Categorization for Fast Intra Prediction Mode Decision in H.264/AVC

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Abstract — *Fast intra prediction mode decision is one of the most important topics in H.264/AVC. There have been three types for fast intra prediction mode decision. These types are based on mode features, block features, and edge or directional information. In this paper, we propose an algorithm for each type. Through extensive simulations, we show that our proposed algorithm using an unconditional DC mode for the type based on mode features significantly saves up to 82.13% of the entire encoding time compared to H.264 reference software while reducing negligible peak signal-to-noise ratio (PSNR) values and slightly increasing bitrate. Another proposed algorithm using a ratio of variance along the horizontal direction to variance along the vertical direction for the type based on edge or directional information keeps a bitrate increment as 0.45% on average while reducing entire encoding time and slightly increasing PSNR values.*[1]

Index Terms — H.264/AVC, Video coding, Intra prediction, Mode decision

I. INTRODUCTION

H.264 is a powerful video coding standard in terms of PSNR value and visual quality. One of the coding approaches uses variable block sizes of macroblock (MB) modes. Although H.264 provides a rate-distortion optimization (RDO) technique for determining the best mode, it still consumes much time and remains complex due to heavy computational load in order to check all combinations of modes for each MB. These are the obstacles to implementing an encoder for real-time applications such as video telephony and video conferencing.

Fig. 1 summarizes the mode decision algorithm based on Lagrangian cost function for minimizing mode cost in H.264 [1]. For intra prediction, H.264 uses three different block sizes: intra-16×16, intra-8×8, and intra-4×4. Intra-4×4 has nine different modes such as vertical mode, horizontal mode, DC mode, and diagonal modes based on a variety of angles for intra-luma prediction among these modes. Intra-8×8 using 8×8 transform consists of nine modes which are similar to intra-4×4's modes. Intra-16×16 has four modes including the vertical mode, horizontal mode, DC mode, and plane mode.

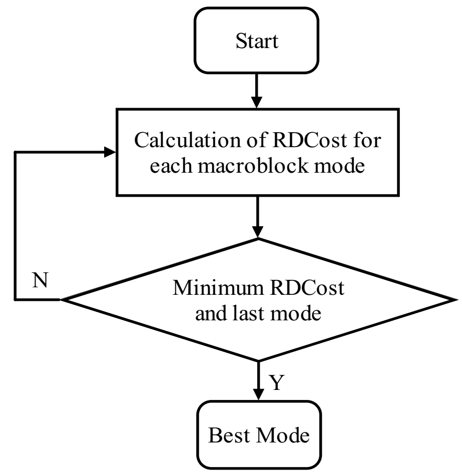

Fig. 1. Mode decision algorithm in H.264.

For intra-chroma prediction, intra-8×8 has four modes but these modes have different orders from intra-16×16's mode orders.

In terms of the studies on H.264, there have been many proposed algorithms for fast intra prediction mode decision. In these algorithms, researchers have tried to reduce complexity while ensuring acceptable visual quality. Tsai *et al.* [2] used an intensity gradient technique to make an efficient intra prediction. In addition, Pan *et al.* [3] proposed a fast mode decision algorithm for intra-frame coding using local edge information of each macroblock. La *et al.* [4] used dominant edge direction to make a fast mode decision. Lin *et al.* [5] developed a simple algorithm based on direction detection of the edge inside the block. Furthermore, Wang *et al.* [6] proposed a fast algorithm based on dominant edge strength. The above algorithms have limitations in coding performances and time consumption; thus, we will improve these metrics through our proposed algorithms.

In this paper, we categorize the existing algorithms for fast intra prediction mode decision into three types based on mode features, block features, and edge or directional information. First, for fast intra decision based on mode features, researchers used mode conditions [7], inter mode information [8], and neighboring of the selected modes [9]. Second, for fast intra decision based on block features, researchers employed information of blocks, such as spatial correlation [10]-[12] and neighboring blocks [13], [14]. Third, for fast intra decision based on edge or directional information, researchers used edge information [3]-[6] and directional features [2].

