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Performance Evaluation of Diamond Search Algorithm for Recent Video Coding Standards

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Abstract: Many fast Block based Motion Estimation (BMME) algorithm was proposed and developed to achieve high compression ratio for recent video coding standards. In block matching motion estimation search patterns with different shapes or sizes and center-biased characteristic of motion vector distribution have a large impact on the searching speed and quality of performance. This study reviews about performance evaluation of different types of diamond search algorithm especially used for fast and low bit-rate video conferencing applications. Diamond Search (DS), Directional Diamond Search (DDS), Cross Diamond Search (CDS), New Cross Diamond Search (NCDS), Small Cross Diamond Search (SCDS) algorithms are simulated and compared based on the average number of search points, Peak Signal to Noise Ratio (PSNR) and searching speed. These algorithms are widely accepted and implemented by the various video compression standards.

Key words: Motion estimation, motion vector distribution, PSNR, diamond search, CDS

INTRODUCTION

In video coding systems, video compression plays an important role due to limited channel bandwidth and high compression ratio. Motion Estimation (ME) has proven to be effective to exploit the temporal redundancy of video sequences and is therefore an integral part of MPEG-1, MPEG-2, MPEG-4, H.261, H.263 and H.264 video compression standard (Bhaskaran and Konstantinides, 1995; Kuhn, 1999). Block-Matching Algorithm (BMA), the most commonly used in the standardized block based coding schemes, searches the best match block of the current frame from the candidate blocks inside the search window in the previous frame. The Full Search (FS) algorithm can find the optimal matching block by exhaustively checking all candidate blocks within the search window. However, its computational requirement is expensive. To overcome this problem many fast block-matching algorithms have been developed such as Three-Step Search (TSS) (Jing and Chau, 2004), New Three-Step Search (NTSS) (Li *et al*., 1994), Four-Step Search (FSS) (Po and Ma, 1996), Block-Based Gradient Descent Search (BBGDS) (Liu and Feig, 1996), Diamond Search (DS) (Zhu and Ma, 1997), etc. These fast algorithms use different search patterns and search strategies to find motion vector with much less number of search points compared to the FS algorithm. In real world sequences, based on the motion vector distribution characteristics >80% of the blocks can be regarded as stationary and Quasi-stationary blocks and most of the motion vectors are enclosed in the central area. The TSS is extremely easy but unable to find the best matching block. Comparing TSS, the performance of NTSS and FSS is improved gently but the zero-vector coding block needs 17 search points .The BBGDS carries on the search by the length of 3×3 and it is easy to fall into locally optimum point. Among them DS employs diamond shaped pattern which results in faster searching speed without affecting the image quality. To enhance the performance of DS, a number of algorithms were proposed based on initial search pattern prediction and early termination.

This study implements and evaluates different types of diamond search algorithms such as Diamond Search (DS) (Zhu and Ma, 1997), Small Cross Diamond Search (SCDS) (Cheung and Po, 2002a), Directional Diamond Search (DDS) (Jia, 2003), Cross Diamond Search (CDS) (Cheung and Po, 2002b), New Cross Diamond Search (NCDS) (Lam *et al*., 2003; Zhu *et al*., 2009).

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BLOCK MATCHING ALGORITHM

Block based motion estimation algorithms is the most popular method due to their effectiveness and simplicity for hardware implementation. The main idea behind block matching estimation is the partitioning of the target (predicted) frame into square blocks of pixels and finding the best match for these blocks in a current (anchor) frame (Lu and Liou, 1997; Vijaykumar *et al*., 2011; Ahmadi and Azadfar, 2008). To find the best match, a search inside a previously coded frame is performed and the matching criterion is utilized on the candidate matching blocks. The displacement between the block in the predictor frame and the best match in the anchor frame defines a motion vector. In the encoder, it is only necessary to send the motion vector and a residue block, defined as the difference between the current block and the predictor block. The best match is usually evaluated by a cost function which based on the Block Distortion Measure (BDM) (Lu and Liou, 1997) (e.g., Mean Square Error (MSE), Mean Absolute Error (MAE) and Sum of Absolute Difference (SAD) or other criteria like bit-rate and number of motion vectors.

$$SAD(i,j) = \sum_{m=0}^{N-1}\sum_{n=0}^{N-1} |CB(m,n) - RB(m+i, n+j)| \quad (1)$$

Where:

N = The block size

CB and RB = Respectively the pixel values in the current block and the reference block

