A Pentagonal Fast Block Matching Algorithm for Motion Estimation Using Adaptive Search Range

Yu-Chan Lim, Kyeong-Yuk Min, Jong-Wha Chong

Dept. of Electronic Engineering, Hanyang University, Seoul, Korea

ABSTRACT

In this paper, we present a PFBMA (Pentagonal Fast Block Matching Algorithm) using adaptive search range. The proposed algorithm classifies images into dynamic and static images by a motion equation and performs block matching using adaptive search range. The motion equation calculates the degree of motion in a MB (Macro Block). A MB declared as static by this equation is matched with a small fixed search range and a MB declared as dynamic is estimated with three different search ranges. In this search pattern, more points are allocated in the region of high MV (Motion Vector) probability which is found by smaller matching error and these searching points appear like a pentagonal shape. This proposed pentagonal search pattern also considers search direction to avoid a local minimum. The experimental results show that the proposed algorithm achieves the low computational complexity and better image quality compared with other conventional fast block matching algorithms.

1. INTRODUCTION

In recent years, studies on fast block-matching algorithms for significantly reducing the computational complexity have achieved more and more image quality and many effective algorithms have been proposed. Motion estimation procedure produces displacement vector of a block between two consecutive frames. In the reconstruction of current frame, these motion vectors between current and previous frame are used. SAE (Sum of Absolute Error) is generally used for block matching method, and equation (1) shows the SAE. After obtaining these values, the position of the block with the least value is chosen as the motion vector.

$$SAE = \sum_{m=x}^{x+N-1} \sum_{n=y}^{y+N-1} \left| I_k(m,n) - I_k(m+dx, n+dy) \right| \quad (1)$$

$$-w \le dx,\ \mathrm{dy} \le \mathrm{w}$$

Where $I_k(m,n)$ represents the luminance in the current block of $N \times N$ pixels at coordinates (m,n) and $I_k(m+dx,n+dy)$ represents the corresponding pixel value in the block of the previous frame at the coordinates $(m+dx,n+dy)$.

FSBMA (Full Search Block Matching Algorithm) that shows relatively good performance in image quality produces displacement vectors by searching all pixels in the search area. Despite the simplicity and ease of hardware implementation, FSBMA still requires heavy computational cost. Therefore simple and efficient algorithms, which reduce the computational complexity, are proposed [1]-[9]. TSS (Three Step Search) method searches the area under the assumption that the SAE decreases the monotonically and significant computational reduction and good error performance. But there are some possibilities of motion vector to be trapped in the "near-local minimum," so that it has the possibility making incorrect motion vector [3]. SES (Simple and Efficient Search) algorithm compares the each step SAE and chooses one direction for the next search, which has the least SAE decreasing direction [6]. The performance is superior for the small motion of the images. But the performance degrades regarding the large and irregular movement image.

In this paper, proposed PFBMA classifies search ranges for static and dynamic mode from D_{AB} that means degree of motion and can be calculated by SAE. The search range and points are fixed in the static image, and are classified into three search modes by D_{AB} in the dynamic image. There are more search points on the direction that has the smallest SAE among other search points, and there is also one search point in the opposite direction, so that the search points form the pentagonal shape. The proposed algorithm reduces the computational complexity and achieves better image quality than the conventional fast block matching algorithms.

2. THE PROPOSED PFBMA ALGORITHM

The proposed PFBMA adaptively decides the search range with SAE values, so that it searches the range of the high probability for a searching MV. In the proposed algorithm, search range is adaptively decided for each of

$D_{AB} \leq 1$ and $D_{AB} > 1$ on Equation (2).

