A NEW CROSS DIAMOND SEARCH ALGORITHM FOR BLOCK MOTION ESTIMATION

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ABSTRACT

In block-matching motion estimation, the search pattern with different shape and size can impact the search performance very much. Based on the study of the search pattern and the motion vector distribution, a new cross-diamond search (NCDS) algorithm using the asymmetric diamond search pattern is proposed in this paper, in which two asymmetrical search patterns are employed instead of other popular square-shaped or diamond-shaped search patterns. Simulation results demonstrate that the proposed NCDS algorithm outperforms other well-known fast block matching algorithms greatly. And the performance is also better than the most recent cross diamond search (CDS) algorithm in terms of mean absolute distortion and the number of the search points.

1. INTRODUCTION

Block-matching motion estimation (BMME) is exploited by many video-coding techniques/standards, such as ISO MPEG-1/2/4 and ITU-T H.263, to reduce the temporal redundancy between the successive frames. BMME aims at finding a block from a reference frame (past or future frame) that best matches a predefined block in the current frame. The minimizing of a matching criterion is used, which in most cases is the mean absolute distortion (MAD) between this pair of blocks. The best-matched block in the search window producing the minimum block distortion (MBD) is searched for. However, the motion estimation is quite computationally intensive if the full search (FS) is used. Therefore, fast block matching algorithms (BMAs) are highly desired to speed up the process without serious distortion. Many efficient methods have been developed, such as the three-step search (TSS) [1], new three-step search (NTSS) [2], four step search (4SS) [3], block-based gradient descent search (BBGDS) [4], diamond search (DS) [5] and cross diamond search (CDS) [6]. These fast BMAs use different search patterns and search strategies trying to find the optimum motion vectors more efficiently and effectively compared with the FS.

In this paper, a new fast BMA with two asymmetrical diamond search patterns is proposed, called the new cross diamond search (NCDS) algorithm. In Section 2, the relationships between the search pattern and the motion vector probability (MVP) distribution characteristics are analyzed. The NCDS algorithm will be explained in Section 3. In Section 4, the simulation results are given out and NCDS algorithm is compared with other fast BMAs, and the conclusion is drawn in Section 5.

2. SEARCH PATTERN AND THE MVP DISTRIBUTION CHARACTERISTICS

In the fast BMAs, a search pattern with different shape and size has significant impact on the efficiency and effectiveness of the search results. The search pattern must be designed according to the characteristics of the MVP distribution to obtain the most improvement. As a fact, every new understanding or recognition of the MVP distribution characteristics is followed by some important updates on the search pattern and the significant enhancement on the search results. TSS using the square-shaped search pattern (SSSP) with the different intervals in the different steps is based the assumption that the motion vectors distribute uniformly around the search center, so the search points distribute uniformly in the search window. After the examination on the motion field of the real world image sequences, the center-biased characteristic of MVP distribution is brought forward and some fast BMAs are proposed based on it, such as NTSS, 4SS and BBGDS. These new algorithms use some smaller SSSPs in the first step trying to find the motion vector in the most possible region. Additionally, the halfway-stop technique is incorporated in the algorithm, which becomes the popular part in the later BMAs. The recognition of the MVP distribution characteristics of the real world sequences has some further evolution in DS and CDS. The diamond center-biased (DCB) and cross center-biased (CCB) MVP distribution characteristics are discovered, and the diamond-shaped and cross-shaped search patterns are exploited respectively in DS and CDS. They can gain the similar or even better performance by computing less search points, especially for the stationary or quasi-stationary image sequences. Three types of search patterns are used in CDS, cross-shaped and large/small diamond-shaped search pattern, to make the speed-quality trade off. Almost all the search algorithms incorporate the coarse search in the first step and the refined search in the following steps, based on the basic hypothesis that the distortion of the matching blocks increases monotonically away from the global minimum point in all directions [2].

For an in-depth study on the MVP distribution, eight well-known sequences with different motion speeds and scopes (Coastguard, CIF×300 frames; Football, SIF×125 frames; Forman, CIF×300 frames; Garden, SIF×115 frames; Hall, CIF×300 frames; Miss America, CIF×150 frames; Stefan, SIF×300 frames; Tennis, SIF×150 frames), are computed to obtain the true motion vectors (MVs) by the FS and MAD as the block distortion measure (BDM) is employed. Block size is 16×16 and search window size is ±7. The MVP distribution accumulated at the corresponding positions of the one-quarter search window is shown in Table 1. The DCB and CCB MVP distribution characteristics can be drawn from Table 1. The cross-shaped search pattern (CSSP) is adopted effectively as the initial search pattern in the coarse search of CDS. But the statistical data of the MVs shows that the large diamond search pattern is not used economically for its big size. Because the first step (coarse search) gives us the most possible direction of the motion vector's location. While we are approaching the optimal solution closer and closer in some certain search paths, the candidate positions of the motion vector are more limited in a certain region, which means the large search pattern is wasteful in the middle steps. The distribution of MVs after MBD in the first step having been calculated can demonstrate the detail. Table 2 lists the distribution of MVs on the condition below:

Condition 1: the point (2, 0) has the MBD in the cross-shaped search pattern (Table 2*a*);

Condition 2: the point (0, 2) has the MBD in the cross-shaped search pattern (Table 2*b*).

