Hindawi Publishing Corporation
International Journal of Digital Multimedia Broadcasting
Volume 2009, Article ID 141986, 8 pages
doi:10.1155/2009/141986

Research Article

Intra-Skip in Inter-Frame Coding of H.264/AVC

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Received 16 June 2008; Revised 15 January 2009; Accepted 2 February 2009

Recommended by Ennio Gambi

In inter-frame coding of H.264/AVC standard, not only seven inter-partition modes but also intra-modes are taken into account for seeking the best coding mode so as to maintain higher encoding efficiency by sacrificing the speed of H.264/AVC encoder. Aiming at intra-skip, this paper proposes a novel mathematical model for intra-skip in inter-frame coding to alleviate the complexity of the process; the model provides remarkable performance increment by cutting down encoding time while accompanying very minor bitrate increase. The critical advantage of this proposed scheme most emphasized on is that it can optimize H.264 encoder in conjunction with any proposed fast inter- and intra-methods which are focusing on inter-partition mode decision, motion search algorithms, and fast intra-algorithms.

1. Introduction

The latest established video compression standard H.264/AVC [1] is recognized to be a major international standard in the next generation video compression techniques, because of higher coding efficiency and better performance in various environments, compared to previous video coding standards. In the inter-frame coding of H.264/AVC standard, intra-modes are also calculated, for seeking the best coding mode in order to obtain low bitrate and high fidelity, also for images that would be better encoded by intra-mode prediction, such as background images that frequently change in a video sequence [2]. Cheng et al. pointed out in [3] that the encoder speed would be accelerated significantly and dramatically if all computations of intra-modes were skipped in inter-frame coding, which means only seven inter-modes are taken into consideration, and all intra-modes are excluded in inter-frame coding. But the experimental results show that this choice would also result in picture fidelity deterioration and high bitrate. Lee and Jeon put forward a method [4] by which designated partition blocks are intra-skipped and also present a new mathematic model for inter-frame coding. The performance increment is dramatic while in some cases this method will miss some blocks that should have passed intra-predictions in inter-frame coding.

Afterwards, Cheng et al. [5] put forth an advanced method about P frame based on the idea that the decision for intra-skip is generated by three fixed adjacent blocks. And the speed of the encoder with this method is obviously accelerated in P frames. Pan et al. [6] introduced a new scheme mainly focusing on inter-frame. Recently, Kim et al. [7] proposed a simple method which is to adopt minimum RDcost of adjacent blocks as the threshold for intra-skip, and therefore intra-skip is reintroduced in the coding process.

The remainder of this paper is going to analyze the whole procedure of the inter-frame coding first and then to present a new mathematic model for inter-frame coding not only aiming at P frames, but also addressing B frames, in Section 2. The results of experiments and comparison to some well-known algorithms are presented in Section 3. Finally, in Section 4, the conclusion and discussion are presented.

2. Inter-Frame Coding Procedure

2.1. Prediction Modes. To achieve higher coding efficiency, H.264/AVC employs rate distortion optimization (RDO) [1, 8] to seek the best coding result in terms of maximizing image quality and minimizing resulting transmission data bits. That is to say, in order to achieve rate distortion optimization, the encoder has to encode the video sequence by exhaustively testing all the possible mode combinations, including different intra- and inter-prediction modes, for each block that minimizes the difference between the original and its reconstruction to be encoded. As a result, due to the dramatically increased computation load of sequence coding, practical applications of an H.264 encoder are limited at large especially for real time visual communication.

The whole procedure of inter- and intra-modes in inter-frame coding is comprised of three parts. First, calculate the mincost of intra-partition modes. Second, figure out the mincost of intra-modes. And at last, compare mincost of inter-partition modes with mincost of intra-modes to decide final coding mode. If mincost of intra-mode is less than mincost of inter-mode, the final coding mode will be intra- and vice versa. In the following parts, this procedure is specified.

2.2. Intra-Modes in Inter-Frame Coding. In intra-modes, a prediction block is formed based on the previously encoded and reconstructed blocks and is subtracted from the current block prior to encoding. That means intra-modes only exploit spatial redundancies within the same frame instead of previously encoded frames as in inter-modes. The prediction mode for each block that minimizes the difference (RDcost) between original block and its prediction is selected as the best intra-mode.

