An Adaptive and Efficient Selective Multiple Reference Frames Motion Estimation for H.264 Video Coding^{*}

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Abstract. In the popular video coding standard H.264/AVC, many advanced techniques are employed. One important technique is the use of multiple reference frames motion estimation. However, the computational load increases with the number of references frames. In this paper, we suggest a selective multiple reference frames motion estimation (SMRFME) architecture which takes use of the information of the 1st reference frame to determine whether it is necessary to search remaining reference frames. In addition, three early termination schemes are applied to the remaining reference frames of the candidate modes. The simulation results demonstrate that the proposed algorithm can achieve up to 77% of time saving compared to the multiple reference frames full search algorithm, while maintaining a high coding performance.

Keywords: H.264, multiple reference frames, selective multiple reference frames motion estimation (SMRFME), early termination, AZB, region based.

1 Introduction

The international video coding standard H.264/AVC has been approved by ITU-T as recommendation H.264 and by ISO/IEC as international standard MPEG-4 part 10 advanced video coding (AVC) [1]. The state-of-art H.264/AVC achieves significantly better performance in both PSNR and video quality at the same bit-rate compared with prior video coding standards. The improvement is typically 2-3 dB in PSNR, or equivalently 40%-60% in bit-rate reduction. One important technique is the use of multiple reference frames motion estimation (ME), and the computational complexity of H.264/AVC increases with the number of reference frames employed. The full selection procedure provides the best coding efficiency, but the five-fold increase in computation load is unbearable.

Many fast and efficient multi-frames ME algorithms have been investigated in recent years to reduce the computation cost and maintain coding performance. Some algorithms attempt to use context-based or histogram-similarity based method to

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speed up the multiple reference frames ME [2]. Some other algorithms attempt to reduce the computation using various prediction methods for selecting the initial search point [3]-[4]. In most of researches investigated perform the multiple reference frames ME mode by mode and select the best macroblock (MB) mode by considering the rate-distortion (RD) optimization technique. It is observed that most of the MB modes are finally predicted using the first reference frames, and just few of them are predicted with other reference frames. Another observation is that if the MB mode predicted using the 1st frame has a bad motion cost (*MCOST* is shown in equation 1), it is then less likely to be the best mode predicted from its other reference frames. In this paper, based on these observations we propose a selective multiple reference frames ME (SMRFME) scheme which performs the 1st reference frame ME first and performs remaining reference frames only for those modes with good *MCOST* predicted using the 1st reference frame.

$$MCOST(s, c) = SAD(s, c) + \lambda_{MOTION} \cdot Bit(\Delta MV) \quad (1)$$

where $SAD(s, c)$ is the sum of absolute differences between original block s and candidate matching block c . λ_{MOTION} is the Lagrange multiplier for ME. ΔMV is the difference between the predicted MV and the actual MV. $Bit(\Delta MV)$ is the number of bits representing the ΔMV .

2 Statistical Analysis of Multi-Reference Frames ME (MRFME)

In the inter mode decision, 7 different block-size modes, varying among 16x16(m_1), 16x8(m_2), 8x16(m_3), 8x8(m_4), 8x4(m_5), 4x8(m_6) and 4x4(m_7), are performed in each MB to achieve the best coding efficiency, in addition to the skip mode (m_0). These modes form a two-level hierarchy inside a MB. The first level L1 includes modes of 16x16, 16x8, 8x16, while the second level L2 includes modes of 8x8, 8x4, 4x8 and 4x4. In the H.264/AVC reference software baseline encoder, the multiple reference frames ME is conventionally performed mode by mode with full search of five reference frames, as illustrated in Fig. 1.

In most video sequences lots of background or motionless MBs are finally determined as a skip mode or L1 modes after computationally expensive rate distortion optimization. The MBs belonging to a high detail or fast motion area must be further split into L2 modes to get the best coding efficiency. In addition, most of MB modes end up with being predicted using the 1st reference frame. An intensive experiment was conducted on many CIF and QCIF video sequences, to evaluate the distribution of best reference frame in each sequence.

The results conducted on 10 test video sequences are displayed in Table 1 for QP=28. As shown, most of MBs are predicted from 1st reference frame (78%). We have observed that the MB mode, with a bad *MCOST* on the 1st frame prediction, is then less likely to be the best MB mode predicted from its other reference frames.

