Search Range Adjustment and Motion Vector Prediction for Fast Motion Estimation

Using Neighbouring Motion Vectors and Distortions for Adjustment of a Search Range and a Starting Point

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Abstract: The block matching algorithm has been widely used for motion estimation, but it suffers from heavy computational complexity. Many researchers in video processing area have proposed fast motion estimation algorithms by adopting various ways to reduce its complexity. In this paper, we introduce a conventional method controlling a search range and defining a new starting point, and also discuss our proposed method which supplements previous work by using neighbouring block's motion vectors and distortions. Consequently, we obtained remarkable performance about 80 times faster than full search and 2.6 times faster than conventional algorithm with small video quality improvement in terms of PSNR. Therefore, the proposed method can be applied for real-time video processing applications.

1 INTRODUCTION

Motion Estimation (ME) and Motion Compensation (MC) are important parts for video coding standards, such as MPEG-1/2/3, H.261/263/264 and HEVC. The purpose of ME and MC is to remove temporal redundancy between successive frames in video sequences. The most popular method of ME algorithms is the Block Matching Algorithm (BMA) which is utilized by many video coding standards. BMA divides frames up into rectangular blocks and match up with other blocks in reference frames. BMAs are the most effective way because it has very simple structure and also convenient to implement. They find the optimal motion vector from the minimum distortion value in terms of Sum of Absolute Difference (SAD), sum of squared difference (SSD), and Mean Squared Error (MSE).

The Full Search (FS) is the most straightforward BMA; it calculates distortions and finds an optimal motion vector between the current block and all possible locations in pre-defined search window. However, FS suffers from computational complexity and it is heavy burden to implement real-time video processing. Therefore, many fast motion estimation (FME) algorithms to reduce complexity of FS have been proposed for last few decades without peak-to-noise ratio (PSNR) loss. For example, Three-Step Search (TSS), Four-Step Search (FSS), Hexagonal Search (HS), and Enhanced Hexagonal Search (EHS) are taken the coarse search using geometric search patterns that evaluates only few points in the search window. Successive Elimination Algorithm (SEA), Multilevel Successive Elimination Algorithm (MSEA), Normalized Partial Distortion Search (NPDS), Adjustable Partial Distortion Search (APDS) and Search Range Adjustment and Matching Point Decimation (SRAMPD) are also proposed for FME.

In this paper, we briefly review about SRAMPD in Section 2, SRAMPD predicts motion vector and improves search speed by reducing search widow size. Proposed methods that compensate defects of SRAMPD are introduced in Section 3. Experimental results compared with other algorithm are illustrated in Section 4. Finally, we conclude our method with some discussions in Section 5.

2 CONVENTIONAL METHOD

In this Section, we introduce a search range

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adjustment method in SRAMPD since it is a basic idea of proposed algorithm. For reducing the search range without noticeable video quality loss, SRAMPD proposed a starting point decision and an adaptive search range adjustment using a spatial correlation between adjacently located motion vectors. Since we cannot obtain the motion vector of the current block until ME of the current block is accomplished, SRAMPD firstly predict the motion vector ($\mathbf{mv}_\mathrm{p}$) by applying median function to neighbouring motion vectors (left, upper and upper left) as follows,

$$\mathbf{mv}_p = median(\mathbf{mv}_l, \mathbf{mv}_u, \mathbf{mv}_{ul}). \qquad (1)$$

For an adaptive search range, SRAMPD calculates SAD($\mathbf{mv}_p$) of new starting point which is located at $\mathbf{mv}_p$ and also evaluates SADs of its neighbouring blocks which are located left, upper and upper left position relative to new starting point is collected in $\mathbf{C}$ = [SAD($\mathbf{mv}_p$) SAD_l SAD_u SAD_{ul}], respectively. Finally, a search range is determined by,

$$D = \max\left(0, \min\left(R, round\left(\frac{R \cdot \max(\boldsymbol{C})}{T_{SAD}}\right)\right)\right). \qquad (2)$$

The function round( ) gives the nearest integer value of input data, R is a maximum value of given search range and T_{SAD} is a threshold value which is set to 8 to control search range. Also, R·max(**C**) is normalized by pixel numbers in the block.