In inter-frame coding, intra-modes are also taken into consideration, including intra 4 × 4, Intra 16 × 16 and intra 8 × 8 (optional since JM9.3). intra 16 × 16 has four directional predictions (Intra_16 × 16_Vertical, Intra_16 × 16_Horizontal, Intra_16 × 16_DC, Intra_16× 16_Plane) while intra 4 × 4 has nine different directional predictions (Intra_4 × 4_Vertical, Intra_4 × 4_Horizontal, Intra_4 × 4_Diagonal_Down_Left, Intra_4 × 4_Diagonal_Down_Right, Intra_4 × 4_Vertical_Right, Intra_4 × 4_Horizontal_Down, Intra_4 × 4_Vertical_Left, Intra_4 × 4_Horizontal_Up, Intra_4 × 4_DC).

2.3. Whole Procedure of Inter-Frame Coding. The entire flow inter-frame coding is shown in Figure 1. First, determine whether initial SKIP mode is adopted, which is different from SKIP mode with no coefficients later. If not, calculate seven inter-mode predictions to seek the best inter-mode and consider the corresponding cost as BEST_INTER_COST. Then, calculate intra-mode predictions to get the BEST_INTRA_COST. Finally, compare BEST_INTER_COST and BEST_INTRA_COST to obtain the best mode among all possible modes in inter-frame coding.

2.4. The Analysis and Effect of Intra-Skip in Inter-Frame Coding. The purpose of using intra-modes in inter-frame coding is to improve image fidelity and to possibly provide more precise mode prediction so as to reduce the bitrates of coded sequences by sacrificing coding speed. Thus, whether the intra-modes are frequently adopted in inter-frame coding may become an issue.

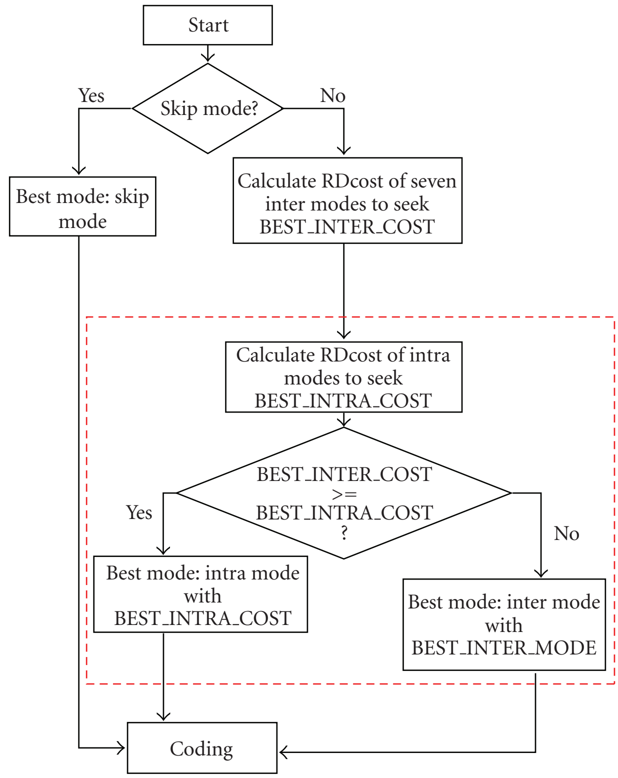

Figure 1: Flowchart of inter-frame coding.

Admittedly, a considerable amount of transmission bits is saved on the condition that RDcost of best intra-mode is lower than RDcost of best inter-mode. This means that, as the RDcost of best inter-mode is larger than the RDcost of best intra-mode, it possibly indicates that the current block is in a rapid or median motion. As a matter of fact, if the background images are changing, the complicated procedure of greatly changing match-block search in motion compensation will cost a lot of bits for motion vector predicted (MVP), and a nonoptimized prediction will require a lot of extra transmission bits for the residual [9, 10]. As a result, in this situation, intra-modes in inter-frame coding is a better choice for encoding current block. However, taking more possible modes into account in inter-frame coding sacrifices encoder's coding speed [11, 12]. Hence, the possibility that intra-modes are unnecessary to be calculated and could be skipped is largely determined by the motion of current image to be encoded.

