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Comparative analysis of various search center selection methods for fast motion estimation

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Abstract
Initial search center (ISC) prediction or motion vector (MV) prediction helps in estimating an initial search center for finding a refined motion vector in order to speed up the entire process of motion estimation (ME). Finding an appropriate initial MV leads to an early detection of actual motion vector. Various methods have been listed in literature for finding the best possible ISCs. In the current work we have presented a comparative analysis of various methods for estimating the initial search centers. Apart from detailing all these methods we have given the experimental results to find the effect of each of these methods on the video quality, time and accuracy of prediction. Video quality is calculated in terms of peak signal to noise ratio (PSNR) and accuracy of prediction is calculated by finding the difference between the predicted MV and the motion vectors obtained from full search (FS) algorithm as FS is considered as a standard algorithm which estimates the best possible MVs. The comparison of all these methods have been made by applying them on various video test sequences.

Keywords: Motion estimation; Motion vector; Initial search center; temporal redundancy; spatial redundancy.

1. Introduction
The increasing use of video data in different walks of life has led to an overwhelming need to compress the video data. This compression has to be achieved with less number of calculations and without deteriorating the video quality. The task of finding the motion between two consecutive frames is termed as motion estimation (ME). Lot of research has been devoted to finding the motion vectors (MVs) which are used to represent the motion. Various techniques have been developed in literature towards ME process. These include pixel based, region based and block based motion estimation techniques [1]. Block based techniques are most common among the three techniques and have been used in various international standards like MPEG-1, MPEG-2, H.261 and H.263. The reason lies in the simplicity, robustness and effectiveness of these techniques.
Block based motion estimation (BBME) is based on the idea of partitioning a video frame in to elementary blocks. Each block in the current frame is then matched against the candidate blocks in a particular search area/region in the reference frame. This gives the best match for the current block and thus gives its displacement. This displacement is known as the MV of that block. Matching criteria that have been used in different approaches include mean square error (MSE), mean absolute error (MEA) and sum of absolute differences (SAD).Figure 1 shows the block matching in block based motion estimation.
The most standard algorithm for ME is full search (FS) [2]. It is based on exhaustively matching each of the candidate blocks in the search window to find the best match for the current block. This algorithm is the simplest algorithm for MV estimation and gives the most optimal results. But the computational complexity of this algorithm prohibits its use in real time applications. The research then focused onto reducing the number of search points. Three step search (TSS) [3] was the first algorithm to use this idea and reduce the number of search points to be visited for finding the best match. TSS was followed by new three step search (NTSS) [4], four step search (FSS) [5] and diamond search (DS) [6]. Each of these algorithms aimed to reduce the number of search points in one or the other way thus reducing the computational burden of FS. All these methods are based on fixed search pattern and assume that the error surface is unimodal and so they have a high probability of getting trapped into local minima.

