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Low-Cost H.264/AVC Inter Frame Mode Decision Algorithm for Mobile Communication Systems

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Abstract One of the important issues of green mobile networking is the low energy consumption for either mobile devices or transmissions. To adapt this, a low-cost Inter frame mode decision (MD) algorithm is proposed for H.264/AVC encoder to reduce the computational complexity of the original encoding procedure in this paper. The information extracted from macroblock (MB), such as energy, temporal domain mode similarity and so on, which can be used to pre-estimate the optimal mode of the MB is investigated and utilized to eliminate the redundant mode candidates. The performance evaluations including quantitative analysis and PC simulations show that the proposed algorithm is an energy-efficient source coding because it can reduce around 85% Inter frame encoding time with little quality loss. It can be widely implemented in green mobile networking systems with H.264/AVC standard to realize the real-time video signal coding.

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1 Introduction

As the latest video compression standards, H.264/AVC [1] has shown its strong coding ability. It employs various coding techniques, such as multiple references, variable block size (VBS) Intra/Inter mode decision (MD), de-blocking filter and so on, to increase the coding efficiency. It achieves the equivalent quality of the reconstructed video signal with only 50% bitrate of the previous video coding standards [2], and is widely used for low bitrate video coding in various multimedia terminals. Especially, it has replaced MPEG-4 Simple Profile [3] in the low resolution digital video market and rapidly become the protagonist for multimedia communication services. However, the huge computational complex of the encoder limits its applications. In general, the Inter frame is the magistral frame type in the different pulse code modulation (DPCM) system because the residual information can reduce the data amount during the coding process. In H.264/AVC, the VBS MD is employed by the Inter frame to get the improved performance for the prediction. Multiple Inter mode candidates ranged from 16×16 to 4×4 are available for each macroblock (MB) to achieve the most accurate prediction. In addition, SKIP (DIRECT) and Intra modes are also permitted in the Inter frame MD to further ameliorate the encoding performance. However, the incidental side-effect is the high computational complexity which affects the purpose of the real-time multimedia communications. According to the mentioned codec bottleneck, the fast MD algorithm for H.264/AVC Inter frame encoding has become an important research topic, and numerous proposals have been released in the past several years. M. Knesebeck et al proposed an efficient early-termination MD algorithm for H.264/AVC encoder in [4] where the correlation between the rate-to-distortion cost (RDCost) of the 16×16 pixel motion search and the cost of the potential best mode is utilized to stop the motion search before all possible options in advance. Considering the status of the Intra modes in Inter frame MD, M. Kim et al proposed an Intra skip decision algorithm for the Inter frame coding of H.264/AVC in [5] by utilizing the motion, temporal and spatial homogeneity characteristics of the video sequences. In [6], M.E. Eduardo et al proposed a fast Inter MD algorithm for H.264/AVC with multiple adaptive thresholds. All these proposals can reduce the computational complexity of the original Inter frame MD significantly with only slight quality loss. To future reduce the complexity, a very low-cost Inter frame MD algorithm for H.264/AVC encoder is proposed in this paper. The information, such as MB activity, temporal mode similarity, and so on, are used to estimate the optimal MB mode in advance to early stop the original MD procedure. The performance evaluations show that the proposed algorithm can reduce around 85% encoding time compared with the original H.264/AVC encoder while guaranteeing the original video quality.

This paper is organized as follows. Section 2 presents an overview of the MD procedure in H.264/AVC encoder at first, and then, several state-of-the-art fast Inter frame MD algorithms are introduced and analyzed briefly. Section 3 releases the proposed low-cost Inter frame MD algorithm for H.264/AVC encoder. To confirm the proposed algorithm, Section 4 gives the performance evaluations which include the quantitative analysis and PC simulation results. Finally, the conclusions are drawn in Section 5.

2 Existing H.264/AVC inter frame MD algorithms

In H.264/AVC encoder, the VBS-based Inter frame MD supports for a range from 16×16 to 4×4 samples as shown in Fig. 1, where the SKIP mode is a particular case of the 16×16 and no transmit either residual signal or motion vector (MV). In addition, the Intra modes are also available in the Inter frame MD to increase the coding efficiency for the MBs which cannot be predicted by Inter mode accurately.