3 PROPOSED ALGORITHM

3.1 Motion Vector Prediction

SRAMPD use the median function for prediction but it cannot get accurate motion vector because neighbouring motion vectors are not always reliable and there are many outliers in the motion vector field. These error vectors can be propagated spatially and it leads video quality degradation, as well. If we find the correct starting point ideally, ME is not necessary because the predicted motion vector will be a final motion vector. For this reason, we proposed a more accurate motion vector prediction method using distortion values corresponded to neighbouring motion vectors.

First, collect SADs include zero vector and neighbouring MVs like, $\mathbf{S}$ = [SAD($\mathbf{mv}_z$) SAD($\mathbf{mv}_l$), SAD($\mathbf{mv}_u$), SAD($\mathbf{mv}_{co}$)] and evaluate a motion vector of the minimum SAD of **S** as:

$$\mathbf{mv}_{p\_new} = \arg\min_{\mathbf{mv}}(\mathbf{S}), \qquad (3)$$

$\mathbf{mv}_z$ means the zero vector and $\mathbf{mv}_{ur}$ is the motion vector of the block located upper right position relative to current block. $\mathbf{mv}_{co}$ is the co-located motion vector in the reference frame and it can be substituted for $\mathbf{mv}_{ur}$ when the previous motion vector field is not exist.

Additionally, we consider the consistency of the reference motion vectors. If two motion vectors have same magnitude and direction, proposed method considers the other motion vector as unreliable motion vector. This motion vector is skipped when proposed algorithm is calculating the predicted motion vector.

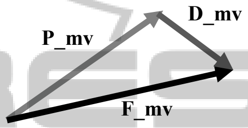

Figure 1: The description of P_mv, D_mv and F_mv.

Figure 1 shows the relationship of motion vectors resulted by motion vector prediction and motion estimation. **P_mv** is the predicted motion vector, **F_mv** is the final motion vector and we define the difference motion vector that is **D_mv** which is the result of ME for measuring the accuracy of prediction methods.

Table 1: The Comparison about the average length (pixels) of D_mv.

Sequence	SRAMPD	Proposed
Akiyo	0.03	0.01
Coastguard	0.29	0.04
Container	0.16	0.03
Flower	0.61	0.13
Foreman	1.25	0.43
Mobile	0.39	0.05
Stefan	2.08	0.30
Mother	0.98	0.28
Table	0.80	0.18
Average	0.73	0.16

Table 1 presents the accuracy of motion vector prediction method in SRAMPD and proposed algorithm. The prediction accuracy is significantly increased since the average length of **D_mv** is decreased about 4.6 times. It means the predicted motion vector is more similar to the final motion vector. Therefore, the search range can be reduced more than conventional method for speed-up improvement.

Table 2: The results of reference methods and proposed algorithm in terms of time per frame and PSNR.

	FS		NPDS		APDS		SRAMPD		Proposed	
Sequences	Time	PSNR	Time	PSNR	Time	PSNR	Time	PSNR	Time	PSNR
Akiyo	0.401	42.34	0.039	42.23	0.019	42.32	0.012	42.32	0.0030	42.32
Coastguard	0.413	30.43	0.045	30.32	0.029	30.44	0.013	30.42	0.0053	30.43
Container	0.438	38.17	0.044	38.15	0.026	38.16	0.012	38.03	0.0038	37.99
Flower	0.452	25.89	0.046	25.82	0.033	25.90	0.014	25.85	0.0076	25.87
Foreman	0.407	31.81	0.044	31.69	0.036	31.82	0.016	31.88	0.0062	31.84
Mobile	0.467	25.04	0.046	24.84	0.028	25.02	0.018	24.97	0.0071	25.01
Stefan	0.419	23.90	0.048	23.73	0.049	23.89	0.017	24.71	0.0064	25.00
Mother &daughter	0.415	40.05	0.044	39.94	0.036	40.00	0.012	39.75	0.0047	39.87
Table	0.463	31.46	0.045	31.23	0.029	31.42	0.012	31.47	0.0042	31.27
average	0.430	32.12	0.045	31.99	0.032	32.11	0.014	32.16	0.0054	32.18
Speed-up ratio	1.000		9.659		13.590		30.764		80.190	
PSNR difference		0.000		-0.127		-0.014		0.035		0.057

