Advances in Dynamical Systems and Applications (ADSA).
ISSN 0973-5321, Volume 16, Number 2, (2021) pp. 591-603

https://www.ripublication.com/adsa.htm

Block Based Motion Estimation Algorithms: Analysis

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Abstract

The latest video coding standards and techniques are being developed for multimedia applications and the immense importance is given to h.26x series for video processing. Motion estimation process is being used to decrease the amount of data needed for data transmission and storage. Motion estimation process is inevitable as it eradicates the temporal redundancy in video sequences between successive frames. This paper describes motion estimation algorithms, their search procedure, complexity, advantages, and limitations. A topical survey conducted on motion estimation algorithms which includes full search algorithm, many fast search and full search block-based algorithms is given in this paper. A complete assessment on motion estimation algorithms based on the empirical results conducted on several test video sequences is reported.

Keywords: Motion estimation, videocoding, minimum block distortion measure, temporal / spatial redundancy.

1. INTRODUCTION

Online videos are the latest trend in present day technology and it has a great scope in future. Video coding reduces the raw data in video sequence by eliminating spatial and temporal redundancies. Motion estimation technique is used in video coding to remove the temporal redundancy in video signal. Block based motion estimation technique is commonly used motion estimation technique which is being used in several video coding standards for example h.26x series, MPEGX series [1] – [6].

The full search (FS) algorithm is an optimal algorithm but requires a greater number of computations. In order to overcome this problem, many fast block matching algorithms were developed. This paper gives the complete analysis of the algorithms from the past 40 years and the comparison is drawn between some known algorithms in terms of computational complexity and distortion. The rest of the paper is organized as follows.The section 2presents the analysis of fast search blockbasedmotion estimation algorithms. The section 3 presents the comparison of some famous algorithms. Lastly, the conclusions are presented in section 4.

2. BLOCK BASED MOTION ESTIMATION ALGORITHMS

The block-based motion estimation algorithm is mainly aimed to estimate the motion (motion vector) between macro block of current frame and perfectly matched candidate block of reference frame. The simple matching criterion is sum of absolute difference (SAD). It is used to calculate the distortion between the macro block of current frame and candidate block in reference frame. The *SAD*between an$M \times N$ size macroblock withtop-left corner at (p, q) and an$M \times N$ size candidate block withtop-left cornerat $(p + x, q + y)$ is defined in the eq (1).

$$SAD\ (x,y)=\sum_{i=0}^{M-1}\sum_{j=0}^{N-1}\left|I(p+i,q+j)-R(p+x+i,q+y+j)\right| \qquad (1)$$

where I (., .) and R (., .) denotecurrent frame and reference frame pixelvalues. The co-ordinates of motion vector $x$and $y$are defined in the eq (2).

$$(x,y)=\arg\min_{(\hat{x},\hat{y})\in R} SAD(\hat{x},\hat{y}) \qquad (2)$$

where $R= \{(\hat{x},\hat{y}) \mid -s\leq \hat{x}, \hat{y} \leq d\}$ and$d$represents the search range. It is obvious from eq (2) that the *SAD*criterioninvolves $(M \times N)-1$ addition operations,$M \times N$absolute operations and $M \times N$subtraction operations.So, we can calculate that one SAD computation with $3 \times M \times N$ operationsroughly.

The FS algorithms requires huge computational cost. To decrease the cost, several fast searchblock-based motion estimation algorithms [7]- [50] are proposed by having a small drop in distortion i.e. peak signal- to- noise ratio (*PSNR*). These algorithms may be classified into the five categories: reduction innumber of search points [7]–[27], predictive motion estimation [28]–[34], adaptive search pattern switching strategy [35]–[38], multi-resolution motion estimation [39]–[45] and fractional-pixel interpolation [46]–[50]. The recently used fast search block-based motion estimation algorithms fall into any of the above category or may use any combination of them.

Usually, the fast search block matching algorithms which falls under first category i.e., reduction in number of search points category [7]- [27] are given huge importance and developed in large number due to the following assumption. The presumption is that the error between a macroblock and a candidate block increases continuously as the search point moves away from optimal search point.In three step search (TSS)algorithm [7], the search processapplies rectangular search pattern withnine search points as shown in Fig. 1 (a). The step size at first step is obtained by rounding $s/2$, where s is search range. The step size becomes halves in the following steps and if step size becomes one at any step, then the search terminates as shown in Fig. 1 (b). and Fig. 1 (c). Totally, this TSS algorithm takes$\log_2(s + 1)$steps and $1 + 8[\log_2(s + 1)]$ checking points.