Based on the Rate-to-Distortion Optimization (RDO) theory, the full search algorithm (FSA) is implemented in H.264/AVC encoder, and the RDCost of all the 11 mode candidates are computed by using the function shown in Eq. 1 to find the best one which has the minimum RDCost value, where D_{Mode} in Eq. 1 is the distortion between the original and reconstructed MB values; R_{Mode} is the encoding rate of each MB or sub-MB, and λ_{Mode} is the Lagrange multiplier that weights the relative importance of the distortion and the rate terms.

$$RDCost_{\text{Mode}} = D_{\text{Mode}} + R_{\text{Mode}} \times \lambda_{\text{Mode}}$$
$$\lambda_{\text{Mode}} = 0.85 \times 2^{(QP-12)/3} \tag{1}$$

Since 4×4 integer DCT and variable length coding (VLC) are performed [1], 4×4-block can be defined as the basic unit of the RDCost computing. Under this definition, the RDCost computing load of each mode candidate can be deduced, for instance, it is 16 units for *Inter* 16×16, and $9 \times 16 = 144$ RDCost computing units for *Intra* 4×4 due to the 9 prediction directions. According to recent H.264/AVC reference software program JM15 [7], the total number of the RDCost computing unit for one MB of the Inter frame is 768 [8] which implies that around 4 millions RDCost computing units are needed for just 1 second HDTV encoding. It affects the purpose of the real-time video signal coding and wastes the power of electronic devices.

To reduce the computational complexity of the Inter frame MD in H.264/AVC, an efficient early-termination MD algorithm is proposed in [4]. The authors take advantage of the correlation between the RDCost of the 16×16 pixel motion search and the cost of the potential best choice of the block size in order to terminate the MD procedure before the implementation of the FSA. This algorithm can reduce over 37% original complexity while maintaining the video quality. However, it depends on the content of the input video signal seriously, and the time reduction has large difference for various video sequences. Moreover, the MB categories classified by the thresholds are coarse, and the redundant mode candidates still exist which is the reason that the computational complexity reduction in [4] is very limited.

Considering the status of the Intra mode candidates for Inter frame MD in H.264/AVC, M. Kim et al proposed an Intra mode skip decision algorithm in [5]. It bases on the fact that except the sudden scene change or fast moving objects, most of the natural video regions are coded by using Inter modes. This observation provides the possibility to eliminate the Intra mode candidates from the Inter frame MD procedure. The tem-

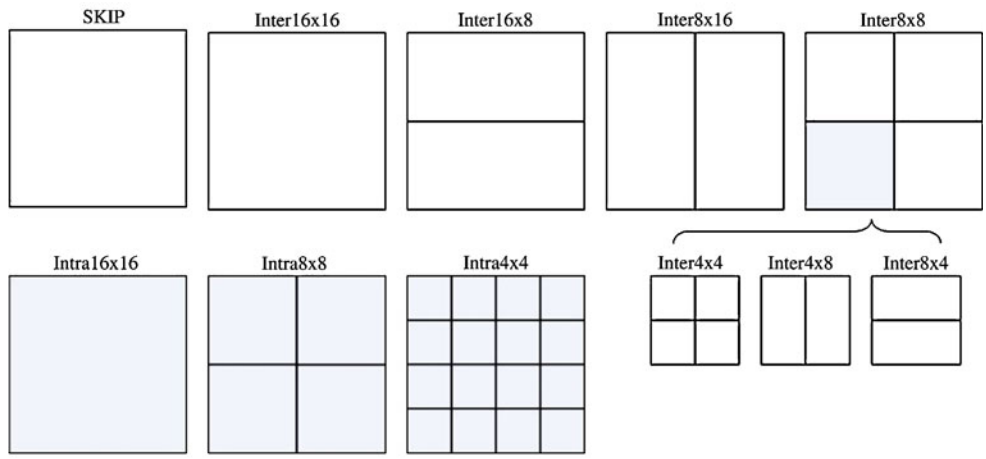


Fig. 1 Mode candidates for inter frame MD in H.264/AVC encoder

poral/spatial homogeneity is computed by the sum of absolute difference (SAD) between the original block and its prediction block of the best Inter/Intra mode, respectively. The full Intra mode searching is skipped from the Inter frame MD to reduce the encoding time when a region's temporal homogeneity is stronger than the spatial homogeneity. Although the video quality is not affected much, the total encoding time reduction of [5] can only reach from 3 to 10% for different test video sequences due to the small partition of this kind region in Inter frame.

In [6], M.E. Eduardo proposed a fast Inter MD algorithm for H.264/AVC encoder, which relies on the "on-the-fly" estimation of the RDCost statistics to make precise and reliable decisions about the optimal mode for each MB. The key point of this algorithm is the definitions of the adaptive thresholds which are used to early stop the original Inter MD procedure. The simulation results show that around 60 and 50% encoding time can be reduced for B and P frames, respectively, and the video quality is guaranteed at the same time. However, since the adaptive thresholds are defined based on the frame contents, the complexity reduction is sensitive to different input video sequences. Moreover, the encoding time reduction is limited because only the RDCost value is regarded as the judging factor while neglecting other important information which can also be used to estimate the optimal mode.

