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Research Article

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SAD and Statistics Based H.264 Intra Mode Decision

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Abstract

H.264 provides good compression ratio in video coding standards among mainstream resolution, such as 720p, 1080p and below. It's main video codec standard recently used. In order to achieve the compression ratio, Ratio Distortion Optimization (RDO) is employed to choose the best mode for every macro block, which results in high computation complexity, and makes it difficult for real-time applications. This article toke statics on the best mode's distribution, results show that, a best mode always tends to be the mode with a smaller Sum of Absolute Differences (SAD), and when a best mode has a larger SAD, this mode usually is a most-probable mode too. Based on this feature, a fast H.264 intra mode decision method is presented and embedded in H.264 reference code JM9.3. Simulations show that, this method can reduce ~ 49% computational complexity on average, with negligible degradation on PSNR and Bitrate.

Keywords: H.264, Intra Mode Decision, Intra Mode Selection, Most-Probable Mode (MPM), Termination, Sum of Absolute Differences (SAD), Rate Distortion Optimization (RDO)

1. Introduction

The video coding standard H.264 has garnered significant attention since its release, primarily due to its high compression ratio and its practicality among mainstream resolution 720p, 1080p and below [1].

The H.265 was accepted as a ITU-T standard at 2013, and H.266 was released at 2020. Compared to these standards, H.264's codec complexity is significant reduced. These standards are based on improved hardware performance, while H.264's codec is also complex. Research on the algorithm of H.264 is very important.

Reports indicate that compared to previous video standards, H.264 can achieve approximately 50% bit rate savings. However, this improved compression rate comes at the cost of increased computational complexity. The decoding capacity of the H.264 main profile is three times that of the MPEG4 simple profile, while the encoder's computational complexity has increased by more than an order of magnitude [2]. The main reasons are twofold: first, H.264 employs as many modes as possible to enhance prediction accuracy and reduce bit rate; second, mode selection is conducted through Rate Distortion Optimization (RDO), which exhaustively searches all modes to choose the one with the lowest distortion and bit rate. For intra prediction, previous video standards such as H.261/H.263 and MPEG-1/2/4 operated in the transform domain; in contrast, H.264 uses decoded neighboring block pixels to predict the current block pixels, representing a spatial-domain prediction approach. It features two prediction types: Intra_16x16 and Intra_4x4. Intra_16x16 supports four prediction modes, while Intra_4x4 supports nine prediction modes. In recent JM models, an additional Intra_8x8 type has been introduced, which shares the same prediction modes as Intra_4x4 but with a block size of 8x8. This paper focuses solely on the Intra_16x16 and Intra_4x4 types.

Due to the extensive use of various modes in H.264 to achieve high compression ratios, recent research has focused on optimizing intra/inter mode selection to reduce encoder computational complexity, a topic previously absent in video standard studies. In intra mode selection, F. Pan et al. employed image orientation fields to filter potential modes for RDO selection, while C.L. Yang et al. analyzed the prediction characteristics of several Intra_16x16 modes and assigned different prediction mode ranges based on these characteristics for varying image types [3,4]. However, these two approaches exhibit significant optimization differences for

diverse image properties. This paper investigates the relationship between the Sum of Absolute Differences (SAD) of the best mode and the Most Probable Mode (MPM), proposing a novel intra mode selection method. It adopts the stepwise approach commonly used in mode selection—first filtering the most probable modes based on SAD and MPM, followed by RDO selection. Experimental results demonstrate that this method can reduce computational time by ~49% without significantly affecting PSNR and bitrate, while maintaining stable optimization performance across different image types. The paper is structured as follows: Section 2 summarizes the intra mode selection process in H.264; Section 3 explains the principles and workflow of the fast mode selection method; Section 4 presents experimental results and analysis; and Section 5 conclusions are made.