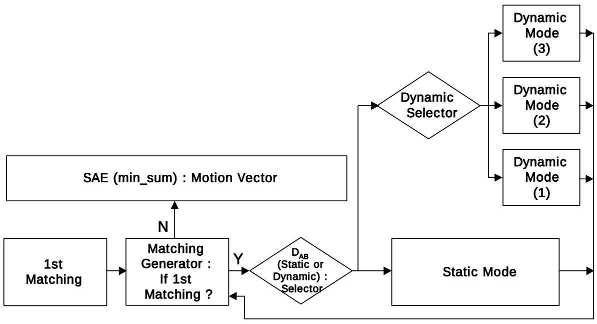
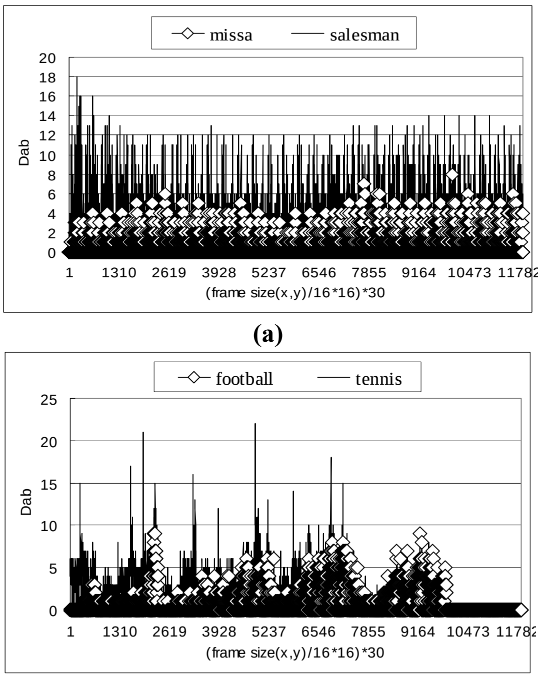


Fig. 1. The block diagram of the PFBMA



(b)

Fig. 2. The D_{AB} distribution derived from the PFBMA for 30 frames.

$$D_{AB} = \left| \frac{A(SAE_{center}) - B(Min_{SAE})}{A(SAE_{center})} \right| \qquad (2)$$

The conventional DSWA (Dynamic Search-Window Adjustment) exploits the search point with the smallest and second smallest SAE [3]. However, the proposed algorithm decides the adaptive search range, based on equation (2) and figure 4, using the point (B) with the minimum SAE in the first step and the point (A) on the center of MB in the second step. In order to search the correct MV, MV is searched on comparison with the point (A) as center in the static image where the possibility of MB is high to be in the center. $A(SAE_{center})$ in equation(2) represents the SAE value on the center (A) in figure 4, and $B(Min_{SAE})$ means the minimum SAE value of 8 point(1st) around $A(SAE_{center})$. Therefore, D_{AB} is used as a criterion value to decide the adaptive search range. The example is showed in figure 4 and 6.

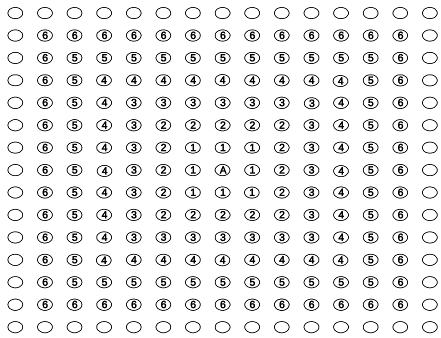


Fig. 3. Hierarchical layer processing [8].

2.1. PFBMA ALGORITHM: Case_1 ($D_{AB} > 1$)

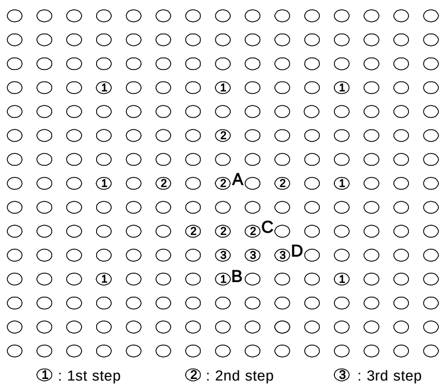


Fig. 4. The PFBMA procedure (w=±7). The motion vector is A→B→C→D = (2, 3) in the example. If (A), (B): SAE (A) small or equal than SAE (B). → Search point (C). →If (A), (C): SAE (A) large than SAE (C). → Search point (D).