3 Proposed low-cost MD algorithm

3.1 Step 1: temporal domain SKIP mode mapping

Although VBS is supported for H.264/AVC Inter frame MD, the probabilities of the selected MB modes are unequal. According to Table 1, SKIP mode occupies the dominant status to be selected as the final optimal mode for different test video sequences because of the homogeneous data information in Inter frame. The research report in [8] also proves our observation which prompts us if the MBs whose final optimal modes are SKIP can be detected in advance without implementing the FSA, the entire MD complexity can be reduced significantly.

It is the fact that the play speed of the video sequence is very fast that dozens or even hundreds of video frames are played within 1 second to maintain the continuity and smoothness of the video signal so that the temporal similarity exists in any video signal except the sudden change of the scene. Therefore, the mode similarity in the temporal domain is the common phenomenon among the continuous video frames [9]. This characteristic is utilized to early estimate SKIP mode for the MBs in Inter frame. Because of the motion of the video signal along the temporal domain, the results of the second column in Table 2 are not very satisfied, where the "conditional probability (1)"

Table 1 Probability analysis of MB mode selection

Sequence	*SKIP* (%)	*Inter* 16 × 16 (%)	*Inter* 16 × 8 (%)	*Inter* 8 × 16 (%)	*Inter* 8 × 8 (%)	*Intra* (%)
Ballroom	61	14	5	5	8	7
Exit	68	15	3	5	4	5
Race	71	11	4	2	10	2
Rena	47	21	3	7	15	7

Table 2 Conditional probability of SKIP mode for the current MB

Sequence	Conditional probability (1) (%)	Conditional probability (2) (%)
Foreman	90.66	99.83
Mobile	74.74	96.78
Bus	85.33	98.99
Football	90.34	99.52
Average	85.27	98.78

means the probability that the optimal mode of the current MB is SKIP when the modes of the same position MBs in the reference frames are SKIP. Therefore, the investigation with only the same position MB in the reference frame is not accurate enough. The third column of Table 2 marked as "conditional probability (2)" gives out the probability that the optimal mode of the current MB is SKIP when the optimal modes of the same position MB and its neighboring MBs in the reference frame as shown in Fig. 2 are all SKIP, where P_n in Fig. 2 means the current Inter video frame, P_{n-1} and P_{n+1} are the pre-encoded Inter frames in bi-directions. The results show us that if all modes of the surveyed MBs in the reference frames are SKIP, it is very likely that the optimal mode of the current MB is SKIP (up to 98% in average). Therefore, the MBs with the SKIP mode trend may be pre-detected by using the temporal domain mode mapping, and the other original mode candidates for these MBs can be eliminated to reduce the redundant RDCost computing.

3.2 Step 2: mode candidate grouping by MB energy

Through the mode mapping technique in step 1, some MBs whose modes tend to be SKIP can be pre-determined according to the mode information of the related MBs in the reference frames, and the other mode candidates for these MBs can be skipped directly. However, the remained MBs should perform FSA to find the final optimal modes so that the MD redundancy still exists after the step 1. With our study we found that the Inter MD block sizes highly relate to the MB information amounts defined as MB energy (MB_{energy}) in this paper. If MB_{energy} is small, it implies that the MB belongs to small information image region, and the larger block sizes are enough for MB Inter MD. Else if MB_{energy} is large, it implies that the MB includes detail information, and the partitions of Inter MD for this MB should be small to guarantee the prediction accuracy. In order to assess the status of the MB_{energy}, the sum of the absolute pixel values within the MB is calculated as Eq. 1 where *block_index* is the index of the luminance 8×8 block within the MB, *pixel* and i are the residual pixel value in 8×8 sub-block and its position index, respectively.

