Block Based Motion Estimation using Hybrid Hexagon Kite Cross Diamond Search Algorithm

Narapaneni Ragasudha, Deepak Singh and Sukadev Meher

Abstract—**Motion Estimation plays a key role in a motion compensated hybrid DCT video coding scheme. To reduce the computational complexity in finding the best match of the block, many fast search algorithms have been proposed. The proposed Hybrid Hexagon Kite Cross Diamond Search (HYBHKS) algorithm is based on the adaptive switching of the Hexagon Search (HEXS) and Kite Cross Diamond Search (KCDS) patterns for obtaining the best match in a fast way. In order to have good initial position, spatial and temporal correlation is used for motion vector prediction. Experimental results show that HYBHKS performs better than KCDS and HEXS in terms of number of search points maintaining similar compression ratio, structural similarity index and peak signal to noise ratio.**

Index Terms—**Asymmetrical kite pattern, cross-centre biased characteristic, motion estimation, motion vector prediction, spatial correlation, temporal correlation.**

I. INTRODUCTION

Motion Estimation (ME) is a process of determining the motion vectors of the objects that describe the transformation of one frame to another in a video. It reduces the temporal redundancy of the video. Easiest way to determine the motion vectors is to divide the frame to blocks and match it from the search window in the reference frame. This is called Block Matching Algorithm (BMA) [1]. Block matching is done comparing the block in the current frame with the blocks in the search window of the previous reconstructed frame since the decoder consists of only the reconstructed frames. This further reduces the error introducing at the transmitter. When the best match is found, it is compared with the current block and the residual error is encoded and transmitted along with the corresponding motion vector. The best match is evaluated in terms of Sum of Absolute Differences (SAD) or Mean Square Error (MSE) [2]. In this paper, SAD is used for calculating the block distortion. For an N×N block, SAD is defined as

$$SAD = \sum_{i=0}^{N-1}\sum_{j=0}^{N-1}\left|C_{ij} - R_{ij}\right| \quad (1)$$

Where C_{ij} is a block of current frame and R_{ij} is a block in reference area and C_{00} and R_{00} are the top-left samples in the current and reference areas respectively. Thus, the best match is found out using SAD and the displacement of the best matching block is determined as the required Motion Vector (MV). Full Search (FS) algorithm [1] which computes all the points in the search window is a computational intensive algorithm. To reduce the computational complexity with similar distortion measure as FS many search pattern algorithms have been proposed thence. Logarithmic Search (LS) [2], Three-Step Search (TSS) [1], New Three-Step Search (NTSS) [1], Four-Step Search (FSS) [1], Diamond Search (DS) [3], Kite Cross Diamond Search (KCDS) [4], Hexagonal Search (HEXS) [5] etc. are one such. The property of centre-biased motion vector distribution is exploited and used in most of the search algorithms since nearly 80% of the blocks in the consecutive frames are stationary or quasi-stationary. This phenomenon is exploited in NTSS using additional search points in 3×3 neighborhood around the centre for early termination. FSS uses square search pattern in 5×5 neighborhood around the centre. DS uses diamond search pattern around the centre. But it requires at least 13 search points to decide whether the block is stationary or not. Kite Cross Diamond Search (KCDS) Algorithm is a step ahead to this. It uses Small Cross Diamond Pattern in first step which results in fast motion estimation of the stationary block. Then it uses asymmetrical kite-shape pattern in second step to improve speed in searching quasi stationary blocks. Then it uses DS for further traversal. Hexagonal Search (HEXS) algorithm uses hexagon pattern which is an approximation to ideal circular shape pattern with only 7 search points. It effectively traverses large motion blocks.