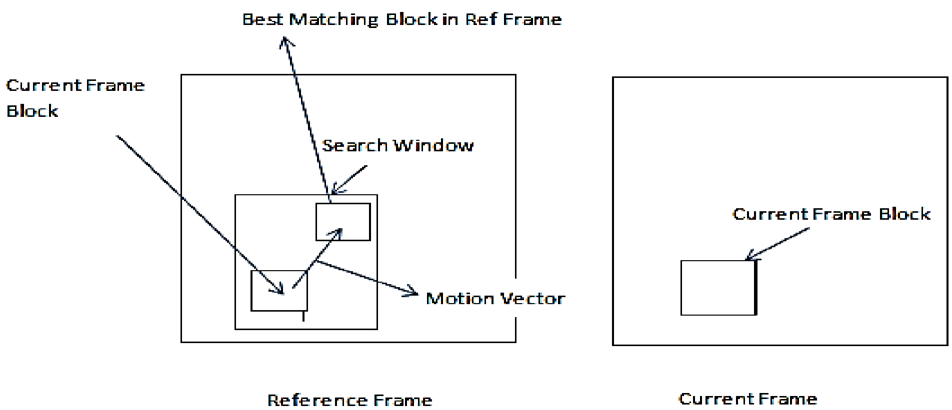

Fig 1: Block based motion estimation

In order to avoid these disadvantages a new category of algorithms were proposed which were based on adaptive patterns rather than the fixed patterns in the previous approaches. Adaptive rood pattern search (ARPS) [7] algorithm is very famous algorithm in this category. It used the concept of ISC to speed up the entire process of ME. The concept of ISC is based on the idea of predicting the MVs and then carrying the search around these ISCs. If there is accuracy in finding the ISC then the predicted motion vector (PMV) lies in the region or is close to the actual MV and consequently less number of steps would be needed to find the actual MVs. Also this would eliminate the possibility of being trapped in local minima.

Various methods have been given in literature for finding the ISCs. In the current work we have tried to analyze all these methods and provide the experimental results of each of these methods to access their performance. The comparisons have been made in terms of video quality given by PSNR, time taken and the accuracy of prediction in comparison to FS algorithm. No previous work has given the comparisons of these methods. So clear cut advantages and disadvantages of each of these methods in terms of various parameters have never been highlighted. Thus the current work would be beneficial for future researchers and would provide guidelines as to use which method as per the requirement.

The paper is divided into four sections. Section 2 gives an overview of various methods of predicting ISC. Experimental results giving the comparison of all the methods are given in section 3. Section 4 gives the conclusion of the entire experimental work.

2 Initial search center prediction

Prediction of initial search center aids in finding the accurate search center for block matching and thus leads to a significant reduction in the number of search points to find the motion vector.

Two types of similarities can be defined in different frames of video sequences:

i) Spatial redundancy
ii) Temporal redundancy

i) Spatial redundancy: It is based on the fact that an object is usually spanned through various blocks and thus the motion of all these blocks would be almost same leading to similar MVs. So if this type of coherence is considered then the assumption is that the MV of the current block could be correlated to the MVs of its neighboring blocks in the current frame.

ii) Temporal redundancy: is based on the idea that objects move with similar motion over the successive frames. So the MV of the current block could be predicted from the MVs of its collocated block and neighboring blocks in the reference frame.

The number of neighbors that could be defined for a particular block in the current frame is four whereas in the reference frame there are eight neighbors and one collocated block. A diagrammatic representation of all the neighbors in the current and the reference frame is given in figure 2.

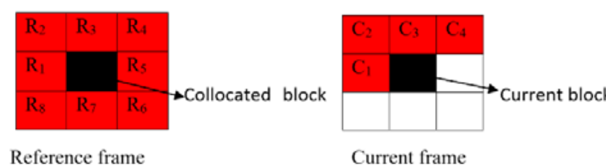

Fig 2: Spatial and temporal neighbors

In the initial use of ISC only the spatial neighbors were used to predict the MVs. The leftmost block in the current frame i.e. C_1 was used by Nee and Maa [7] to predict the motion vector.

H.26 standard has used the median of left, top and top right blocks in current frame to calculate the ISC i.e.:

$$ISC = median\ (C_1, C_3, C_4) \quad (1)$$

Equation (1) has been one of the most used methods for predicting ISCs. It has also been used by Jing and Chau [8], Tsai *et al.* [9] and Ishfaq Ahmad [10] to find initial estimation of motion vectors.

Lee [11] has used the median of left, upper and upper left blocks to find the initial motion vector i.e.

$$ISC = median\ (C_1, C_2, C_3) \quad (2)$$

The use of all the four neighbors of the current frame to find the ISC was given by Ismail *et al.* [12]. So in this case

$$ISC = median\ (C_1, C_2, C_3, C_4) \quad (3)$$

Along with spatial neighbors, temporal neighbors were used by Ismail *et al.* [13] to attain a better prediction of ISC. Along with the idea of using both the spatial and temporal neighbors (C_1, C_3, C_4, R_1, R_3, R_4), they have used the basic concept that the immediate neighbors are more close to the

current block than the rest of the neighbors. So more weight is assigned to immediate neighbors (C_1, C_3, R_1, R_3) in comparison to the distant neighbors (C_4, R_4).
In a very recent work Lin *et al.* [14] have proposed a cross prediction model for predicting the motion vectors. Median of five neighboring blocks of the current and reference frame have been used to attain a better prediction model.
All the above mentioned models have used different neighbors in predicting ISCs but none of the author has listed the advantages of using a particular model over the previously defined methods.
The section provides the implementation details of comparison of all the above said models.