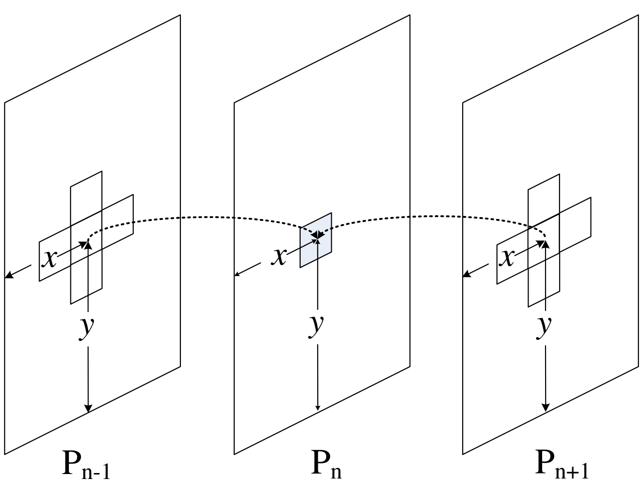


Fig. 2 SKIP mode temporal mapping

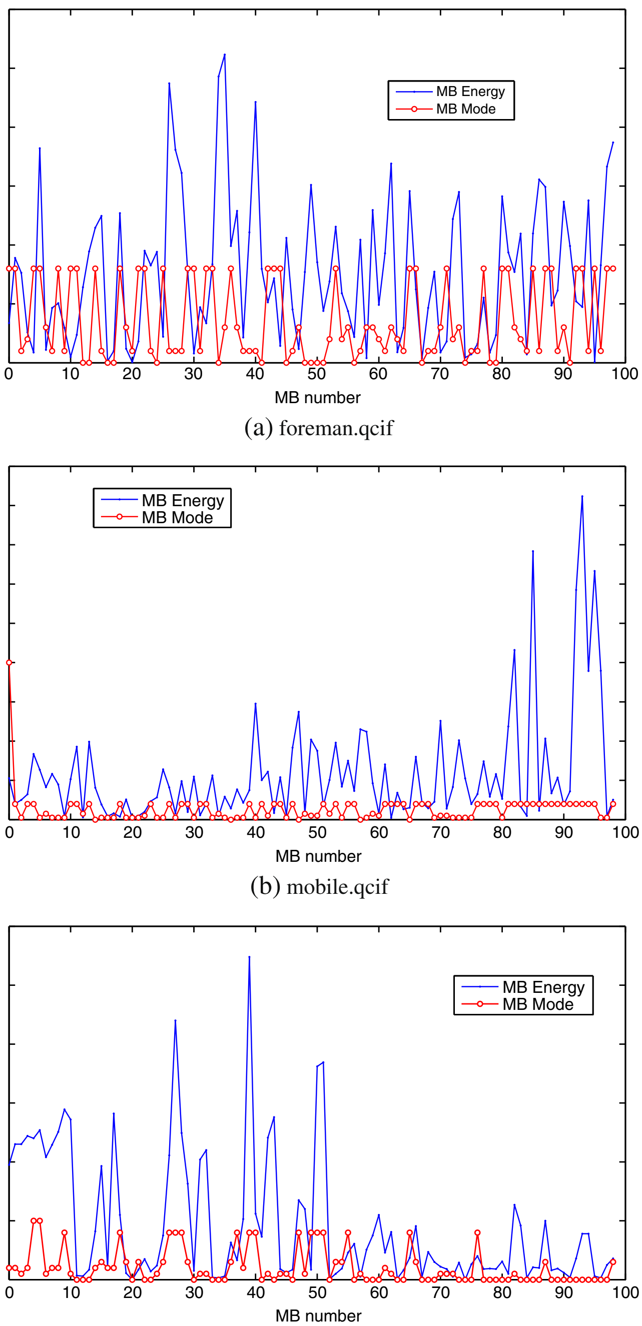
$$MB_{\text{energy}} = \sum_{\text{block\_index}=0}^{3} \sum_{i=0}^{63} |pixel[block\_index][i]| \quad (2)$$

Figure 3 gives the histograms of the MB_{energy} and the corresponding MB optimal mode for various test video sequences by implementing the original H.264/AVC encoder. It is obvious that the optimal mode of the MB highly relates with its energy. When MB_{energy} is higher, the smaller block sizes, such as *Inter* 8×8, *Inter* 8×4, are utilized to predict the MB in detail. On the other hand, when MB_{energy} is lower, the MB is judged to be homogeneous region, and little information is included so that the larger block sizes are enough to guarantee the prediction accuracy.

With the observation context, the step 2 of the proposed algorithm can be described as follows where τ_{low} and τ_{high} are QP-based MB energy thresholds which are generated experimentally.

- Calculate MB_{energy} for each MB of the Inter frame;
- If $MB_{\text{energy}} < \tau_{\text{low}}$, the mode in the skip group of Table 3 is selected as the mode candidate for Inter MD;
- Else if $MB_{\text{energy}} > \tau_{\text{high}}$, the modes in the small group of Table 3 are selected as the mode candidates for Inter MD;
- Else, the modes in the large group of Table 3 are selected as the mode candidates for Inter MD.

With these operations, the number of original mode candidates can be reduced to 1, 4 or 7, and the corresponding RDCost computing for the eliminated mode



(a) foreman.qcif

(b) mobile.qcif

(c) news.qcif

Fig. 3 MB energy and its corresponding optimal mode

candidates can be skipped to reduce the computational complexity.