The quality of the video is judged based on the peak signal to noise ratio (PSNR) and structural similarity index (SSIM) [6]. PSNR can be calculated as

$$PSNR = 10\log_{10}\sum_{i=1}^{M}\sum_{j=1}^{N}\left(\frac{255^2}{(I(i,j)-\hat{I}(i,j))^2}\right) \quad (2)$$

where $I\ (i, j)$ is the original frame and $\hat{I}(i,j)$ represents the reconstructed frame at the decoder. SSIM is a quality measures which compares two images. SSIM of two images x and y is determined by the formula

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$$SSIM(x,y)=\frac{(2\mu_x\mu_y+C_1)(2\sigma_{xy}+C_2)}{(\mu_x^2+\mu_y^2+C_1)(\sigma_x^2+\sigma_y^2+C_2)} \quad (3)$$

where μ=mean, σ^2=variance, $C_1=(K_1L)^2$ and $C_2=(K_2L)^2$ where L is the dynamic range of the pixel values (255 for 8-bit gray-scale images) and K_1 and K_2 are very small values close to zero($K<<1$).

The contribution of this paper is to propose a good ME algorithm that can adaptively switch the search patterns by classifying the motion type of the block along with maintaining the quality of the video. The proposed algorithm first predicts the motion vector using spatial and temporal correlation then categorizes whether the block is stationary, quasi- stationary or large motion blocks. Then accordingly the search pattern is selected adaptively.

The paper is organized as follows. Motion Vector Prediction is explained in section-II. The proposed algorithm is discussed in section-III. Obtained results are depicted in section-IV and the conclusion is made in section-V.

II. MOTION VECTOR PREDICTION

Motion vector of a block is highly correlated to its neighboring blocks in spatial and temporal domains known as spatial correlation [7] depicted in fig.1 and temporal correlation [7] depicted in fig.2 respectively. In HYBHKS motion vector prediction of current block (CB) is done by considering the motion vectors of upper block (UB), left block (LB), zero motion vector of current frame and collocated block in previous frame based on the minimum SAD value. The obtained position will be a good starting point for our search. SAD value at this position is used for categorizing the block. Further refinement is done using various algorithms.

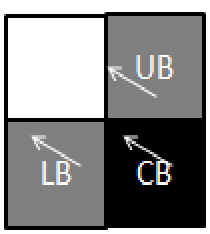

Fig.1. Spatial correlation

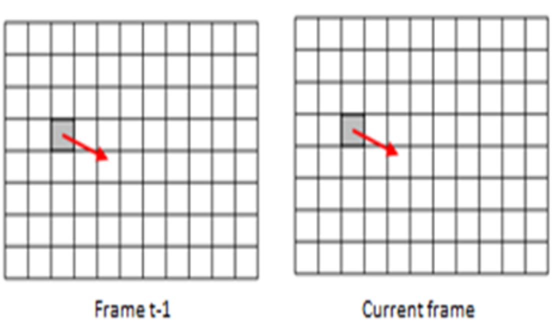

Fig.2. Temporal correlation

III. HYBRID HEXAGON KITE CROSS DIAMOND SEARCH (HYBHKS) MOTION ESTIMATION ALGORITHM

A. Search Patterns

The proposed HYBHKS algorithm uses five search patterns- Small Diamond Search Pattern (SDSP), Large Diamond Search Pattern (LDSP) [3], Kite Search Pattern (KSP) [4], Hexagonal Search Pattern (HSP) [5] and Efficient Hexagonal Inner Search Pattern (EHISP) [8].

SDSP and LDSP are illustrated in Fig.3. KSP consists of two types of patterns- with vertical symmetry shown in fig.4 (a), 4(c) and with horizontal symmetry shown in fig.4 (b), 4(d). HSP is illustrated in fig.5 and the inner search of the hexagon is done efficiently and effectively using the EHIS pattern shown in fig.6.

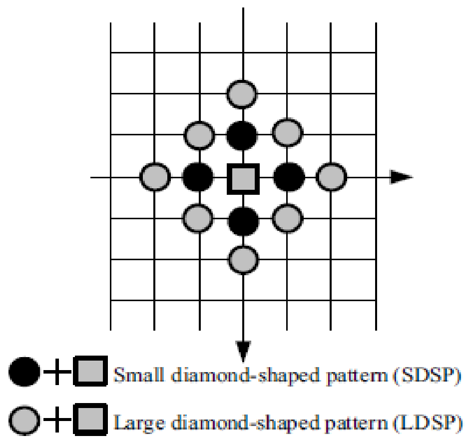

Fig.3: Diamond Search Patterns [3]