3. Simulation Results

Various models of ISC have been used to evaluate the performance of each of them in terms of peak signal to noise ratio (PSNR), time and the accuracy of prediction model. Various video test sequences have been taken to evaluate the comparisons. Various ISC prediction methods (A) by Nee & MA, (B) in equation (2), [C] in equation (3), [D] in ref [13], [E] in ref (14) are compared. Simulations have been done by taking the search window of size ±7, block size of 16×16 and 15fps. MATLAB Version 7.6.0.324 (R2008a) is used on Windows 7 platform over a PC with Intel® Core™i5-2450MCPC with installed memory of 6GB and 64 bit operating system and processor speed of 2.5 GHz.
PSNR basically is a quantitative measure of the quality of video. It can be defined as

$$PSNR = 10\log_{10}\frac{(2^n-1)^2}{MSE} \quad (4)$$

where MSE is the mean square error between the original frame and the generated motion compensated frames. Number of bits to represent a pixel is given by n. PSNR is calculated for different types of video sequences and is shown in table 1.

Table 1: PSNR comparison table

Sequences	[A]	[B]	[C]	[D]	[E]
Mdaughter	42.5785	42.5785	42.5915	42.6028	42.6277
Hall	35.5261	35.538	35.5262	35.5262	35.5436
Highway	34.5539	34.554	34.5589	34.5589	34.561
Foreman	19.6565	20.7012	19.6878	20.6318	20.7008
Stefan	23.0568	24.1248	23.0568	23.5246	24.1421
Football	21.6467	21.6755	21.6527	21.6485	21.6755
Salesman	37.3711	37.7711	37.7737	37.7737	37.7737
Tennis	20.5171	20.5285	20.5244	20.5251	20.5291
Average	29.3633	29.6840	29.4215	29.5990	29.6942

The results in table clearly indicate that prediction model [E] gives the best results.
Accuracy of prediction of each of the models is given by finding the distance between the estimated MV from a given model to the actual MV obtained from full search method. Full search is considered as a standard method for motion estimation and thus it gives the best MV for any candidate block. It is calculated by finding the difference between the actual MV and predicted ISC, and then finding the sum of all these differences. The lesser this distance the more accurate is the prediction model. Table 2 gives a comparison of accuracy in terms of these distance values for different prediction models. The distance calculation indicates that there in improvement in prediction from the standard model used for ISC prediction in H.264 in [B].

Table 2: Accuracy comparison table

Sequences	[A]	[B]	[C]	[D]	[E]
Mdaughter	655	602	641	651	542
Hall	378	295	346	336	265
Highway	1050	975	980	946	875
Foreman	98	76	56	81	66
Stefan	890	812	845	765	612
Football	200	173	180	170	157
Salesman	36	12	21	11	9
Tennis	999	976	990	920	913
Average	538	490	507	485	430

4. Conclusion

In the current work, we have given a comparative analysis of the various ISC prediction methods based towards fast motion estimation. The methods are based on using the MVs from spatial neighbors and temporal neighbors from the reference frame. Simulations have been done and comparisons are done on the basis of PSNR and accuracy for various test video sequences containing fast motion as well as slow motion. The results indicate that the MV can be predicted with more accuracy if the future temporal MVs from the reference frame are also included in MV prediction as done in [14]. The method gives more accuracy while maintaining high video quality in terms of PSNR. So the use of future blocks in predicting initial search centers is the key to enhance accuracy and video quality.

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