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From the above categorization, we propose three algorithms for the three above-mentioned types. Instead of checking all combinations of modes for each MB, we directly select the best mode which is observed from our research as a representative algorithm using mode features. We also examine a condition of block boundary as a representative algorithm using block features. Lastly, we use a ratio of variance along the horizontal direction to variance along the vertical direction as a representative algorithm using edge or directional information of our categorization. Through extensive simulations using the same test sequences and the initial conditions, we will show that our proposed algorithms significantly reduce entire coding time while simultaneously ensuring negligible increase in bitrate and decrease in PSNR value.

II. PROPOSED ALGORITHMS

In this section, we represent three proposed algorithms for fast intra prediction mode decision. First, we propose an unconditional DC mode decision algorithm, a representative algorithm using mode features. We also propose an algorithm using a condition of block boundary to select the DC mode as a representative algorithm using block features. Finally, we propose an algorithm using a ratio of variance along the horizontal direction to variance along the vertical direction as a representative algorithm using edge or directional information in our categorization.

A. Fast Intra Prediction Mode Decision Using an Unconditional DC Mode

In this subsection, we categorize our proposed algorithm as a representative algorithm using mode features since we use a characteristic of the DC mode in intra-4×4 and intra-16×16 for intra-luma prediction. We will present how to determine the best mode for both intra-chroma and intra-luma prediction.

First of all, we determine the intra-chroma modes. In the proposed algorithm, four intra-8×8 modes for intra-chroma prediction are calculated by the sum of absolute Hardamard transform differences (SATD). The best mode has the minimum SATD.

For luma-prediction, we use fidelity range extensions (FRExt) as a setting option for this algorithm. By our research on intra-4×4 and intra-16×16, we investigate that the DC mode is the superior prediction mode among the various candidates. Fig. 2 shows an example of this investigation for "Mobile" (CIF) sequence. Other test sequences have similar statistics of mode selection as shown in Fig. 2. Therefore, the DC mode is chosen as the best candidate for the prediction mode which is strongly agreed for 4×4 intra prediction mode in [15], and both 16×16 luma prediction and 8×8 intra-chroma prediction in [16]. In this way, we select the DC mode as the best prediction mode for intra-4×4 and intra-16×16 predictions. We repeat the above-mentioned processes for the next macroblock.

Fig. 3 shows the flowchart of the proposed intra-mode decision algorithm using an unconditional DC mode. The

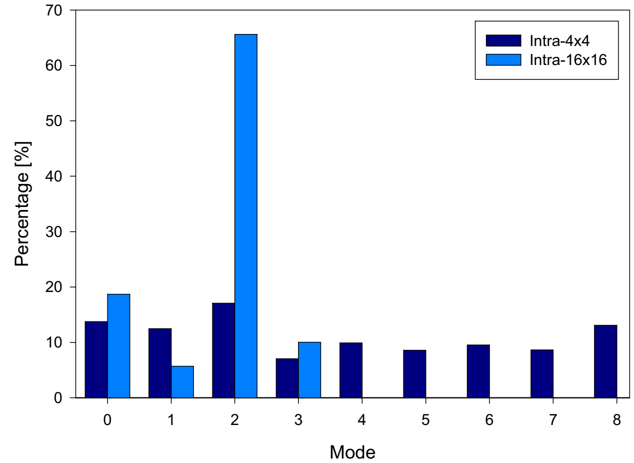


Fig. 2. Statistics of mode selection for "Mobile" (CIF) sequence.

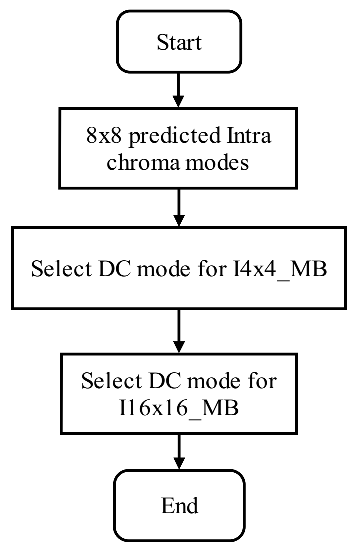


Fig. 3. Flowchart of fast intra-mode decision algorithm using an unconditional DC mode (Algorithm I).

proposed algorithm consists of the following steps.