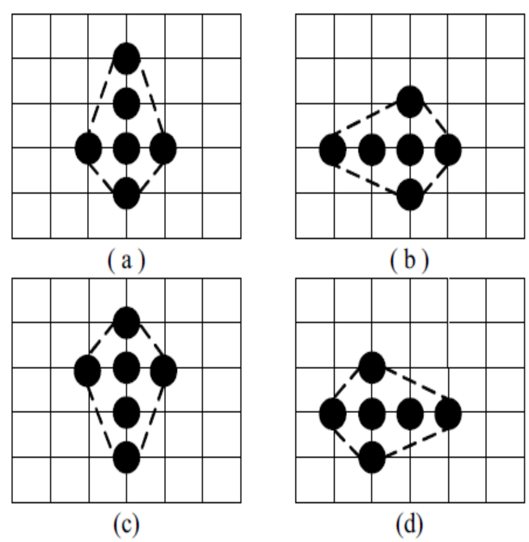

Fig.4: Kite Search Patterns [4]
(a) Up kite (c) Down Kite
(b) Left Kite (d) Right Kite

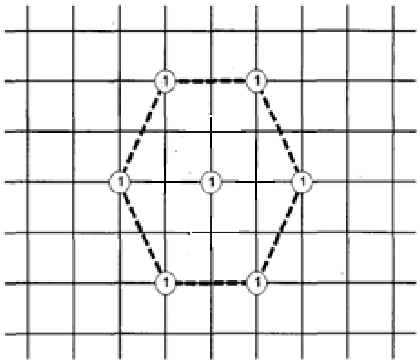

Fig.5. Hexagonal Search Pattern [5]

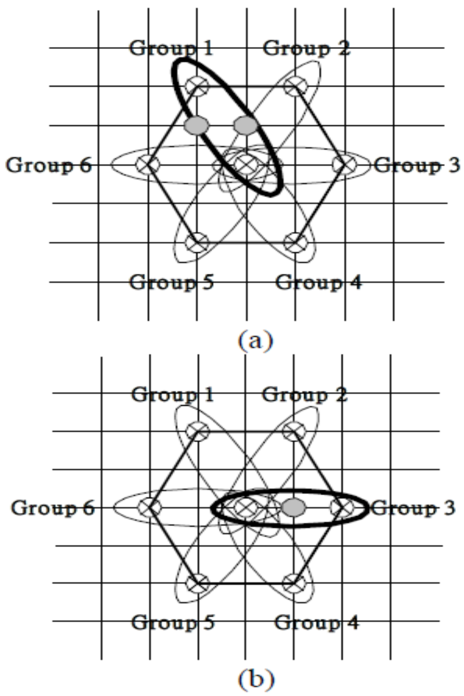

Fig.6. Efficient Hexagonal Inner Search Pattern [8]