The updated version of TSS algorithm, new three step search (NTSS) algorithm [9], proposed by Renxiang Li et al. While taking comparison between NTSS and TSS, NTSS has better motion prediction quality and computational complexity although NTSS has same regularity and simplicity as those of TSS algorithm. The main reason for the success of NTSS algorithm is that the motion vector distribution of real-world video sequences is center biased. NTSS algorithm carries at the further checking of 8 additional search points (total 17) along with the original search point of TSS. NTSS algorithm employs half way stop technique to identify stationary and quasi stationary blocks.

In the first search step of NTSS,the minimum BDM point is located at three possible locations: (1) the minimum BDM point may be located at the search window centeras shown in Fig. 2 (a). In this case, search stops, and block is considered as a stationary block with (0,0) motion vector. (2) the minimum BDM point may be locatedat any one of the eight search points around the search centeras shown in Fig.2 (b). Here,the search stops after checking the 8 search points around the minimum BDM and the block is considered as a quasi-stationary block. (3) the minimum BDM point may be locatedat any one of the remaining eight search points then the block is neither stationary nor quasi stationary.The search undergoes entire TSS procedure.

The algorithm which searches along only one direction at a time i.e., either horizontal or vertical is called one-at-a-time search (OTS) algorithm [12]. It is a one-dimensional gradient descent search algorithm. The search procedure of OTS algorithm takes place in the following way. In the first step, OTS carries out the search in horizontal direction until the minimum BDM value lies between two higher BDM values. In the second step, OTS carries out the search in vertical direction until the minimum BDM value is found out. The example for illustrating the OTS search procedure to locate motion vector (3,3) is shown in Fig. 3 (a).

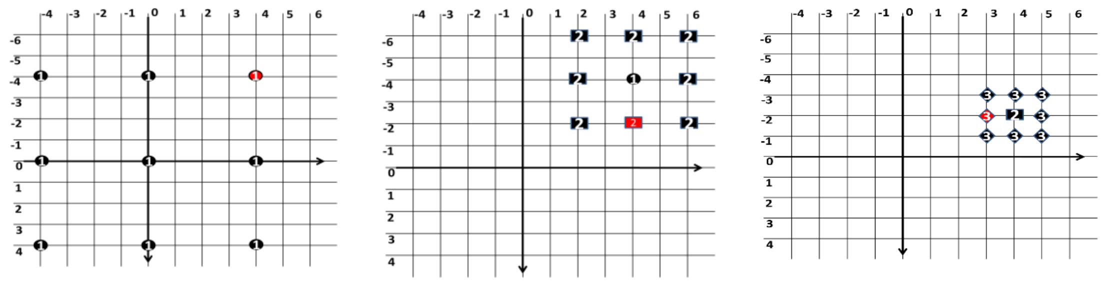
Block based gradient descent search (BBGDS) [14] and directional gradient descent search (BGDS) [15] are the examples for OTS based motion estimation algorithms. BBGDS is an example for the 2-D gradient descents search motion estimation algorithm. In BBGDS the search procedure for the minimum BDM block is carried along the block based gradient descent direction. At every search step, square search pattern comprising of nine search points is applied. The motion estimation is done by surrounding the search center in all the eight directions with eight search points. The search terminates when the minimum BDM search point is placed at the search center. The example for the illustration of BBGDS search procedure to locate motion vector at (-2-2) is shown in Fig.3 (b).

The search procedure for the DGDS is done in the following way. At first, the eight directional minimum search points are found out by using OTS principle in eight directions. In the second step, the minimum one among the eight directional search points is taken as the search center for the next step. This search is carried out until the least one among the eight directional search point is search center. An example for the illustrating of DGDS search procedure to locate motion vector (5, 2) is shown in Fig. 3 (c).

One of the most prominent motion-based algorithms is diamond search (DS) algorithm [16]-[17]. It searches motion vectors with two search patterns which are of in diamond shape. One is large in size i.e., large diamond search pattern (LDSP) and other one is small in size i.e., small diamond search pattern (SDSP). Mainly, LDSP spots a small area of global minimum and the SDSP traces the global minimum in that specified small area. The search procedure for DS algorithm is as follows. The first step is to check a search points of LDSP placed at search window center. The SDSP is placed at minimum BDM point if the minimum BDM point is search center. The LDSP is placed at minimum BDM point if the minimum BDM point is not a search center. At any search step, if the minimum BDM point is search center then the search stops and the minimum BDM point of SDSP becomes final motion vector. An example to illustrate DS algorithm search procedure to find motion vector at (3, -2) is shown in Fig. 4 (a).