- *Step 1:* Determine the best mode among the four intra-8×8 intra-chroma modes for intra-chroma prediction.
- *Step 2:* Select the DC mode as the best mode for Intra_4×4 luma prediction.
- *Step 3:* Select the DC mode as the best mode for Intra_16×16 luma prediction.
- *Step 4:* Repeat the above processes for the next macroblock until we check the last of macroblocks.

B. Fast Intra Prediction Mode Decision Using a Condition of Block Boundary to Select the DC Mode

This section presents our proposed algorithm for fast intra prediction mode decision by checking boundary pixels of every block to select the DC mode. This algorithm is considered as the representative algorithm using block features.

The main motivation for the proposed algorithm is represented in Fig. 4. If the pixel values of block boundary are the same or similar values, we conclude that all values inside

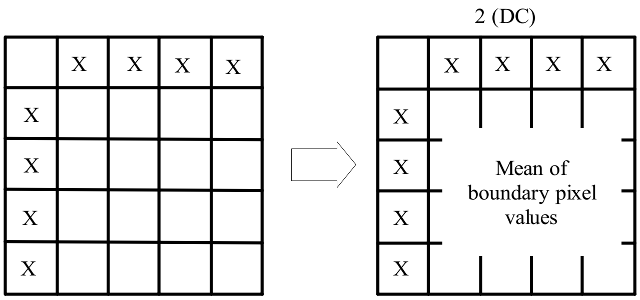


Fig. 4. Condition to select the DC mode.

the block are the same or similar to the pixel values of block boundary. This means we can use the DC mode as the best mode for fast intra prediction mode decision.

For intra-chroma prediction, we use the RDO technique given in H.264 to determine the best mode. This means four intra-8×8 modes for intra-chroma prediction are calculated by SATD and the best mode has the minimum SATD.

For intra-luma prediction, we apply the following procedure in both intra-4×4 and intra-16×16. First, we determine boundary variance and threshold for this block. Then, we compare the variance with the threshold to determine the best mode. If the variance is smaller than the threshold, this means the pixel values on boundary are the same or similar; we choose the best mode as the DC mode. Otherwise, we use the RDO technique given in H.264 among other modes to determine the best mode for this block. The threshold is adaptive since it is determined by a quantization step size for each block. We summarize the proposed algorithm as follows.

Algorithm II: Fast intra prediction mode decision using a condition of block boundary to select the DC mode

// Intra-chroma prediction
best mode ← best mode by RDO for 8×8 intra chroma.

// Intra-luma prediction
// Determine the best mode for I4×4
σ_{b1} = *boundary variance of I4×4.*
$th_1 = (Qstep^2 + 8)/16$
if $\sigma_{b1} < th_1$ **then**
    best mode ← DC mode
else
    best mode ← best mode by RDO
end if

// Determine the best mode for I16×16
σ_{b2} = *boundary variance of I16×16.*
$th_2 = (Qstep^2 + 32)/64$
if $\sigma_{b2} < th_2$ **then**
    best mode ← DC mode
else
    best mode ← best mode by RDO
end if

C. Fast Intra Prediction Mode Decision Using a Ratio of Variances

In our proposed algorithm, we check the ratio of the variance along the horizontal direction to the variance along the vertical direction for each block. Hence, we categorize the proposed algorithm in this subsection as a representative algorithm using edge or directional information.

Fig. 5 represents a rule for the proposed algorithm. If each column inside a block consists of the same or similar values as shown in Fig. 5(a), we use the vertical mode as the best mode. On the other hand, if each row inside a block consists of the same or similar as shown in Fig. 5(b), we select the horizontal mode as the best mode.

