MULTI CONSTRAINTS SHORTEST PATHS IN MOTION ESTIMATION FOR OPTIMAL RATE DISTORTION IN VIDEO COMPRESSION

Rajender Kumar

[1]Associate Professor, Department of ECE, Bhagat Phool Singh Mahila Vishwavidyalaya, Sonipat, India

Abstract: State of the art technologies like multiple reference frame (MRF), Variable Size Block Matching (VSBM) and quarter pixel accuracy are used in video coding standards and strive to reduce temporal and spatial redundancies. It is evident from the literature review that around 70 %-90% of total computational power is used in motion estimation. Thus, reduction in redundancy and computational complexity of motion estimation is one of dominating research area in the area of video coding. Quad tree based algorithms for variable size block matching (VSBM) is one of the most popular technique available to reduce computational complexity along with redundancy in motion estimation. In this investigation, an efficient quad tree algorithm which is based on edges homogeneity with Lagrange multiplier optimization algorithm is used in motion estimation for finding multiple paths with multiple constraints with user defined rate distortion requirements. This algorithm permits adaptive bit allocation between Displaced Frame Difference (DFD) and Motion Vector Field (DVF). The rate distortion optimization (RDO) allows for trade-off between distortion and rate and it is build based upon quad tree with active and inactive region using edges homogeneity present in the frame. The simulation results calculate K-MCSP with provided constraints with optimal rate and distortion. It is now depends upon user to select the appropriate path depending on their requirements and constraints.

Keywords: motion estimation, video coding standards, quadtree, A* prune algorithm, Lagrange operator.

1. INTRODUCTION

Joint Video Team (JVT) which is formed by combining two premier international standardization organizations, ISO/IEC and ITU-T proposed H.264 AVC and H.265 High Efficiency Video Coding (HEVC), which are the most popular video coding standards [1-3]. Some of major goals of these video codec are to improve compression performance and reduction of bit rate. These goals are achieved at motion estimation part of encoder in video

codec with variable block size and multiple reference frame (MRF) by minimizing the numbers of blocks and prediction error using variable block size matching [4].Variable block size techniques brought a significant change in quality of the video and are therefore found implemented in advance video coding standards like H.264 and H.265 HEVC but is also the most time-consuming component at encoder end. A number of new algorithms have been proposed by researcher for reducing the computation complexity and adaptively selecting the block sizes [5]. Fig. 1 shows various classifications of research methods to solve RD problem.

