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A Survey on Rate-Distortion Optimized Bandwidth Efficient Motion Estimation Using Arps Algorithm

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Abstract

H.264 is one of the video coding standards which provide high quality video at considerably lower bit rates compared to previous Standards such as JPEG, MPEG. In general H.264 intra prediction offers nine prediction modes for 4x4 and 8x8 luma blocks, four prediction modes for 16x16 luma blocks. Thus Intra frame coding requires more number of bits than inter frame coding which results in buffer control difficulties. Here Rate-Distortion optimization technique plays an important role in minimizing bit rates and maximizing coding quality by selecting best coding mode out of nine prediction modes. This paper gives vast survey on different rate- distortion optimization techniques.

Keywords: Rate-Distortion optimization, Motion estimation, Intra prediction

Introduction

Digital video streams represent huge amount of data at high definition resolutions. In order to achieve efficient transmission in limited bandwidth and storage of multimedia content in limited storage space video compression plays a vital role. Video compression techniques reduce the amount of data needed to transmit or store video by using some mathematical algorithms to the source video to generate a compressed file. An inverse algorithm is used to yield a video that shows almost the similar content as the original source video. Therefore the time taken to compress, decompress, display and send a file is known as latency. The basic communication problem arises in maintaining specified reproduction fidelity while conveying source data using a low bit rate or maintaining highest fidelity within an available bit rate. Hence in either case, a fundamental tradeoff is made between bit rate and fidelity. The ability of a source coding system to make this tradeoff well is called its coding efficiency or rate-distortion performance, and the coding system is referred to as codec i.e., a system comprising a coder and a decoder. In video compression schemes the rate distortion efficiency is mainly based on interaction between possible various motion representations, waveform coding of various refreshed regions and differences. Video codec's implemented with different standards are not compatible with other standards i.e., content of the video that is compressed using one standard (H.264) cannot be decompressed with a different standard (MPEG-4). This is because one algorithm cannot correctly decode the output from a different algorithm but it is likely to employ many different algorithms in the same software, which would then facilitate multiple formats to be compressed. Different video compression standards make use of different methods of reducing data, and results in different latency, quality and bit rate.

H.264 Encoder

H.264 which is a latest standard in a sequence of video coding standards H.261 of ITU-T is also known as International standard 14496-10 or MPEG part 10 Advanced video coding (AVC) of ISO. The design of H.264 encoder depends largely on the algorithms used for motion estimation, selection of required transformation, entropy coding technique as well as on the rate-constrained encoder control. The basic block diagram of H.264 video encoder is shown in figure (1).The step-by-step operation of video encoding proceeds as follows [15]. Preliminarily the video is fed as input to the encoder which is converted into sequence of frames (or) pictures. The first frame (or) picture is divided into blocks known as macro blocks coded in Intra mode which uses prediction within the frame without depending on other frames [10]. For all left over frames of a sequence Inter coding mode is used. Here instead of encoding pixel values for each block, the encoder will seek to find a block analogous to the one it is encoding on a previously encoded frame, known as reference frame. This process is carried out by a block matching algorithm. If an exact match is found in reference frame a vector known as motion vector is used which points to the matching block position at the reference frame to encode the block. This process of motion vector determination is called ME (motion estimation).

