is accumulated into the current partial distortion till the current partial distortion is greater than the normalized minimum distortion. The accumulated partial distortion is hence defined as

$$D_k = \sum_k d_k \quad , \tag{6}$$

where k<=16, and the current normalized minimum distortion D_{n} is defined as

$$D_{\text{n}} = \frac{k}{16} D_{\min}. \tag{7}$$

The k value can be obtained while (6) is greater than the current normalized minimum distortion D_{n}. The comparing procedure is stopped if the accumulated partial distortion of the candidate vectors is greater than the current normalized minimum distortion, which is defined as

$$D_k > \frac{k}{16} D_{min}. \tag{8}$$

Because the proposed algorithms adopt the sorting order of calculation based on pixel's non-uniform distribution, while the accumulated partial distortion is greater than the current normalized minimum distortion, the proposed algorithms can be more rapidly than NPDS with uniform distribution to discard the impossible MVs. It means that the proposed algorithms soon discarding the incorrect MVs are more possibility than that of NPDS. This is because the pixel-group value of the first sorting order is always greater than that of the other sorting orders; the removed probability of the first sorting order is also greater than that of the other sorting orders. This discovery reveals that the proposed algorithms can promote the accurateness of achieving correct MVs. In summary, the proposed method executes the following procedures to acquire the optimal MVs. Fig. 1 illustrates a flowchart of the proposed algorithms.

1) For each input MB, the sorting order of each pixel of each sub-MB is determined.

2) The accumulated partial distortion D_1 based on (2) is estimated and examines (3) to judge that whether the matching is stopped or not. If the matching procedure is finished, then the optimal MV is obtained. Otherwise, go to the next step.

3) Through (6), calculate the accumulated partial distortion initially from k = 1, and use (8) to judge if the matching is ended or not.

4) The optimal MV is obtained if the matching is terminated. On the contrary, the procedure from k toward k+1 till k>16, and go to the next step.

5) The optimal MV is obtained if k>16. Otherwise, iterate from step 2 to step 4.

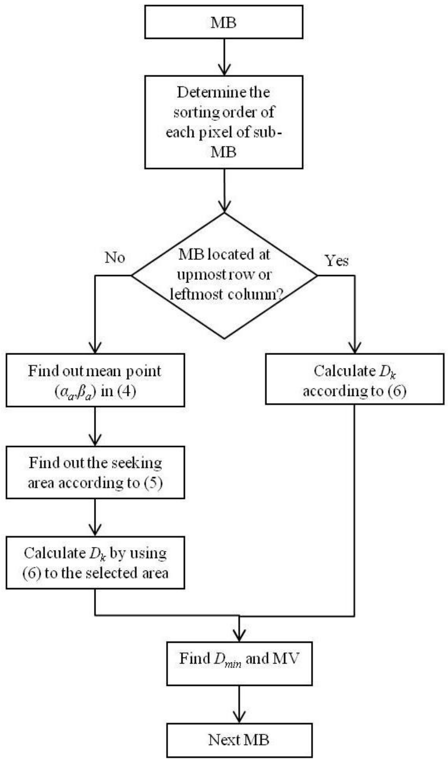

Figure 1. Illustration of the proposed method.

III. EXPERIMENTAL RESULTS

Four CIF sequences with distinct levels and styles of motion content, namely Foreman, Missa, Mobile, Garden, which have 180, 149, 140 and 86 frames, respectively, were performed by using the proposed algorithms in this section. Simultaneously, the proposed approach was competed with four block motion estimation algorithms including FS, TSS, DS and NPDS, by using PSNR measure and calculation. In this paper, the size of SAD block is designed as 16 and the size of search range is provided as 7.