3.3 Further mode candidates reduction based on the optimal mode probability

With the implementations of proposed step 1 and step 2, the number of the original mode candidates can be reduced significantly. However, the MBs which select the modes of the large or small group of Table 3 will still bear the nasty RDCost computing for the multiple mode candidates. Therefore, it is necessary to further reduce the selected mode candidates to achieve more optimistic computational complexity reduction. Firstly, let's focus on the probabilities of the 4 mode candidates in the large group of Table 3. According to Table 1, most of the MBs are encoded with SKIP mode, and *Inter* 16 × 16 mode takes the second status followed by *Inter* 16 × 8 and *Inter* 8 × 16. The related statistical analysis in [10] also hints that the PRI exits among the mode candidates. With this discovery, the main idea is to compare the RDCost values between the neighboring modes in the order as SKIP, *Inter* 16 × 16 and *Inter* 16 × 8/*Inter* 8 × 16. For instance, the RDCost of SKIP (R_{SKIP}) and *Inter* 16 × 16 ($R_{\text{Inter } 16\times16}$) are calculated and compared. If R_{SKIP} is less than $R_{\text{Inter } 16\times16}$, the MD procedure is stop immediately, and the SKIP mode is selected as the final optimal mode. With this thread, the probability-based MD procedures for the MBs who select the modes in the large group of Table 3 as the mode candidates are described as follows.

Table 3 Mode candidates grouping by MB energy

Grouping	Selected mode candidates
Skip group	*SKIP*
Large group	*SKIP*, *Inter* 16 × 16, *Inter* 16 × 8, *Inter* 8 × 16
Small group	*Inter* 8 × 8, *Inter* 8 × 4, *Inter* 4 × 8, *Inter* 4 × 4, *Intra Modes*

Start

Calculate R_{SKIP} and $R_{\text{Inter } 16\times16}$;

– if ($R_{\text{SKIP}} < R_{\text{Inter } 16\times16}$)
{

– SKIP is selected as the final optimal mode;

– Stop the MD procedure immediately;
}

– else if ($R_{\text{SKIP}} > R_{\text{Inter } 16\times16}$)
{

– Calculate $R_{\text{Inter } 16\times8}$ and $R_{\text{Inter } 8\times16}$;

– Select the mode which has the minimum RDCost value as the final optimal mode among *Inter* 16 × 16, *Inter* 16 × 8 and *Inter* 8 × 16;
}

Finish

Table 4 The order of the mode candidates in the small group (MC: mode candidate)

MC	*Inter* 8 × 8	*Inter* 8 × 4	*Inter* 4 × 8	*Inter* 4 × 4	*Intra* 8 × 8	*Intra* 16 × 16	*Intra* 4 × 4
m	1	2	3	4	5	6	7

The similar phenomenon exists in the small group of Table 3, consequently, we could reduce the mode candidates of this group with the same way. Firstly, the mode candidates in the small group of Table 3 are ordered from *Inter* 8 × 8 to *Intra* 4 × 4 and indexed with m from 1 to 7 as shown in Table 4 based on the probabilities to be selected as the optimal mode. And the RDCost values are compared between the neighboring modes to judge the stop point, and Fig. 4 gives the detailed flowchart of the proposed probability-based early MD stop procedure for the MBs which select the modes in the small group as the mode candidates.

4 Performance evaluations

4.1 Quantitative analysis

To confirm our proposed algorithm in theory before the PC simulation, the quantitative analysis should be done at first. According to the proposed procedure, it is obvious that the number of mode candidate and final RDCost computing load are probability-based values. Since the computational complexity is decided by the RDCost computing load, only the RDCost computing unit reduction of the proposed algorithm is included in this discussion. Firstly, several probabilities are defined as follows.

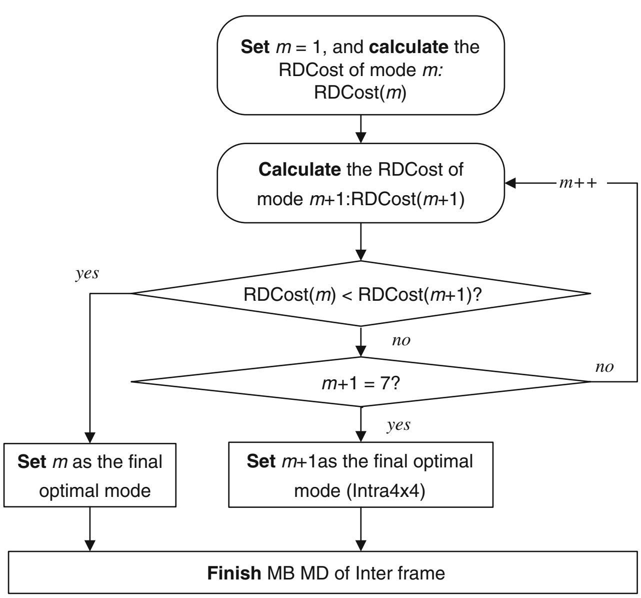


Fig. 4 Flowchart of the probability-based mode candidate reduction for the small group of Table 3

– $P_{\text{SKIP\_M}}$: the probability of SKIP mode MBs detected by temporal domain SKIP mode mapping in step 1;
– $P_{\text{SKIP\_G}}$, $P_{\text{large\_G}}$ and $P_{\text{small\_G}}$: the probabilities for the SKIP, large and small groups of Table 3 which are detected by MB_{energy}.