The PFBMA algorithm for the case that $D_{AB} > 1$ is summarized as follows (shown in the figure 4):

Step 1: Operate the block matching for 8 points except the center (A) to find point (B) having the least SAE.

Step 2: Compare SAE value on point (A) with least SAE value on point (B). The block matching searches 6 points according to result of the comparison.

Step 3: Find point (C) with least decision value out of the 6 points searched by the block matching. And then, compare SAE value on point (A) with that on point (C).

The block matching searches 3 points are searched according to result of the comparison. Finally, the vector from center (A) to the point (D) with least SAE value out of the searched 3 points is regarded as a final motion vector.

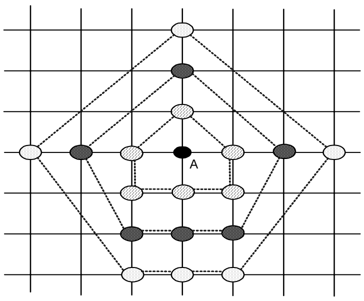


Fig. 5. An example of Pentagonal of the search 2nd step: D_{AB} of the three-search pattern (If B(Min_{SAE}) position of bottom).

Figure 4 show that the proposed algorithm uses not only the decided direction but also the opposite direction (left, right, top) 2-pixel far from the point (A) for matching. Therefore, this method reduces the possibility of the near-local minimum and improves the reconstructive image quality and also compensates the motion in the image having variable motion. In addition, the proposed PFBMA can find the correct MV by the opposite matching and comparison routine with pentagonal shape of search points. It is because the proposed algorithm selects one out of the three pentagonal patterns as to D_{AB} value that has irregular distribution as shown in the figure 2(b), without concerning dynamic or static motion, and does matching with the selected pentagonal pattern in the figure 5.

Also as a result of adopting the summation-half-stop technique, it maintains the good characteristics compared with the conventional algorithms. The summation-half-stop technique (X_{shs}) is summarized as follows [6]:

$$Total\_error = Error_{sum} - X_{shs}, \quad X_{shs} = Error_{BLK} - Error_{ACC}$$

$Error_{sum}$: Sum of error at each step.
$Error_{BLK}$: Match error within one block.
$Error_{ACC}$: SAE accumulated until SAE accumulated > minimum SAE so far in the search window.

MV cannot occur in the block that has larger error summation than the previous error summation because MV is obtained from the block having the minimum error. Therefore during the block matching if the previous error summation is large then accumulation is stopped and matching for next block is implemented. This results the reduction of the matching complexity.

2.2. PFBMA ALGORITHM: Case_2 ($D_{AB} \le 1$)

The figure 3 and table 1 show the results of the hierarchical simulation for FSBMA. From table 1, PSNR values for pixels are different as to images. From this fact, the proposed algorithm can improve PSNR for less error by searching compared with conventional fast block matching algorithms.

Therefore, the correct MV can be found by searching MV from the point which is 2-pixel away from the starting point (a) considering that error is minimum from the distance 2 pixels in the static image as shown in the figure 6. It means that the correct MV can be found by the almost fixed D_{AB} in the static image as shown in the figure 2 (a).

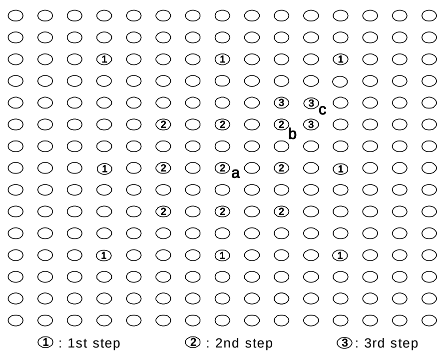


Fig. 6. The PFBMA procedure (w=±7). The motion vector is A→B→C→D = (3, −3) in the example. If (a), (b): SAE (a) large than SAE (b) →Search point (c).

3. EXPERIMENTAL RESULTS

The PFBMA algorithm is simulated using the CIF (90frames/s with 352×240 pixels/frames and 352×224 pixels/frames) and the CCIR-601 (90frames/s with 352×288 pixels/frames). It uses the search range of ±7 pixels.