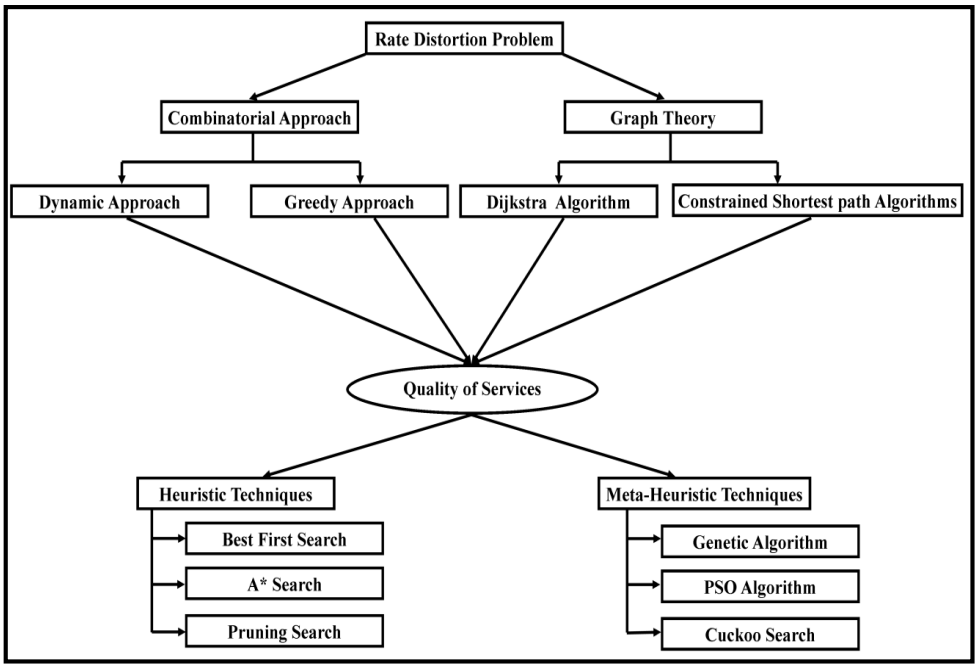

Fig. 1 Classification of research methods to solve R-D problem

In VBSM algorithms, complex motion can be described by smaller blocks while stationery content or uniform motion by larger blocks. However, selection of an appropriate block is one of the biggest problems and this gives rise to an interesting optimization problem without an efficient solution to this problem and is termed as NP hard. This practical problem can be tackled by using quad tree decomposition where each node has four children or none. At top of quad tree, block size is 16*16 and at bottom of 3rd level it is 4*4. The quad tree is pruned in active region and inactive region according to some threshold on edges present in frame to obtain blocks which are of variable sizes.

The rest of paper has been organized in the following order. Discussion on the quad tree technique and the method based on edge based algorithm which is used for video compression is presented in section II. Dijkshetra's algorithm considering multi constraint shortest path and rate distortion optimization is discussed in section III. The efficiency of the proposed edge-based quad tree algorithm in order to estimate the motion of the video compression without compromising on the big trade and computational complexity is

highlighted in Section IV with the help of the experimental results. Section V concludes the findings of the study.

2. CONTENT BASED QUAD TREE ALGORITHM FOR VIDEO COMPRESSION

Fixed and Variable size block matching algorithms are used to find optimal rate distortion in video compression with different searching algorithms such as Dikshtra, A* search algorithm with pruning etc. There are numerous techniques to match variable block size in motion estimation; one of the vital techniques among them is quadtree which finds significant contribution in motion estimation [6]. In this method, each of the frames is first considered and divided into four number of blocks of size 16*16, after that each of the 16*16 blocks is considered and divided into four 8*8 blocks, which in turn is again sub divided into four 4*4 blocks. A decision criterion is applied to see if each variable size block should be encoded as single 16*16 block or further or four independent 4*4 blocks. A 2N*2N image block is decomposed into an $(N-n_o+1)$ level hierarchy of square blocks with the help QT structure. The blocks produced by this decomposition at level n has a size of 2n*2n, where, $0 \leq n_o \leq N$ as shown in fig. 2.