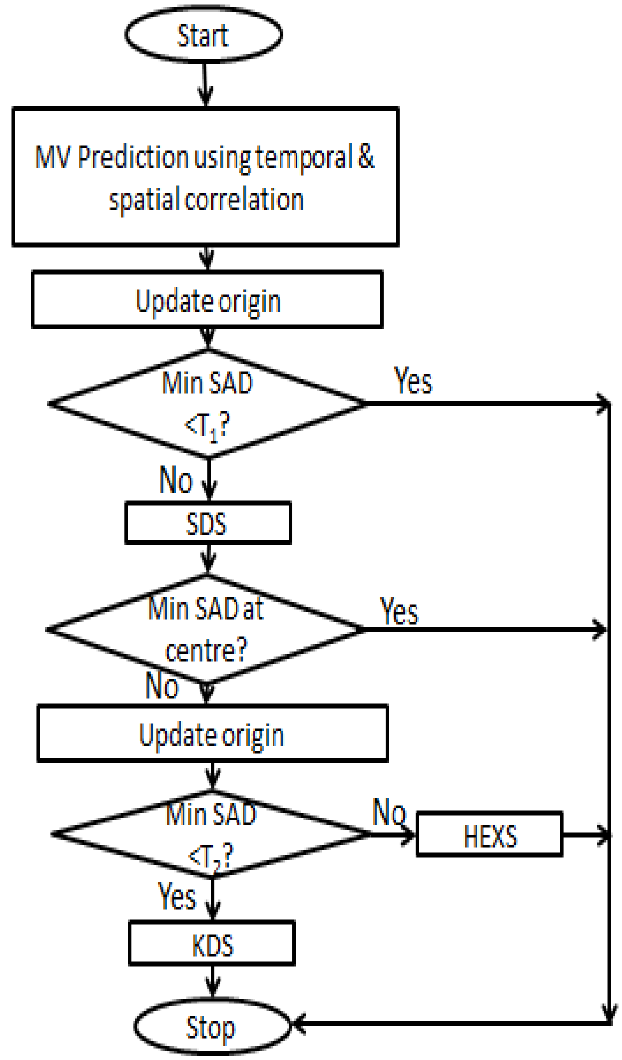

Fig.7. HYBHKS Algorithm

B. HYBHKS Algorithm

HYBHKS Algorithm uses motion vector prediction in the initial step for initial classification of the motion type of the block. Then minimum SAD value is compared with threshold T_1 to classify it as quasi-stationary. If not Small Diamond Search pattern is used and searched at 5 points. If the minimum SAD is at centre, then the search is terminated. Otherwise based on the minimum SAD value, the motion is classified as small motion or large motion and different search patterns like KCDS and HEXS are performed respectively. The flow chart of HYBHKS is depicted in fig.7.

The algorithm is described as follows:

Step 1(MV Prediction):- SAD is calculated at four search points obtained from the motion vectors of upper block (UB), left block (LB), zero motion vector of current frame and collocated block in the previous frame. The minimum SAD position is calculated and the origin is updated to that position. If the minimum SAD value is less than T_1, the block is classified as quasi-stationary and the search is terminated. Otherwise, go to step 2.

Step 2 (SDS):- The minimum SAD point is calculated from the 5 search points of SDSP pattern centered at the updated location in the search window. If it is found at center, search is stopped otherwise the center is updated to new minimum SAD point and proceed to next step.

Step 3 (Motion Type Judgment):- The minimum SAD value in step 2 is compared with the threshold T_2. If it is less than T_2 the motion of the block is judged as slow motion and the search proceeds to step 4. Otherwise it is classified as large motion and step 5 is performed.

Step 4 (KDS) [4]:-

(a). Kite Search:- Based on the direction of the minimum SAD position in SDSP, the corresponding directional kite is selected from the KSP shown in fig.5 and searched at 6 positions. If the minimum SAD is obtained at the centre of the kite, the search is terminated else proceed to step 4(b) after updating the center.

(b). Diamond Search: - SAD is calculated at nine points of LDSP shown in fig.3. The minimum SAD is calculated and the center is updated to the minimum position. This is repeated

till the minimum position is found at the centre. Then SDSP is performed for diamond inner search.

Step 5 (HEXS) [5]:-

(a). Hexagonal Search:- SAD is calculated at the seven points of HSP shown in fig.6. The centre is updated to the minimum SAD position. This step is repeated till the minimum position is found at the center. Then proceed to step 5(b).

(b). EHIS:- The hexagon is divided into six groups as shown in fig.6. If one of group1, group 2, group 4 or group 5 has the second minimum SAD point then only two inner points close to that group are searched. It is illustrated in fig.6 (a). If group 3 or group 6 wins only one point is searched as illustrated in fig.6 (b).

C. Calculation of Compression Ratio:

The bit stream is obtained by encoding the error coefficients of the current frame and the predicted frame using ME algorithm in H.262 format [9]. Compression ratio is determined by dividing the actual size of video with the new size of the reconstructed video.

IV. Experimental Results

Various experiments are conducted to verify the performance of the proposed method. CIF (352×288) video sequences akiyo, foreman and mobile are taken as test vectors. All experiments are performed using MATLAB version 7.0.10.499 (R2010a) on an Intel® core(TM) i5-2400 CPU @ 3.10GHz.

