國立交通大學

資訊科學與工程研究所

碩 士 論 文

減少 H.264/AVC 的框間模式選取中所使用的測試次數並以多執行緒加速運算

Reducing the number of used tested modes in inter mode decision for H.264/AVC and accelerating with multithreading

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摘　　要

模式選取在 H.264 的編碼程序中由於它的時間複雜度是一個瓶頸。在本文中，我們提出了一種新的方法來將框間模式選取的測試次數由原來的七次降為三次。詳細地，我們辨認最小的兩個框間模式的輕量成本，並檢查它們的相鄰與否，來決定保留或捨棄一些模式。我們還平行化一部分的程式碼來加快執行時間。實驗結果證明，無論何種視訊類型的情況，所提出的方法在執行時間方面改進了效能，並仍保持幾乎相同的視訊品質與幾乎沒有改變的編碼視訊大小。

關鍵字：模式選取，框間模式，H.264，成本，提前終止，山谷

[葉柏宏君於碩士論文口試通過後，由於健康因素無法於短期內完成其論文之結構修正，僅能以此論文初稿形式作結]

－林正中

Reducing the number of used tested modes in inter mode decision and accelerating with multithreading

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ABSTRACT

Mode decision at the encoder processing of H.264 is a bottleneck due to its time complexity. In this paper, we propose a new method to reduce the original 7 inter modes to 3. In particular, we identify the smallest 2 light-weight costs of inter modes, and check if they are neighbors or not, to determine whether to save or discard some of the modes. We also parallelize a part of the code to speed up the executing time. The experimental results demonstrate that the proposed methods improve the performance in terms of executing time, regardless of the video types in consideration, and still keep almost the same video quality with almost no change in encoded video size.

Keywords : mode decision, inter mode, H.264, cost, early termination, valley

[Contents of Mr. Yeh's master thesis presented here is in its preliminary draft form, of which the completion is infeasible in a limit period of time due to Mr. Yeh's physical condition.]

-- Cheng-Chung Lin

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僅以此篇獻給你們！

Table of Contents

List of Figures

List of Tables

Chapter 1. Introduction

1.1 Overview of H.264

H.264/MPEG-4 AVC [1][2] is a standard for video compression developed by the ITU-T Video Coding Experts Group (VCEG) together with the ISO/IEC Moving Picture Experts Group (MPEG). The encoding schemes of H.264 have 2 types, which are intra and inter coding based on spatial and temporal characteristics, respectively.

The is shown in Figure 1-1 [3].

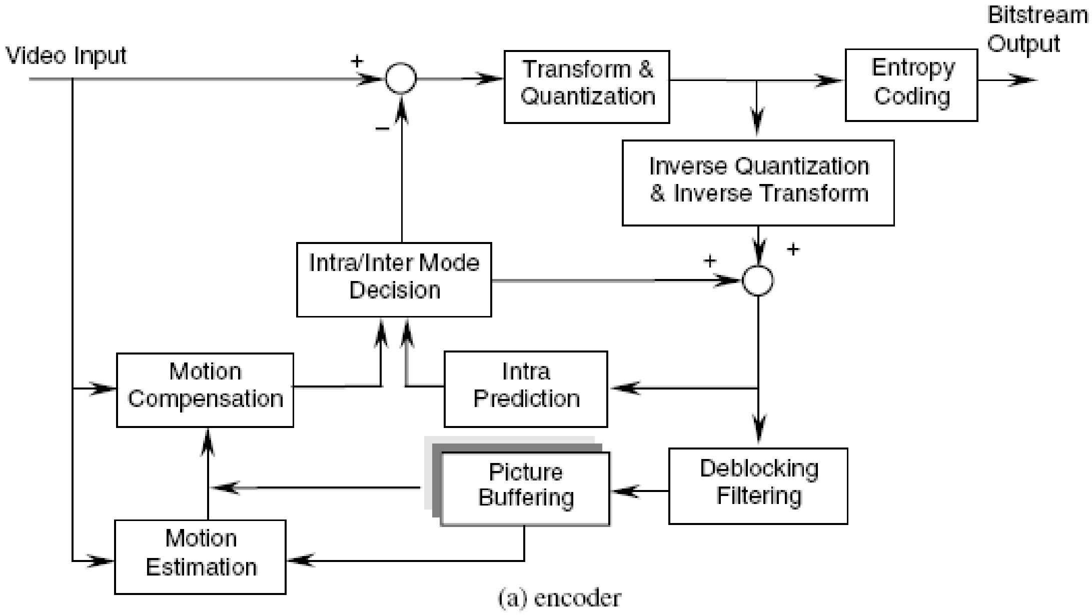


Figure 1-1: The encoder block diagram of H.264 [3].