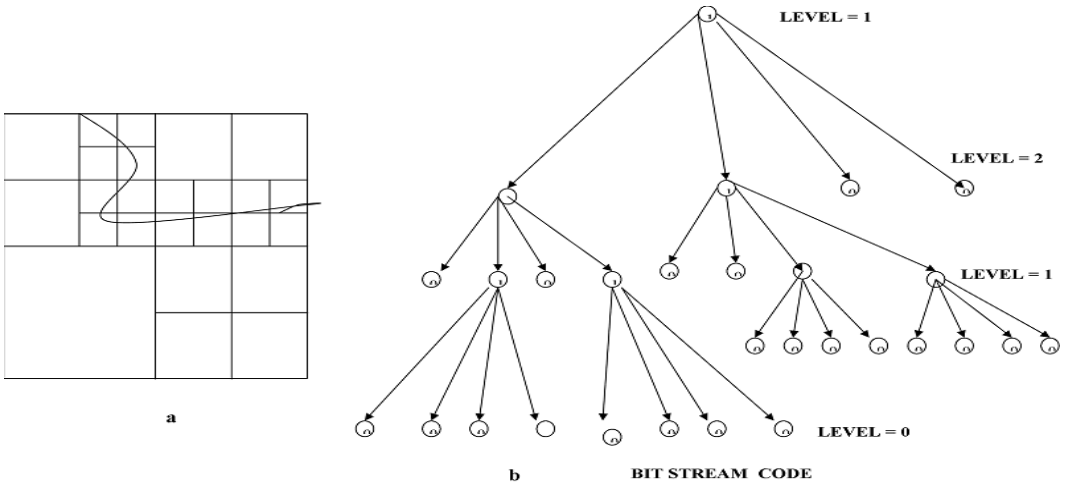

Fig.2 Frame decomposition Using Quadtree and its presentation

Block based motion estimation algorithms are extensively used to exploit the temporal redundancies in video coding. But it is very difficult to estimate accurately the blocks located on boundaries of moving objects. As it is well known fact that human eyes are sensitive to edge details, therefore if edge detection techniques are including with motion estimation which improves the quality of the video.

The standard quad tree decomposition algorithms used in many image compression applications show poor rate distortion performance and creates blocking in the reconstructed image. These problems can be solved by improving rate distortion performance with optimal threshold adjustment on edges present in the active region of frame and assign optimal bits

allocation for leaves coding. In this paper, we have presented an improved quadtree algorithm for motion estimation based on one of the important feature, namely edge intensity present in given frame. Edge detection technique is used to produce an excellent image quality []. In this proposed Quad Tree decomposition, performance of 3*3 edge detector as used for homogeneity decision is investigated. The new quad tree decomposition algorithm with threshold on edges is as follows:

1. Find number of edges and edge intensity at each level using 3*3 edge detector based on active and inactive regions present in the frame. Enter the threshold value of edges for each block in current frame.
2. If number of edges in active region is greater than threshold value then split the parent node into 4 children nodes.
3. Otherwise don't split region of interest and assign motion vector.
4. Repeat steps 2 & 3 for each 16*16, 8*8 and 4*4 micro-block present in current image.

Now to find optimal solution, coding bits are split into displaced frame difference (DFD) and displaced vector field (DVF) that closely resemble the size of micro-blocks. This problem escorts to rate distortion optimization in video compression. Lagrange multiplier is used to trade off between the bit rate and distortion. Lagrange multiplier optimization is gaining importance because of its effectiveness, conceptual simplicity and evaluate done in an optimized fashion []. Lagrange multiplier optimization technique is used for calculating optimal K- multiple constraints shortest paths.

3. MULTI CONSTRAINTS SHORTEST PATHS IN VIDEO COMPRESSION

The block matching technique is the most popular tool in motion estimation and compensation, used for video compression techniques and Rate Distortion Optimization (RDO) problem is related to it. RDO problem is related to the family of NP hard problem which uses Lagrange's parameter to solve and find constrained path with some constraints which is to be achieved [9-12]. As bandwidth available for transmission is a dynamic parameter, whenever requirement changes, it MCSP (Multiple Constraints Shortest Path) procedure can be used effectively each time to find the best possible optimal solution with acceptable bit rate with reasonable loss in image quality. It is always time consuming to use all MCSP each time for finding best feasible solution. In order to find the best feasible solution in least possible time according to variation in dynamic parameters, K-MCSP (K-multiple constraints shortest path) method can be considered. Considerable reduction in time can be achieved as the selection of the best feasible path is done from multiple pre computed paths. A modified A* prune algorithms is used for MCSP which allows for

controlling the contribution of different constraints simultaneously and also allows to choose from K paths which are produced due to variation in the dynamic parameters. In this work, A modified A* prune algorithm is used to solve Rate distortion Optimization (RDO) problem. Lagrangian bit allocation techniques is used for an efficient bit allocation between DFD (D) and DVF(R) given by Eq. 1 [13].

$$\mathbf{J = D + \lambda * R} \tag{1}$$

In Eq. 1, λ is Lagrangian Operator as dynamically changing constraints like bandwidth or quality of services, we proposed to use K-MCSP algorithm for finding one or multiple feasible paths subject to multiple constraints.