In this paper the 'IPPP' format is used in order to reduce the propagation of error when compared to 'IPPPP…' format. Quantization parameter is set to 24 and frame rate as 25fps. The constants K_1 and K_2 in SSIM calculation are set to 0.05. Threshold T_1 is set as 300 and threshold T_2 is set as 600 after extensive observation. The average PSNR, SSIM, computational complexity, encoded bitrate and compression ratio are calculated for the test videos foreman_cif and mobile_cif and are tabulated in tables I and II respectively. Computational complexity is expressed in terms of average number of search points checked per macro-block. The input video is considered in 4:2:0 YUV format. The results are compared with FS, HEXS and KCDS algorithms. It is observed that the proposed HYBHKS algorithm performs well with reduced computational complexity and low encoded bit rate maintaining similar PSNR, SSIM and compression ratio values.

PSNR of luminous (Y) component and Encoded bit rate are determined for various Q values Q=24, 30, 36 and 42 and rate distortion curves are plotted in fig.8 and fig.9. From these figures it is evident that the proposed HYBHKS algorithm performs well with high PSNR and low encoded bit rate. Fig.10 shows the original and reconstructed frame (frame no.23) of the video Akiyo_cif using full search, diamond search, kite cross diamond search, hexagonal search and our proposed hybrid hexagon- kite cross diamond search algorithms. It is observed that the frame is reconstructed properly without compromising with the quality of the video using very few search points per macro-block.

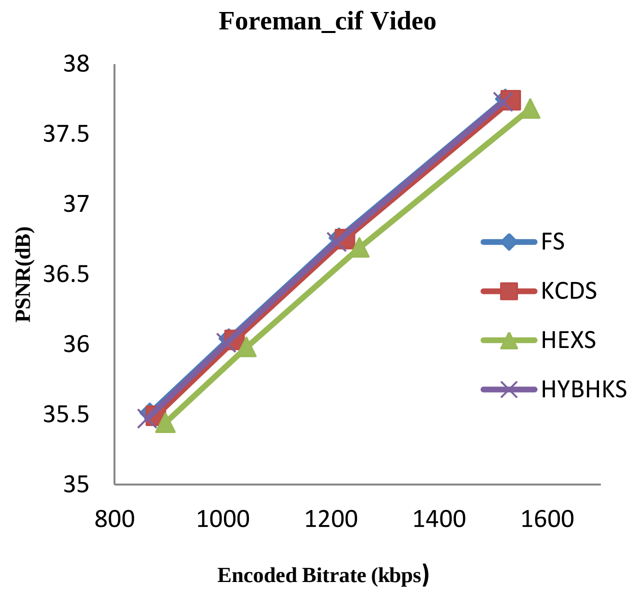

Fig.8: Rate Distortion Curve of Foreman_cif video

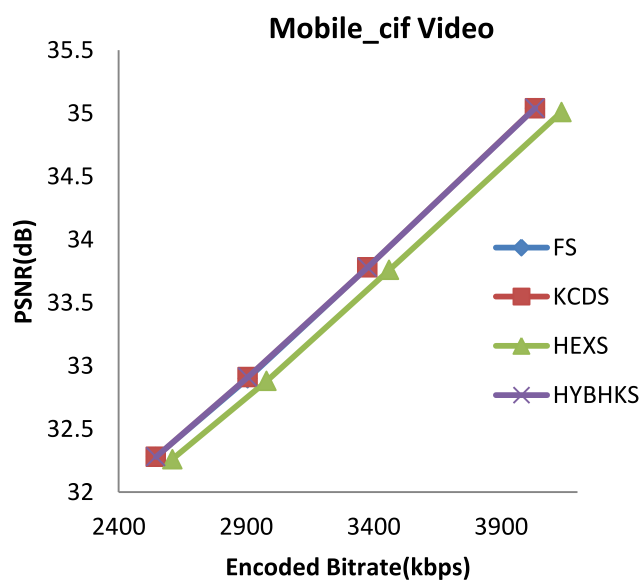

Fig.9: Rate Distortion Curve of Mobile_cif video

TABLE I: Performance comparison of FS, KCDS and HEXS with proposed HYBHKS algorithm for Foreman_cif@25fps video