The MVP distribution on Condition 1 or 2 shows the positive correlation between the location of the MBD in the first step and the most possible direction of the motion vector. In Table 2*a*, MVs are concentrated obviously in the horizontal direction; in Table 3*b*, MVs are concentrated in the vertical direction. The correlation of the conditional MVP distribution is observed as another most dominant characteristic. Based on this characteristic, the search points in the direction or near the MBD point in the previous step are the proper candidate ones to be selected to compose the search pattern in the next step, and the search pattern should be more converged in the horizontal or vertical direction.

A new cross diamond search (NCDS) algorithm is proposed in the next section.

3. NCDS ALGORITHM

3.1. Search patterns

The NCDS algorithm uses the CSSP as the initial one in the first step, the same as CDS (depicted in Fig.1). As the positive correlation between the location of MBD in the coarse search and the most possible direction of MV, the large diamond-shaped search pattern is compressed in horizontal and vertical direction respectively to achieve two new search patterns: horizontal diamond-shaped search pattern (HDSP) and vertical diamond-shaped search pattern (VDSP) (Fig. 1), which are used in the middle steps of NCDS algorithm. In both patterns, the point at a distance of 2 from the center point is called the distant point and the point at a distance of 1 is called the near point.

3.2. The NCDS algorithm

HDSP and VDSP are repeatedly used if the MBD does not occur at the center of the search pattern. The switching strategy of different patterns is determined by the location of the local MBD in the last used search pattern.

Step 1: (starting) The CSSP is centered at the origin of the search window and set as the current search pattern (CSP) in consideration of CCB MVP distribution. BDM is checked with MAD criterion on all nine points in the CSP.

Step 2: (1^{st} switching) If MBD occurs at the center of the CSP, the search stops; otherwise, update the CSP, put the center of the CSP on the MBD point and go to step 3. If MBD occurs at the points in the horizontal direction, the CSP is switched to the HDSP; otherwise, the CSP is switched to the VDSP. (Fig.2*a*)

Step 3: (2^{nd} switching) If MBD occurs at the center of CSP, go to step 4; otherwise, update the CSP and repeat step 3. If MBD occurs at the near point, the CSP is switched to the other kind of diamond search pattern; otherwise, maintain the CSP unchanged. (Fig.2*b*)

Step 4: (ending) Check other two points (the hollow squares in Fig.1). Select the MBD point from these two points ad the central point as the final result of the MV.

3.3. Analysis on NCDS algorithm

First, although the HDSP and VDSP are not symmetrical, the number of the new points to be checked in each middle step is the same (three gray points in Fig.2), which is no more than that of DS or CDS. In the last step, only two points need to be checked (in some cases one of them has been checked in the previous step), so NCDS can save at least 2 check points compared to DS and CDS.

Second, HDSP and VDSP are used alternately by the indication of the previous step. So the number of the search steps is reduced to the minimum as the search path is the most direct one; and the number of search point is the minimum as the size is the smallest, only five points.

Third, the HDSP and VDSP both have two distant points with distance of 2 from the center point, which can avoid the trap of local minimum distortion and improve the performance.

4. EXPERIMENTAL RESULTS

The NCDS algorithm is simulated using the luminance of some popular sequences which consist of different types of motion content: “Miss America”, “Football”, “Stefan” and “Coastguard”. The MAD as the BDM, block size of 16, and search window size of ±7 is used for all BMAs. The MV obtained by FS is considered as the true MV. The proposed DDS algorithm is compared against five other BMAs: FS, NTSS, BBGDS, DS, and CDS in six aspects: 1) MAD; 2) mean square error (MSE); 3) number of search points (NSP) for each block; 4) peak signal noise ratio (PSNR) of the compensated frame; 5) distance from the true MVs; and 6) probability of finding the true MVs (they are all the average values over all frames in the sequence).

Table 3 lists the simulation results. When applied to stationary or quasi-stationary sequence, such as “Miss America”, the NCDS and CDS algorithm have the similar performance according to the PSNR of the compensated frame while the search speed (measured by the number of search point) of NCDS is slightly faster than that of CDS. But when applied to the sequence having large motion content and various motion directions, the NCDS can speed up the search progress significantly. Take the sequence “Coastguard” as the example, the NSP of NCDS and CDS are 12.831 and 16.857 respectively. The NCDS achieves 31.38% speed-up with only 0.008dB of degradation in the quality, and other aspects of NCDS and CDS are all quite similar. In “Football” and “Stefan”, NCDS gives about 14.85% and 27.87% speed-up while introducing only 0.126dB and 0.033dB degradation respectively. Fig.3 and 4 illustrate the frame-by-frame comparison of PSNR and NSP after applying FS, NTSS, DS, CDS and NCDS to “Coastguard” and “Stefan”.