And according to the probability theory [11],

$$P_{\text{SKIP\_M}} + P_{\text{SKIP\_G}} + P_{\text{large\_G}} + P_{\text{small\_G}} = 1 \tag{3}$$

Correspondingly, the RDCost computing units for the probabilities are defined as $R_{\text{SKIP\_M}}$, $R_{\text{SKIP\_G}}$, $R_{\text{large\_G}}$ and $R_{\text{small\_G}}$, respectively, and Eqs. 4–7 calculate the average values for them according to the RDCost computing unit definition in [8]. It should be noted that if the optimal mode is judged as SKIP by temporal mode mapping or MB_{energy}, SKIP mode will be the only mode candidate, therefore, $R_{\text{SKIP\_M}}$ and $R_{\text{SKIP\_G}}$ equal to 16. For large and small groups in Table 3, various RDCost computing units exist because the further probability-based mode candidate reductions is implemented. Therefore, the average RDCost computing units are given by Eqs. 6 and 7 for easy discussion. For instance, two possible values of the RDCost computing unit exist for large group, 32 and 64, therefore, the average value 48 given in Eq. 6 is employed in our discussion.

$$P_{\text{SKIP\_M}} = 16 \tag{4}$$

$$P_{\text{SKIP\_G}} = 16 \tag{5}$$

$$P_{\text{large\_G}} = \frac{32 + 64}{2} = 48 \tag{6}$$

$$P_{\text{small\_G}} = \frac{672 + 688 + 704}{3} = 688 \tag{7}$$

With the definitions, the RDCost computing of the proposed algorithm (R_{proposed}) can be calculated as follow.

$$R_{\text{proposed}} = P_{\text{SKIP\_M}} \times R_{\text{SKIP\_M}} + P_{\text{SKIP\_G}} \times R_{\text{SKIP\_G}} + P_{\text{large\_G}} \times R_{\text{large\_G}} + P_{\text{small\_G}} \times R_{\text{small\_G}} \tag{8}$$

Considering the probabilities relationship in Eqs. 3 and 8 can be deduced to Eq. 9.

$$R_{proposed} = 16 + 32 \times P_{large\_G} + 672 \times P_{small\_G} \quad (9)$$

Focusing on Eq. 9, the RDCost computing unit of the proposed algorithm is a probability-based variable. Figure 5 shows the mutative trends which include the different situations of the groups' probabilities. Notes that the solid line in Fig. 5 denotes the RDCost computing unit for the original FSA, and it always equals to 768 since RDCost for any mode candidate should be calculated (here, *Intra* 8×8 is ignored since it is an option in many JM codec versions). It is obvious that the proposed algorithm can reduce RDCost computing load evidently in any case. In detail, P_{large_G} causes the change into different lines, and with the increase of P_{large_G}, the large group will more tend to be selected, and the other original mode candidates will be considered as the redundant modes and skipped. Because of the middle RDCost computing unit, the total complexity is slightly increased with the increase of P_{large_G}. On the other hand, with fixed P_{large_G} (each dashed line in Fig. 5), the RDCost computing load increases dramatically with the increase of P_{small_G} because of the huge RDCost computing units in the small group. When $P_{large\_G} = 0$ and $P_{small\_G} = 1$, the proposed MD procedure goes through the small group in Table 3, the RDCost computing unit is 672, and our proposed algorithm gets the minimum complexity reduction (around 13%). On the other extremity, When $P_{large\_G} = P_{small\_G} = 0$, it implies that the optimal mode of MB is detected as SKIP by temporal domain mode mapping or MB_{energy}, the RDCost computing unit is only 16, and the proposed algorithm achieves maximum complexity reduction (around 98%). According to the statistical analysis in Table 1, the probability of selecting the small group is very slight, and the optimal mode always falls into the SKIP or large group. Therefore, the complexity reduction of the proposed algorithm tends to the maximum value rather than the minimum value. For instance, the RDCost computing unit for "exit" sequence is 84 which means that around 90% MD complexity reduction is achieved by our proposed algorithm.