ME Algorithm	PSNR (dB)	SSIM	Encoded Bit Rate (kbps)	Comp. Ratio	Search Points
FS	37.75	0.9035	1523.21	19.97	196.63
KCDS	37.74	0.9034	1533.34	19.83	16.06
HEXS	37.68	0.9023	1569.23	19.38	14.05
HYBHKS	**37.73**	**0.9032**	**1519.01**	**20.02**	**10.09**

TABLE II: Performance comparison of FS, KCDS and HEXS with proposed HYBHKS algorithm for Mobile_cif@25fps video

ME Algorithm	PSNR (dB)	SSIM	Encoded Bit Rate (kbps)	Comp. Ratio	Search Points
FS	35.04	0.9314	4033.51	7.54	196.63
KCDS	35.04	0.9314	4033.50	7.54	7.53
HEXS	35.01	0.9309	4137.74	7.35	8.39
HYBHKS	**35.04**	**0.9314**	**4033.80**	**7.54**	**7.26**

V. CONCLUSION

In this paper, a fast hybrid motion estimation algorithm with very low computational complexity is proposed. This algorithm first predicts motion vector using spatial and temporal correlation then classifies the type of motion of the block. Based on the particular threshold value the search pattern is selected. It employs five search patterns- Small Diamond Search Pattern (SDSP), Large Diamond Search Pattern (LDSP), Kite Search Pattern (KSP), Hexagonal Search Pattern (HSP) and Efficient Hexagonal Inner Search Pattern (EHISP). Experimental results depict that the proposed HYBHKS algorithm has low computational complexity with similar PSNR and compression ratio.

REFERENCES

[1] M.Jakubowski and G.Pastuszak, "Block-based Motion Estimation Algorithms- a survey", Opto-Electronics review 21(1), 2013, pp.86-102.

[2] Iain E.G. Richardson, Video Codec Design. London, John Wiley & Sons Ltd. 2002.

[3] Shan Zhu and Kai-Kuang Ma, "A Novel Diamond Search Algorithm for Fast Block Matching Motion Estimation," IEEE Trans. On Image Processing, Vol.9, No.2, pp.287-290, February 2000.

[4] Chi Wai Lam, Lai-Man Po and Chun Ho Chang, "A Novel Kite Cross Diamond Search Algorithm for Fast Block Matching Motion Estimation," IEEE Trans. Int. Symp. Circuits and Systems (ISCAS), vol.3, pp.729-732, April 2004.

[5] Ce Zhu, Xaio Lin, Lap-Pui Chau, Keng-Pang Lim, Hock-Ann Ang, Choo-Yin Yong, "A Novel Hexagonal Search Algorithm for Fast Block Matching Motion Estimation," IEEE Transaction on Acoustics, Speech and Signal Processing, pp.1593-1596, November 2000.

[6] Zhou Wang, A.C.Bovik, Hamid Raheem Sheikh and Eero P. Simoncelli, "Image Quality Assessment: From Error Visibility to Structural Similarity", IEEE Transaction on Image Processing, vol.13, No.4, pp.600-612, April-2004.

[7] Alexis M.Tourapis, "Enhanced Predictive Zonal Search for Single and Multiple Frame Motion Estimation", SPIE proceedings on Visual Communications and Image Processing, volume 4671, pp.123-133, January 2002.

[8] Chorng-Yann Su, Yi-Pin Hsu, and Cheng-Tao Chang, "Efficient Hexagonal Inner Search for Fast Motion Estimation," IEEE Trans. On Image Processing, vol.1, pp.1093-1096, May 2005.

[9] International Telecommunication Union ITU-T Recommendation H.262, 1996 Edition.

Fig.10. Frame 23 of the test video Akiyo_cif and its corresponding reconstructed frames using FS, DS, KCDS, HEXS and proposed HYBHKS algorithms.