5. CONCLUSION

In this paper, the new cross diamond search algorithm is proposed using the cross-shaped and horizontal/vertical diamond-shaped search patterns. Experimental results show that the proposed NCDS algorithm improves the search speed significantly, up to 31.38% compared to CDS with almost the same distortion. The NCDS algorithm outperforms other popular fast BMAs in efficiency and effectiveness, and is suitable for a variety of video applications.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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Table 1 Average distribution of MVP for search window ±7

Radius $\|p\|$ (vert.)	Radius $\|p\|$ (hor.)							
	0	1	2	3	4	5	6	7
0	0.3127	0.1511	0.1394	0.0379	0.0163	0.0127	0.0059	0.0185
1	0.0618	0.0388	0.0166	0.0096	0.0074	0.0058	0.0042	0.0112
2	0.0122	0.0092	0.0057	0.0061	0.0032	0.0020	0.0018	0.0059
3	0.0056	0.0045	0.0032	0.0045	0.0022	0.0014	0.0016	0.0048
4	0.0040	0.0027	0.0021	0.0022	0.0018	0.0010	0.0013	0.0039
5	0.0019	0.0029	0.0015	0.0020	0.0012	0.0008	0.0008	0.0040
6	0.0035	0.0019	0.0011	0.0014	0.0018	0.0007	0.0012	0.0034
7	0.0028	0.0019	0.0015	0.0031	0.0024	0.0020	0.0022	0.0113

Table 2 The distribution of MVs after the first step search

(*a*) The distribution of MVs on *Condition 1*

Radius p (vert.)	Radius p (hor.)							
	0	1	2	3	4	5	6	7
-2	0	52	231	252	109	96	86	300
-1	0	199	883	754	668	960	284	563
0	0	0	55559	13695	3306	2207	841	2245
1	0	182	986	556	313	271	235	725
2	0	70	223	286	140	112	121	463

(*b*) The distribution of MVs on *Condition 2*

Radius p (vert.)	Radius p (hor.)						
	-3	-2	-1	0	1	2	3
5	51	35	62	145	61	32	57
4	58	102	123	472	183	83	62
3	106	129	277	1068	407	219	146
2	234	263	510	2921	557	168	167
1	85	92	138	0	116	133	311
0	46	0	0	0	0	0	93

Table 3 Simulation results of NCDS compared to other BMAs

	MAD	MSE	NSP	PSNR (dB)	Distance	Probability (%)
Miss America sequence						
FS	2.3485	11.963	225	37.402	0.0000	100.000
NTSS	2.3726	12.110	21.534	37.348	1.6968	0.69922
BBGDS	2.3817	12.139	12.235	37.337	1.8607	0.65759
DS	2.4466	12.815	17.314	37.097	2.3896	0.57315
CDS	2.3845	12.234	12.419	37.305	1.8381	0.66109
NCDS	2.3839	12.245	12.130	37.302	1.8253	0.66844
Football sequences						
FS	10.467	381.59	255	22.389	0.00000	100.000
NTSS	10.828	414.12	22.313	22.035	0.88855	46.446
BBGDS	11.122	446.17	15.282	21.720	0.89305	64.942
DS	10.964	429.07	17.376	21.892	0.56825	90.670
CDS	11.049	437.77	15.634	21.803	0.61480	89.042
NCDS	11.220	450.89	13.613	21.677	0.71875	84.178
Coastguard sequences						
FS	4.6112	60.621	255	30.602	0.00000	100.000
NTSS	4.6562	62.449	21.291	30.555	0.08497	0.97716
BBGDS	4.7046	65.107	14.540	30.465	0.11053	0.98190
DS	4.6692	63.739	17.667	30.518	0.08024	0.98918
CDS	4.6705	63.692	16.857	30.521	0.08082	0.98892
NCDS	4.6747	63.997	12.831	30.513	0.08358	0.98747
Stefan sequences						
FS	10.686	449.91	255	23.594	0.0000	100.000
NTSS	11.327	502.46	25.525	23.108	1.1193	0.81635
BBGDS	12.183	579.32	17.064	22.273	1.5606	0.76034
DS	11.685	537.01	19.477	22.714	1.3362	0.56029
CDS	11.764	543.83	18.818	22.646	1.3826	0.80019
NCDS	11.818	549.13	14.716	22.613	1.4264	0.78159