3.2 Search Range Adjustment

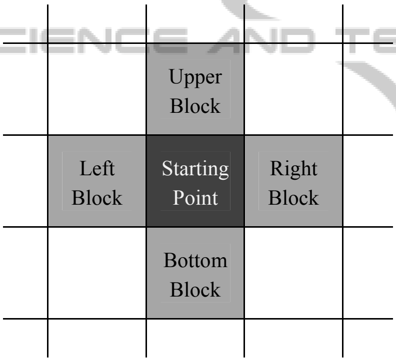

Figure 2: The location of reference blocks.

In SRAMPD, the author refers to left, upper and upper-left block of initial point for the search range adjustment. However, in reference frame, there also exist right and bottom block, and it is more correlated with initial point than upper-left position since, in video sequence, the dominant edges are horizontal and vertical direction. Therefore, in proposed algorithm, we refer to left, upper, right and bottom block's distortion value for the search range control. The modified collection of SADs follows,

$$C'=[SAD(\mathbf{mv}_p)\ SAD_l\ \ SAD_u\ \ SAD_r\ \ SAD_b]. \tag{4}$$

The equation (2) is used in proposed method to obtain a search range; however, we changed the threshold value experimentally that is much larger than SRAMPD about 4 times and we utilized average of C' instead of maximum SAD because the proposed method of motion vector prediction is more accurate than conventional algorithm. Also,

4 EXPERIMENTAL RESULTS

To evaluate performance of the proposed algorithms, we compare them with FS, NPDS, APDS and SRAMPD in terms of time per frame and PSNR. We use speed measurement as time per frame because each sequences have the different number of frames. The experimental setup is as follows: the block size of 16 x 16, the search window size of ±16. Eight CIF (352 x 288 pixels) video sequences, "Akiyo", "Coastguard", "Container", "Flower", "Mobile", "Stefan", "Mother & daughter" and "Table", are used.

Table 2 shows the performance of the proposed algorithms. The proposed algorithms are about 2.6 times faster than SRAMPD, averagely. Especially, in "Flower" sequence, 5.31 times faster than conventional method. The proposed method obtains good performance for almost every sequence even if the sequence has the fast motion characteristic. In "Table" sequence, we cannot get a better result in terms of PSNR because there is a scene change at 131th frame. When the scene is completely shifts, the common characteristics include the motion vector filed is not ordinary. Proposed method use the co-located motion vector in reference frame, it can be a weak-point if there is breakpoint caused by scene change or fast and unpredictable motions.

From Table 3, we can observe the search window size that is almost 2.5 times smaller than SRAMPD; therefore, our method for search range adjustment yields speed-up improvement in terms of time. Especially, for "Akiyo" and "Container", proposed algorithm achieves remarkable results since they have slow motion characteristic. Even the object in the sequence moves fast, we still obtain the gain about both PSNR and speed up improvement.

Table 3: The Comparison about the average search window size.

Sequence	SRAMPD	Proposed
Akiyo	11.51	2.81
Coastguard	12.55	5.35
Container	11.22	2.98
Flower	12.80	7.51
Foreman	13.36	5.73
Mobile	15.24	7.58
Stefan	13.83	5.91
Mother	10.98	3.52
Table	11.18	3.98
Average	12.52	5.04

5 CONCLUSIONS

In this paper, we proposed a new search range adjustment and a motion vector prediction method by adopting adjacently located block’s motion vector and SADs. Using the proposed motion vector prediction, we find the almost correct initial point. Therefore, we additionally reduced the search range and also computational complexity. Comparing with conventional algorithm, experimental results confirmed that our method achieves about 2.6 times faster speed with small PSNR improvement.

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