Considering a network with graph $G = (V, E)$ where V= set of nodes formed by quad tree and E= set of links in quad tree. Each link (i, j) ϵ E is associated with R non negative and additive QoS: $w_r(i,j)$, r= 1,2,-,-, R. The cost function W_o defined as

$$\boldsymbol{W_o(i,j) = \sum_{r=1}^{R} a_r * w_r\,(i,j)} \tag{2}$$

Now to find the first K-MCSP from source (s) to destination (t) node with constraints on rate and distortion is

$$\boldsymbol{w_r(p(s,t) \overset{\text{def}}{=} \sum_{\substack{(i,j)\epsilon p(s,t) \\ \forall(1,\ldots\ldots,R)}} w_r\,(i,j) \le c_r(s,t)} \tag{3}$$

A* search algorithm [7-8] with proper pruning technique is used to solve K-MCSP problem defined in Eq.3 where K is any positive integer. In this paper, five best feasible multiple constraints shortest paths are found with two constraints i.e DVF and DFD.

4. EXPERIMENTAL ANALYSIS OF K-MCSP USING IMPROVED QUAD TREE WITH A* PRUNE ALGORITHMS

Extensive experimental results have been carried out on several test sequences such as Mother Daughter and Foreman for improved quad tree algorithm with variable threshold on edges. Displacement field difference (DFD) i.e distortion and displaced vector field (DVF) i.e rate are calculated for each block size 16*16, 8*8 and 4*4 respectively. The DVF are calculated using exhaustive/full search for motion estimation and motion vectors are coded with DPCM technique. Displacement field difference (DFD) is coded with Huffman entropy coding. The performance of proposed approach is evaluated using extensive experimental simulation conducted on

a 2.0 GHZ PC with 2 GB main memory with MATLAB. The efficiency of improved algorithm is performed using PSNR, Total coded bits and average computational complexity. The video sequences taken for experimental simulation is listed below in Table 1 with its motion characteristics.

Table 1: Video sequences taken for experimental simulation with variable motion

Name of Video Sequence	**Type of video format**	**Motion Characteristics**	**Resolution**
Foreman	QCIF	Background is static but objects are moving with large motion.	176×144
Mother Daughter	CIF	The background is static but objects movement is very small, blocks are mostly quasi stationary.	352×288

It is shown from the experimental simulation that the performance can be dramatically improved by reducing the bits requirement for encoding the motion vectors and allocating the data bits to the residual encoding, which eventually improves the quality of the picture. With very low bit rate applications this coding strategy proves to be very advantageous. The number of bits required for DFD and DVF for each of the K shortest paths is computed along with the corresponding PSNR values. The best of the shortest path is selected for reconstruction of the frame in our study. Table 1, Table 2 and Table 3 show multiple constraint shortest paths for two different test sequence with their rate (DVF), distortion (DFD), PSNR and computational complexity with and without improved quadtree algorithms for motion estimation respectively.

The constraints for both Rate and distortion as per our A* prune algorithm to given values below:

K: 5 DVF constraints: 20000 DFD constraints: 20000 Count: 24334 List Size: 10

Table 2: DVF-DFD values for frame -2 at Block Size=16, 8 and 4 and QP=16, 32, 64 with improved and traditional quadtree algorithms for Foreman Video sequence

Block Size	**16**	**8**	**4**
DVF	1577	1574	1928
DFD	7624	12396	17644
Total Bits	9201	13970	19572
PSNR	20.8078	20.4887	20.5158

Table3: DVF-DFD values for K-paths for frame-5 at QP=64

K-paths → **Metrics parameter ↓**	**1**	**2**	**3**	**4**	**5**
DVF	1577	1625	1637	1673	1757
DFD	7624	7576	7565	7535	7479
Total bits	9201	9201	9202	9208	9236
PSNR	20.8078	20.8002	20.8002	20.7607	20.7587
Time Complexity (ms)	24.3367	24.8929	25.4652	26.0755	26.7320
Time for Quad-tree loop (ms)	6.5918				

Table 2 shows that both DVF and DFD satisfy required the constraints set for rate and distortion respectively. Only five feasible paths are obtained for the given constraints. The total bits and PSNR are shown for each path. It is concluded from Table 3 that all the paths provided by improved algorithm are feasible solutions, and do not violated the limitation imposed on the constrained. Figure 3 shows the original and reconstructed frame along with quadtree structure of foreman video sequence constructed by improved quadtree algorithm.