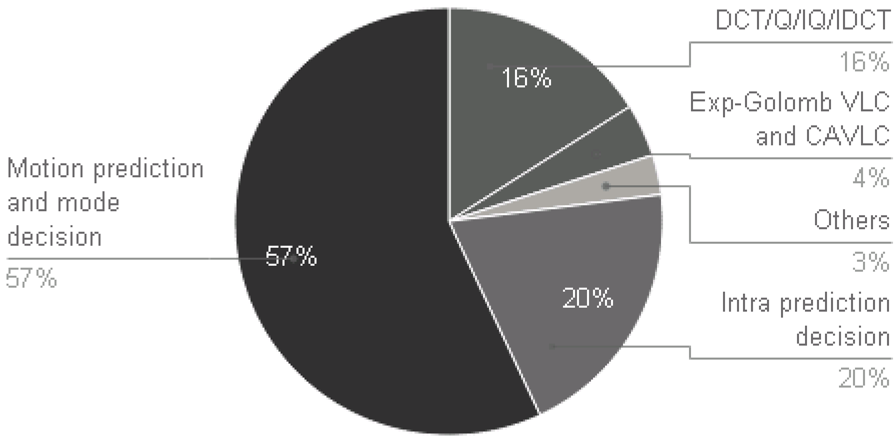
Intra-prediction

Multiple reference Inter-prediction

The earlier video coding standards such as MPEG-4 and H.263 [,] perform motion estimation between only one previous picture and the current picture for the P-picture encoding, that is, only recently previous I- or P-picture is used as a reference picture. The drawback is if a part of the subject picture is lost due to channel error or packet loss,…. To the H.263 v. 2 (H.263+) Annex N, in order to suppress temporal error propagation, it started to provide reference picture selection mode. H.263++ for both error resilience and coding efficiency. and be adopted in H.264. In the H.264/AVC standard, in order to improve coding efficiency, it provides various block sizes and multiple reference frame based motion estimation.

MB reconstruction

Figure 1-2 shows the run-time percentage of several major function modules in the H.264 encoder [4]. As can be seen from Fig. 1-2, motion prediction and mode decision take the largest portion of computational complexity. Hence, in order to reduce the complexity of H.264 encoder, it is worth to develop the fast inter mode decision.



1.2 Issue

1.3 Motivation

Some studies [3]-[5] focus on exploiting the parallel opportunities for intra mode decision. However, there are a few studies to discuss about inter mode decision level in parallel. We will try to seek the level(s) in inter mode decision hierarchy which can be executed in parallel.

Chapter 2. Background

2.1 Mode decision scheme in H.264

A 16x16-pixel luminance MB (macroblock) to be encoded has 7 inter prediction modes distinguished by different block sizes, including MB partitions of sizes 16x16, 16x8, 8x16, and P8x8, where P8x8 can be sub-divided into sub-MB partitions of sizes 8x8, 8x4, 4x8, and 4x4, as shown in Fig. 1. There is also a 16x16 SKIP mode, which is reserved for two MBs that have no residual. For each valid mode, inter prediction involves two steps, including motion estimation (ME) and reference frame selection. More specifically, inter prediction performs motion estimation for every ref. frame, searches the best predictive block in a search window, and then selects the best ref. frame, as illustrated in Fig.1.

In the selection of the best predictive block, H.264 adopts the RDO (rate-distortion optimized) criterion as the performance index (which is referred as RD cost):

$$J = Distortion + \lambda \bullet Rate, \tag{1}$$

where the Lagrange multiplier λ is used to introduce the constraint introduced by bitrate $Rate$, and $Distortion$ is the distortion cost. The smaller RD value is, the better the performance of video compression becomes.

The cost used by motion estimation is named $MCOST$ shown next:

$$J_{Motion} = SAD(s,c) + \lambda_{Motion} \bullet R(\Delta mv), \tag{2}$$

where $SAD(s,c)$ is the sum of absolute differences between each pixel in the original block s and the predictive block c. Δmv is the motion vector difference between predicted mv and actual mv. $R(\Delta mv)$ is the number of bits representing Δmv via table lookup. It is a light-weight cost, which means it is a predictive value, not the real reconstructed value.