In addition, the procedure of intra-skip is irrelevant to the procedures of motion search and seven inter-mode and nine intra-mode predictions. Hence, intra-skip can accomplish higher performance increment together with any fast motion search algorithm and any fast inter-/intra-algorithm [9–17].

Consequently, performing intra-skip or not, which largely depends on the motion range of objects and background in sequences, also plays a key role in inter-frame coding compared to the procedure of motion search and block match [13–15]. The purpose of this paper is to focus on intra-skip and present a method to decide whether intra-modes are to be adopted or skipped in inter-frame coding by early estimation and detection.

2.5. The Proposed Mathematical Model for Intra-Skip. Since the adjacent blocks are highly correlated with the current block to be encoded, the information of encoded blocks is essential for current block. Consequently, whether encoded block was intra-skip or not is a substantial point to indicate the possibility of intra-skip for current block. In addition, according to the analysis of intra-skip in Section 2.4, it can be noted that the values of RDcost of best inter-mode largely represent the changing speed of image background and motion ranges of objects in sequences. As a result, this paper adopts the values of encoded blocks' BEST_INTER_COSTs (RDcost of best inter-mode) that are assigned to different weighted coefficients as multipliers due to the encoded blocks' various distances from current block for predetermining whether the time-exhaustive process of intra-mode predictions is necessary or not for current block. A mathematical model is proposed in order to correctly skip the blocks' intra-mode predictions in inter-frame coding. The model is provided as follows:

$$G(K) = \underbrace{\lambda_1 J_1 + \lambda_2 J_2 + \lambda_3 J_3 + \lambda_4 J_4 + \lambda_5 J_5 + \cdots + \lambda_K J_K}_{K \text{ reference}}$$

$$\begin{gathered} \max(\lambda_1, \lambda_2, \ldots, \lambda_K) \leq 1, \\ \min(\lambda_1, \lambda_2, \ldots, \lambda_K) \geq -1, \\ \text{sum}(\lambda_1, \lambda_2, \ldots, \lambda_K) \leq (1 + 0.5), \\ \lambda_n = f(a_0, q, n). \end{gathered} \tag{1}$$

In the model, J_1 is latest encoded block's RDcost of the best inter-mode and K is the number of reference blocks. J_K denotes the RDcost of the best inter-mode in the prior Kth encoded blocks. For example, J_1 is the latest block's RDcost of inter-, which is encoded prior to current block, and J_2 is prior to J_1. In the model, λ_1 denotes the weighted coefficient of latest encoded block's RDcost of inter-. And the weighted-coefficient λ_K is the prior Kth block's weighted coefficient of the RDcost of that block, the values of which are decided by the weighted-coefficient function $f(a_0, q, n)$. This function that plays a key role in this model can be an arithmetic/geometric progression. $G(K)$, which is adopted for intra-skip decision, is the weighted average RDcost of K reference blocks. The constraint conditions in this model are weighted coefficients λ_K, which are provided based on the experimental results of more than thirty sequences (here 0.5 covers most of situations. In most cases according to experimental results, it ranges within (0.2, 0.3)). The procedure of implementation is presented in Algorithm 1, and the proposed method is illustrated in Figure 2 (gray parts) compared to the original procedure in Figure 1.

In Step (2), all the J_i taken into consideration for $G(K)$ are the RDcost values obtained with best inter-mode rather than RDcost values obtained with best final coding mode.

BEGIN
(1) Initialize K (number of reference blocks) and then select a weighted-coefficient function $f(a_0, q, n)$.
(2) Get current block's RDcost of best inter-mode, BEST_INTER_COST.
(3) Calculate $G(K)$ by the mathematic model proposed above.
(4) Compare the value of $G(K)$ and the value of BEST_INTER_COST.
If *BEST_INTER_COST* $< G(K)$, skip intra-modes (red line in Figure 2). Otherwise, do intra-modes prediction and compare the value of *BEST_INTER_COST* with BEST_INTRA_COST to decide final coding mode.
(5) Encode the block and go to Step (2) for the next block.
END

Algorithm 1

2.6. Analysis of the Proposed Model. Most of advanced inter-coding algorithms conceived for speeding up the H.264 encoder are largely concentrating on the computation of the BEST_INTER_COST (Step (2)) because partition mode decision and motion search algorithm are exhaustively calculated in this step [9–18]. However, the proposed mathematic model is carried out after this step; consequently it can optimize the H.264 encoder in cooperation with any advanced fast partition modes and search algorithms. Hence, the speed of the encoder will be accelerated immensely if we adopt this mathematical model together with fast approaches for partition modes and search algorithms.