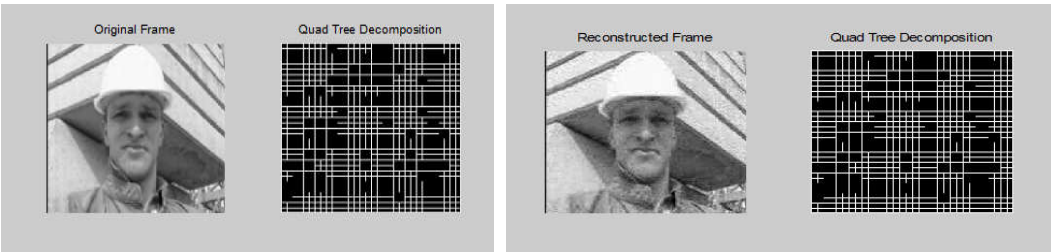

Fig.3 Original and Reconstructed Frame 5 of Foreman Video Sequence for path 3 for improved quadtree algorithms

Similarly Table 4 shows that both DVF and DFD satisfy required the constraints set for rate and distortion respectively for mother daughter frame. It is clearly shown from Table 5 that five feasible paths are obtained for the given constraints using our improved quadtree compared to only three paths in traditional quadtree algorithm.

Table 4: DVF-DFD values for frame -2 at Block Size=16, 8 and 4 and QP=16, 32, 64 with improved and traditional quadtree algorithms for Foreman Video sequence

Block Size	**16**	**8**	**4**
DVF	614	920	1604
DFD	578	5599	19969
Total Bits	1192	6519	21573
PSNR	34.1227	34.1227	34.1227

Table 5: DVF-DFD values for K-paths for frame-5 at QP=64

K-paths → **Metrics parameter** ↓	**1**	**2**	**3**	**4**	**5**
DVF	614	626	644	662	686
DFD	578	564	546	531	515
Total bits	1192	1190	1190	1193	1201
PSNR	34.1227	34.1227	34.1229	34.1229	34.1229
Time Complexity (ms)	30.4023	31.1381	31.9158	32.7887	33.8059
Time for Quad-tree loop (ms)	7.5918				

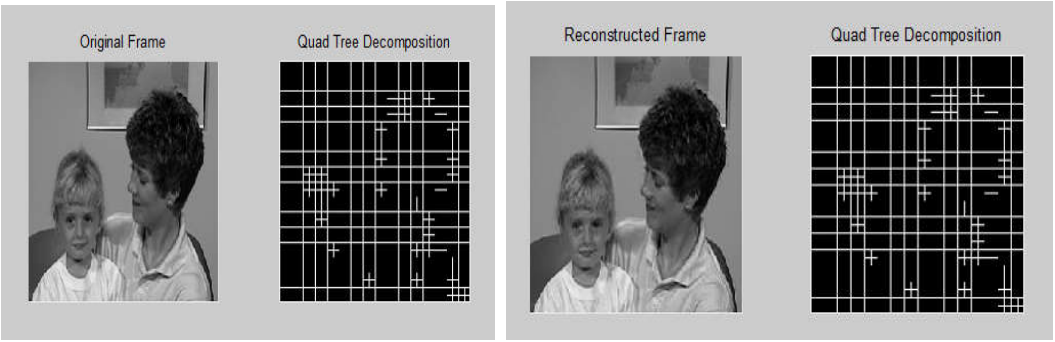

Fig.4 Original and Reconstructed Frame 5 of Mother Daughter Video Sequence for path 3 using improved quadtree algorithm

Fig. 5 shows the residual frame after subtracting reconstructed frame and original frame Mother Daughter Video Sequence for given constraints.