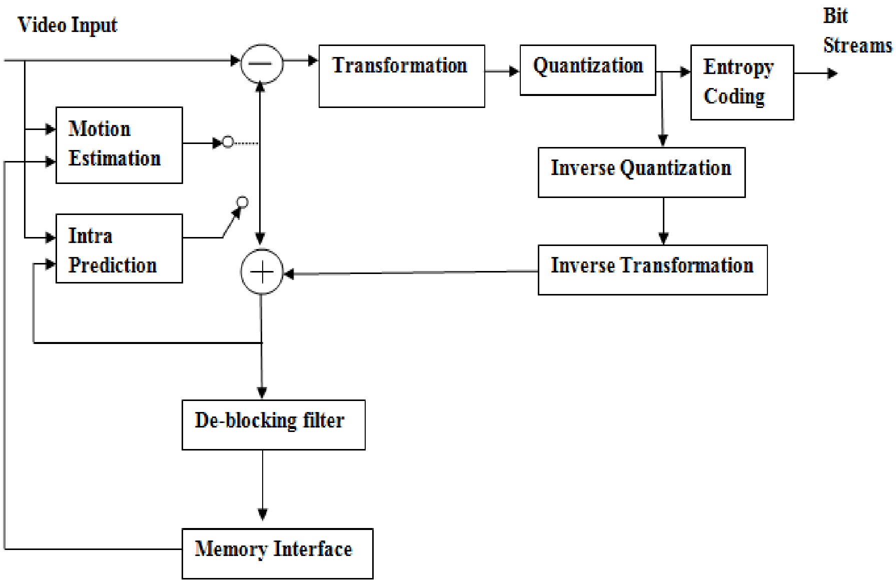

Figure 1: H.264 Video Encoder

The obtained difference between the original and its predicted one which is well known as residual or prediction error is given as input to the transform block [16] which converts the spatial domain into frequency domain. Thus the transformed coefficients are quantized, entropy coded and transmitted with prediction side information. For the prediction of the subsequent encoding frames, the quantized coefficients are constructed by inverse quantization and inverse transformation inorder to decode the residual. The residual is then added to the prediction and the result is fed to deblocking filter to smooth out block-edge discontinuities. The final frame is then stored for further process.

The primary block of video encoder is transform block which plays a vital role in video compression. Here a brief introduction about transformation and types are discussed.

(a) Transformation:

The basic principle of transform coding is image pixels exhibit a certain level of correlation with their neighboring pixels. Correspondingly in a video transmission system, neighboring pixels in successive frames show very high correlation. Therefore, these correlations can be utilized to predict the pixel value from its respective neighbors. Hence, a transformation is defined to map this correlated data into uncorrelated (transformed) coefficients. Basically the transformation is a lossless operation. As a result, the inverse transformation provide a perfect reconstruction of original image. The following are the different transforms [12] used for compression.

A. Discrete cosine transform:

It is a technique for converting a signal in spatial domain into elementary frequency components i.e., it decorrelates the image data. After decorrelation without losing compression efficiency each transform coefficient can be encoded independently. The advantages of DCT is it minimizes blocking artifacts and needs less processing power but gives less compression ratio.

B. Integer discrete cosine transforms:
DCT have the weakness of inverse mismatch problems between encoder and encoder, limited block size scalability and complicated hardware implementation. Consequently an integer DCT is implemented which overcomes the problems of DCT. Integer DCT can be implemented as a direct 2D matrix multiplication or as 1D using additions, shift operations and subtractions which is commonly referred as 'butterfly' [11].

C. Discrete wavelet transforms:
Unfortunately DCT gives less compression ratio, so a new transform is exploited to achieve better compression ratio without losing most of the image information known as wavelet transform. Wavelet transform is based on diminutive waves, of unstable frequency and restricted duration which are popularly known as wavelets. It carries out multiresolution image analysis. There are different families of wavelet function namely Haar wavelet, Symlet wavelet, Daubechies wavelet, Biorthogonal wavelet, coiflet wavelet etc. Thus, wavelet transform gives better compression ration but requires more processing power.

D. Hybrid transform :
It is compromise approach of DCT and DWT. Hybrid DCT-DWT transformation is suitable for regular applications as it gives more compression ratio and produces a good quality of reconstructed image but achieving image clarity is partially tradeoff.

(b) Entropy Coding:
The Baseline and Extended profiles of H.264/AVC supports two variable length coding techniques-context adaptive variable length coding (CAVLC) and universal variable length coding (UVLC). CAVLC encodes quantized transformed coefficients where as UVLC is used to encode other type of syntax elements. Context-based adaptive binary arithmetic coding (CABAC) is other type of entropy coding which is not supported in Baseline and extended profiles. The H.264 standard adopts backward zig-zag scanned run–length coding with CAVLC. After performing intra/inter prediction, transformation, quantization of residuals, CAVLC[13] is used to encode the quantized transformed coefficients. Context adaptive coding offer better coding efficiency than UVLC over the whole quality range. After transformed and zig-zag scanned, the non-zero coefficients are generally sequences of ±1. CAVLC coder indicates the number of high-frequency +/-1 coefficients by using trailing 1's. The number of non-zero coefficients in neighboring blocks is correlated whose coding efficiency can be enhanced by using different VLC tables.

Rate-Distortion Optimization

The following glossary helps understanding of rate control issues.

Bit rate: Bit rate refers to the bits per second consumed by a sequence of pictures, i.e., bit rate = (average bits per picture) / (frames per second).