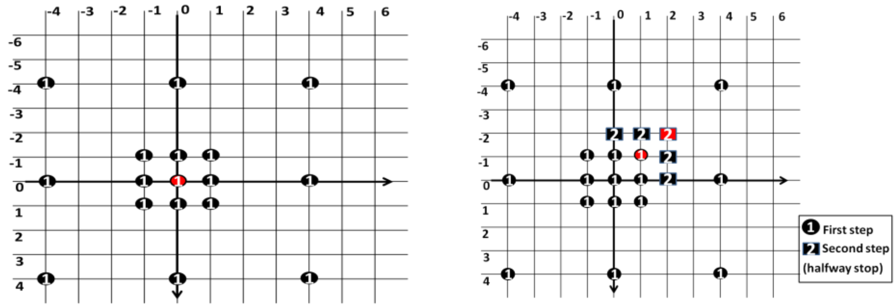
The hexagonal search (HS) algorithm [18] improves the search speed of DS at the slight degradation in PSNR. Indeed, the main modification in HS over DS is that the coarse search in HS is performed bya large hexagon search pattern. When compared to LDSP, the large hexagon search pattern is closer to circle. So, the results obtained by HS are more accurate than those of DS. The Fig. 4(b) shows an example of searching motion vector by HS algorithm.

The search speed of HS is further enhanced by some algorithms [19] - [21] which mainly speeds up the coarse search procedure of HS. An enhanced HS (EHS)in [19]examines only a most probable part of coarse search, an enhanced hexagonal search using point-oriented inner search (EHS-POIS)in [20] examines only two most probable coarse search points and the algorithm an enhanced hexagonal search using direction-oriented inner search (EHS-DOIS) in [21] examines only one most probable coarse search point. These algorithms calculate group-sum distortions with a few computations and utilize them for selecting these most probable search points.



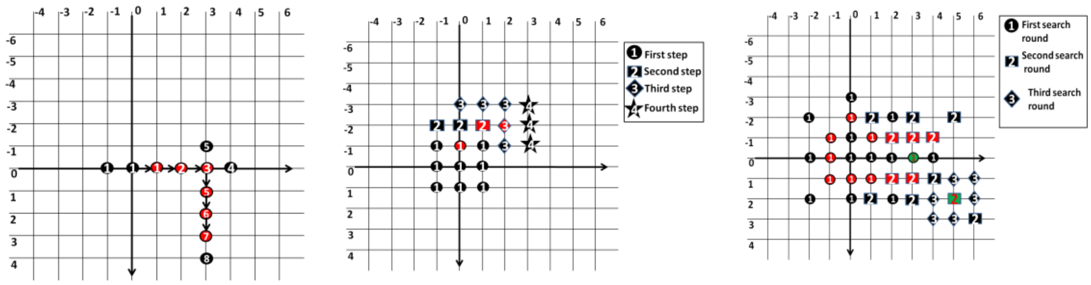
(a) (b) (c)

Fig. 1. The rectangular search patterns of TSS at (a) first search step (assume $s = \pm 7$) (b) second search step, a rectangular search pattern is placed around minimum search point of first search step and step size is half of the first step (c) third search step, a rectangular search pattern is placed around minimum search point of second step and step size is half of the second step. The minimum search point is highlighted with red color.



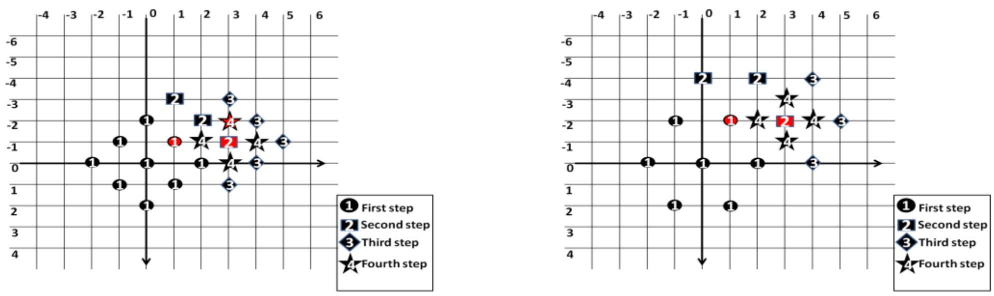
(a) (b)

Fig.2. An example of a search procedure of NTSS for (a)a stationary block with (0,0) motion vector(b) a quasi-stationary block with motion vector (2, −2). Each search point is indicated by its search step number and red colored point is the minimum search point.



(a) (b) (c)

Fig. 3. An example of a search procedure of (a) OTS for finding motion vector (3, 3) (b) BBGDS for finding motion vector (2, -2) (c) DGDS for finding motion vector (5, 2). Each search point is indicated by its search step number and red colored point is the minimum search point.