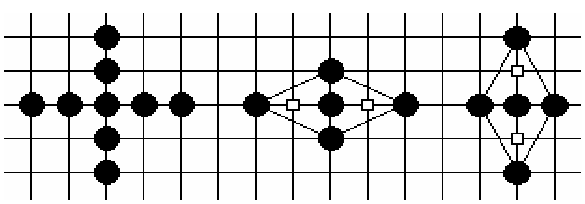
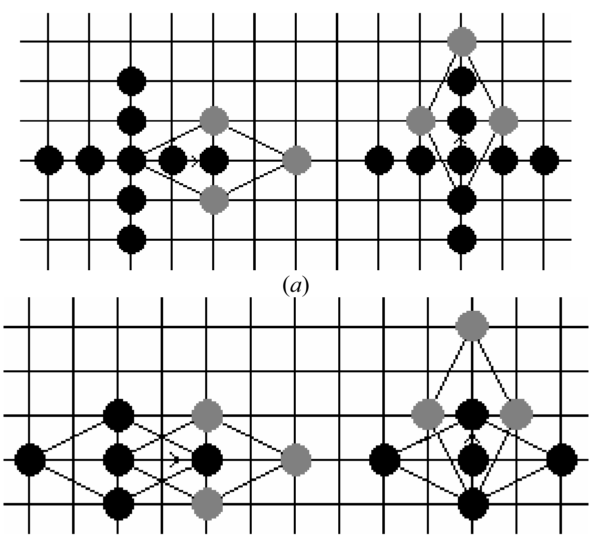


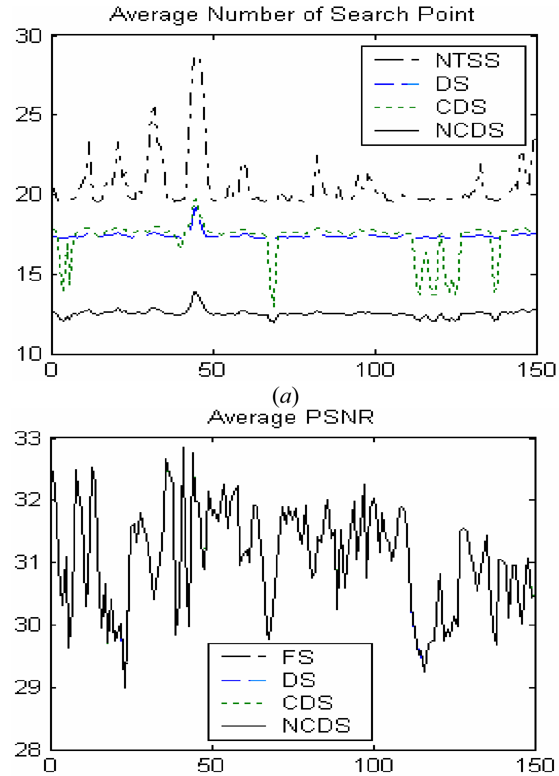
Fig.1. Search patterns used in NCDS: CSSP, HDSP and VDSP



(*a*)

(*b*)

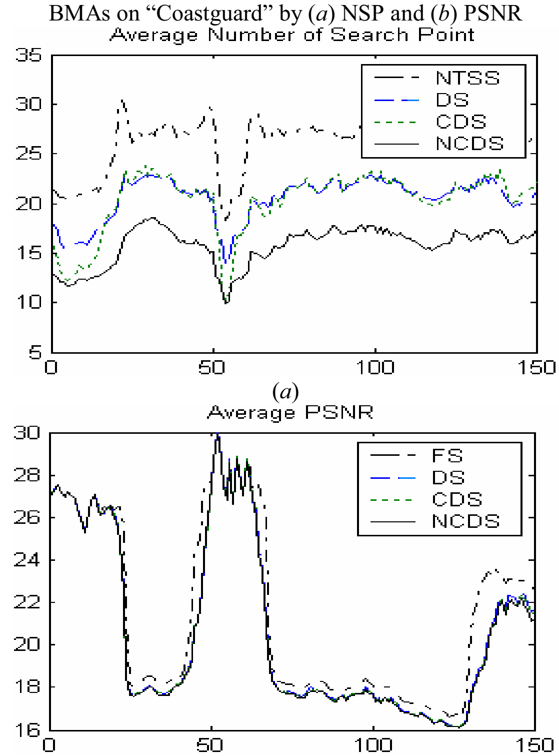
Fig.2. The switching strategy of NCDS in (*a*) first switching and (*b*) second switching



(*a*)

(*b*)

Fig.3. Frame-wise performance comparison between different BMAs on "Coastguard" by (*a*) NSP and (*b*) PSNR



(*a*)

(*b*)

Fig.4. Frame-wise performance comparison between different BMAs on "Stefan" by (*a*) NSP and (*b*) PSNR