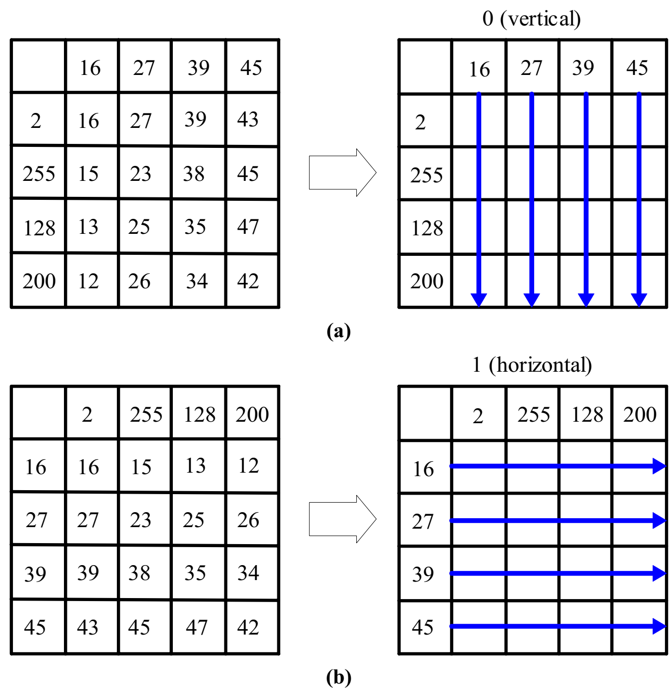


Fig. 5. Condition to select (a) vertical and (b) horizontal modes.

We formulate the above-mentioned characteristics as follows. First, we calculate mean value of each row and that of each column for each block as:

$$\begin{cases} E(x) = \dfrac{1}{N}\displaystyle\sum_{y=0}^{N-1} I(x,y) \\ E(y) = \dfrac{1}{N}\displaystyle\sum_{x=0}^{N-1} I(x,y) \end{cases} \quad (1)$$

where E_x and E_y are the mean values along y and x axes of block I in size $N \times N$, respectively. Then, we compute the variances along the horizontal and vertical directions as:

$$\begin{cases} \sigma_v = \dfrac{\displaystyle\sum_{x=0}^{N-1}\left\{\dfrac{1}{N}\sum_{y=0}^{N-1}\{I(x,y)-E(x)\}^2\right\}}{N} \\ \sigma_h = \dfrac{\displaystyle\sum_{y=0}^{N-1}\left\{\dfrac{1}{N}\sum_{x=0}^{N-1}\{I(x,y)-E(y)\}^2\right\}}{N} \end{cases} \quad (2)$$

where σ_v and σ_h denote the variances along the vertical and horizontal directions for block I in size $N \times N$, respectively. Finally, we determine the ratio of the variance along the horizontal direction to the variance along the vertical direction from the above results as:

$$R = \begin{cases} \dfrac{\sigma_v}{\sigma_h} - 1 & \text{if } \sigma_v \geq \sigma_h \\ -\dfrac{\sigma_h}{\sigma_v} + 1 & \text{if } \sigma_v < \sigma_h \end{cases} \quad (3)$$

By using (3), we calculate the ratio of the variances for each block to determine the best mode for intra-4×4 and intra-16×16 predictions. We then prove that the ratio of the variances is a good parameter to determine the best mode at least for promising candidates as modes 0 and 1 by showing two evidences.

The first evidence is statistics of the ratio of the variances for intra-4×4 and intra-16×16. Fig. 6 shows the statistics of the ratio of the variance along the horizontal direction to the variance along the vertical direction for "Mobile" (CIF) sequence. The figure indicates that modes 0 and 1 are significantly different from other modes. Other test sequences have similar statistics of modes for intra-4×4 and intra-16×16. Hence, the ratio of the variances is a good parameter to determine the best mode for fast intra prediction mode decision.