(a) (b)

Fig. 4. An example of a search procedure for finding motion vector (3, -2) with (a) DS (b) HS. Each search point is indicated by its search step number and red colored point is the minimum search point.

The temporal and/or spatial correlation among motion vectors are being effectively utilized by the algorithms that belong to predictive motion estimation category [28]–[34] for reducing the computational cost considerably.In [31], the motion vector of any macroblock is obtained effectively with the help of city block lengths of the neighboringblocks. These city block lengths predict the motion activity of macroblock. An appropriate search strategy and search center are chosen according tothe motion activity. The search speed is further enhanced by terminating the search initiallythroughinspecting (0, 0) predictor.In [32], the median predictor and the motion vectors of collocated blocks are also being used to improve the search performance of [31] further. In [32] also,the search speed is further enhanced by an adaptivehalfway stop technique. Another motion prediction algorithm [34] which improves the search performance of [32] by utilizing most probable predictors and efficient threshold calculationseffectively.

In algorithms [35] – [38], an adaptive switching strategy is employed to speeds up the search process. These algorithms dynamicallyapply different search patterns according to the motion activity. For example, the algorithm in [38] predicts motion activity of a block before finding motion vector to that block. Then, the popular center biased search patterns such as NTSS, DS and BBGDS are employed for obtaining motion vector if the motion activity is small. If the motion activity is not small then the non-center-biased search patterns such as TSS and 4SS are usedfor obtaining motion vector.This algorithm calculates an error descent rate for predicting the motion activity of a block.

The multiresolution algorithms [39]– [45] perform motion estimation at various resolution levels. A particular level is obtained by sub sampling and spatial low-pass filtering of its lower level. The motion vectors found at one level are used as initial motion vectors at next level. Since these initial motion vectors are closer to the optimal motion vectors, the search range can be reduced as level moves to finest level. The algorithms belong to fractional-pixel motion estimation (FPME) techniques [46]–[50]achieve further reduction in bit rate i.e., improvement in video quality by applyin fractional-pixel interpolation (FPI) algorithms.

3.RESULTS

This section presents the simulation results to evaluatethe performances of popular algorithms. The search performance evaluationsof thesealgorithms are presented with parameters PSNR andaverage number of search points (ANSP) per block. The PSNR and ANSP measure the motion prediction quality and computational complexity respectively.The performance of all the algorithms are analyzed with first 100 frames of ten video sequences with the size of HD, CIF and QCIF. These video sequences have different motion contents. Kirsten-Sara and Akiyo test video sequences have small motion content. The motion contents in suzie, mobile, and flower test video sequences are at medium level.Rocket launch, cricket, rhinos, robot boat, foreman test videos have large motions.The block size isset to 16×16. The search range is set to±63for HD test video sequences (rocket launch and kirstensara) and set to ±15 for the remaining (QCIF and CIF) video sequences.

Table 1 summarizes ANSP of NTSS, DS, HS, EHS-DOIS and DGDS algorithms. The PSNR of these algorithms are summarized in table 2. These tables clearly show that the fast search algorithms enhance the search speed but lower the PSNR with respect to full search algorithm.It can be observed from table 1 that EHS-DOIS requires a small number of search points when compared to other algorithms.On an average, EHS-DOIS requires 10.59 search points. All the algorithms except NTSS demand almost same ANSP if the motion content of the video sequences (Akiyo and Kirsten-Sara)is small. However, the ANSP is very small in EHS-DOISregardless of motion activity in video sequences.

It can be observed from table 2 thatthe DGDS shows good PSNR when compared to other algorithms. Roughly, DGDS shows 0.406dB higher PSNR at the little decrement in search speed when compared to DS(refer table 1). With respect to search speed, EHS-DOIS is surely best among all the algorithms.With respect to motion prediction quality, DGDS is surely better one. In order to observe the performances of all the algorithms more visibly, the frame-by-frame comparison of ANSP and PSNR of all the algorithmsusing suzie video sequence are shown in Fig. 5 (a) and Fig. 5 (b) respectively. Among all the algorithms, DGDS shows good PSNR values and EHS-DOIS shows higher search speed.