Distortion: It refers to the difference between the source image and the reconstructed image afterwards it has been decoded. In H.264 Sum of squared difference is used to compute distortion.

Quantization Parameter (QP): It determines the step size for relating the transformed coefficients with a finite set of steps. For large QP values, the value of the transformed coefficients decrease due to which zero coefficient will be more, as a result the output encoding bits become less. On the other hand if the QP is smaller, the output encoding bits will become more as the value of the transformed coefficients increase. In H.264, QP increase of each unit lengthens the step size by 12% and decreases the bit rate by 12%.

H.264 offers 7 modes for inter (temporal) prediction (16x16, 16x8, 8x16, 8x8, 4x8, 8x4, 4x4), 9 modes for spatial(intra) prediction of 4x4 blocks namely vertical, horizontal, DC, diagonal down left, diagonal down right, vertical right, vertical left, horizontal up and horizontal down, 4 modes for intra prediction of 16 x 16 macro blocks: vertical, horizontal, DC and plane and one skip mode. Each 16 x 16 macro block can be splitted into several ways. Thus, mode selection for each macro block is a critical and time-consuming. An algorithm called rate-distortion optimization (RDO) is used for selection of the optimal mode

Another crucial application of rate distortion optimization techniques is to resolve the problems of bit allocation, i.e., how to achieve the optimal solution of number of bits distributed among different macro blocks and pictures in order to obtain the minimum total distortion within the limited total bits and the issue is referred as rate control.

The algorithm mainly involves the following three steps:

1) An complete pre-calculation of all viable modes to find out the bits and distortion of each.
2) Both bit rate and distortion are considered for the evaluation of metric.
3) Metric with minimum value is selected.

A. A Lagrangian optimized rate control algorithm:

Usually there are a number of parameters that can be chosen for every Macro block (MB) which decides the overall rate and the distortion of the coded bit streams. Rate control algorithm is one which is used to select the parameters to in order to achieve a target bit rate. On the other hand coding parameters of every macro block (MB) should be selected very carefully to achieve efficient R-D encodings. In the Lagrangian optimized mode decision method, the Lagrangian multiplier (λ) is computed with an empirical formula using the selected Quantizer Parameter (QP) for every MB:

$$\lambda = 0.85 \times 2^{\{(QP-12)/3\}}$$

During the encoding process, the rates (R) and the distortions (D) are computed for all coding modes of every MB. The mode that has the minimum J is selected as the optimum mode for every MB using the below formula:

$$J = D + \lambda \times R.$$

Thus Lagrangian optimized rate control algorithm controls the encoded video bit rate by adjusting the λ value for every picture. The encoder examines different combinations of MB mode and QP for every MB and finds the optimum setting that meets the rate constrains. To achieve the acceptable encoding delay, the number of QPs to search is minimized.

B. Pixel similarity based technique

A pixel similarity based technique[5] bring down the amount of computations carried out by H.264 intra prediction algorithm and as a result drastically reduces the power consumption of hardware implementation of H.264 intra prediction. The key idea of this technique is that if the current block neighboring pixels are same then the H.264 intra prediction equations are modified for the specific block. Generally H.264 Intra 4x4 modes use 13 neighboring pixels A,B,C,D,E,F,G,H,I,J,K, L,M for prediction calculations. Table 1 shows a prediction calculation which uses some of these neighboring pixels to predict a 4x4 block. If the neighboring pixels used by the mode are all equal the prediction equation is simplified to a constant value.

As an example the prediction equation used by DC mode is given in equation (1). If the neighboring pixels A, B, C, D, I, J, K, L are equal, we can substitute one of the neighboring pixels, e.g. pixel A, in place of every neighboring pixel in equation (1). Therefore, the equation (1) simplifies to A as shown in figure (2)

$$\text{Pred}\,[y,x] = [(A+B)+(C+D)+(I+J)+(K+L)+4] >> 3 \quad (1)$$

$$\text{Pred}[y,x]=[8A+4]>>3=A \quad (2)$$

Therefore the technique lessens the amount of computations carried out by 4x4 luminance, 16x16 luminance, and 8x8 chrominance prediction modes up to 68%, 39%, and 65% respectively with a small comparison overhead and also minimizes the power consumption of a 4x4 intra prediction hardware up to 57%.