In the table2 and table3, Sub-CIF, Sub-CCIR-601 videos are 2:1 down sampled and low-pass filtered by an anti-aliasing filter. Table2 gives us a measure of the static image (missa), the dynamic image (football), (table tennis) that has relatively wide and irregular movement. The experimental results describe image quality of PSNR and the computational complexity.

From the table 2, all algorithms have the better PSNR value except for FSBMA. Especially for image quality, PFBMA is very close to FSBMA at Sub-CIF and Sub-CCIR-601. Following these results, we can know that this algorithm shows a very better ability with the TSS, SES and NTSS for not only the large or small images but also small and irregular images of all. Also, In spite of the change of the resolution, PFBMA achieves better image quality than conventional fast block matching algorithms.

Table 3 shows averages of the computational complexities of the conventional block matching and proposed algorithms. From the table 3, the proposed algorithm can reduce the average of the computational complexity into 5.71%, and 10.42% for TSS, 6.69% for SES and 7.09% for NTSS. The computational complexities for the Sub-CIF and Sub-CCIR-601 also reduce into 5.69%. In other words, the proposed PFBMA can achieve the average decrement of the computational complexity capacity by 94.3% less than FSBMA, and the PSNR improvement better than SES, TSS and NTSS.

4. CONCLUSIONS

This paper proposed the algorithm that D_{AB} classifies search ranges for the case of $D_{AB} > 1$ and $D_{AB} \leq 1$. From the simulation results, the proposed algorithm gains much better image quality compared with the conventional partial search algorithms for not only the large or small images but also irregular images. The proposed pentagonal search pattern method also considers search direction to avoid a local minimum. PFBMA, a new search algorithm was proposed for the further reduction of computational complexity for motion estimation and adopted the summation-half-stop technique to reduce the computational complexity.

5. REFERENCES

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TABLE Ⅰ
Center Position using the FSBMA Based on
PSNR Matching Criterion [dB]

In pixel	PSNR[dB]			
	Tennis	Football	Missa	Salesman
1	24.26	18.59	36.42	34.42
2	26.31	19.83	**37.40**	**35.47**
3	27.31	20.68	37.38	35.25
4	27.74	21.29	36.04	35.31
5	28.10	21.67	35.45	35.35
6	**28.17**	**21.89**	35.09	35.32

TABLE Ⅱ
AVERAGE PSNR OF THE FIRST 90 FRAMES

Algorithm	PSNR[dB]			
	Tennis	Football	Missa	Average
FSBMA	22.034	22.080	37.672	27.262
TSS	21.334	21.482	35.799	26.205
SES	20.756	20.965	35.273	25.664
NTSS	20.993	20.941	36.712	26.215
PFBMA	**21.497**	**20.952**	**37.350**	**26.599**
Algorithm	Sub-CIF & Sub-CCIR-601			
FSBMA	24.478	21.100	39.431	28.336
TSS	24.178	20.934	38.867	27.993
SES	23.189	20.078	38.156	27.141
NTSS	23.689	20.667	39.356	27.904
PFBMA	**24.344**	**20.856**	**39.412**	**28.204**

TABLE Ⅲ
AVERAGE COUNT MATCHED OF THE FIRST 90 FRAMES
(per pixels)

Algorithm	Computability (×1000)				
	Tennis	Football	Missa	Average	%diff
FSBMA	18565	19960	24144	20889	100%
TSS	1935	2089	2508	2177	10.42%
SES	1248	1347	1602	1399	6.69%
NTSS	1320	1423	1708	1483	7.09%
PFBMA	**1084**	**1090**	**1407**	**1193**	**5.71%**
Algorithm	Sub-CIF & Sub-CCIR-601				
FSBMA	4274	4274	5622	4723	100%
TSS	476	482	626	528	11.17%
SES	314	313	403	343	7.26%
NTSS	325	329	425	359	7.60%
PFBMA	**236**	**261**	**312**	**269**	**5.69%**