Journal of Zhejiang University SCIENCE A
ISSN 1009-3095 (Print); ISSN 1862-1775 (Online)
www.zju.edu.cn/jzus; www.springerlink.com
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Improved fast intra prediction algorithm of H.264/AVC*

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Received Nov. 20, 2005; revision accepted Feb. 17, 2006

Abstract: With advanced prediction modes of intra prediction, intra coding of H.264/AVC offers significant coding gains compared with previous video coding standards. It uses an important tool called Lagrangian rate-distortion optimization (RDO) technique to decide the best coding mode for a block, but the computational burden is extremely high. In this paper, we proposed an improved fast intra prediction algorithm including block type selection and mode decision algorithm based on analysis of edge feature of a block. Our algorithm filters out unlikely block type and candidate modes to reduce the RDO calculations. Experimental results showed that the proposed algorithm can reduce the computation complexity of intra prediction from 52.90% to 56.31%**,** with 0.04 dB PSNR degradation and 2% increase of bit rate.

Key words: H.264, AVC, Intra prediction, Video coding
doi:10.1631/jzus.2006.AS0101 **Document code:** A **CLC number:** TN919.8

INTRODUCTION

Intra prediction of H.264/AVC is conducted in the spatial domain (ITU-T Rec. H.264/ISO/IEC 14496-10 AVC, 2003). A prediction block is formed based on previously coded and reconstructed blocks. And the difference between current block and the prediction is coded. From Fig.1, we can see intra 4×4 prediction coding is conducted for samples *a~p* of a block using *A~Q* as prediction samples. In luma samples intra prediction, there are two block types, which are intra 4×4 and intra 16×16 block. In H.264/AVC FRExt (Fidelity Range Extension), it added intra 8×8 prediction. But most profiles of H.264 do not support intra 8×8 prediction. In this paper we only discuss the typical block type intra 4×4 and intra 16×16. Intra 4×4 prediction has 9 directional prediction modes (Fig.2). Intra 16×16 is suitable for smooth image with 4 directional prediction modes, including vertical, horizontal, DC, and plane mode (Fig.3). The chroma samples prediction technique is similar to intra 16×16 prediction of luma.

The reference software of H.264 uses full search algorithm (H.264/AVC reference software JM9.5, 2005) that computes the RDO cost for each prediction mode, and then chooses the best one with minimum cost to be the final prediction mode. The complexity is extremely high and it is the bottleneck in intra coding. Therefore, we need to develop a more efficient algorithm.

Few approaches have been proposed on fast intra prediction algorithm. In (Pan *et al*., 2005), it is based on the local edge information, and thus adopts the edge direction to predict the possible mode. In (Meng and Au, 2003), a threshold is proposed to terminate early the computation of the most probable mode. And in (Cheng and Chang, 2005), it is based on the fact that the optimal mode and other good modes have similar direction. However, these previous approaches still have some defects. In this paper, we proposed a fast block type selection algorithm and

* Project (No. 60472040) supported by the National Natural Science Foundation of China

Q	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*
I	*a*	*b*	*c*	*d*				
J	*e*	*f*	*g*	*h*				
K	*i*	*j*	*k*	*l*				
L	*m*	*n*	*o*	*p*				

Fig.1 A 4×4 block and its neighboring samples

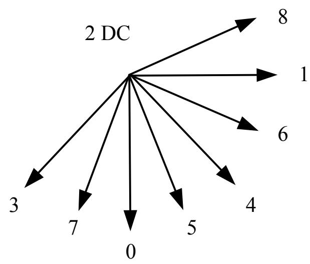

Fig.2 Direction of 9 modes of intra 4×4

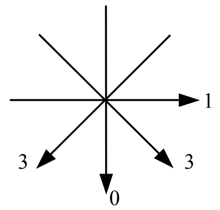

Fig.3 Direction of intra 16×16 MB

improved the mode decision algorithm in (Pan *et al.*, 2005). Together with the two fast algorithms, the computation time of intra prediction can be saved from 52.90% to 56.31% and yielded fewer bit rate increments and less loss of PSNR.

This paper is organized as follow. In Section 2, we propose our fast algorithm. In Section 3, shows the experiment results. And Section 4 gives the conclusion.