.

Fig. 5 residual frame after subtracting reconstructed frame and original frame Mother Daughter Video Sequence

5. CONCLUSION

In order to reduce the computational requirement of the encoder, many researchers have focused in the area typically acknowledging the fact motion estimation typically represents around 70 to 90% of an entire encoder computational requirement. In this paper, an attempt has been made to introduce a computationally efficient improved quadtree algorithms for motion estimation with multiple constraints on rate and distortion imposed. Lagrange multiplier optimization technique is used for minimizing the sum of distortion of block and 'λ' times bits needed to code it, where 'λ' is the Lagrangian parameter. The pruning /merging motion estimation algorithm which is based on the philosophy of quad tree structure leads to substantial improvement in the quality of the reconstructed picture without much distortion and is also significantly helpful in reducing the computational requirements as shown in Fig.3and Fig. 4 respectively. A* prune algorithm for multiple constrained shortest path is used for variable size block matching technique which generates lower overall bit rates without compromising both DVF and DFD constraints simultaneously and satisfying both as well.

REFERENCES

[1] Gary J. Sullivan (2005), Video Compression—From Concepts to the H.264/AVC Standard, proceedings of the IEEE, Vol. 93, No. 1

[2] T. Wiegand, G. J. Sullivan and A. Luthra (2003), Draft ITU-T Rec. H.264/ISO/IEC 14496-10 AVC, JVT of ISO/IEC MPEG and ITU-T VCEG, Doc. JVT-G050r1

[3] CCITT Recommendation H. 120 (1989), Codec for videoconferencing using primary digital group transmission, Geneva, 1989.

[4] N. Ahmed, T. Natrajan, and K. R. Rao (1984), Discrete cosine transform, IEEE Trans. Compu., vol. C-23, pp. 90-93

[5] Gary J. Sullivan and ThomasWiegand (1998), Rate-distortion optimization for video compression," vol. 15, pp. 74–90, Nov

[6] D. J. Vaisey and A. Gersho (1987), Variable block-size image coding, Proc. IEEE International Conference on Acoustics, Speech, and Signal Processing, Dallas, TX, USA, pp. 1051-1054, doi: 10.1109/ICASSP.1987.1169563

[7] Hart, P. E.; Nilsson, N.J.; Raphael, B. (1968). "A Formal Basis for the Heuristic Determination of Minimum Cost Paths". IEEE Transactions on Systems Science and Cybernetics. 4 (2): 100–7. doi:10.1109/TSSC.1968.300136

[8] Yan, Yumeng. (2023). Research on the A Star Algorithm for Finding Shortest Path. Highlights in Science, Engineering and Technology. 46. 154-161. 10.54097/hset.v46i.7697.

[9] G. J. Sullivan and T. Wiegand (1998), Rate-distortion optimization for video compression, IEEE Signal Processing Magazine, vol. 15, no. 6, pp. 74–90

[10] T. Wiegand, H. Schwarz, A. Joch, F. Kossentini, and G. J. Sullivan (2003), Rate-Constrained Coder Control and Comparison of Video Coding Standards, IEEE Transactions on Circuits and Systems for Video Technology, Vol. 13, No. 7, pp.688-703

[11] Antonio Ortega and Kannan Ramchandran (1998), Rate-distortion methods for image and video compression, vol. 15, pp. 23–50.

[12] Raffaele de Forni and David S. Taubman (2005), On the benefits of leaf merging in quad-tree motion models, Genova, Italy, vol. 2, pp.858 – 861

[13] H. Everett (1963) Generalized Lagrange Multiplier Method for Solving Problems of Optimum Allocation of Resources", Operational Research, vol. 11, pp. 399-417.