2. Recommended Intra Mode Selection Methods for H.264

This article uses the H.264 JVT reference software JM9.3 as the model. Full Search (FS) checks every possible intra mode to select the best mode [5]. The main steps for selecting FS intra mode are as follows:

(1) Find the best Intra_16x16 mode

a. Perform Hadamard transform on the residuals of 16 4x4 blocks, extract the DC parts of the 16 4x4 blocks to form a 4x4 block, and perform Hadamard transform on this block;
b. Add the absolute values of all Hadamard transform coefficients to obtain the cost of each 16x16 block. Calculate the cost of each prediction mode according to the above method, and select the one with the minimum cost as the optimal Intra_16x16 prediction mode.

(2) Find the best Intra_4x4 prediction mode

a. Predict 4x4 blocks using 9 different modes;
b. For each mode of 4x4 blocks, calculate its RDcost, which is defined as follows:

$$RD\cos t = SSD + \lambda_{mode} \times Rate \quad (1)$$

Among them, SSD is the sum of the squared differences of pixel values between the original block and the reconstructed block; The λ_{mode} of is $0.85 \cdot 2^{QP/3}$;Rate represents the number of bits required to use this prediction mode. The specific calculation process is as follows: first, convert/quantify the predicted residuals and calculate the Rate; Then, the converted/quantized values are reverse converted/quantized, and the reverse converted/quantized values are added to the predicted values for image reconstruction. The difference between the reconstructed values and the original values is used to calculate the SSD. The optimal mode is the mode with the minimum RDcost. Find the best mode for 16 4x4 blocks separately.

(3) Find the best intra prediction mode

For the two prediction types, based on the mode selection results of the above two steps, use equation (1) to calculate the RDcost of the macro block. The prediction type with the smallest RDcost is the optimal prediction type, and the prediction mode under this prediction type is the optimal prediction mode. From the above analysis, it can be seen that the computational complexity of the FS method is very large. Mainly, it requires conversion/quantization for each mode, and the reverse conversion/quantization process. For certain patterns, these processes are completely unnecessary when their predicted values differ significantly from their actual values. The method proposed below utilizes this feature to accelerate the prediction process.

3. Fast H.264 Intra Mode Selection Methods

The main idea for optimizing the intra frame mode selection process in H.264 is to use the two modes with the smallest SAD and combine them with the most probable mode to form up to three candidate modes.This method is mainly used for predicting Intrax4x4 types. This is because Intra_16x16 only has 4 prediction modes, and there is very little room for selection; The mode selection method for Intra_16x16 is based on the Sum of Absolute Transform Differences (SATD) in the transform domain, and the computational complexity is not significant. In addition, some methods have been adopted to suspend the mode selection process to avoid unnecessary calculations. The principle of the fast mode selection method will be explained in detail below.

3.1. Most Probable Mode

The most probable mode refers to the predicted mode of the current block based on the mode of the surrounding blocks that have already undergone mode selection. This is mainly because the image is spatially continuous, and adjacent blocks have correlation, so a block may inherit the prediction mode of surrounding blocks. In the H.264 protocol, the most probable mode is obtained through the following method. Among them, intra4x4RedModeA and intra4x4RedModeB respectively represent the prediction modes of the left block and the upper block of the current block.

Predintra4x4predmode = Min (intra4x4PredModeA, intra4x4PredModeB) (2)

In the actual encoding process, there exists a flag indicating whether the best mode is the most probable mode. If the best mode is the most probable mode, then this bit is high and there is no need to encode the best mode; Otherwise, this bit is low and the pattern needs to be encoded.

3.2. Principle of Fast Mode Selection Method

The intra mode selection process of H.264 is to predict the image in the spatial domain, transform/quantize the predicted residuals, and then encode and output them. The final code flow depends on the prediction residuals, so the compression rate is closely related to the sum of the absolute values of the residuals SAD. Statistics made on the relationship of the best mode and the SAD.

Figure 1 shows the percentage of the best mode in different SAD sorted modes. Among them, 0 to 8 are the sorting of SAD patterns, where 0 represents the pattern with the smallest SAD and 8 represents the pattern with the largest SAD; The best mode refers to the mode calculated using RDO. The statistics are for the Intra4x4 prediction type.