PROPOSED ALGORITHM

Improved approach for computing edge information

In (Pan *et al.*, 2005), the Sobel operator is applied to all pixels of the whole picture, except the pixels in boundaries because there are fewer neighboring pixels. For a pixel $P_{i,j}$ in a luma (or chroma) picture, the corresponding edge vector $\boldsymbol{D}_{i,j}=\{dx_{i,j}, dy_{i,j}\}$ is defined as:

$$dx_{i,j}=P_{i-1,j+1}+2P_{i,j+1}+P_{i+1,j+1}-P_{i-1,j-1}-2P_{i,j-1}-P_{i+1,j-1},$$
$$dy_{i,j}=P_{i+1,j-1}+2P_{i+1,j}+P_{i+1,j+1}-P_{i-1,j-1}-2P_{i-1,j}-P_{i-1,j+1}. \quad (1)$$

And the amplitude of the edge vector can be roughly estimated by

$$Amp(\boldsymbol{D}_{i,j})=|dx_{i,j}|+|dy_{i,j}|. \quad (2)$$

The mode of each pixel is determined by its edge direction $Ang(\boldsymbol{D}_{i,j})$, and then the corresponding $Amp(\boldsymbol{D}_{i,j})$ will be added to the mode cell of the edge histogram. A 16×16 block or 4×4 block can be used to calculate all the pixels of the block.

However, in the actual implementation, we observed that the direction features of the block, especially the 4×4 block, can be preserved roughly by most pixels. For each MB, we only calculate the pixels which are not boundaries of MB. Therefore, we can reduce the computation complexity, and avoid judging whether current MB is in the picture boundaries.

Then the edge histogram are computed for intra 4×4, intra 16×16 for luma component and intra 8×8 for chroma component.

Block type selection

Intra coding block type is highly dependent on the smoothness of the block. Intra 4×4 is well suited for an MB with detailed information, while intra 16×16 is well suited for a smooth one (compare Figs.4 and 5). In Fig.5, each pane refers to an MB. The black pane is an MB coded as intra 16×16, while the white one refers to intra 4×4. We can see the correlation between the smoothness and the coded block type. From the information on the edge map, which we have already created, we can find the block smoothness feature. Therefore, by analyzing the information, we choose the probable block type instead of the full-search in JM (H.264/AVC reference software JM9.0, 2005).

If a block is not smooth, the differences between pixels should be large. From Eqs.(1) and (2), we can see that $dx_{i,j}$, $dy_{i,j}$ and $Amp(\boldsymbol{D}_{i,j})$ can express the differences of pixels. The cell edge histogram with global maximum is called the primary mode. If its amplitude is very high, the probable block type should be intra 4×4.

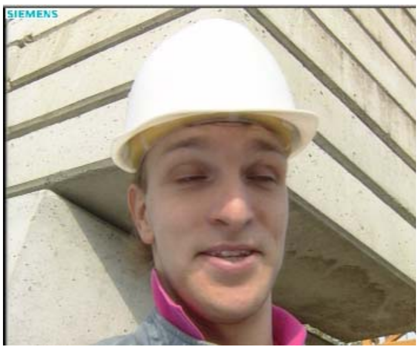

Fig.4 First frame of Foreman_CIF

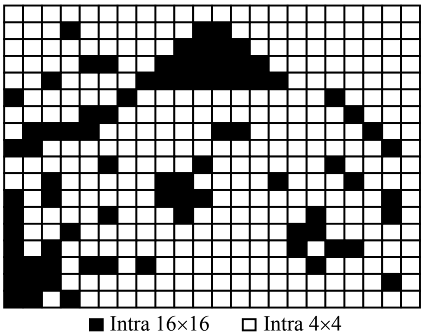

Fig.5 Block type map of the first frame of Foreman_CIF

The experiment results proved our views. In Fig.6, every 3 cells (black, white and gray) make up a group, while each cell gives an amplitude of a directional prediction mode. Each group is a 16×16 edge histogram of an MB. We avoid the DC mode, because it is not a directional mode and is always a candidate mode in the later mode decision algorithm. The number of MB in Fig.6 is 1D, and we can classify these MBs into two kinds. One kind is with feature 1 of the amplitudes being very low, even the primary mode's amplitude. In contrast, the other is with feature 2 of the primary mode amplitude being much higher.