Fig. 1. Conventional Multi-Reference Frames Motion Estimation

Table 1. The distribution of the best reference frame

QP=28		Distribution of the best reference frame				
sequence		t-1	t-2	t-3	t-4	t-5
QCIF	claire	96.70	1.18	1.10	0.35	0.68
	grandma	96.32	1.46	1.34	0.35	0.53
	foreman	73.50	11.68	8.72	3.32	2.77
	football	78.52	8.95	6.28	3.14	3.12
	carphone	75.66	8.75	8.41	3.54	3.65
CIF	container	91.68	3.69	2.07	1.40	1.17
	tempete	54.74	14.55	16.17	7.69	6.84
	mobile	46.87	16.14	16.86	10.32	9.81
	paris	93.13	3.51	2.01	0.78	0.57
	stefan	72.36	10.79	9.51	3.89	3.46
Avg.		77.95	8.07	7.25	3.48	3.26

3 Proposed Fast MRFME Algorithm

Based on the analysis above, we propose a fast MRFME algorithm which takes use of the characteristics of the video sequences.

3.1 Selective MRFME Scheme (SMRFME)

From the statistical analysis described previously, the conventional multiple reference frames ME proposed in the reference software encoder, checking all reference frames

equally likely for each mode, might not be an efficient scheme. To reduce the computation cost and maintain coding performance several fast and efficient multiple reference frames ME algorithms have been investigated in recent years. In [2], the context-based method was proposed to speed up the multiple reference frames ME. In [2], after the 1st frame for all seven modes are performed, several context-based adaptive criteria are used to determine whether it is necessary to search the next reference frames. The procedure repeats until all 5 reference frames have been checked. The algorithm shows more efficient than the conventional one due to that most of best MB modes have been obtained in the 1st reference frame prediction (as can be seen in Table 1), and the prediction in all other reference frames can be skipped with negligible degradation.

The algorithm proposed in [2], to whatever extent it occurs, doesn't consider that the probability is very low for a MB mode with a bad *MCOST* predicted in the 1st frame, which becomes the final best MB mode predicted from its other reference frames. To improve the computation efficiency, in this section we propose a selective multiple reference frames ME algorithm. The SMRFME scheme is illustrated in Fig. 2. The SMRFME scheme is briefly summarized as follows:

Fig. 2. Selective Multi-Reference Frames Motion Estimation

Assume $MCOST_{1,best}$ as the best *MCOST* predicted in the 1st reference frame among all MB modes, which is given by

$$MCOST_{1,best} = \min\{MCOST_{1,i}, i = 0,1,2,3,4,5,6,7\} \quad (2)$$

where $MCOST_{1,i}$ represents the $MCOST$ in mode i . Define the ratio of the $MCOST$, $\beta_{MCOST,i}$, as

$$\beta_{MCOST,i} = \frac{MCOST_{1,i}}{MCOST_{1,best}} \quad (3)$$

To speed up the multiple reference frames decision process, after the 1st reference frame prediction only the modes with $\beta_{MCOST,i}$ less than a threshold β are still performed ME for other reference frames. To determine the threshold β for SMRFME, we examine the cumulative distribution function (CDF) of the best modes finally predicted from other reference frames that still can be acquired with this criterion, as a function of β for several test sequences. The results are demonstrated in Fig. 3. As shown, a very large number of the best modes can be identified when $\beta = 1.2$, i.e., the mode with $MCOST$ value $MCOST_{1,i} \geq 1.2MCOST_{1,best}$ are unlikely to obtain the best reference frame in its remaining reference frames.

Fig. 3. CDF of the hit rate as a function of factor (β)

3.2 Early Termination Algorithms for Remaining Reference Frames

Though the SMRFME scheme can bring out good coding performance, it achieves 41% of computation reduction on average. Although the remaining reference frames of least possible modes are discarded, five reference frames of the candidate modes are still performed. In this section, three early termination algorithms are proposed to further quicken the process of searching reference frames.