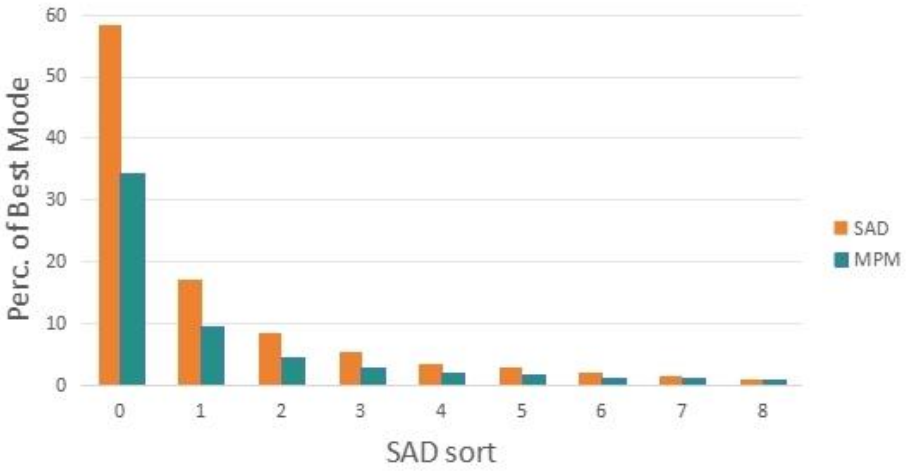


Figure 1: Perc. of SAD Sort (left strap) and MPM (right strap) be Best Mode

It can be seen that the percentage of the minimum SAD mode is best mode, is about 56%. The best mode is close to 70% in the two modes with the smallest SAD.Therefore, using SAD as a guide for mode selection has practical significance.

However, as shown in Figure 1, a significant portion of the modes with larger SAD may still be the best mode. If this portion is ignored, it will have a significant impact on the results of mode selection. By studying these special cases, it was found that the best mode with large SAD are mostly the same as the surrounding patterns. Therefore, we calculated the proportion of the most probable mode among the best mode, as shown by the black bars in Figure 1. It can be seen that in the modes with smaller SAD, the proportion of the best mode being the most probable mode is relatively small; For patterns with larger SAD, the best mode is almost always the most probable mode.

In addition, this article adopts the method of an early termination of the mode selection process to accelerate the calculation speed. Statistics results show that, the SAD of the best mode for Intra_16x16 is generally less than Th, and when the SAD is greater than Th, the Intra_4x4 mode can be used. Th is a threshold.

In addition, the mode selection process for Intra_16x16 occurs prior to Intra_4x4. When calculating a 4x4 block, if the sum of the RDcosts of the blocks that have already undergone mode selection in this macro block, denoted as S-RDcost-4, is greater than the RDcost of the optimal Intra_16x16 mode, the Intra_4x4 mode selection can be aborted. Statistics are made on the impact of these early termination, and results show that these terminations have almost no impact on PSNR and bit rate.

This article select two Intra_4x4 modes with the smallest SAD and the most probable mode, totally 3 modes as candidate modes, compare 9 modes in RDO-on mode. Which will significantly reduce the computational complexity of the hardware resources.

Based on statistics results, several early terminations are mode during the prediction process.

3.3. Mode Selection Process

According to above principles, the mode selection process of the fast mode selection method based on SAD and statistics is as follows:

1. Intra_16x16 mode selection process
1.1 Use 4 different modes to predict the macro block;
1.2 Calculate SAD under 4 modes and sort them;
1.3 If the smallest SAD is less than Th16_1, jump to 1 to select the mode for the next macro block;
1.4 If the difference Diff16 between the smallest SAD and the second smallest SAD is greater than Th16_2, jump to 2 for mode selection;
1.5 If the smallest SAD is greater than Th16_3, jump to 2 for mode selection;
1.6 Calculate the SATD of four modes and compare them, selecting the smallest as the optimal Intra_16x16 mode;

2. Intra_4x4 mode selection process
2.1 Use 9 different modes to predict 4x4 blocks respectively;
2.2 Calculate SAD under 9 modes and sort them;
2.3 If the difference Diff4 between the smallest SAD and the second smallest SAD is greater than Th4_1, jump to 3 to continue mode selection
2.4 If QP>28 and the mode with the smallest SAD is MPM, select this mode as the best 4x4 mode, jump to 3 to continue mode selection;
2.5 Select the two modes with the smallest SAD and MPM as candidate modes;
2.6 Use the RDO method recommended by H.264 to calculate the mode selected in the previous step;
2.7 Add the RDcosts of the 4x4 blocks that have already undergone mode selection in the current macro block to obtain S-RDcost4, and compare it with the RDcost of the Intra_16x16 mode (RDCost16).