When RDO option is enabled, mode decision will adopt the mode cost called the $RDOcost$ shown next:

$$J_{Mode} = SSD(s,c,Mode \mid QP) + \lambda_{Mode} \bullet R(s,c,Mode \mid QP), \tag{3}$$

where $R(s,c,Mode \mid QP)$ denotes the bit number for coding this block associated with choosing $Mode$, SSD is the sum of squared difference between the original block s and the reconstructed block c, and λ is the Lagrange multiplier, QP is the macroblock quantization parameter.

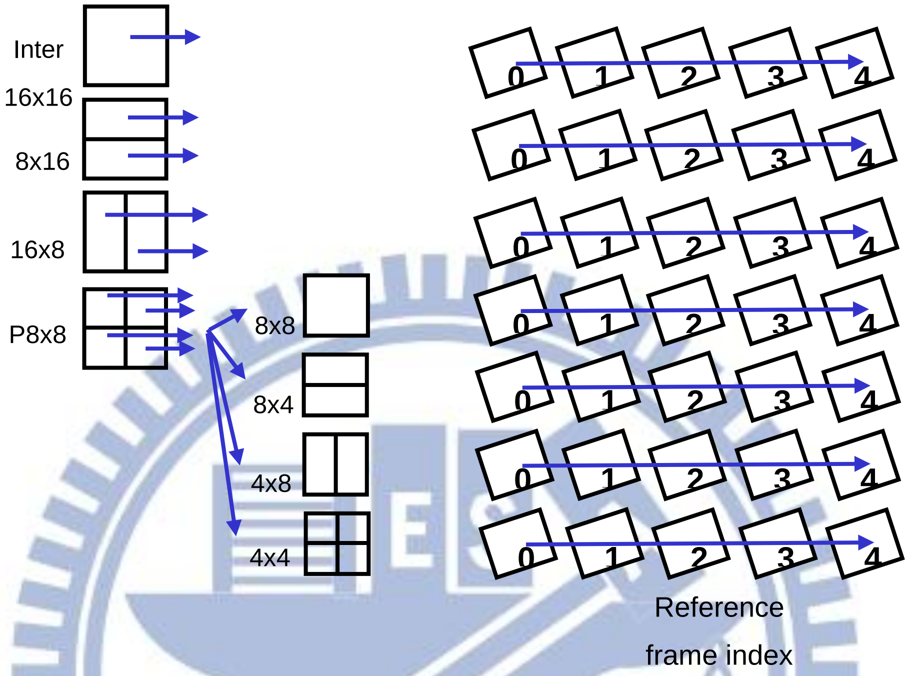


Figure 1 : Inter coding with 5 reference frames.

For the P8x8 type, there are 4 8x8-sized blocks which can have a uniform subtype mode, or have separate subtype modes. The official implementation of inter mode decision process of H.264 (JM [2]) involves the following steps:

1. Perform motion estimation and reference selection of 16x16, 16x8, 8x16 MB type.
2. Make sub-MB mode decision, for each 8x8 block.
3. Determine each subtype mode as the whole P8x8 MB type.
4. Reconstruct the candidate block of each MB type and compute $RDOcost$
5. Finally decide the MB type as the resulting inter mode.

When RDO option is enabled, for candidate blocks of each mode, the stage of reconstructing the block and computing *RDOcost* is time consuming. To speed up the computation, a number of techniques under the name of fast inter mode decision (as opposed to exhaustive mode decision) try to exclude some unlikely modes depending on spatial and temporal characteristics, leading to suboptimal result.

2.2 Related Work Brief Review

Exhaustive inter mode decision requires a lot of time to perform ME and compute *RDOcost* for each mode. Hence many studies focus on reducing the number of modes to be checked.