2.7. Weighted-Coefficient Function. The core of the proposed mathematical model is the weighted-coefficient function, which in a large sense should be optimized so as to gain higher performance and mistake less blocks that should have been coded in intra-modes, since the threshold of intra-skip is generated by the weighted-coefficient function. In this paper, we propose a geometric progression for this model:

$$\begin{gathered} G(K) = \sum_{i=1}^{K} \lambda_i J_i; \qquad \lambda_n = f(a_0, q, n), \\ F(\lambda) = \sum_{i=1}^{n} \lambda_i = a_0 + a_0 q + a_0 q^2 + a_0 q^3 + \cdots + a_0 q^n. \end{gathered} \tag{2}$$

According to more than thirty sequences' experimental results obtained with various weighted coefficient functions, a statistic survey indicates that the best performance increment is derived from conditions set as follows:

$$a_0 = 0.5, \qquad F(\lambda) = 1.2, \qquad K = 4. \tag{3}$$

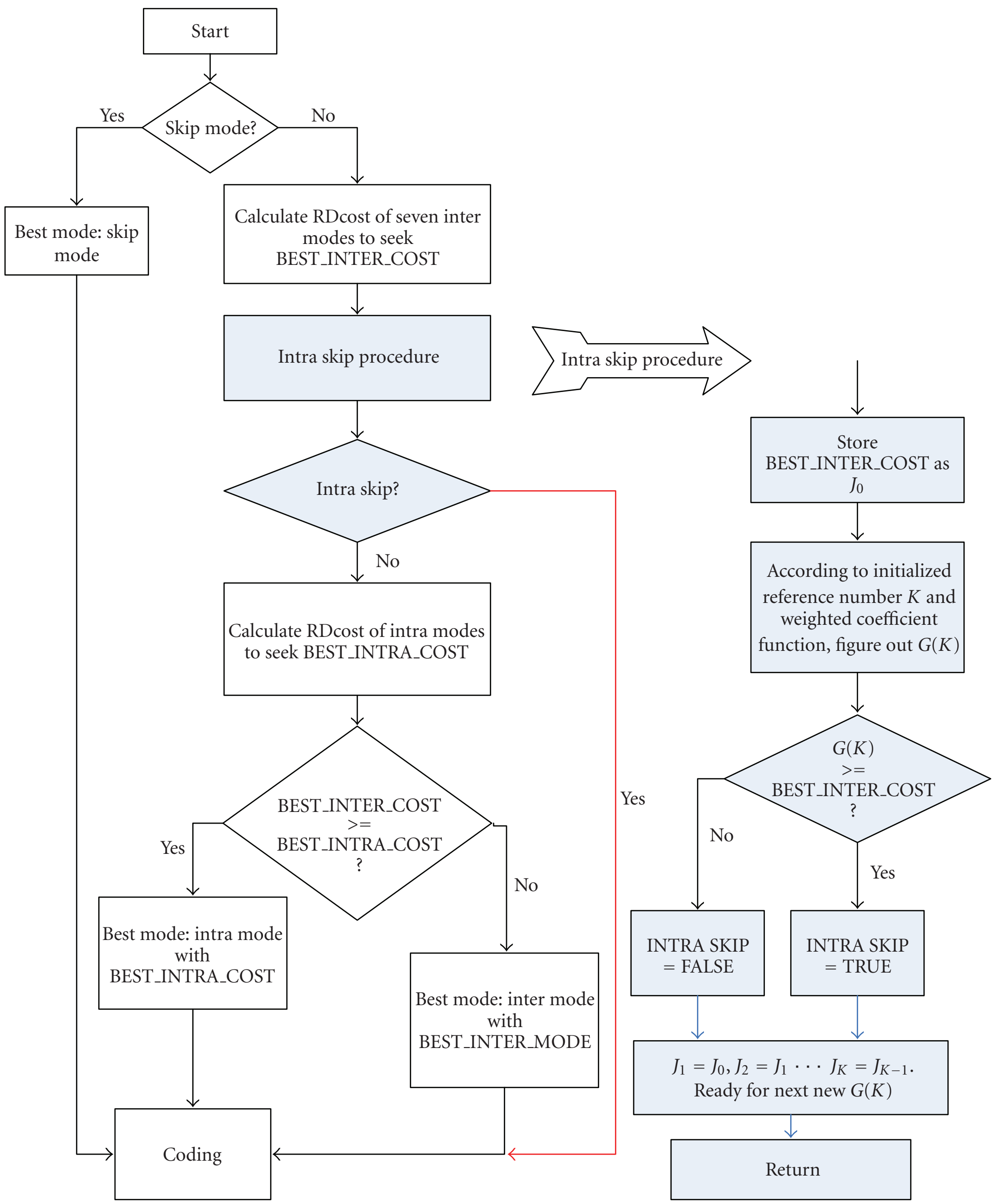

FIGURE 2: Flowchart of inter-frame coding with intra-skip.

They are right for a geometric progression in this model. According to Newton's Iteration Method of solving equation, the function can be expressed as follows:

$$\begin{aligned}
&0.5 + 0.5 \times q + 0.5 \times q^2 + 0.5 \times q^3 = 1.2, \\
&f(q) = 0.5 \times q^3 + 0.5 \times q^2 + 0.5 \times q - 0.7 \\