Tables I and II show the PSNR measure and amount of computation of the FS, TSS, DS, NPDS and the algorithms of this survey, respectively. As expressed in Table Ⅰ, the proposed algorithm revealed better PSNR than the TSS, DS and NPDS algorithms. The improvement of average

PSNR by employing the proposed algorithm is 0.12 dB which compared with the NPDS algorithm. The maximum PSNR improvement from the proposed algorithm is 0.16 dB by the simulative result of the Foreman sequence. Therefore the experimental result proved that the proposed algorithm own a better PSNR exhibition than the TSS, DS and NPDS algorithms.

In Table II, the computing operations of FS, TSS, DS, NPDS and the proposed algorithms are compared. The operations of absolute, addition/subtraction, comparison, and left-shift are abbreviated to "Abs.", "Add.", "Com.", and "LS.", respectively. As shown in Table II, the speed of the proposed algorithm is 17.34 times of the FS algorithm for the Garden sequence. The proposed algorithm is 1.46 times as fast as the DS algorithm on average, and has the better PSNR exhibition. Additionally, the speed of the proposed algorithm is 1.47 times of the NPDS algorithm on average, and also has the better PSNR exhibition.

TABLE I. AVERAGE PSNR FOR DIFFERENT TEST VIDEOS

	FS	TSS	DS	NPDS	**Proposed**
Foreman	32.76	32.17	32.46	32.57	32.68
Missa	39.09	38.46	38.74	38.96	39.01
Mobile	23.32	22.98	23.24	23.13	23.19
Garden	23.97	23.39	23.77	23.84	23.88

TABLE II. AVERAGE NUMBER OF OPERATIONS PER BLOCK FOR DIFFERENT TEST VIDEOS

BMA	Abs.	Add.	Com.	LS.	Total	Speedup
FS	51688.31	103376.61	424.29	0	155489.21	1
TSS	5920.94	11841.88	57.72	0	17820.54	8.72
DS	4374.57	8749.15	60.59	0	13184.31	11.79
NPDS	4191.42	8382.85	484.35	198.66	13257.28	11.73
Proposed	2830.15	5681.55	326.22	127.71	8965.63	17.34

IV. CONCLUSIONS

In this paper, a partial distortion algorithm for accelerating the process of motion estimation in video coding was proposed. Due to adopting the property of pixel's non-uniform distribution in intra-frame, the proposed approach thus increase more possibility than NPDS to early discard the incorrect MVs. The proposed algorithm need not additional calculation over NPDS for forecasting the MVs. Implemented results demonstrated that the proposed algorithm obtains better PSNR exhibition and less calculating operations than several conventional algorithms like DS and NPDS algorithms. Except its higher possibility than NPDS of discarding the invalid MVs, the proposed method possesses significantly lower calculating operations than conventional schemes, while preserving fine visual quality. However, the proposed approach does not need more calculation than NPDS to forecast the MVs.

ACKNOWLEDGMENT

The authors would like to thank the National Science Council, Tai-wan, for financially supporting this research under Contracts No. NSC 101-2221-E-244 -018.

REFERENCES

[1] H. Schwarz, D. Marpe, and T. Wiegand, "Overview of the scalable video coding extension of the h.264/avc standard," *IEEE Trans. on Circuits and Systems for Video Technology*, vol. 17, no. 9, pp. 1103-1120, 2007.

[2] T. Wiegand, G. J. Sullivan, G. Bjontegaard, and A. Luthra, "Overview of the h.264/avc video coding standard," *IEEE Trans. on Circuits and Systems for Video Technology*, vol. 13, no. 7, pp. 560-576, 2003.

[3] "Iso/iec cd 13818-2 –itu-t h.262 (mpeg-2 video): Information technology—generic coding of moving pictures and associated audio information: Video," 1995.

[4] "Iso/iec cd 11172-2 (mpeg-1 video): Information technology—coding of moving pictures and associated audio for digital storage media at up to about 1.5 mbits/s: Video," 1993.

[5] H. Yu, F. Pan, and Z. Lin, "Content adaptive rate control for h.264," *Int. J. of Innovative Computing, Information and Control*, vol. 1, no. 4, pp. 685-700, 2005.