If it is less than, jump directly to 1 for mode selection of the next macro block;

3. Compare the results of selected Intra_16x16 and Intra_4x4 modes, and select the best one from the two prediction types as the best mode for the macro block.

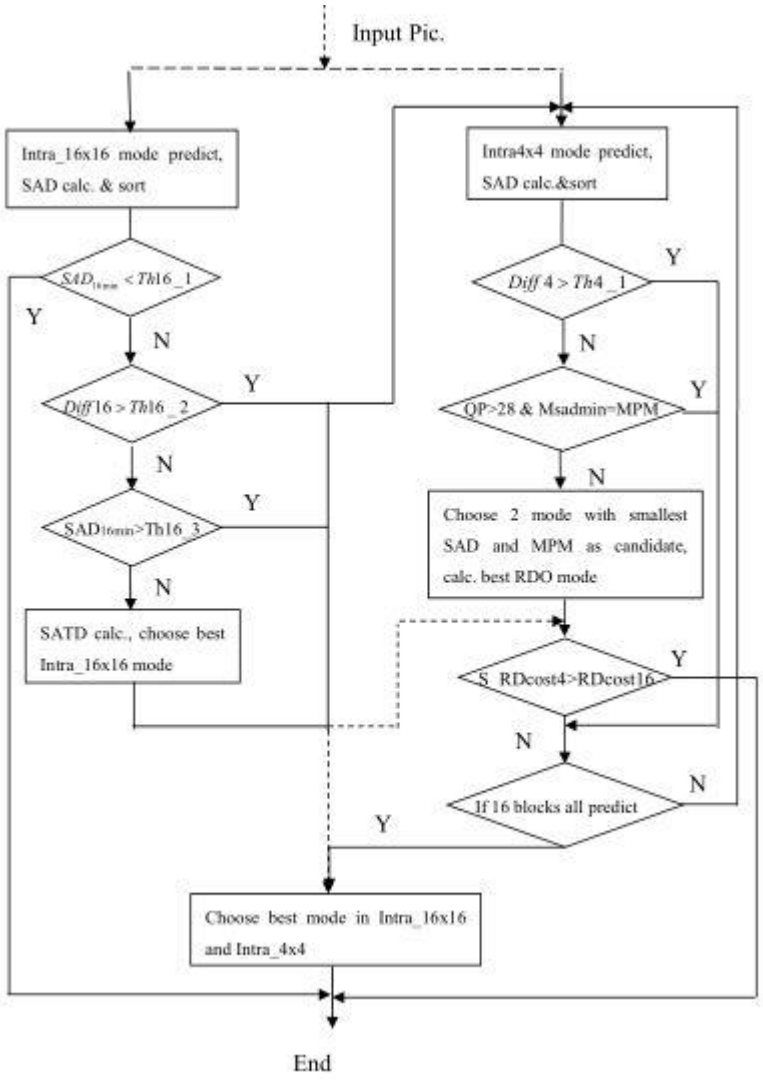


Figure 2: Diagram of Mode Selection Process

4. Experimental Results and Analysis

Embed the algorithm proposed in this article into JM9.3 and compare it with JM9.3's RDO algorithm. The parameter settings for the experiment are: quantization parameter of 28, input sequence of 298 frames of QCIF images, using full I-frame encoding. The comparison results are shown in Table 1.

