BLOCK MATCHING MOTION ESTIMATION ALGORITHMS

1. OVERVIEW

Many fast block matching algorithms have been developed to alleviate the heavy computations of FS. These are based on various techniques like fixed search pattern, variable search range, hierarchal and multi resolution algorithms, sub-sampling techniques, partial distortion elimination, spatio-temporal correlation etc. Among early block ME algorithms, fixed search pattern algorithms are the most famous, these algorithms reduce the computational requirement significantly by checking only some points inside the search window, while keeping a good error performance when compared with FS algorithm. Some of the famous algorithms are as follows:

2. THREE STEP SEARCH ALGORITHM

Originally proposed by Koga et al. [1], this is a fine-coarse search mechanism. The search pattern of TSS is shown in Figure 1. The first step involves search based on 4-pixel/4-line resolution at nine locations i.e. 9x9 search window, with the center point corresponding to zero MV. The second step involves search based on 2-pixel/2-line resolution i.e. 5x5 search window around the location determined by the first step. This is repeated in the third step with 1-pixel/1-line resolution and a search window of 3x3. The last step yields the MV. The TSS is one of the most popular BMAs and is also recommended by RM8 of H.261 and SM3 of MPEG owing to its simplicity and effectiveness. For a maximum displacement window of 7 i.e. d=7, the number of checking points required is (9+8+8)=25. For larger search window (i.e. larger d), TSS can be easily extended to n-steps using the same searching strategy with the number of checking points required equals to [1+8\{log2(d+1)\}].
3. 2D-LOGARITHMIC SEARCH ALGORITHM

2D-logarithmic search (2DLOG) has been proposed by Jain et. al. in 1981 [2]. It uses a (+) cross search pattern in each step. The initial step size is d/4. The step size is reduced by half only when the minimum BDM point of previous step is the center one or the current minimum point reaches the search window boundary. Otherwise, the step size remains the same. When the step size is reduced to 1, all the 8 checking points adjacent to the center checking point of that step are searched. Two different search paths are shown in Figure 2. The top search path requires (5+3+3+8)=19 checking points. The lower-right search path requires (5+3+2+3+2+8)=23 checking points.

Figure 1. Search pattern of three step search algorithm.

Figure 2. Two search paths of 2DLOG search algorithm.
4. ORTHOGONAL SEARCH ALGORITHM

The orthogonal search algorithm (OSA) is proposed by A. Puri et al. in 1987 [3]. It consists of pairs of horizontal and vertical steps with a logarithmic decrease in step size. Two search paths of OSA are shown in Figure 3. Starting from the horizontal searching step, three checking points in the horizontal direction are searched. The minimum checking point then becomes the center of the vertical search step that also consists of three checking points. Then step size is decreased to half and same search strategy is used. The algorithm ends with step size equal to one. For \(d=7\), the OSA algorithm requires a total of \((3+2+2+2+2+2)=13\) checking points. For general case, the OSA algorithm requires \([1+4\{\log_2(d+1)\}]\) checking points.

![Figure 3. Two search paths of orthogonal search algorithm.](image)

5. CROSS SEARCH ALGORITHM

The cross search algorithm (CSA) has been proposed by Ghanbari in 1990 [4]. It is also a logarithmic step search algorithm using a (X) cross searching pattern in each step. Figure 4 shows two search paths of CSA. As shown in Figure 4, there are five checking points placed in a cross pattern in each step.

The initial step size is half of \(d\). As the step size is decreased to one, a (+) cross search pattern (as
shown in lower-left side of Figure 4 is used if the minimum BDM point of the previous step is either the center, upper left or lower right checking point. Otherwise, (X) cross search pattern (as shown in upper right side of Figure 4 is used. For d=7, the number of checking points required is (5+4+4+4)=17. For the general case, the number of checking points required is \[5+4\log_2(d)\].