[6] C. Stiller and J. Konrad, "Estimating motion in image sequences," *IEEE Signal Process. Mag.*, vol. 16, no. 4, pp. 70-91, 1999.

[7] L. Jianwen and E. E. Konofagou, "A fast normalized cross-correlation calculation method for motion estimation," *IEEE Trans. on Ultrasonics, Ferroelectrics and Frequency Control*, vol. 57, no. 6, pp. 1347-1357, 2010.

[8] M. G. Sarwer and Q. M. J. Wu, "Adaptive variable block-size early motion estimation termination algorithm for h.264/avc video coding standard," *IEEE Trans. on Circuits and Systems for Video Technology*, vol. 19, no. 8, pp. 1196-1201, 2009.

[9] K. H. Ng, L. M. Po, K. M. Wong, C. W. Ting, and K. W. Cheung, "Multiple block-size search algorithm for fast block motion estimation, in information," in *Proc. International Conf. Communications and Signal Processing*, 2009, pp. 1-4, 2009.

[10] N. Sangkwon and K. Chong-Min, "Activity-based motion estimation scheme for h.264 scalable video coding," *IEEE Trans. on Circuits and Systems for Video Technology*, vol. 20, no. 11, pp. 1475-1485, 2010.

[11] L. W. Lee, J. F. Wang, J. Y. Lee, and J. D. Shie, "Dynamic search-window adjustment and interlaced search for block-matching algorithm," *IEEE Trans. on Circuits and Systems for Video Technology*, vol. 3, no. 1, pp. 85-87, 1993.

[12] Z. Shan and M. Kai-Kuang, "A new diamond search algorithm for fast block-matching motion estimation," *IEEE Trans. on Image Processing*, vol. 9, no. 2, pp. 287-290, 2000.

[13] T. Jo Yew, S. Ranganath, M. Ranganath, and A. A. Kassim, "A novel unrestricted center-biased diamond search algorithm for block motion estimation," *IEEE Trans. on Circuits and Systems for Video Technology*, vol. 8, no. 4, pp. 369-377, 1998.

[14] C. D. Bei and R. M. Gray, "An improvement of the minimum distortion encoding algorithm for vector quantization," *IEEE Trans. on Communications*, vol. 33, no. 10, pp. 1132-1133, 1985.

[15] B. Montrucchio and D. Quaglia, "New sorting-based lossless motion estimation algorithms and a partial distortion elimination performance analysis," *IEEE Trans. on Circuits and Systems for Video Technology*, vol. 15, no. 2, pp. 210-220, 2005.

[16] C. K. Cheung and L. M. Po, "Normalized partial distortion search algorithm for block motion estimation," *IEEE Trans. on Circuits and Systems for Video Technology*, vol. 10, no. 3, pp. 417-422, 2000.

[17] C. H. Cheung and L. M. Po, "Adjustable partial distortion search algorithm for fast block motion estimation," *IEEE Trans. on Circuits and Systems for Video Technology*, vol. 13, no. 1, pp. 100-110, 2003.

[18] C. H. Yeh, M. T. Wu, and S. J. Chern, "Correlation-based normalized partial distortion search algorithm for motion estimation," *Optical Engineering*, vol. 44, no. 8, 2008.

[19] C. H. Yeh, M. T. Wu, and S. J. Chern, "Coarse-to-fine partial distortion search algorithm for motion estimation," *Int. J. of Innovative Computing, Information and Control*, vol. 5, no. 9, pp. 2523-2530, 2009.

Ming-Te Wu received the Ph.D. degree from the Department of Electrical Engineering Department at National Sun Yat-Sen University, Kaohsiung, Taiwan, R.O.C., in 2009. He is currently an assistant professor in Information Technology Department at Kao Yuan University, Kaohsiung, Taiwan. His research interests include image/video processing, video de-interlacing, transcoding and motion estimation.