4. CONCLUSION

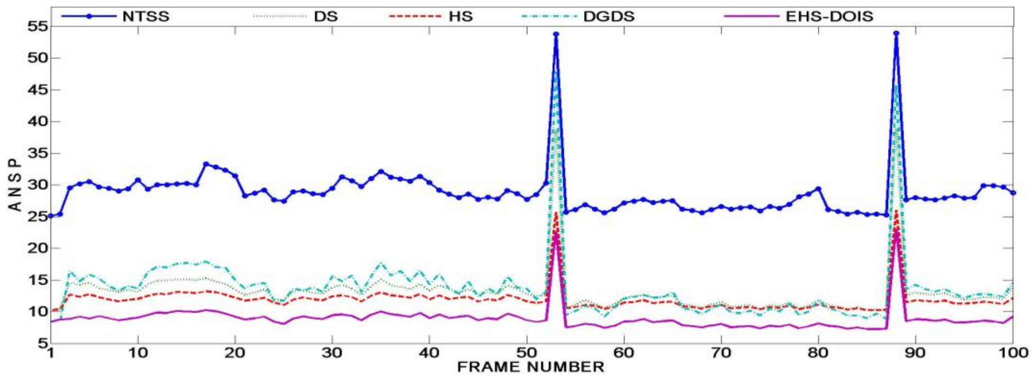
The last forty years' research of multimedia develops many block matching algorithms with an intention of enhancement in search speed. This paper has presented basic search procedures of well-known fast search block matching algorithms.A complete analysis of well-knownand state-of-the-art algorithms in respect of their search speed and block distortion measures is presented.

Table 1. The average number of search points (ANSP) per block in each algorithm.

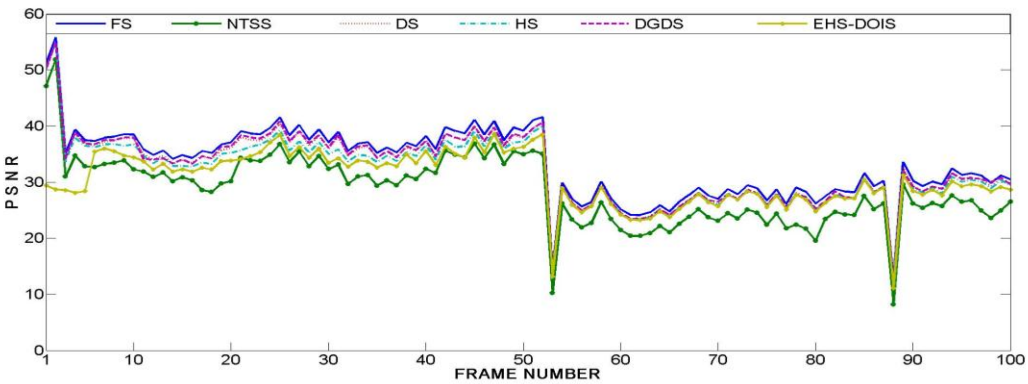
Video sequence	FS	NTSS	DS	HS	DGDS	EHS-DOIS
Foreman	782.21	29.23	17.16	13.04	18.63	10.63
Mobile	869.33	26.05	10.73	9.31	11.59	7.73
Rhinos	869.33	38.46	33.13	33.06	34.47	16.89
Robot boat	869.33	36.72	34.45	29.98	33.04	16.18
Suzie	782.21	24.39	12.51	10.44	11.16	8.50
Akiyo	782.21	18.44	8.22	8.64	8.872	8.03
Cricket	869.33	27.23	18.08	13.73	16.38	10.85
Flower	869.33	28.77	13.09	11.89	12.96	8.75
Kirsten-Sara	14061.54	26.03	8.37	8.05	8.11	7.59
Rocket launch	14061.54	26.36	17.37	13.23	16.85	10.76

Table 2. The degree of motion prediction quality of every algorithm with respect to full search algorithm.

Video sequence	FS	NTSS	DS	HS	DGDS	EHS-DOIS
Foreman	28.89	25.30	28.15	28.03	28.28	26.70
Mobile	24.29	21.71	23.52	23.85	23.87	22.71
Rhinos	30.23	25.03	27.62	27.81	28.40	27.66
Robot boat	30.62	26.30	29.21	29.10	29.54	28.83
Suzie	35.90	30.49	35.02	35.10	35.25	33.87
Akiyo	44.16	43.52	44.16	44.16	44.16	43.25
Cricket	35.95	31.26	33.66	33.95	34.99	33.19
Flower	33.69	29.26	33.02	33.19	33.35	31.47
Kirsten-Sara	44.74	44.05	44.18	44.21	44.39	42.45
Rocket launch	38.95	33.20	37.53	37.69	37.90	36.20



(a)



(b)

Fig. 5. Comparison among the fast search motion estimation algorithms with respect to (a) average number of search points (ANSP) per block and (b) average PSNR per frame with respect to full search algorithmfor “Flower” video sequence.

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