&\Longrightarrow q_{K+1} = q_K - \frac{f(q_K)}{f'(q_K)} \\
&\qquad = q_K - \frac{0.5 \times {q_K}^3 + 0.5 \times {q_K}^2 + 0.5 \times q_K - 0.7}{1.5 \times {q_K}^2 + q_K + 0.5} \\
&\Longrightarrow q = 0.664643.
\end{aligned} \tag{4}$$

Therefore, $G(K) = \sum_{i=1}^{4} a_0 q^{i-1} J_i$; $G(K)$ is adopted as the self-adaptive threshold for intra-skip in the procedure of inter-frame coding.

3. Experimental Results

To verify the performance of the algorithm proposed in this paper, several common and typical QCIF (Foreman, Carphone, and Highway) and CIF (Paris, Mobile, and Bus) sequences are specified. Our experimental environment is based on JM10.1 [19], which is developed for H.264 reference, and the simulation environment of experiments is P4 1.7 G +256 M, VC+ +6.0+sp5 in Windows XP+sp2.

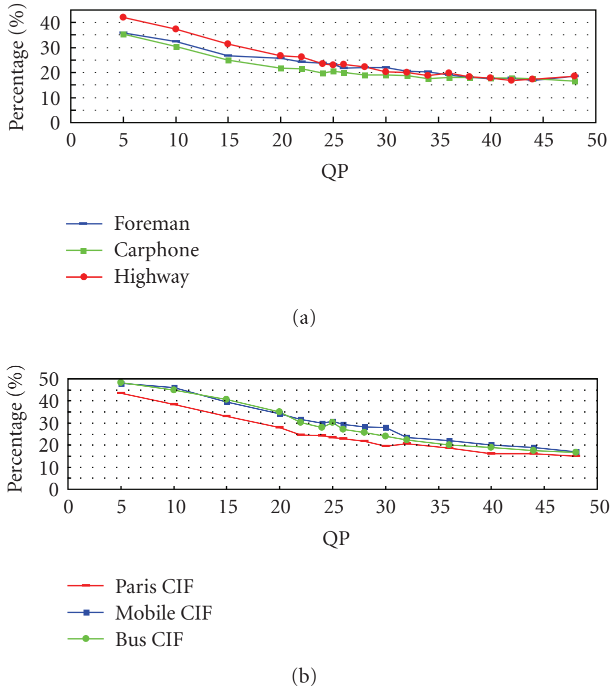

FIGURE 3: The speed acceleration percentage of standard H.264 encoder with mathematic model.

TABLE 1: Encoder parameters used in the experiments.

Use Hadamard	Yes	Frame rate	30 fps
Search range	16	Enable open GOP	Disable
NumRef frames	5	RD optimization	1
Symbol mode	CABAC	Context init method	1
Sequence type	IBPBP/IBBPBBP	Sequence format	QCIF/CIF

Experimental results are tested with the conditions indicated in Table 1, which strictly follow the simulation contexts suggested by JVT.