The second evidence is probability density estimate of ratio of the variances. Fig. 7 shows the probability density estimate of the ratio of the variance along the horizontal direction to the variance along the vertical direction obtained in all our test sequences. Since the probability density estimate of mode 2 (DC mode) overlaps those of modes 0 and 1, we exclude the probability density estimate of mode 2 in Fig. 7(a). We then consider the DC mode as a special case. Fig. 7 indicates that modes 0 and 1 are significantly different from other modes for both intra-4×4 and intra-16×16. Therefore, through the probability density estimate of the ratio of the variances, we can say that the ratio of the variance along the horizontal direction to the variance along the vertical direction is a good parameter to select modes 0 and 1 for fast intra prediction mode decision.

In the proposed algorithm, we use the RDO technique given in H.264 to determine the best mode for intra-chroma prediction. It is similar to the above-mentioned algorithms; four intra-8×8 modes for intra-chroma prediction are calculated by SATD. The best mode has the minimum SATD.

For intra-luma prediction in intra-4×4 blocks, we first calculate the ratio of the variances, called R, by using (3). Based on the above-mentioned statistics in Fig. 6, we determine the thresholds for intra mode decision. We select modes 0 and 1 if R is smaller than -10 and greater than or equal 10, respectively. If R lies in [-10,-1), we use the RDO technique given in H.264 to determine the best mode among modes 0, 2, 5, 7, and the most probable prediction mode (MPM). Note that the MPM is used only for intra-4×4 blocks

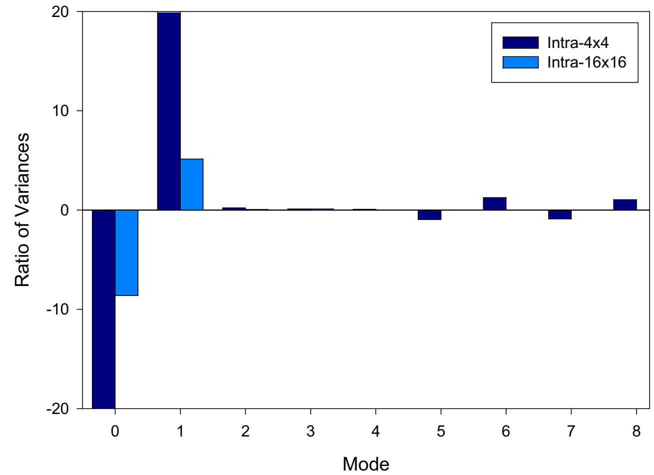
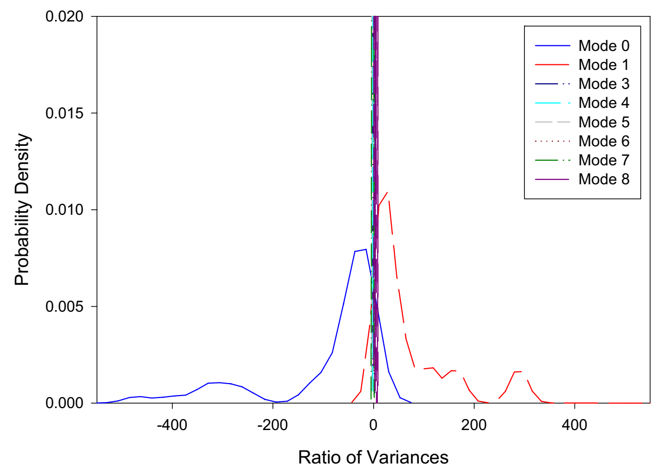
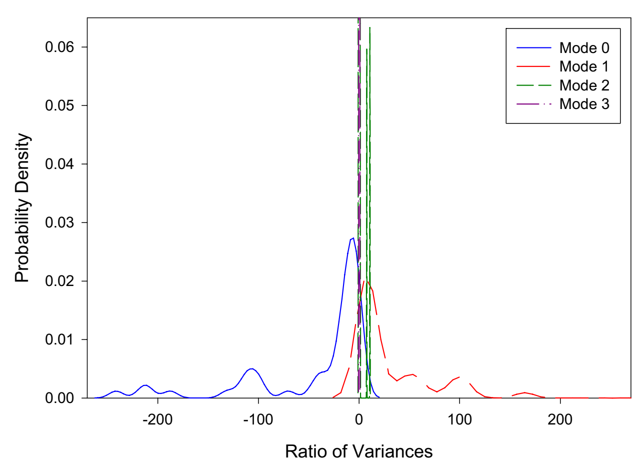


Fig. 6. The ratio of the variance along the horizontal direction to the variance along the vertical direction for "Mobile" (CIF) sequence.