Peak Signal to Noise Ratio (PSNR) characterizes the motion compensated image created by predicted motion vectors and blocks from the reference frame:

$$PSNR = 10\log_{10}\left\{\frac{(2^b-1)^2}{MSE}\right\} \quad (2)$$

Where:

b = The number of bits per pixel

MSE = Mean Square Error

MV distribution: For an in-depth statistical analysis on the MV distributions, commonly used video sequences with different motion contents are simulated by exploiting FS algorithm to these video sequences with a search range (+15, -15). Figure 1 shows that optimal MV distributions with certain intervals and regions from the search window. The motion vector have their own character such as motion vector distribution probability is decreasing from center to circumference, 81% motion vector probably locate in the square region which has five or two pixel distance from the center, 77% MV probably locate in diamond and cross region, especially 45.44% MV

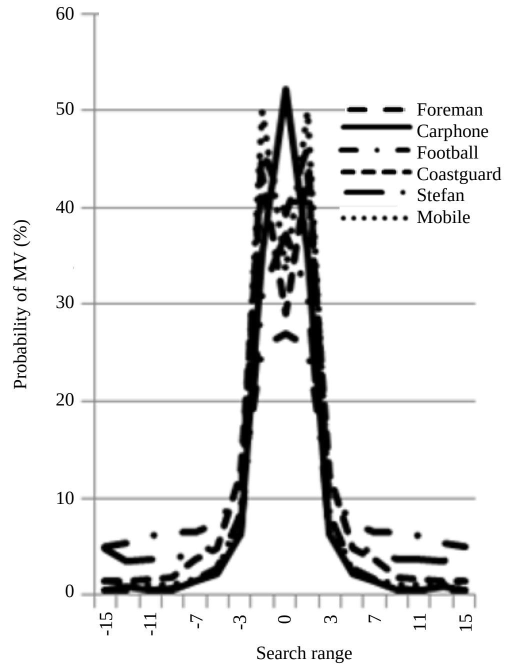

Fig. 1: Motion vector distribution for various video sequences

is zero and MV distribution probability at horizontal and vertical direction is larger than the other place which has the radius. Based on the MV distribution at the center Diamond search algorithm was proposed. To enhance the performance of Diamond search algorithm many algorithms was proposed such as Directional Diamond Search (DDS), Cross Diamond Search (CDS), New Cross Diamond Search (NCDS) and Small Cross Diamond Search (SCDS).

DIFFERENT TYPES OF DIAMOND SEARCH ALGORITHMS

Diamond search: DS was proposed by Zhu *et al*. (2009). It consists of two types of search patterns. The outer search pattern is a Large Diamond Search Pattern (LDSP) and the inner search pattern is a Small Diamond Search Pattern (SDSP) as shown in Fig. 2a and b. The first step starts with LDSP using nine search points at the center with a distance of one if the minimum SAD is at the center location the algorithm goes to SDSP. Otherwise, LDSP is repositioned to get minimum SAD. The SDSP around the new search origin and the location with minimum SAD is the best match. As the search pattern is neither too small nor too big and the fact that there is no limit to the number of steps, this algorithm can find global minimum very accurately.

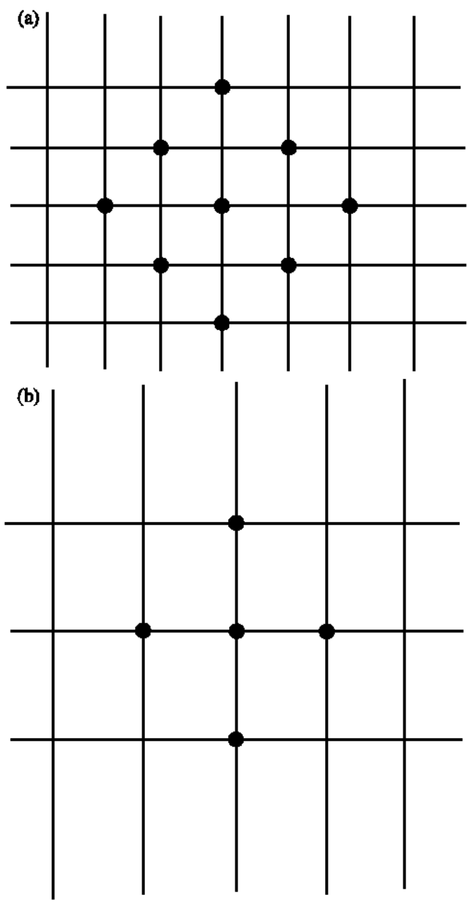

Fig. 2: Diamond search pattern a) LDSP; b) SDSP

Observation: DS algorithm consumes less number of search points and better PSNR than the other fast motion estimation algorithms and consumes more number of search points than other diamond search algorithms.