Figure 3, shows the speed increment by comparing the JM standard encoder combined with the mathematic model proposed in this paper to the original JM standard encoder. In this figure, the percentage of speed increment is defined as follows:

$$\text{PERCENTAGE}\,(\%) = \frac{\text{Time}_{\text{original}} - \text{Time}_{\text{new}}}{\text{Time}_{\text{original}}} \times 100\%, \quad (5)$$

where $\text{Time}_{\text{original}}$ is JM10.1 standard encoder's coding time and Time_{new} is the optimized encoder's coding time we proposed. From Figure 3, it can be seen that the percentage of whole encoder has accelerated by 35% (QCIF)/ 45% (CIF) as QP is 5 and about 25% as QP is 25. The trend is that the smaller QP is, the coding speed increment the encoder shows.

The percentage of missing blocks that should have passed intra-mode prediction is shown in Table 2. The percentage is the ratio of number of missed blocks over all blocks that need intra-calculations. From the table we can see that almost all blocks in inter-frame coding are intra-skipped correctly. In QCIF sequences, less than 0.206043% (maximum) is

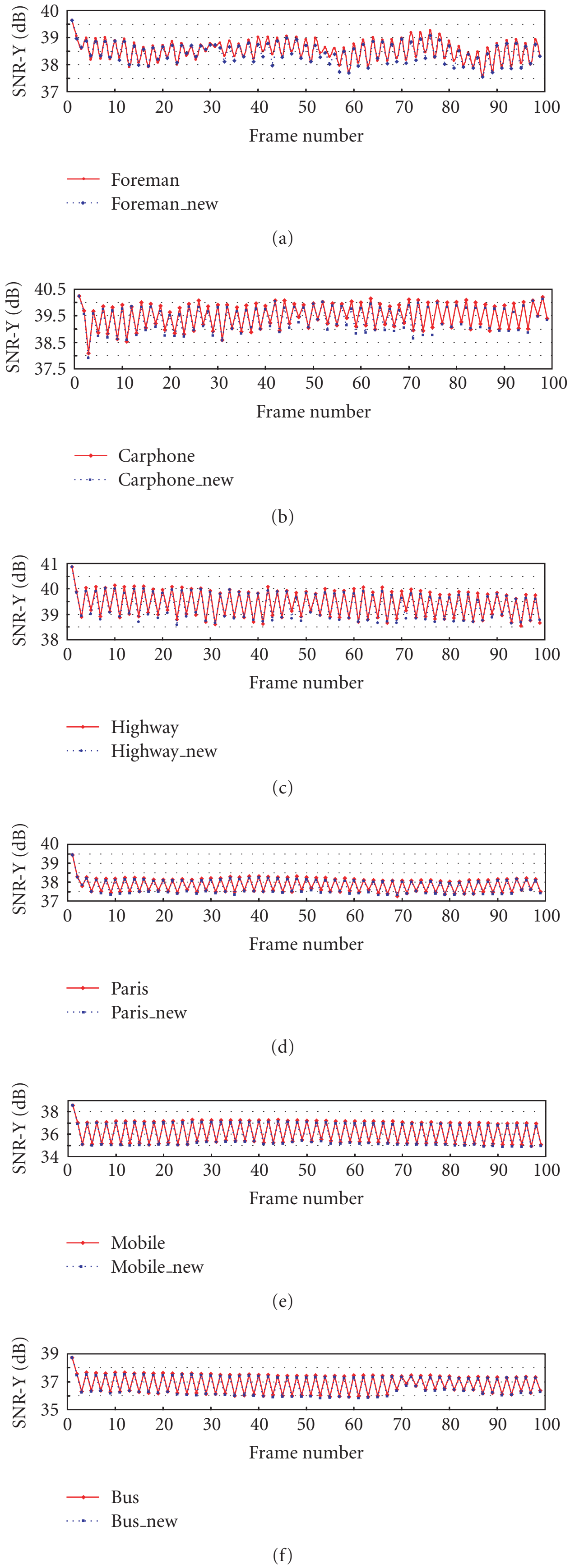

FIGURE 4: PSNR-Y comparisons of six test sequences.