3.2.1 Region Based Algorithm (Denoted as Region Based)

Generally, the correlation between the adjacent frames is very strong. Our investigation revealed that the continuity of the motion can be explored in order to simplify the multi-reference frames selection. Assume an object is moving in a video sequence and keeps the similar appearance in adjacent frames. The best reference frame of previous frame can be used as the maximum reference frame of current frame. An example is given in Fig. 4, which illustrates the best reference frame for each macroblock in two successive encoded frames of Foreman, where 0 to 4 are the best reference index (ref_idx). It is clearly shown that the MB in frame_(t) are highly correlated with their co-located or surrounding MB in the frame_(t-1). Fig. 5 shows the MB in current and its co-located and neighbouring MBs in reference frame, where co-located (E') and surrounding (A-I) MBs form a region. For the frame_(t), we first check the ref_idx of the region in previously encoded frame_(t-1). To avoid additional computation complexity, we just find out the maximum ref_idx in the region. We use the maximum ref_idx to determine the maximum searched frame for the frame_(t). The maximum searched frame is defined as

$$\text{Maximum searched frame} = \max\{\text{ref_idx}_A, \text{ref_idx}_B, \dots, \text{ref_idx}_I\} \quad (4)$$

Fig. 4. The ref_idx of the two adjacent frames in Foreman

Fig. 5. Region based macroblocks

3.2.2 Detection of All Zero Coefficients Algorithm (Denoted as AZB)

In motion estimation process, the SAD between the current block and its best matching block can be used to detect all zero blocks. If it is detected that the transformed and quantized coefficients are very close to zero, the remaining reference frames can

be terminated. In order to save the DCT and quantization, a nearly sufficient condition for early zero-block detection is derived [5]. If all the SAD blocks are smaller than threshold ($3.5 \cdot Q_{step}$), the ME process of the remaining reference frames is terminated immediately.

3.2.3 Detection of Monotonic Increment Algorithm (Denoted as Monotonic)

We can see from Table 1 that the probability that ref_{t-1} , ref_{t-2} and ref_{t-3} are selected as the best reference frame is very high, more than 93% on average. Thus, the $MCOST$ s of ref_{t-1} , ref_{t-2} and ref_{t-3} can also be used to determine whether or not search ref_{t-4} and ref_{t-5} . When the $MCOST$ of ref_{t-3} is largest among the first three reference frames, these three $MCOST$ s will most likely be monotonic increment. The probability that ref_{t-4} and ref_{t-5} selected as the best reference frame is very little. For this condition, the ME procedure of the ref_{t-4} and ref_{t-5} is omitted.

3.2.4 Analysis of Our Proposed Early Termination Algorithms

The hit rate analysis of these three algorithms is shown in Table 3. It can be seen that the average hit rate of these three algorithms reaches 95%, 89% and 97%, respectively. Thus, we can get the good coding performance in simulation.

Table 3. The hit rate analysis

Sequence		Region based	AZB	Monotonic
QCIF	football	94.51%	92.89%	95.24%
	coastguard	94.01%	91.98%	98.37%
	trevor	95.69%	93.19%	99.28%
	claire	97.58%	98.03%	99.42%
	foreman	92.49%	83.60%	96.58%
	tennis	96.04%	90.09%	97.73%
CIF	bus	94.42%	88.56%	97.30%
	dancer	94.31%	91.32%	98.69%
	waterfall	93.00%	89.59%	97.14%
	news	97.16%	96.52%	99.39%
	stefan	93.27%	84.88%	96.18%
	mobile	97.18%	72.23%	89.01%
AVG.		94.97%	89.41%	97.03%

4 Experimental Results

To evaluate the performance of the efficient selective multiple reference frames ME algorithm, our proposed algorithms were implemented in H.264 reference encoder JM12.2. The proposed algorithms were tested on 4 QCIF (176x144) and CIF (352x288) sequences which represent different motion activities. The test conditions for simulation are given as follows:

Table 4. Simulation condition

# of coded frames	100	GOP structure	IPPP...
# of reference frames	5	Search range	±16
RDO	on	QP	20, 24, 28, 32, 36
Entropy coding	CAVLC	Resolution	1/4 pixel
Intra mode	on	Inter mode	on

Table 5. Performance comparison for QP=28

(a) PSNR comparison

QP=28		PSNR comparison (dB, Δ (dB))					
Sequence		Orig.	SMRFME	Rgeion based	AZB	Monotonic	Proposed
QCIF	football	34.547	-0.011	-0.028	-0.009	-0.018	-0.023
	coastguard	34.682	-0.013	-0.025	0.006	-0.017	-0.035
	trevor	36.912	0.003	-0.008	-0.023	0.000	-0.016
	claire	39.823	0.061	0.004	0.008	0.007	-0.015
CIF	bus	35.718	-0.017	-0.020	-0.005	-0.006	-0.037
	dancer	40.609	-0.001	-0.003	-0.017	-0.001	-0.025
	waterfall	35.454	-0.004	-0.036	0.004	-0.029	-0.052
	news	38.585	-0.013	-0.020	-0.016	-0.016	-0.033
Avg.			0.001	-0.017	-0.006	-0.010	-0.030