M	A	B	C	D	E	F	G	H
I	a	b	c	d				
J	e	f	g	h				
K	i	j	k	l				
L	m	n	o	p				

Figure 2: 4x4 Luma block and neighboring pixels

Table 1: 4x4 Intra Modes And Corresponding Neighboring Pixels

4x4 Intra Modes	Neighboring pixels
Vertical	A,B,C,D
Horizontal	I,J,K,L
DC	A,B,C,D,I,J,K,L
Diagonal Down left	A,B,C,D,E,F,G,H
Diagonal Down Right	A,B,D,C,J,K,I,L,M
Vertical Right	A,B,C,D,I,J,K,M
Horizontal Down	A,B,C,I,J,K,L,M
Vertical Left	A,B,C,D,E,F,G
Horizontal Up	I,J,K,L

C. Based on Rate- distortion cost adaptive motion vector resolution:

Without considering the statistical properties of the local image, inter coding with a fixed motion vector resolution based on adaptive decision scheme for threshold selection depending on RD cost inorder to improve coding efficiency is a new method. In this method initially at the slice level the strength is selected with the RD cost reduction based on the previously coded slice. According to the sub-pixel motion the larger the RD cost reduction, the larger the selected motion vector resolution. This larger motion vector resolution is set as threshold value. An adaptive mechanism for threshold selection at the coding unit (CU) depth is done using the PMVR method [4]. In the progressive motion vector resolution (PMVR) scheme the MV resolution is progressively adjusted using the magnitude of the motion vector difference (MVD) as shown in figure. 3. Both rate reduction and encoding time saving can be achieved since the MV resolution is determined by the MVD.

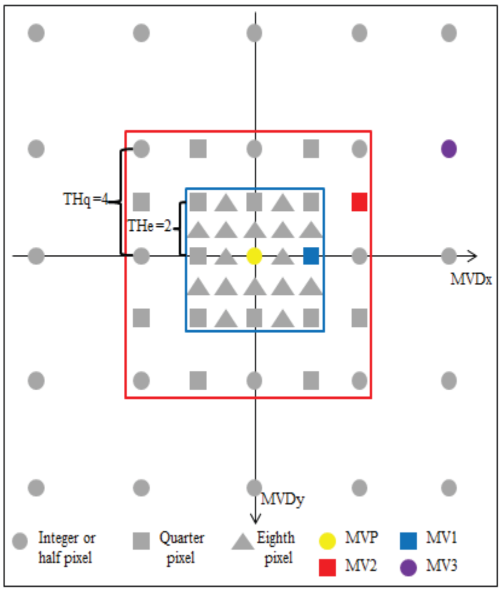

Figure 3: PMVR

D. Enhanced Mode Selection Algorithm:

In this algorithm the selection of mode is made based on factors- homogeneity and temporal movement. Once the class is decided, to decide the best mode among the sub modes, sub-mode selection algorithm is used. Initially the algorithm [3] checks for skip condition to see whether the 16x16 block has movement or not. If block movement is zero then skip mode is selected or else decision is made between class 16(16x16, 8x16, 16x8) and class 8(8x8, 4x8, 8x4, 4x4).Now homogeneity of the block is checked based on probability based macro block mode selection. Class 16 is chosen if the macro block is homogenous or else class 8 is chosen.

E. Fast mode decision algorithm based on macro block classification

This algorithm computes $R_{inter\ 16x16}$ of current macroblock and compares it with predefined threshold value. Current macroblock is determined as simple motion macroblock (skip, inter 16x16,inter 16x8 and inter 8x16) if $R_{inter\ 16x16}$ is less than threshold or else it is considered as complex motion macro block (inter 4x8, inter 8x4, inter 8x8,inter 4x4,intra 16x16,intra 4x4). Thus the algorithm reduces the total encoding time 47% to 65% of H.264.

The flow chart of the fast mode decision algorithm is shown in Figure.4. Due to this search orders [2], a lot of unnecessary computations can be saved and computationally intensive modes especially the intra modes calculation can be avoided. In addition, the algorithm is very easy to implement in both hardware and software and it does not require extra module because in the process of rate-distortion cost computation the calculation of $R_{inter\ 16x16}$ is a necessary step.