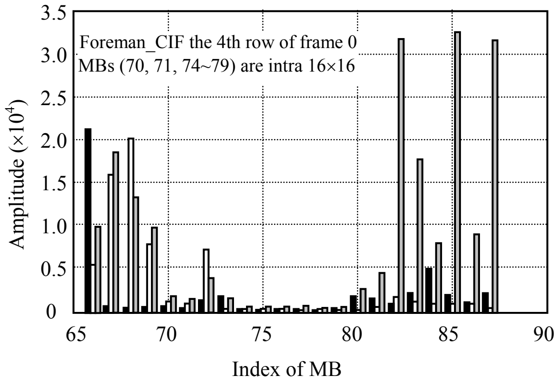

Fig.6 Edge histogram of MBs (Nos. 66~87)

Fig.6 shows that MBs 70, 71, 74, 75, 76, 77, 78, 79, which have feature 1, are finally coded as intra 16×16 by using full-search of JM, while others are coded as intra 4×4. What we should notice is that a few MBs with feature 1 can still be coded as intra 4×4, taking MBs 70 and 80 for example. But the MBs with feature 2 can be surely coded as intra 4×4.

Observation of other samples revealed that the law still works. Fig.7 is a statistical comparison of 40 block samples and shows that some lower values of the intra 4×4 are very close to the higher values of intra 16×16, but the highest values of intra 4×4 are far more larger than the highest ones of intra 16×16.

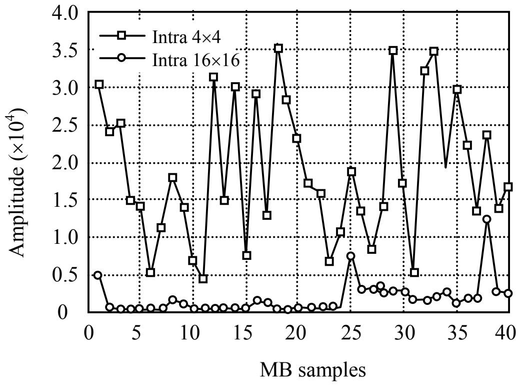

Fig.7 Amplitude comparison of intra 4×4 and intra 16×16

Therefore, after creating the edge histogram of 16×16 block, we can use a threshold T to predict the block type. If the amplitude of the primary mode is larger than T, we coded the block as intra 4×4. Otherwise, examination of both block types will be adopted for further mode decision. From experiments, we found that generally, T=10000 is better.

Frequently, especially when applied to a picture with detailed information, the algorithm can filter out the unnecessary intra 16×16 mode decision and final block type selection. The computation complexity can be reduced considerably. Furthermore, the edge histogram can be used in the next step of the fast mode decision algorithm.

Improved mode decision algorithm

After selecting the block type, which mode of the selected block type is the best mode should be decided. We only choose some possible modes to be candidate mode for RDO computation. The approach is similar to that of the algorithm in (Pan *et al*., 2005), but we improved it by changing the selection method of candidate mode.

It is observed that the current block's best mode is highly correlated to its neighbor blocks. A most probable mode can be obtained from left and above blocks (Fig.8). A probability list is generated by (ITU-T Rec. H.264/ISO/IEC 14496-10 AVC, 2003) for each combination of the modes of *A* and *B*. Rather than sending the selected mode number, the position of the selected mode in the probability list is sent. It tends to choose the most probable mode as the best mode.

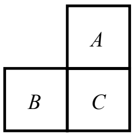

Fig.8 The neighbor block of block C

Therefore, different from the candidate modes selection method of 4×4 block in (Pan *et al*., 2005), we select the primary mode (the cell with global maximum in the histogram), DC mode and the most probable mode to be candidate modes for 4×4 block. RDO computation should be applied to each candidate mode, and then the one with minimum cost is the best mode. Usually, because of the high correlation, the primary mode and the most probably mode are the same. So the number of candidate modes is only 2, instead of 4 in (Pan *et al*., 2005). Even in the worse case, the number is 3, which is still less than 4. For the whole picture, the reduction of RDO computation will be great. Table 1 shows the number of candidate modes, and compares the algorithm of Pan *et al*.(2005)'s and ours. It also shows the number of candidate modes of intra 4×4 in the whole QCIF or CIF picture.

Table 1 Number of candidate modes

Block size	Total number of modes	Number of modes of Pan *et al*.(2005)'s	Numberof modes of ours
One 4×4 block	9	4	3 or 2
QCIF	13932	6192	4644 or 3096
CIF	57024	25344	19008 or 12672

Intra 16×16 of luma and intra 8×8 of chroma both only have 4 modes. Therefore, different from intra 4×4, our choice of the primary mode and DC mode as the candidate modes, is similar to that in (Pan *et al*., 2005).