Cross diamond search: Cross diamond search was proposed by Cheung and Po (2002a, b) based on the centre biased MV distribution exists in real video sequences. CDS exploits the cross-centre biased MV property by applying a nine point cross shaped initial search pattern. The initial search pattern is called Cross Search Pattern (CSP) as shown in Fig. 3. If a minimum SAD is found from the nine search points of the CSP located at the center of search window. If the minimum SAD point occurs at the center of the CSP, the search stops. If the minimum SAD is not at the center two additional search points of the central LDSP closest to the current minimum of the central CSP are checked, i.e., two of the four candidate points located at (±1, ±1). If the minimum SAD found in previous step is located at the middle wing of the CSP, i.e. (±1, 0) or (0, ±1) and the new

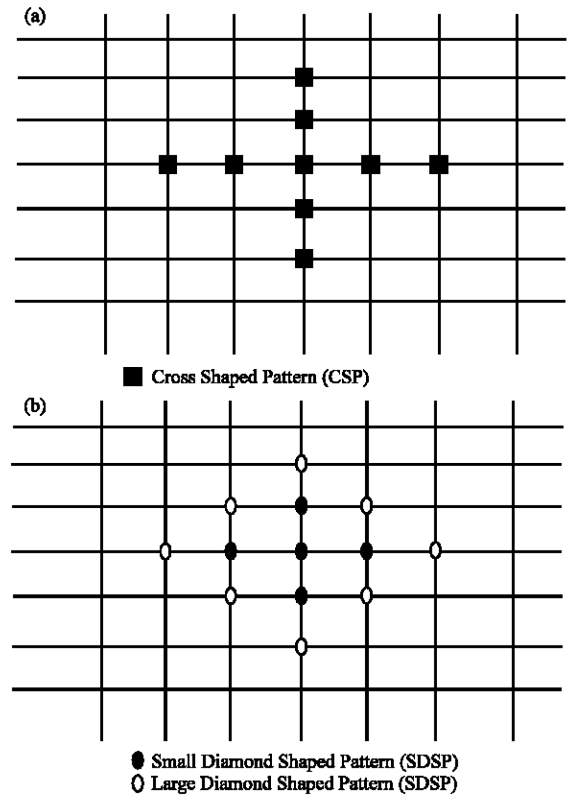

Fig. 3: Cross diamond search pattern; a) LDSP; b) SDSP

minimum SAD found in this step still coincides with this point, the search stops. Otherwise, to achieve minimum SAD, a new LDSP is formed by repositioning the minimum SAD found in previous step as the center of the LDSP. If the new minimum SAD point is still at the center of the newly formed LDSP then go to last step otherwise, this step is repeated again. With the minimum SAD point in the previous step as the center, a new SDSP is formed. Identify the new minimum SAD point from the four new candidate points which is the final solution for the motion vector.

Observation: This algorithm employs a halfway stop technique to find small motion vectors with fewer number of search points and achieves 40% searching speed than DS algorithm.

New cross diamond search: New cross diamond search was proposed by Zhu *et al.* (2009) based on the centre biased MV distribution exists in real video sequences. NCDS exploits the cross-centre biased MV property by applying a five point cross shaped initial search pattern. The initial search pattern is called Small Cross Search Pattern (SCSP). If a minimum SAD is found from the five search points of the SCSP located at the center of search window. If the minimum SAD point occurs at the center of the SCSP, the search stops. If the minimum SAD is not at the center a new SCSP is formed by using vertex in the first SCSP as the center. If the minimum SAD occurs at the center of this SCSP, the search stops. If the minimum SAD is not found in previous step, a Large Cross Search Point (LCSP) is formed by considering three unchecked outermost points and two unchecked points with radius ±2. Otherwise, to achieve minimum SAD, a new LDSP is formed by repositioning the minimum SAD found in previous step as the center of the LDSP. If the new minimum SAD point is still at the center of the newly formed LDSP then go to last step otherwise, this step is repeated again. With the minimum SAD point in the previous step as the center, a new SDSP is formed. Identify the new minimum SAD point from the four new candidate points which is the final solution for the motion vector.

Observations: Based on the number of search points per block NCDS consumes 15 and 35% than CDS and DS algorithm, respectively. Searching speed improves 14% than CDS and 42% than DS.

Directional diamond search: DDS was proposed by Jia (2003) exploiting the asymmetry of Directional Centre-Biased Motion Vector Distribution (DCBMVD) using DDS patterns such as Horizontal Diamond Search Pattern (HDSP) and Vertical Diamond Search Pattern (VDSP) as shown in Fig. 4a and b. In both patterns, five points with distance of two from the centre point is called distant point and the point at a distance of one is called near point. The initial search start with a five point Horizontal Diamond Search Pattern (HDSP) is centered at the origin of the search window and set as the Current Search Pattern (CSP). If the minimum SAD is obtained at the central point in the CSP, the search stops otherwise, repeat this step continuously. If the SAD occurs at the near point, the CSP is switched to the other one otherwise, maintain the CSP unchanged as shown in figure. This process repeats in horizontal and vertical direction till to get minimum SAD which is the motion vector.