QP=28	Method	PSNRY (dB)	BitRate （Kbps）	Bit Incr. （%）	Time (ms)	Time Saving (%)
akiyo	RDO-on	38.982	604		35159	
	Proposed	38.893	610.2	1.0	17762	49.5
coastguard	RDO-on	35.561	971.0		40612	
	Proposed	35.480	971.9	0.09	21271	47.6
news	RDO-on	37.213	829.6		37971	
	Proposed	37.124	840	1.3	18326	51.7
foreman	RDO-on	37.287	693.8		37481	
	Proposed	37.210	695.6	0.3	19054	49.2
Hall	RDO-on	38.176	695		37133	
	Proposed	38.081	699.5	0.6	17804	52.1

Table 1: Comparison of the Results between the Method Proposed in this Article and H.264 RDO-on Mode

Embedding the algorithm proposed in this article into JM9.3, compared with JM9.3's RDO algorithm, where FS (H.264) represents JM9.3's RDO method and Proposed represents the method proposed in this article. Due to the fact that this article only improves the intra mode selection of brightness components, only PSNRY is listed. Bit Incr. represents the bit rate increment of the algorithm proposed in this article relative to H.264 FS, with a negative sign indicating a decrease. Time Saving refers to the reduction in computation time relative to H264 JM9.3.

From Table 1, it can be seen that the reduction in computational complexity is around 49%, which is equivalent to almost doubling the speed; The changes in PSNRY and the increase in bit rate can be ignored, which maintains the compression performance of H.264. It can be also seen that, for various test sequences, whether in terms of speed improvement or compression performance, the performance of the algorithm proposed in this paper is stable. Fig.3 shows the relationship between PSNRY and Bitrate of Akiyo sequence. The two curves in the figure represent the results obtained using the method proposed in this paper and JM9.3 respectively.

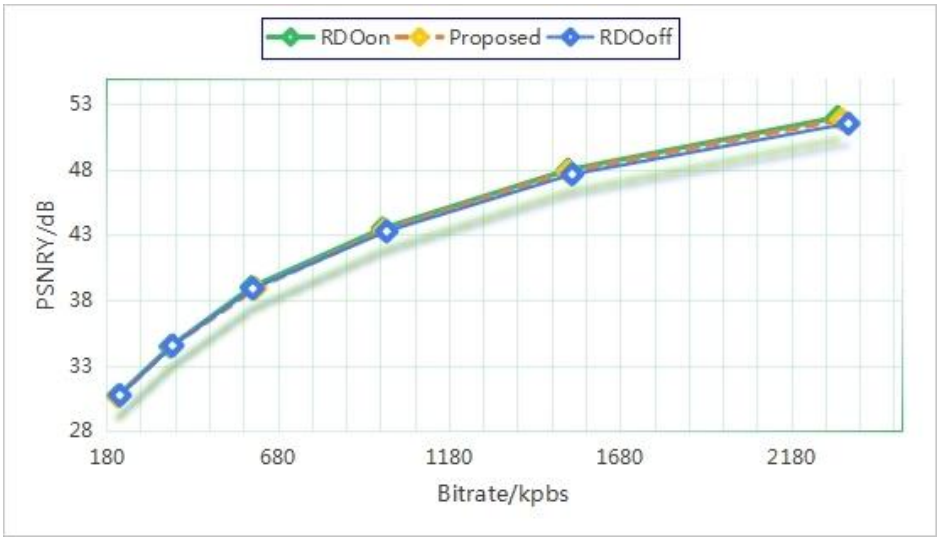


Figure 3: Relationship between PSNRY and Bitrate of Akiyo Sequence

5. Conclusion

This article proposes a fast intra mode selection method based on SAD and statistics [6]. Statistics calculate the percentage of SAD be the best mode, the percentage of MPM be the best mode, finally choose 3 Intra_4x4 modes to calculate the RDO. And more statistics are made on the characteristics of two prediction types, Intra_16x16 and Intra_4x4. Based on the results, early terminations are made in the prediction process.

These strategies significantly reduce the computational complexity

of the hardware resources, up to 52.1%. And the experimental results show that, the changes in PSNR and Bitrate caused by this fast algorithm can be ignored.

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