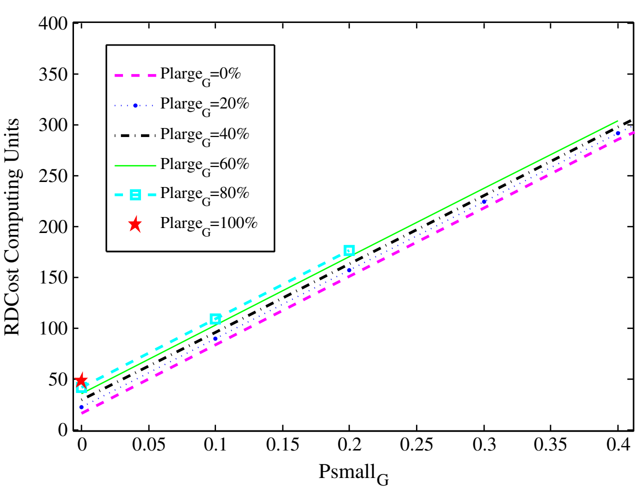


Fig. 5 RDCost computing unit analysis

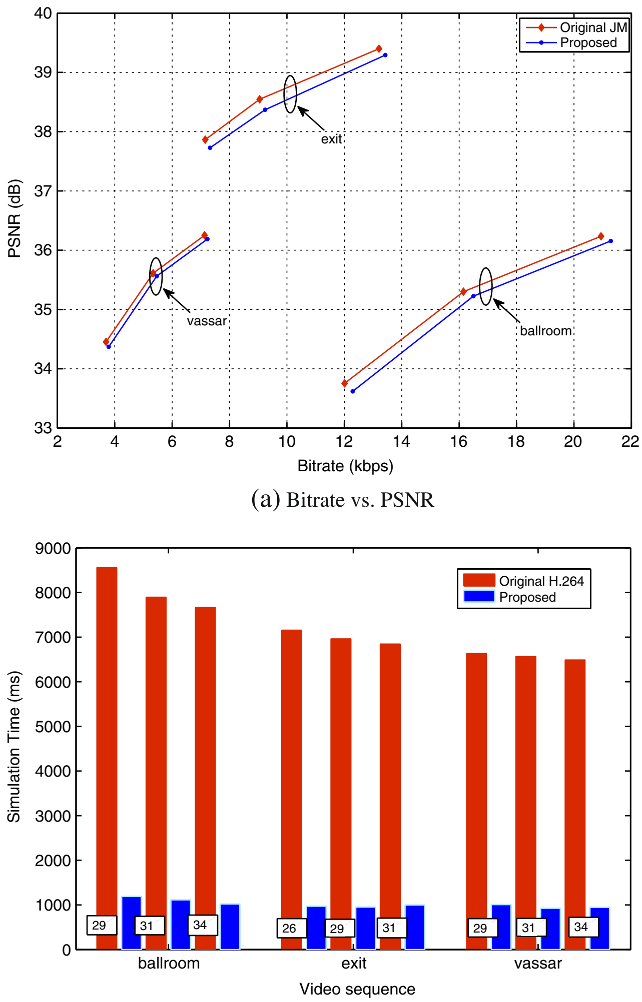
4.2 Simulation results

To verify the performance of the proposed low-cost Inter frame MD algorithm for H.264/AVC encoder in practical, the simulation results are exhibited in this sub-section by implementing the existing and proposed MD algorithms under the simulation environments shown in Table 5. The H.264/AVC reference software JM15.0 is utilized as the core of the codec. Different MERL test video sequences which have a wide range of video motion, texture and bitrate are used to conduct a set of experiments. In this paper, we focus on the implementations on B frame because of it can achieve very low bitrate for easier transmission. Since the target of our works is to establish a low-cost and high quality encoder, the RD performance (video quality and compression efficiency) and the processing time are the two main performances to be evaluated in our experiments.

For digital video coding, quantization parameter (QP) is a very important factor because it can affect the codec character and change the output coding bitrate. Moreover, the proposed algorithm also should be tested by using various test video sequences to verify its universalism. Consequently, the performance should be measured by using various QP values and different video sequences to get the results of different situations. Figure 6 gives the RD performance and encoding time comparisons between the original H.264/AVC codec and the proposed algorithm for different MERL test video sequences with various QP ranged from

Table 5 Simulation environments

Items	Contents
Hardware device	Inter core TM 2: CPU 2.13GHZ, 2 GB RAM
Software support	Visual C++ 6.0, H.264/AVC: JM10.2
Test video sequences	MERL sequences: ballroom, exit, vassar
	Resolution: 640 × 480
	GoP: IBBBB 100 frames
	Format: 4:2:0
	QP: 26–34



(a) Bitrate vs. PSNR

(b) Encoding Time Comparisons

Fig. 6 Performance comparisons between the original and proposed algorithms for MERL video sequences

26–34 to maintain the amplitudes of the output bitrate where the tags inside the histograms denote the QP values. Figure 6b shows us that the proposed algorithm can always reduce over 85% of the simulation time compared with the original H.264/AVC codec. At the same time, the outcome video quality can be guaranteed (Fig. 6a) and the bitrate is controlled effectively because of the reasonable reduction of the mode candidates. It proves that the proposed algorithm is suitable for the varieties of the QP. Meanwhile, the simulation results show us that the proposed algorithm is universal because it can achieve excellent performance for different test video sequences.