One of the approaches to reduce computation is the use of early termination [3]-[4]. The algorithm first performs ME and reference frame selection, and then computes *RDOcost* for a set of modes (16x16 8x8 4x4) to check the characteristics of the cost curve. If it is monotonically decreasing $\left(J_{Mode}(16\times16)<J_{Mode}(8\times8)<J_{Mode}(4\times4)\right)$, which implies that the encoded MB has the tendency to use larger block sizes, the algorithm will examine the larger blocks, namely, 16x8 or 8x16 modes to obtain the minimizing one and then terminate. On the other hand, if the cost curve is monotonically increasing $\left(J_{Mode}(16\times16)>J_{Mode}(8\times8)>J_{Mode}(4\times4)\right)$, the algorithm will examine the smaller blocks, namely, 8x4 or 4x8 modes to obtain the minimizing one and then terminate. If the cost curve does not meet any of the monotonic criteria, all other modes must be tested.

Inter coding has multiple reference frames (MREF), and performs ME for every ref. frame before computing mode cost. Many studies focus on analyzing the statistical characteristics of MREF. An observation is that the best selected reference frame is often the nearest one to the current frame [5]. In [5], the algorithm uses $MCOST$ predicted in the 1^{st} reference frame to select the mode with the minimum cost. In [6], fast multi-reference frames motion estimation (MRFME) not only selects the minimizing mode after the 1^{st} reference frame prediction, but also uses a threshold to determine a potential set of modes for further exploration.

Some researchers exploit the spatial and temporal correlations of MBs in adjacent frames to determine the candidate lists. Zhan et al. [7] obtain the current MB (x,y) on the current frame and seek the co-located MB on the previously encoded reference frame, in order to find the best modes of the co-located MB and its surrounding MBs to adjust the candidate list. Ma et al. [8] use neighboring MBs of current or previous frame and motion history to tune the probability of the modes, which is then sorted to create the candidate list.

In many mode reducing algorithms, when the criterion is not met, they would rather explore the possible better modes for maintaining the quality than definitely reduce the computation. Our study is based on platforms of multi-cores or chips with multithreading. So our primary goal is to take advantage of parallelism by processing a static number of modes, such that the same amount of tasks can be dispatched to each thread at a time. Accordingly, this study does not use the dynamic reduction mechanism.

2.3 Observation and Objective

We can view the monotonic criterion of early termination [3] [4] from a different perspective. Once the monotonic criterion is met, the cost curve exhibits a single valley, as shown in Fig. 2. Once the valley is identified, we can compute the *RDOcosts* at the neighboring two points around the valley, and then find the minimum *RDOcost* among these three points. As illustrated in Fig. 2, the points are clustered at 1 valley (either A1 at 16x16, or A2 at 16x8/8x16) no matter the final results of $J_{Mode}(16\times 8)$ and $J_{Mode}(8\times 16)$ is smaller than $J_{Mode}(16\times 16)$ or not. In other words, our computation is just based on the valley and its two nearest neighbors.

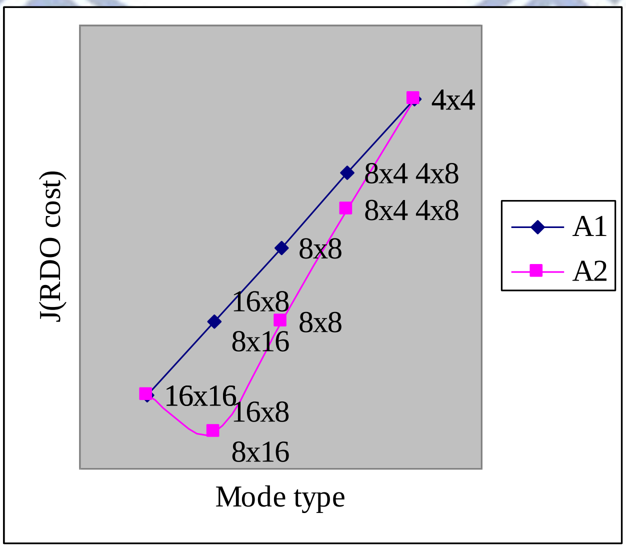


Figure 2 : The valley of early termination.

The aims of this study are three-fold:

1. To enhance the capability of early termination (which can only handle 1 case matching) to fit our demand. The proposed method should be able to handle all situations no matter it is a single valley or other irregular cost curves.
2. To reduce time complexity by examining all tested modes and retaining only a subset as the candidate modes for the original real mode decision.
3. To speed up computation by parallelizing some parallelizable segments of our code.

Chapter 3. The proposed method - Two valleys approximation approach

$RDOcost$ will obtain better Rate-Distortion Optimized compression quality (including video quality and encoding video sizes), but is computationally expensive. When enable one mode, motion estimation, reference frame selection, reconstruct MB need be performed before computing $RDOcost$.