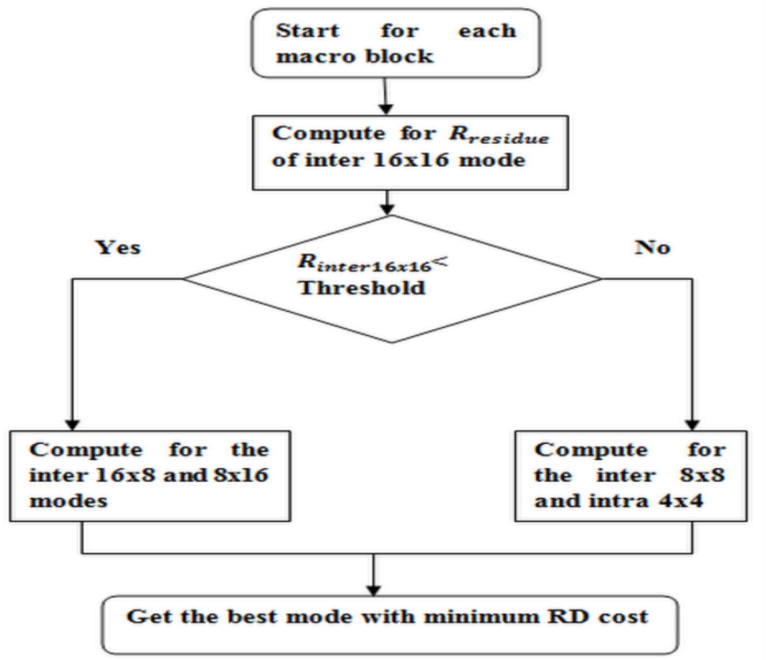

Figure 4: Flow chart of fast mode decision algorithm

F. Hadamard transform based rate-distortion cost estimation

The simplified Rate-Distortion (RD) cost estimation algorithms, based on the Hadamard transform and the distortion evaluation without reconstruction is another new approach. This method comprises of mainly of two aspects, firstly instead of DCT transform a Hadamard transform is applied to a block. Secondly by discarding reconstruction operation and distortion estimation is done due to which intra prediction mode decision can decrease 16.1% coding time. The process flow of Hadamard transform is shown in figure 5.

After the 2D forward transform, the coefficients are quantized and followed by entropy coding to obtain the estimated rate cost [1]. Meantime, the reconstruction procedure is eliminated. Hence the distortion cost can be estimated by the remainders from the quantization process. This method is also implemented in VLSI where 64.9% hardware cost and 60.4% power is saved.

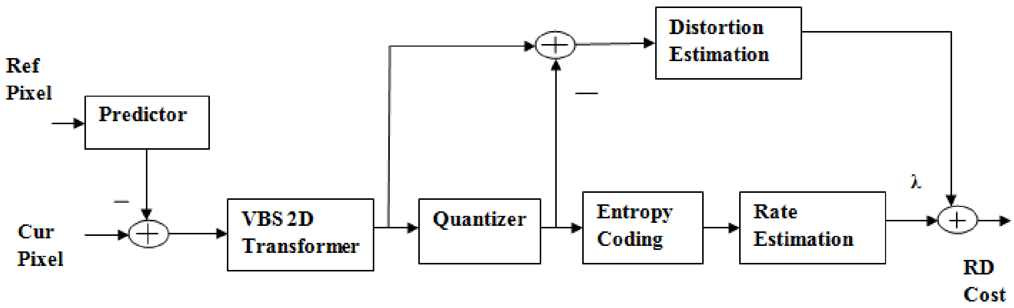

Figure 5: Process flow of Hadamard transform based RD-cost estimation

G. Structural Similarity Index Scheme

It is one of the rate-distortion optimization scheme for mode selection which is based on contrast, similarities of luminance between a distorted image and a reference image but has not been completely developed in the context of image and video coding. SSIM index of image is obtained by calculating average local SSIM indices using a sliding window. The three main steps of SSIM is as follows.

1) Employing SSIM as the distortion measure where both the current MB and neighboring pixels to be coded are taken into account to utilize the properties of SSIM.
2) An adaptive Lagrange multiplier selection method based on an original reduced-reference statistical SSIM Estimation algorithm and a rate model is used at the frame level.
3) At the macro block level, further adjusted Lagrange multiplier is utilized.

RDO problem provoked by SSIM[6] is given as

$$J= (1\text{-}SSIM) + \lambda . R$$

Where SSIM index is given by

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

Whereσ_x ,σ_{xy} and μ_x are the standard deviation, cross correlation and mean respectively.