Except for the original JM codec and our proposed algorithm, several recent proposals in [4–6] are selected as the references which are very relevant with our proposed algorithm to compare the performance. The simulation environments in Table 5 are also employed, and PSNR, Bitrate and simulation time are still considered as the performance to be compared. The output performance of the original H.264/AVC codec are regarded as the benchmarks. Those of the other four fast MD algorithms ([4–6] and the proposed) are compared with the benchmarks, and the differences are recorded as $\Delta PSNR$, $\Delta Bitrate$ and $\Delta Time$ which are calculated by Eqs. 10–12, where the right-bottom marker "FMD" means the fast MD algorithm.

$$\Delta PSNR = PSNR_{FMD} - PSNR_{H.264} \tag{10}$$

$$\Delta Bitrate = \frac{Bitrate_{FMD} - Bitrate_{H.264}}{Bitrate_{H.264}} \times 100\% \tag{11}$$

$$\Delta Time = \frac{Time_{FMD} - Time_{H.264}}{Time_{H.264}} \times 100\% \tag{12}$$

Table 6 Simulation environments

Sequence	Algorithm	$\Delta PSNR(dB)$	$\Delta Bitrate(\%)$	$\Delta Time(\%)$
Ballroom	Ref. [4]	−0.03	+1.33	−59.79
	Ref. [5]	−0.01	+0.08	−25.54
	Ref. [6]	−0.15	+0.88	−67.43
	Proposed	−0.02	+2.03	−85.93
Exit	Ref. [4]	−0.02	+0.56	−60.68
	Ref. [5]	−0.01	+0.02	−21.37
	Ref. [6]	−0.07	+1.72	−72.18
	Proposed	−0.04	+2.05	−86.07
Vassar	Ref. [4]	−0.00	+0.88	−47.32
	Ref. [5]	−0.04	+1.02	−29.02
	Ref. [6]	−0.11	+1.86	−55.59
	Proposed	−0.03	+2.07	−85.38
	Ref. [4]	−0.01	+0.92	−55.93
Average	Ref. [5]	−0.02	+0.37	−25.33
	Ref. [6]	−0.11	+1.49	−65.07
	Proposed	−0.03	+2.05	−85.79

The recorded simulation results in Table 6 are consistent with our analysis in Section 2. Since only Intra mode skipping technique is considered in [5], the simulation time reduction of this method is very limited although the PSNR and bitrate are controlled well. For [4] and [6], although sometimes they can reduce the simulation time up to 60%, the computational complexity reductions seriously depend on the video content so that the simulation time has large change for different video sequences. It is the bottleneck of those methods which limits their applications. It is exciting that our proposed algorithm always achieves best performance among the testing algorithms. The average simulation time reduction is over 85% and the corresponding video quality and bitrate are controlled efficiently. It always achieves the best results in saving encoding time, which is a critical issue in video compression application. Because of the reasonable mode candidate reduction, the bitrate increase is controlled very well so that the original transmission will not be affected. The corresponding video quality can also be guaranteed in the representation of less than 0.04 dB PSNR reduction. Moreover, our proposed algorithm is more flexible for real application because nearly no additional computation exists.

5 Conclusions

To enhance the coding efficiency, the VBS Inter frame MD algorithm is employed in H.264/AVC encoder, and the final optimal mode for each MB can be selected from the multiple mode candidates. However, the following problem is the additional computational complexity which is not suitable for the multimedia communication via mobile networks. Through the study we found that the computational load of the Inter frame MD mainly lies on the complex RDCost computing of each mode candidates, which takes so much encoding time that it is very hard to implement H.264/AVC in real-time multimedia communications. In this paper, we proposed an efficient low-cost Inter frame MD algorithm for H.264/AVC encoder to reduce the original MD complexity. Firstly, the relationship between the mode of the current MB and the modes of the corresponding MBs in the reference frames is utilized to predetermine if the mode of current MB is SKIP or not. And then, the energy of MB is calculate to measure the activity character of the MB, and the original 11 mode candidates are classified into three groups for serving the different MB activity. Finally, the probability-based mode candidate reduction method is implemented to further reduce the redundant computation. The quantitative analysis confirms the proposal in theory, and the simulation results shows that the proposed energy-efficient source coding can reduce over 85% encoding time compared with the original H.264/AVC encoder with little quality loss and bitrate increase. It can be widely employed in the real-time multimedia communication systems, especially for mobile and embedded environments.

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