Observations: Based on the number of search points per block DDS consumes 30% than CDS algorithm, searching speed improves 49.1% than CDS and better PSNR ratio.

Small cross-diamond search: Search patterns and the center-biased characteristics of Motion Vector Distribution (MVD) have a large impact on both searching speed and quality of block motion estimation. SCDS consists of two cross-shaped search patterns as the first two initial steps and large/small diamond-shaped patterns as the subsequent steps for fast Block Motion Estimation (BME). The first small cross-shaped pattern is to fit the cross center biased MVD characteristics of the real-world sequences by evaluating the 5 relatively higher probable candidates located as a cross-shaped pattern at the search-grid center. SCDS employs a halfway-stop technique and could find small motion vectors with much fewer points than the Diamond Search algorithm (DS) while maintains similar or even better quality.

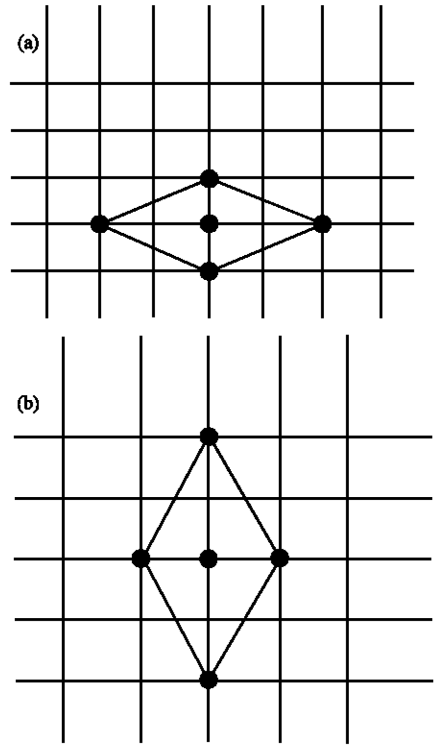

Fig. 4: Directional Diamond search pattern. a) Horizontal diamond search pattern; b) Vertical diamond search pattern

Observations: The improvement of SCDS over DS can be up to 146%, i.e., 2.46 times faster than DS. SCDS is much more robust, provides faster searching speed and smaller distortions than other fast algorithms.

RESULTS AND COMPARISONS

This study discusses about results of different types of diamond search algorithm based on the average number of search points per block and PSNR as shown in Fig. 5 and 6. Results shows that the DDS consumes less

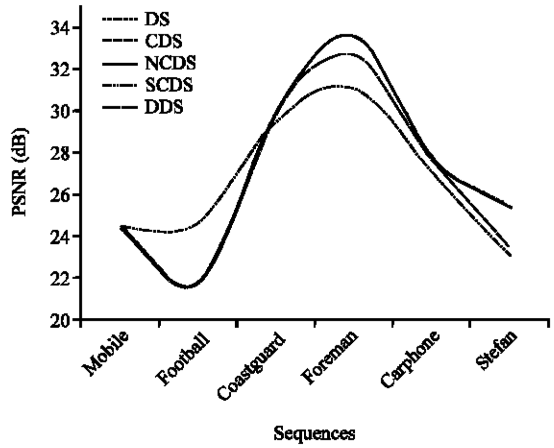

Fig. 5: Performance comparison of Peak Signal to Noise Ratio (PSNR) for various types of diamond search algorithm

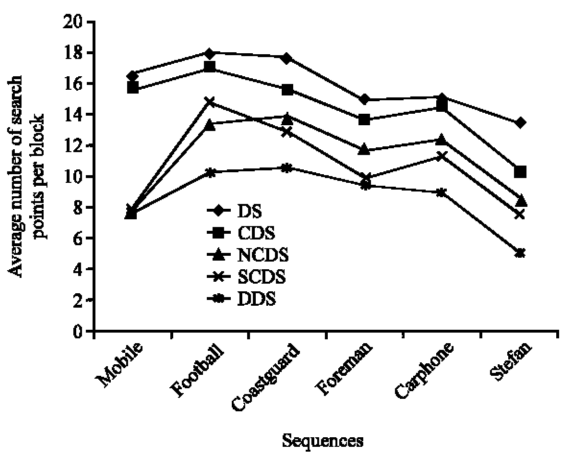

Fig. 6: Performance comparison of average number of search points for various types of diamond search algorithm

number of search points than the other algorithms with better peak signal to noise ratio and also provides faster searching speed.

CONCLUSION

Block matching techniques are the most popular and efficient of the various motion estimation techniques. To reduce computational complexity many fast search algorithms was proposed .Among this diamond search algorithm performs better than other algorithms. To enhance the performance of diamond search algorithm various kinds of techniques was proposed. In this study, various types of diamond search algorithm was discussed and compared in various aspects. From this, it is concluded that DDS algorithm performing best results in terms of searching points and PSNR.

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