$MCOST$ used by motion estimation on each reference frame is a low-complexity cost than $RDOcost$. Reference [5] observes the optimal motion vectors are often determined by the nearest reference frame to the current frame. Which means the smallest $MCOST$ of one mode belongs to the first reference frame than others is very often. In [5], the algorithm performs the 1st reference frame ME to select the mode with the best $MCOST$, as illustrated in Fig. 3. The research [5] provides an approach with a light-weight cost to predict the possible modes. Although it can use a fast approach to predict some possible modes, the compression quality is not like the result of using $RDOcost$. Why not using $MCOST$ to predict $RDOcost$, just retaining a subset of modes to compute real $RDOcost$. This method can collect the costs of all 7 modes and draw the complete cost curve helping us to reach the plan.

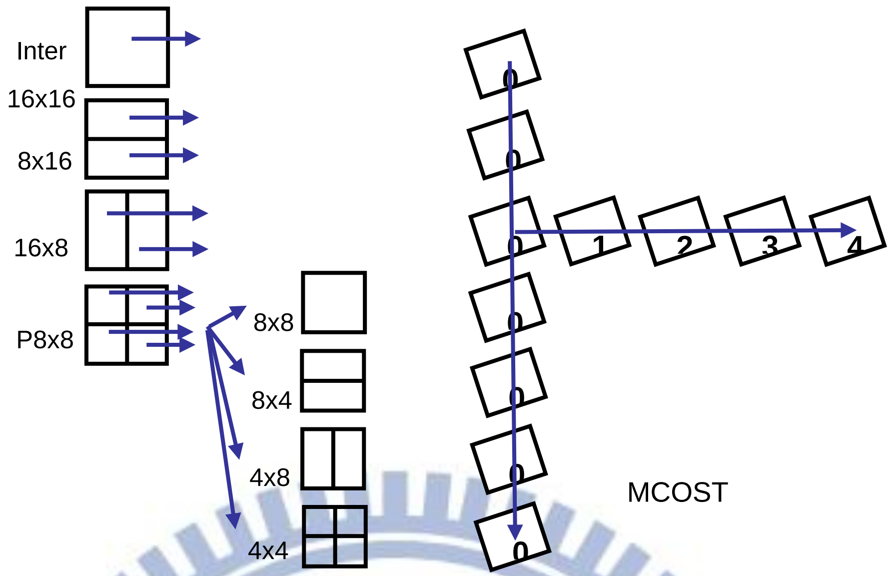


Figure 3 : Reference [5] performs the 1st reference frame ME to select the ideal mode.

In the previous section, chapter 1.3, we have discussed the monotonic criterion of early termination [3] [4], if one valley is formed, the mode with the smallest cost and its neighboring mode will be tested. The cost curve of early termination is "before completion". We know the mode with the smallest *RDOcost* will produce the optimal compression quality. However, whenever testing one mode using *RDOcost*, it needs to spend a lot of time. The process of early termination is as follows, (and shown in Fig. 2,) in the first phase, the algorithm only tests 3 modes (16x16, 8x8, 4x4), and observes a monotonic decreasing trend. In the 2nd phase, they only test 16x8/8x16 modes. We observe either the growing cost curve in the second phase is A1 or A2, the algorithm will decide the relative optimum among the 3 points, the valley and its 2 neighboring points (in this case: 16x16, 16x8/8x16, 8x8) before collecting the complete 7 mode/ *RDOcost* . The method uses 2 neighboring modes to approach the valley.

We have a tool to collect complete 7 modes' light-weight cost curve, and have a model view to know how to obtain a suboptimal result in a limited number of tested modes. The $MCOST$ (obtained from the 1st reference frame prediction [5]) can predict $RDOcost$. The half-complete cost curve (inspired by early termination [3] [4]) will process one valley form, to retain the mode with the current smallest cost and its two neighboring modes. We can use the essence to the complete light-weight cost curve.