Table 2: Percentage of missing blocks that should have passed intra-mode prediction.

QP	Foreman	Carphone	Highway	QP	Foreman	Carphone	Highway
5	0.206043%	0.816145%	1.634520%	28	0.060120%	0.145612%	0.252361%
10	0.193486%	0.481256%	1.623490%	30	0.054728%	0.165596%	0.260022%
14	0.187465%	0.380258%	1.581650%	32	0.087120%	0.182282%	0.225646%
16	0.189675%	0.147836%	1.421860%	34	0.054528%	0.115496%	0.102576%
18	0.192814%	0.253128%	0.834680%	36	0.123371%	0.048085%	0.054058%
20	0.204657%	0.303810%	0.812560%	38	0.118916%	0.000000%	0.000000%
22	0.084360%	0.360890%	0.572460%	40	0.160028%	0.017526%	0.035600%
24	0.084609%	0.219465%	0.535370%	45	0.202456%	0.045680%	0.000000%
25	0.035568%	0.226856%	0.513232%	49	0.186538%	0.032412%	0.000000%
26	0.035920%	0.233686%	0.512358%	—	—	—	—
QP	Paris	Mobile	Bus	QP	Paris	Mobile	Bus
5	0.341728%	1.113545%	1.784902%	28	0.053180%	0.160576%	0.571232%
10	0.303564%	0.928126%	1.658308%	30	0.056657%	0.125496%	0.380022%
14	0.285608%	0.612100%	1.282650%	32	0.077480%	0.182108%	0.456146%
16	0.250000%	0.448850%	1.420890%	34	0.064562%	0.153396%	0.127312%
18	0.205680%	0.546804%	1.048672%	36	0.100935%	0.082750%	0.109980%
20	0.211245%	0.563245%	0.751326%	38	0.108053%	0.024680%	0.056890%
22	0.092586%	0.623486%	0.881235%	40	0.157520%	0.026526%	0.016282%
24	0.094610%	0.480972%	0.853350%	45	0.122456%	0.085610%	0.071200%
25	0.086796%	0.356073%	0.621486%	49	0.191340%	0.061420%	0.092416%
26	0.099802%	0.15690%	0.724680%	—	—	—	—

Table 3: Comparison between the proposed and some well-known methods.

Sequences		QP = 24			QP = 28			QP = 32		
		ΔPSNR	ΔBit	ΔT	ΔPSNR	ΔBit	ΔT	ΔPSNR	ΔBit	ΔT
Carphone (QCIF)	Lee's	0.000	0	1.71	0.000	0.000	2.77	0.000	0.000	0.90
	Pan's	−0.007	0.649	13.74S	−0.001	1.245	10.31	0.000	1.816	5.88
	Kim's	−0.003	0.035	8.93	0.003	0.085	7.54	−0.003	−0.082	3.16
	Proposed	**−0.023**	**0.435**	**24.27**	**−0.033**	**−1.41**	**18.22**	**−0.013**	**−1.40**	**16.95**
Stefan (QCIF)	Lee's	−0.001	0.000	1.85	0.000	0.000	0.00	0.000	0.000	0.34
	Pan's	−0.021	0.366	15.93	−0.024	0.143	14.08	0.000	−1.142	12.45
	Kim's	−0.021	−0.578	14.95	−0.022	−0.554	14.36	−0.001	−1.706	12.07
	Proposed	−0.133	0.44	28.46	−0.223	0 .744	25.56	-0.17	0.352	23.21
Mobile (CIF)	Lee's	0.000	0.000	7.5	0.000	0.000	0.25	0.000	0.000	4.65
	Pan's	−0.132	0.885	24.69	0.013	1.429	23.44	−0.034	2.92	20.28
	Kim's	−0.006	−0.345	36.39	−0.017	−0.694	35.35	−0.020	−0.548	35.44
	Proposed	−0.043	−0.211	35.40	−0.030	−0.422	33.55	−0.043	−1.246	28.20
Bus (CIF)	Lee's	0.000	0.000	5.76	0.000	0.000	1.25	0.000	0.000	1.11
	Pan's	−0.013	0.159	16.37	−0.010	0.404	14.01	−0.001	0.447	12.17
	Kim's	−0.001	0.098	18.82	−0.004	0.44	17.79	−0.001	−0.316	14.84
	Proposed	−0.047	0.84	23.78	0.000	-0.066	20.75	−0.06	−0.164	17.35
Coastguard (CIF)	Lee's	0.000	0.000	2.00	0.000	0.000	0.81	0.000	0.000	2.00
	Pan's	−0.019	−0.238	17.10	−0.006	−0.067	14.53	−0.002	0.165	8.90
	Kim's	−0.020	−0.316	23.36	−0.013	−0.619	20.57	−0.002	−0.948	12.01
	Proposed	−0.013	−0.140	31.79	−0.007	−0.8 1	22.20	−0.043	−1.001	22.51
Paris (CIF)	Lee's	0.000	0.000	2.28	0.000	0.000	2.15	0.000	0.000	4.06
	Pan's	−0.003	0.135	9.31	0.000	1.756	7.07	−0.002	2.273	4.34
	Kim's	−0.002	−0.120	6.36	0.001	−0.023	7.06	−0.001	−0.052	3.98
	Proposed	−0.020	1.04	23.65	0.033	−0.048	22.46	0.030	−0.248	23.43