(a)



(b)

Fig. 7. Probability density estimate of the ratio of the variances for (a) Intra-4×4 and (b) Intra-16×16.

to minimize the prediction modes [1]. In addition, the MPM is also used if either of these neighboring blocks is not available.

If R lies between -1 and 1, we use modes 2, 3, 4, 5, 6, 7, 8, and MPM. Finally, we check modes 1, 2, 6, 8, and MPM by using the RDO technique for the rest case.

The last scenario is intra-16×16 for intra-luma prediction. Similarly to intra-luma prediction in intra-4×4 blocks, we calculate and compare R with the thresholds determined by using the above-mentioned statistics in Fig. 6. Since modes 0 and 1 are significantly different from other modes as shown in Fig. 6 and Fig. 7(b), we choose mode 0 if R is smaller than -1 and mode 1 if R is greater than or equal 1. Otherwise, if R lies between -1 and 1, we determine the best mode using the RDO technique between modes 2 and 3. We summarize the proposed algorithm as follows.

Algorithm III: Fast intra prediction mode decision using the ratio of the variance along the horizontal direction to the varia nce along the vertical direction.

// Intra-chroma prediction
best mode ← best mode by RDO for 8×8 intra chroma.

// Intra-luma prediction
// Determine the best mode for I4×4 luma prediction
Calculate R_1 for I4×4 by (3)
if $R_1 < -10$ **then**
    best mode ← best most by RDO{0, MPM}
else if $-10 \le R_1 < -1$ **then**
    best mode ← best most by RDO{0, 2, 5, 7, MPM}
else if $-1 \le R_1 < 1$ **then**
    best mode ← best most by RDO{2, 3, 4, 5, 6, 7, 8, MPM}
else if $1 \le R_1 < 10$ **then**
    best mode ← best most by RDO{1, 2, 6, 8, MPM}
else if $10 \le R_1$ **then**
    best mode ← best most by RDO{1, MPM}
end if

// Determine the best mode for I16×16 luma prediction
Calculate R_2 for I16×16 by (3)
if $R_2 < -1$ **then**
    best mode ← mode 0
else if $-1 \le R_2 < 1$ **then**
    best mode ← best most by RDO{2,3}
else if $1 \le R_2$ **then**
    best mode ← mode 1
end if

III. Experimental Results and Discussion

In the above section, we categorized fast intra prediction mode decision into three types based on mode features, block features, and edge or direction information. Corresponding to the three types, we propose three fast intra decision algorithms using an unconditional DC mode, a condition of block boundary to select the DC mode, and the ratio of the variance along the horizontal direction to the variance along the vertical direction. We briefly call the three proposed algorithms in the above order as proposed algorithms I, II, and III.

A. Coding Conditions

We implement the three proposed algorithms on the reference software JM11.0 [17]. In addition, we examine various CIF and QCIF sequences, which are adopted as the test sequences in MPEG standard, i.e., Coastguard (QCIF), and Bike, Coastguard, Football, Mobile, Silent (CIF). The system platform is Intel Pentium(R) 4, a processor of speed 3.6GHz, 2.00 GB of DDR RAM, and Microsoft Windows XP for the simulations. Table I shows the simulation conditions.

TABLE I
ENCODING PARAMETERS FOR FAST INTRA-MODE DECISION ALGORITHM.