We will propose our method: Two valleys approximation approach

After the 1st reference frame ME [5], we have $MCOST$ of 7 modes. The cost curve only needs 5 points, so we let the rectangle modes to retain the better one. The remaining 5 modes are 16x16, min(16x8, 8x16), 8x8, min(8x4, 4x8), 4x4, denoted as N1, N2, N3, N4, N5. We just identify the smallest 2 light-weight costs of the 5 modes. If they are neighboring, just retaining the mode with the smallest cost and its 2 neighbors. If they are separated, retaining the 2 modes, adding the lowering valley's one neighbor as the third candidate. Limit these 3 modes to compute $RDOcost$, not to expand too many candidate modes that the consumption of the computation time.

The pseudo code is described as follows:

1. Compute the $MCOST$ of the 1st reference frame for every 7 inter

modes.

2. Reduce from 7 to 5 modes, denoted as a set **N** with elements $N_1 \sim N_5$, as follows:

   $N_1 \leftarrow J_{MCOST}(16\times 16)$,

   $N_2 \leftarrow \min(J_{MCOST}(16\times 8), J_{MCOST}(8\times 16))$,

   $N_3 \leftarrow J_{MCOST}(8\times 8)$,

   $N_4 \leftarrow \min(J_{MCOST}(8\times 4), J_{MCOST}(4\times 8))$,

   $N_5 \leftarrow J_{MCOST}(4\times 4)$.

3. Reduce from 5 to 3 modes, denoted as a set **C**. Compute the top-2 minima of $J_{MCOST}(N_i)$, with $i = 1 \sim 5$. Denote the mode with the smallest $MCOST$ as $N_{\min 1}$ and the bigger one as $N_{\min 2}$.

4. Let $d = |\min 1 - \min 2|$, if $d = 1$, namely $N_{\min 1}$ and $N_{\min 2}$ are adjacent, go to **step5**; otherwise, go to **step6**.

5. Let **C** $\leftarrow N_{\min 1}$, and $N_{\min 1}$'s 2 neighbors, go to **step7**.

6. Let **C** $\leftarrow N_{\min 1}$, $N_{\min 2}$, $N_{\min 1}$'s neighbor, which has smaller $MCOST$ go to **step7**.

7. Use SKIP mode and the 3 modes in **C** for real mode decision, and choose the best mode from the union of **C** and SKIP mode.

Step 2 picks up the orientation (either vertical or horizontal) with smaller $MCOST$ and steps 3-6 select the 2 valleys and the lower one's neighbor, which has smaller $MCOST$. Because step 7 needs very high computation time, we have also implemented a parallel version of step 7 to speed up computation. More specifically, we parallelize the computation of ME and reference frame selection of N_1 (16x16) and

N_2 (min(16x8, 8x16)) modes by 2 threads, if these two modes are both in **C**. Note that the 4 8x8 sub-MBs of the P8x8 mode use the same subtype in the steps 1-6, and use separated subtype modes in step 7.

The task of each thread is independent, and the workloads dispatched to each thread are more or less equal in our design. As how to distribute the threads to map the available computing units, this is determined by the scheduling policy of the library of parallel language or the implement design for a cluster. Here we use the parallel language library that support load balance [9] to be used in our method.

Chapter 4. Experimental results

4.1 Introduction

The proposed algorithm was implemented based on H.264 reference encoder JM 16.2 [2] which uses 7-mode decision. The encoder with 5 reference frames adopts the following settings: full search, search range ± 32, CABAC entropy coding method, and quantization parameter (QP) = 28, 32, 36, 40. The simulation environment is based on Pentium Dual 2.0 GHz, 2 GB DDR2, Fedora 9 Linux kernel 2.6.25, gcc 4.3.0 compiler with OpenMP 2.5 library.

The tested sequences for our experiments are QCIF format: Carphone, Claire, Coasguard; CIF format: Coasguard, Container, Mobile, News, Satefan. The structure of encoded frames is IPPP, in which each sequence will be encoded to the first frame, I frame, and 99 P frames that disable intra modes for inter slices. The frame rate is 30 per second.

Our experiments are based on 3 different conditions, including original 7-mode decision (Original), the proposed algorithm (Proposed), and the proposed parallel version with 2 threads (Proposed (t2)).

In order to evaluate the proposed method in a comprehensive manner, we have two experiments in this section. In the first experiment, we used all video sequences with QP=28 to evaluate the method with 3 performance metrics. In the second experiment, we evaluated the effects of different values of QP on the same video sequence, where the results are shown via RD curves.