wrongly skipped for the sequence Foreman and less than 0.816145% (maximum) and 1.634520% (maximum) for Carphone and Highway, respectively. In CIF sequences, less than 0.341728% (maximum) is incorrectly skipped for the sequence of Paris, and less than 1.113545% (maximum) and 1.784902% (maximum) are for Mobile and Bus, respectively. In most cases only 0.6% or less is intra-skipped incorrectly. The statistic results of Table 2 indicate that this model with weighted coefficients we set has obvious effect on intra-skip.

Figure 4 compares PSNR-Y performance of these sequences when QP is 25. From the figure, it is clear that the PSNR-Y degradation is very minor, although sometimes there is some fluctuation, such as frame number 43 in Foreman sequence and number 70 in Bus sequence.

To compare our proposed scheme with recently proposed well-known methods, IBBPBBP sequence format is also selected in our experiments. Experimental results are presented in Table 3. When the value of ΔPSNR is negative and ΔBit is positive (a negative value of ΔPSNR means decreased PSNR and negative value of ΔBit means decreased bitrate), it corresponds to performance degradation and vice versa. ΔT denotes the percentage of saved encoding time. In the table, Lee's method is in paper [4] and Pan's method is in paper [6] and Kim's method is in paper [7]. They are evaluated against our proposed method. The experimental environment and configuration of JM are the same as shown in Table 1.

From the table, it is shown that in most sequences, the speed acceleration obtained by the proposed scheme is the best among four methods and provides very minor PSNR deterioration. The coding speed in QCIF sequences is almost three times faster than the other three methods, although there is some minor PSNR and bitrate degradation that affect image fidelity. Admittedly, in Mobile sequence, the proposed scheme just keeps the same level compared to Kim's. However, in the Coastguard and Paris sequences, the performance increase is considerable compared to the other three ones.

4. Conclusion

In this paper, we first give a brief introduction about H.264 and then exhaustively specify the whole procedure of inter-frame coding, especially concerning the conjunction of inter-partition modes and intramodes, to demonstrate that intra-skip is a very effective method to increase the speed of the encoder if adopted in the inter-frame coding. After that, we discuss a mathematical model for intra-skip and the critical advantage of this model that can optimize H.264 encoder together with any proposed fast inter-partition mode decision, search algorithms, and fast intra-algorithms. At last, experimental results are provided and illustrated to substantiate the practical value of this model in the inter-frame coding.

The coefficients of the mathematical model proposed in this paper might not bring perfect performance, as there is also some bitrate increase and PSNR degradation on certain circumstances, which means that few blocks are intra-skipped incorrectly. These few blocks therefore lead to incorrect mode prediction that brings out more extra residual to be encoded, which is also confirmed by our experiments. For example, when the proposed method is compared to Kim's method in the CIF sequence Mobile, it does not show great performance improvement like, other sequences because some few blocks are wrongly intra-skipped and lead to inexact prediction. The drawback could be tentatively solved by neural networks applied to PID control field [20, 21] and Fuzzy Control [22, 23] or similar areas for coefficients tracing so as to seek better performance.

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