![Figure 4. Two search paths of cross search algorithm.](image)

6. NEW THREE STEP SEARCH ALGORITHM

The new three step search algorithm (NTSS) has been proposed by Li, Zeng and Liou in 1994 [5]. It is a modified version of the three step search algorithm for searching small motion video sequences. For these video sequences, the motion vector distribution is highly center biased. Therefore, additional 8 neighboring checking points are searched in the first step of NTSS.

Figure 5 shows two search paths with d=7. The center path shows the case of searching small motion. In this case, the minimum BDM point of the first step is one of the 8 neighboring checking points. The search is halfway stopped with matching three more neighboring checking points of the first step's minimum BDM point. The number of checking points required is (17+3)=20. The upper right path shows the case of searching large motion. In this case, the minimum BDM point of the first step is one of the outer eight checking points. Then the
searching procedure proceeds in the same way as in the TSS algorithm. The number of checking points required in this step is \((17+8+8)=33\).

![Diagram showing search paths of new three step search algorithm.](image)

**Figure 5.** Two search paths of new three step search algorithm.

### 7. FOUR STEP SEARCH ALGORITHM

The four step search algorithm (FSS) has been proposed by L. M. Po and W. C. Ma in 1996 [6]. This algorithm also exploits the center biased characteristics of the real world video sequences by using a smaller initial step size compared with TSS. The initial step size is fourth of the maximum motion displacement \(d\) (i.e. \(d/4\)). Due to the smaller initial step size, the FSS algorithm needs four searching steps to reach the boundary of a search window with \(d=7\). Same as the small motion case in the NTSS algorithm, the FSS algorithm also uses a halfway stop technique in its second and third step search. Figure 6 shows two search paths of FSS for searching large motion. For the lower left path, it requires \((9+5+3+8)=25\) checking points. For the upper right path, it requires \((9+5+5+8)=27\) checking points that is the worse case of the algorithm for \(d=7\). Figure 6 shows two search paths of FSS for searching small motion. For the left path, it requires \((9+8)=17\) checking points. For the right path, it requires \((9+3+8)=20\) checking points.
As shown in Figure 6 and 7, there are either three or five checking points required in the second or third step. Moreover, if the minimum BDM checking point of that step is the center one, the step size is reduced by half and the algorithm directly jumps to the fourth step. For general case, the algorithm can be extended as follows. If the step size of the fourth step is greater than one, then another four step search is performed with the first step equals to the last step of the previous search. The number of checking points required for the worst case is \[ 18 \log_2 \left( \frac{d+1}{4} \right) + 9 \].

Figure 6. Two large motion search paths of four step search algorithm.

Figure 7. Two small search paths of four step search algorithm.
8. BLOCK BASED GRADIENT DESCENT SEARCH ALGORITHM

The block based gradient descent search algorithm (BBGDS) is proposed by L. K. Liu and E. Feig in 1996 [7]. This algorithm uses a center biased search pattern of 9 checking points in each step with step size of one. It does not restrict the number of searching steps but it is stopped when the minimum checking point of the current step is the center one or it is reached the search window boundary. There are also overlapped checking points between adjacent steps. The BBGDS algorithm performs better for small motions. Two small motion search paths of BBGDS are shown in Figure 8.

Figure 8. Search pattern of block based gradient descent search algorithm.

9. DIAMOND SEARCH ALGORITHM

The diamond search algorithm (DS) is proposed by S. Zhu and K. K. Ma in 2000 [8]. It is based on MV distribution of real world video sequences. It employs two search patterns in which the first pattern, called large diamond search pattern (LDSP) comprises nine checking points and form a diamond shape. The second pattern consists of five checking points make a small diamond pattern (SDSP). The search starts with the LDSP and is used repeatedly until the minimum BDM
point lies on the search center. The search pattern is then switched to SDSP. The position yielding minimum error point is taken as the final MV. The search process is shown in Figure 9. DS is an outstanding algorithm adopted by MPEG-4 verification model (VM) [9] due to its superiority to other methods in the class of fixed search pattern algorithms.

![Figure 9. Search pattern of diamond search algorithm.](image)

**REFERENCES**