Our proposed improved fast intra prediction algorithm is as follows:

Step 1: Use the method in Section 2.1 to create edge the histogram for intra 4×4, intra 16×16 for luma component and intra 8×8 for chroma components.

Step 2: Perform intra 8×8 prediction routine for chroma components. Use the mode decision algorithm in Section 2. Get the best prediction mode of chroma with minimum $RDCost_{8\times8}$.

Step 3: Analyze the information in the edge histogram. Examine the amplitude of primary mode in the intra 16×16 edge histogram. If it is larger than the threshold T, select intra 4×4 as coded block type for luma. Set the $RDCost_{16\times16}=MaxCost$. Then go to Step 6.

Step 4: Perform intra 16×16 prediction routine for luma component. Use the mode decision algorithm in Section 2. Get the minimum $RDCost_{16\times16}$ and the mode with minimum $RDCost_{16\times16}$.

Step 5: Perform intra 16×16 prediction routine for luma component. Use the mode decision algorithm in Section 2. Get the minimum $RDCost_{4\times4}$ and the mode with $RDCost_{4\times4}$.

Step 6: If $RDCost_{16\times16}>RDCost_{4\times4}$, intra 4×4 is selected; otherwise, intra 16×16 is selected.

RESULTS

For comparison, our proposed algorithm was implemented in the reference software JM9.0 provided by JVT, tested on three CIF sequences (Foreman, Container, Bus). The test conditions are as follows:

(1) Fresh rate is 30.

(2) The period I frame is 1 for all_I frames and 10 for IPPP frame structure.

(3) The number of each sequence is 200.

(4) RD optimization is enabled.

(5) CAVLC is enabled.

In this experiment, we compared the full-search algorithm and our proposed fast algorithm. In these tables, positive number means increasing, and negative number means decreasing.

Table 2 shows the comparison results of *QP*=16, 28 and 40. *Time_avg* is average time saving percentage for encoding the entire sequence. *Time_ intra* is the time saving percentage for intra prediction only. From Table 2, we can see that our proposed algorithm can reduce the computation complexity considerably with negligible loss. The average time saving for the entire sequence is 41.8%, and the time saving of intra prediction is from 52.90% to 56.31%.

Table 2 Comparison results of all_I frames of *QP*=16, 28 and 40

QP	Sequence	*Time_avg* (%)	*Time_intra* (%)	Δ*PSNR* (dB)	ΔBits (%)
16	Foreman	45.83	55.98	−0.02	1.11
	Bus	45.45	56.31	−0.01	1.05
	Container	45.53	55.99	−0.02	1.93
28	Foreman	34.43	54.88	−0.04	2.78
	Bus	45.76	56.09	−0.03	2.25
	Container	36.67	54.87	−0.06	2.17
40	Foreman	39.19	52.96	−0.15	4.12
	Bus	46.75	53.30	−0.08	4.09
	Container	36.67	52.90	−0.12	5.20

Table 3 shows the result of IPPP sequence. The reduction in the time saving is due to the less importance in IPPP sequence.

Table 3 Result of IPPP frames when *QP*=16

Sequence	*Time_avg* (%)	Δ*PSNR* (dB)	ΔBits (%)
Foreman	13.00	−0.43	1.21
Bus	21.74	−0.14	1.23
Container	16.67	−0.21	1.86

Fig.9 shows the RD curves of the all_I frames of sequence Bus, by using full-search and our proposed fast algorithm.

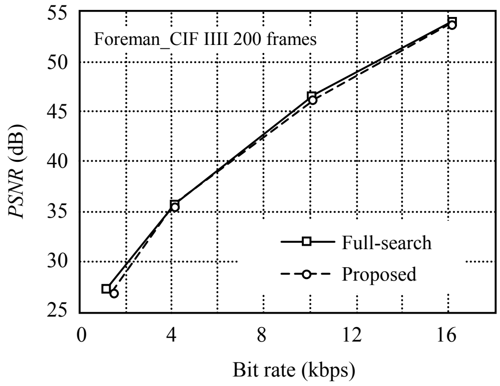

Fig.9 RD curves of Bus of the all_I frames of sequence Bus by using full-search and our proposed fast algorithm

CONCLUSION

In this paper, we proposed a fast intra prediction algorithm for H.264/AVC, including selection of the possible block types and improved mode decision algorithm. It not only reduces by more than half the complexity of the intra prediction, especially for the image with much detailed information, but also yielded almost similar PSNR and negligible increasing of bit rate, compared with the full-search algorithm.

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