4.2 Experiment 1.

In this experiment, we use all video sequences with QP=28, to evaluate 3 performance metrics, including time reduction $(\Delta Time)$, PSNR gain $(\Delta PSNR)$, and bitrate reduction $(\Delta Bitrate)$, as defined next:

$$\Delta Time = \frac{Time_{proposed} - Time_{original}}{Time_{original}} \times 100\% \tag{4}$$

$$\Delta PSNR = PSNR_{proposed} - PSNR_{original} \tag{5}$$

$$\Delta Bitrate = \frac{Bitrate_{proposed} - Bitrate_{original}}{Bitrate_{original}} \times 100\% \tag{6}$$

PSNR is the peak signal to noise ratio, which reflects the encoded video quality. A higher value of PSNR indicates the less distortion. In our experiment, we only adopt luminance Y-PSNR, which is the most important part of PSNR. Bitrate is the bit number needed to encode a video sequence.

The results for all selected video sequences are shown in Table 1, where the average speedup percentages is 43.78% and 51.37%, respectively, for sequential and parallel versions of the proposed method. In particular, the percentage reduction in computing time is about the same among all video sequences, which indicates the proposed method can deal with all kinds of videos effectively.

Table 1 : Experimental Results for QP=28.

Sequence	**Δ Time(%)**		**Δ PSNR(dB)**		**Δ Bitrate(%)**	
	P	***P(t2)***	***P***	***P(t2)***	***P***	***P(t2)***
Carphone	-43.07	-51.11	-0.07	-0.07	2.14	2.77
Claire	-42.66	-52.48	-0.09	-0.05	0.45	1.28
Coastguard	-46.95	-53.31	0.00	0.00	1.49	1.37
Coastguard (CIF)	-46.64	-52.54	0.01	-0.01	1.84	1.73
Container (CIF)	-38.28	-50.58	0.00	-0.01	1.34	1.92
Mobile (CIF)	-45.83	-49.61	0.00	0.00	3.06	2.92
News (CIF)	-41.55	-51.43	0.00	-0.01	1.97	2.17
Stefan (CIF)	-45.29	-49.94	-0.01	0.00	2.67	2.73
Avg.	-43.78	-51.37	-0.02	-0.02	1.87	2.11

For clarity, some sequences' metrics in Table 1 are compared with the results of previous studies, as shown in Tables 2 and 3.

Table 2 : Comparisons with Zhan's method in [7] when QP=28.

Sequence	**Method**	**Δ Time (%)**	**Δ PSNR (dB)**	**Δ Bitrate (%)**
Carphone	***[7]***	-34.23	-0.05	0.37
	Proposed	-43.07	-0.07	2.14
	P (t2)	-51.11	-0.07	2.77

Claire	***[7]***	-70.21	-0.09	1.11
	Proposed	-42.66	-0.09	0.45
	P (t2)	-52.48	-0.05	1.28
Coastguard	***[7]***	-30.64	-0.01	0.14
	Proposed	-46.95	0.00	1.49
	P (t2)	-53.31	0.00	1.37
Container (CIF)	***[7]***	-63.24	-0.04	0.54
	Proposed	-38.28	0.00	1.34
	P (t2)	-50.58	-0.01	1.92
Stefan (CIF)	***[7]***	-22.89	-0.02	0.14
	Proposed	-45.29	-0.01	2.67
	P (t2)	-49.94	0.00	2.73

Table 3 : Comparisons with Ma's method in [8] when QP=28.

Sequence	**Method**	**Δ Time (%)**	**Δ PSNR (dB)**	**Δ Bitrate (%)**
Coastguard (CIF)	***[8]***	-51.74	-0.04	1.64
	Proposed	-46.64	0.01	1.84
	P (t2)	-52.54	-0.01	1.73
Container (CIF)	***[8]***	-61.43	-0.06	4.89
	Proposed	-38.28	0.00	1.34
	P (t2)	-50.58	-0.01	1.92
Mobile (CIF)	***[8]***	-45.97	-0.05	3.43
	Proposed	-45.83	0.00	3.06
	P (t2)	-49.61	0.00	2.92
Stefan (CIF)	***[8]***	-55.90	-0.05	4.39
	Proposed	-45.29	-0.01	2.67
	P (t2)	-49.94	0.00	2.73

Zhan's method [7] is faster on the sequences with large static areas (Claire, Container), but the proposed method (especially the parallel version) reduces the execution time evenly. In comparison with Ma's method [8], for the sequence with low-speed motion (Container), the proposed method (t2) is slower than theirs, but with a better bitrate. For the other sequences, there are no big differences in performance.