C_1 and C_2 are used when the means and variances are nearer to zero to avoid instability.

H. Parallelizing:

Computation time is mainly spent in measuring the rate-distortion cost for both intra and inter modes in selecting the optimal coding mode. One way to speed up the encoder is through Parallel computation. This technique uses three different parallel schemes[7] for H.264/AVC RDO encoder implementation they are- The parallel slice scheme (PSS), Parallel multiple reference frames scheme (PMRFS), Parallel block mode scheme (PBMS) each run over a software DSM-based (distributed shared memory) PC cluster system comprises of a master node along with a number of processing nodes. figure.(6) shows the encoding flow of the parallel H264/AVC encoder. B1 and B2 indicate the barrier operations performed in the overall coding flow.

The system starts with reading the video input frame to the master node. After barrier-B1 each processing node obtains respective image data. Consequently, intra and inter prediction modules take action with parallel computing schemes. Later the processing nodes process all MBs in a frame. Information of all previous MBs are sent to master node at barrier-B2 because only the master node owns of all MBs information, this implementation effect the mode decision module, entropy coding module, and deblocking filter, transform, quantization, inverse transform and inverse quantization module(T, Q, T^{-1}, Q^{-1}) on the master node. According to the respective RD costs, mode decision module selects the absolute reference frame for motion estimation, best coding block mode and motion vector for block from reference frame for motion estimation, best coding block mode and motion vector for block generated by all processing nodes.

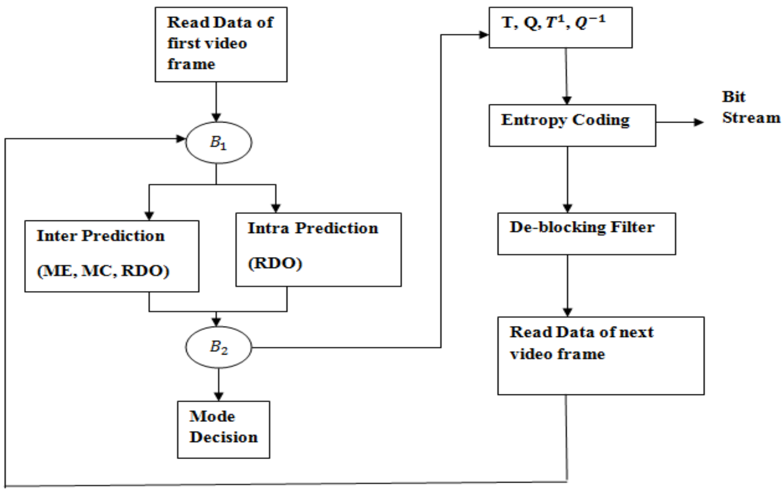

Figure 6: Parallel H264/AVC RDO encoder

I. Transform-Domain Rate-Distortion Optimization:
Mode selection process makes the encoding process tremendously complex, in the computation of the rate distortion cost function, which take account of the SSD (sum of squared difference) between the original and reconstructed image blocks. A rate-distortion optimization accelerator using transform-domain based on FSSD (Fast SSD) and VLC-based rate estimation algorithm[8] is used to minimize the complexity of RDO technique, a new fast sum of squared difference (FSSD) algorithm with an iterative lookup table quantization process is used as shown in figure(7). An efficient hardware implementation of the transform-domain RDO accelerator is also introduced.