(b) Bit-rate comparison

QP=28		Bit rate comparison (bps, Δ (%))					
Sequence		Orig.	SMRFME	Rgeion based	AZB	Monotonic	Proposed
QCIF	football	1060999	0.41	0.08	-0.03	0.03	0.59
	coastguard	279156	0.37	0.55	0.46	0.00	0.58
	trevor	142279	0.12	0.02	-0.18	-0.37	0.07
	claire	32599	-0.39	1.71	-0.46	-0.04	0.10
CIF	bus	1328657	1.05	0.08	-0.08	0.04	1.50
	dancer	608738	0.11	-0.15	0.10	-0.05	0.39
	waterfall	324540	-0.08	0.51	0.18	0.48	0.64
	news	227602	-0.01	0.01	0.00	0.10	0.40
Avg.			0.20	0.35	0.00	0.02	0.53

(c) Time comparison

QP=28		Time comparison (ms, Δ (%))					
Sequence		Orig.	SMRFME	Rgeion based	AZB	Monotonic	Proposed
QCIF	football	137340	-43.37	-15.89	-5.11	-25.60	-60.36
	coastguard	108387	-41.77	-44.09	-10.60	-32.52	-65.41
	trevor	76118	-39.52	-42.04	-20.13	-31.95	-67.74
	claire	49666	-48.18	-47.68	-29.38	-31.71	-71.20
CIF	bus	468038	-44.60	-26.50	-13.13	-27.86	-64.85
	dancer	380253	-41.18	-46.70	-38.39	-36.97	-77.81
	waterfall	347551	-38.85	-22.42	-15.15	-21.72	-56.07
	news	237827	-35.68	-46.11	-27.84	-31.42	-68.91
Avg.			-41.64	-36.43	-19.97	-29.97	-66.54

The simulation results of PSNR gain, bit-rate increment and coding time compared to multiple reference frames full search algorithm (denoted as Orig.) are shown in Table 5. The algorithm which combines SMRFME algorithm with all early termination algorithms is denoted as proposed algorithm. The simulation results show that our proposed algorithm achieves 66% coding time on average. Meanwhile the performance of our proposed algorithm is almost the same as the Orig., with negligible loss in PSNR (0.03 dB loss) and bit-rate (0.53% bit-rate increment).

Fig. 6 depicts the rate-distortion (RD) performance of sequence football and Stefan. Compared with Orig. and our proposed algorithm, the average PSNR drop of our algorithm is negligible. Therefore, the rate-distortion curve of our proposed algorithm and the Orig. algorithm are hardly distinguishable. Table 6 shows that the complexity reduction of our proposed algorithm in various bit-rate. Results also show that our proposed algorithm can reduce computation load efficiently, while keeping good coding performance.

(a) Football.QCIF

(b) Stefan.CIF

Fig. 6. Rate-distortion performance comparison

Table 6. Coding efficiency comparison

(a) Football.QCIF

Football.QCIF	Time comparison (ms, Δ (%))					
QP	Orig.	SMRFME	Rgeion based	AZB	Monotonic	Proposed
20	146613	-44.17	-15.25	-0.27	-24.73	-60.89
24	142596	-44.30	-14.87	-1.60	-25.31	-61.04
28	136813	-43.34	-15.94	-4.96	-25.42	-60.74
32	129417	-40.96	-18.16	-11.51	-25.88	-60.32
36	118116	-37.66	-24.48	-16.71	-26.86	-62.59

(b) Stefan.CIF

Stefan.CIF	Time comparison (ms, Δ (%))					
QP	Orig.	SMRFME	Rgeion based	AZB	Monotonic	Proposed
20	443593	-41.67	-17.66	-8.93	-22.51	-60.72
24	416228	-41.67	-22.16	-12.09	-23.30	-62.92
28	389335	-42.63	-25.80	-13.74	-24.40	-64.41
32	363736	-44.18	-31.59	-16.63	-26.50	-66.16
36	339981	-43.76	-41.35	-20.99	-29.31	-68.86

6 Conclusion

In this paper we present a fast algorithm for multiple reference frames motion estimation in H.264/AVC to reduce the computation. To skip unnecessary reference frames motion estimation, the proposed algorithm uses information of the previous search reference frames and the correlation among the neighboring blocks. Experimental results show that the proposed algorithm reduces the coding complexity notably while achieves similar gain as the multiple reference frames full search algorithm.

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