4.3 Experiment 2.

Another way to reveal more information about the performance is to plot RD curves under different QP values. A RD curve with higher values indicates the video quality and encoded video size are better. The results are shown in Tables 4 and 5, and Figs. 4 and 5.

Table 4 : Results for “Claire” (QCIF).

QP	Δ Time(%)		Δ PSNR(dB)		Δ Bitrate(%)	
	P	***P(t2)***	***P***	***P(t2)***	***P***	***P(t2)***
28	-42.66	-52.48	-0.09	-0.05	0.45	1.28
32	-43.69	-52.84	0.00	0.01	0.57	0.96
36	-44.15	-53.56	-0.01	-0.04	1.06	0.53
40	-43.86	-54.41	-0.06	-0.06	-1.16	-1.55

Table 5 : Results for “Stefan” (CIF).

QP	Δ Time(%)		Δ PSNR(dB)		Δ Bitrate(%)	
	P	***P(t2)***	***P***	***P(t2)***	***P***	***P(t2)***
28	-45.29	-49.94	-0.01	0.00	2.67	2.73
32	-45.79	-51.89	0.00	-0.02	3.72	3.03
36	-44.97	-53.63	-0.01	-0.01	2.65	3.05
40	-42.37	-53.90	-0.01	-0.01	1.54	1.78

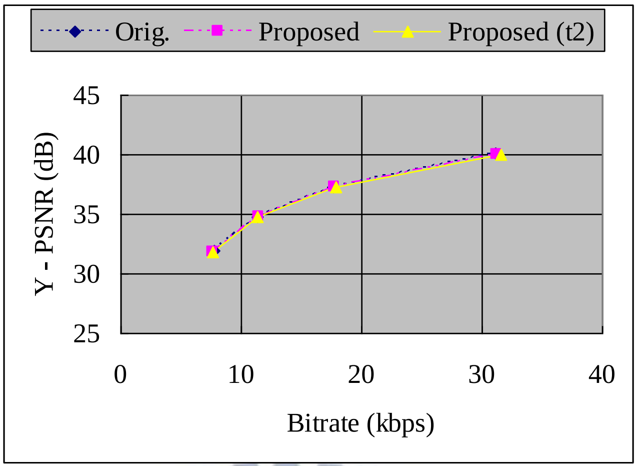


Figure 4 : RD curves for “Claire” (QCIF).

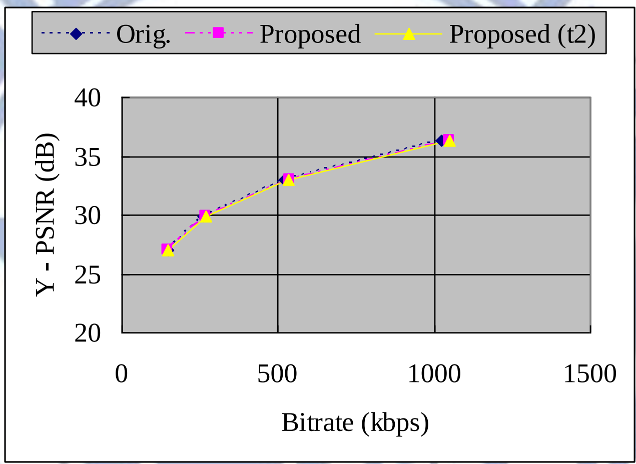


Figure 5 : RD curves for “Stefan (CIF)”.

Tables 4 and 5 show the coding efficiency under different QP values for “Claire” and “Stefan”, respectively. From the original data of Tables 4 and 5, we can generate Figs. 4 and 5, in which we can observe that the RD-curves of the proposed method are very close to the original one. This indicates the proposed method can generate videos with similar quality, and only a little increase in bit numbers.

Chapter 5. Conclusions

In this paper, we have proposed a method that can always reduce the number of modes from 7 to 3, based on the cost curve of the modes and their light-weight costs. We use the method to distribute the computation tasks evenly to achieve better parallelization, such that the overall computing time can be optimized.

The experimental results demonstrate that the proposed method can speed up computation by 40%, with almost the same video quality and a little increase in encoded video size. The multithreaded version of the proposed method again speeds up the computation by 5-10% when compared to the sequential version.

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