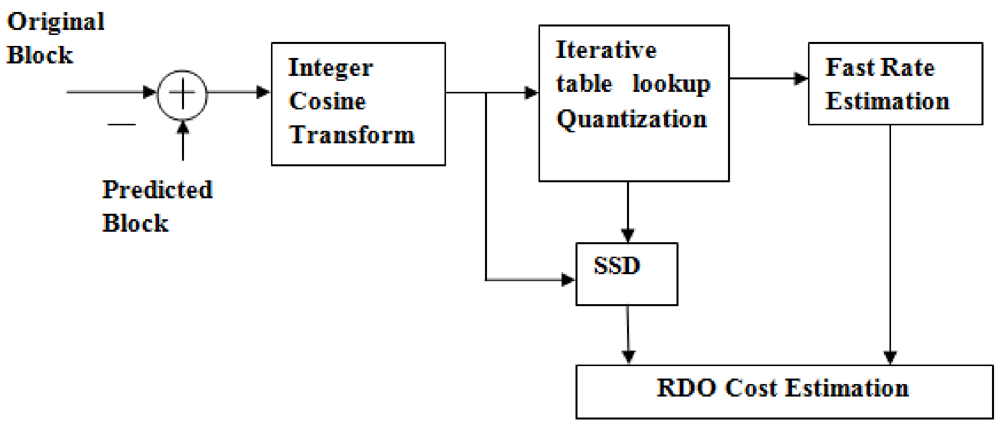

Figure 7: Block diagram of Transform Based RDO

J. Lagrangian Rate Distortion Optimization Based on Laplace Distribution:
A new algorithm Lap- which is based on the Laplace distribution of transformed residuals is capable to adaptively optimize the input sequences which results in improved overall coding efficiency. Initially based on Laplace distribution of transformed residuals, accurate rate and distortion models are developed [9]. Then an adaptive Lagrange multiplier is derived. The proposed Lap- currently works in a fixed-QP environment.

Motion Estimation Using Arps Algorithm

Motion estimation refers to a inter frame coding which is one of the most time consuming unit in video encoder. It uses the temporal redundancy between the video frames. Motion estimation is nothing but estimation of image pixels disarticulation in time sequence from one frame to another.

ARPS algorithm[14] considers the information that the motion in most of the portions in a frame will be usually homogeneous i.e., if the macro block around the current macro block moved in a particular direction then there is a maximum probability that the current block also have a similar motion vector. It uses the motion vector of the macro block to its immediate left to predict its own motion vector. The main structure of the ARP takes the rood shape and its size refers to the distance between centre point and other vertex point. In most of the video sequences, the motion vector distribution is almost in horizontal or vertical directions when compared to other directions. As rood pattern extends in both horizontal and vertical directions, it can abruptly detect the motion vectors and also can jump directly into the local region. This rood pattern search is always the first step; it directly explores the area where there is a high probability of finding a good block matching. The point with the least weight becomes the origin for subsequent search steps and the search pattern is changed to Small Diamond Search Pattern (SDSP). The procedure keeps on doing SDSP until least weighted point found to be at the centre of the SDSP. Symmetric shape of ARP is another advantage which is useful in terms of hardware. Suppose the motion vector of a block is (3, -2). Take the very next block, 6 locations will be considered of which the first location will be the center point itself and the second point will be the point taken from the previous MV i.e. (3, -2). Thus the searching is directly put in a point where there is the highest possibility of getting the exact match. Further, the remaining 4 points are obtained by taking a step size, S = Max (|x|, |y|). According to the example it is Max (|3|,|-2|) = 3 as shown in below figure (8). If the minimum is at the center point itself there is no further searching. Otherwise it goes to SDSP searching.

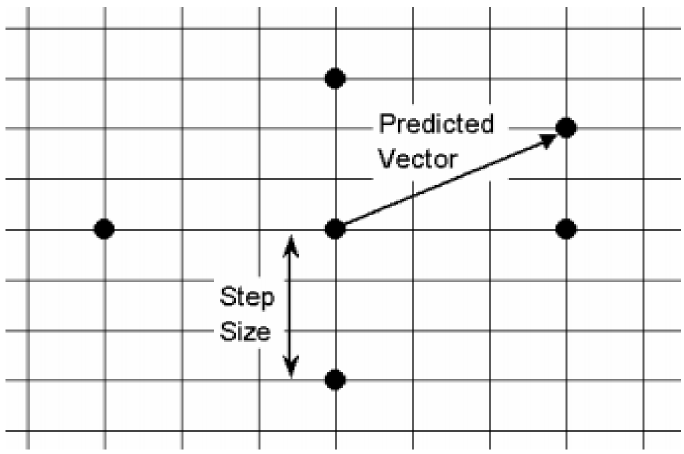

Figure 8: Adaptive rood pattern: The predicted MV is (3, -2), and the step size S = Max (|3|, |-2|) = 3

Conclusion

This paper provides a brief introduction about H.264 Encoder and survey on different rate-distortion optimization techniques. Integer Cosine Transform (ICT) is preferred as the better transform as it requires less computation compared to DCT and wavelet transforms. In intra and inter encoding the best prediction mode can be determined by using rate-distortion optimization processes. Thus the basic Lagrangian optimized rate-distortion cost estimation algorithm gives better bit rate accuracy with little rate-distortion degradation and good PSNR value compared to other techniques.

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