Parameter	Settings
RDO mode	Fast high complexity mode
GOP structure	I I I …
Hadamard transform	Used
Quantization parameters	28, 32, 36, and 40
Number of frames	100

We compare the three proposed algorithms with JM11.0 in terms of PSNR difference, percentage bitrate difference, and run-time percentage difference. These performance metrics are defined as follows:

$$\Delta PSNRY = PSNRY_{proposed} - PSNRY_{JM11.0}\left[dB\right] \quad (4)$$

$$\Delta Bitrate = \frac{Bitrate_{proposed} - Bitrate_{JM11.0}}{Bitrate_{JM11.0}} \times 100\%\ [\%] \quad (5)$$

$$\Delta Time = \frac{Time_{proposed} - Time_{JM11.0}}{Time_{JM11.0}} \times 100\%\ [\%] \quad (6)$$

B. Coding Performances

Table II shows simulation results for the fast intra-mode decision algorithms. In the table, the positive sign indicates an increase, and the negative sign indicates a decrease. All experimental results of the proposed algorithms are compared to those of the original fast intra prediction mode decision algorithm implemented on the reference software JM11.0.

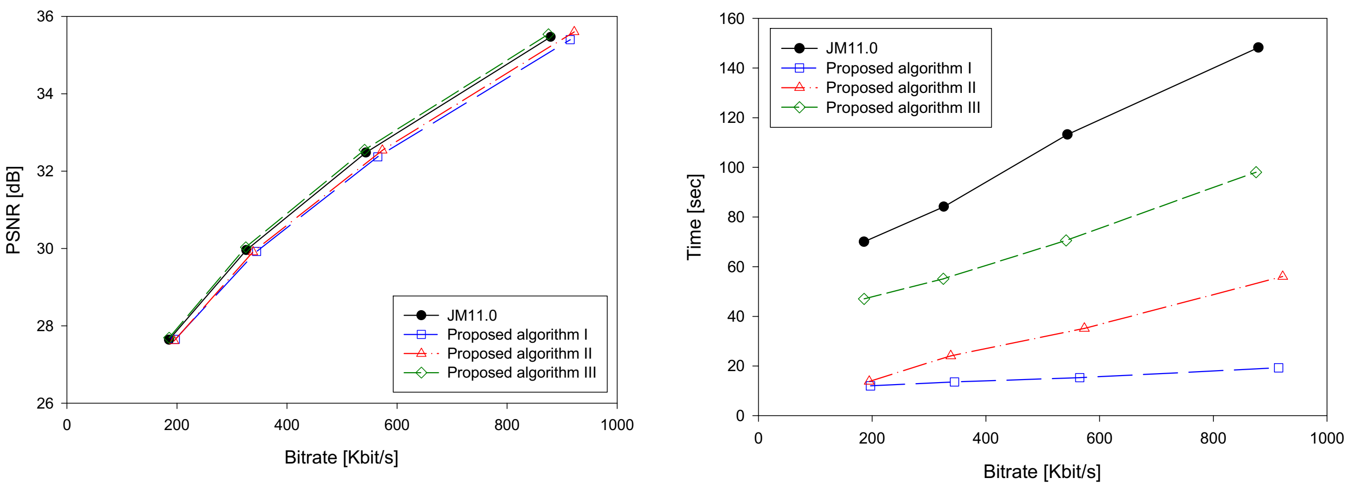
From Table II, our experimental results show that the proposed algorithm I achieves 82.13% time saving on average while ensuring a negligible loss in PSNR values and slight increments in bitrate. The results of time savings are significant while the losses in PSNR and bitrate values are slightly decreasing 0.04 dB and acceptable increasing 4.58% on average, respectively.

Since the bitrate increment of the proposed algorithm I is a little high, we propose algorithm II to reduce this value into 4.42% on average while saving the entire encoding time and slightly increasing the PSNR values. We see that the bitrate increment is still high; therefore, we decide to improve the coding performance by using the proposed algorithm III.

TABLE II
COMPARISON OF CODING PERFORMANCES AND COMPLEXITY REDUCTION WITH ORIGINAL JM11.0

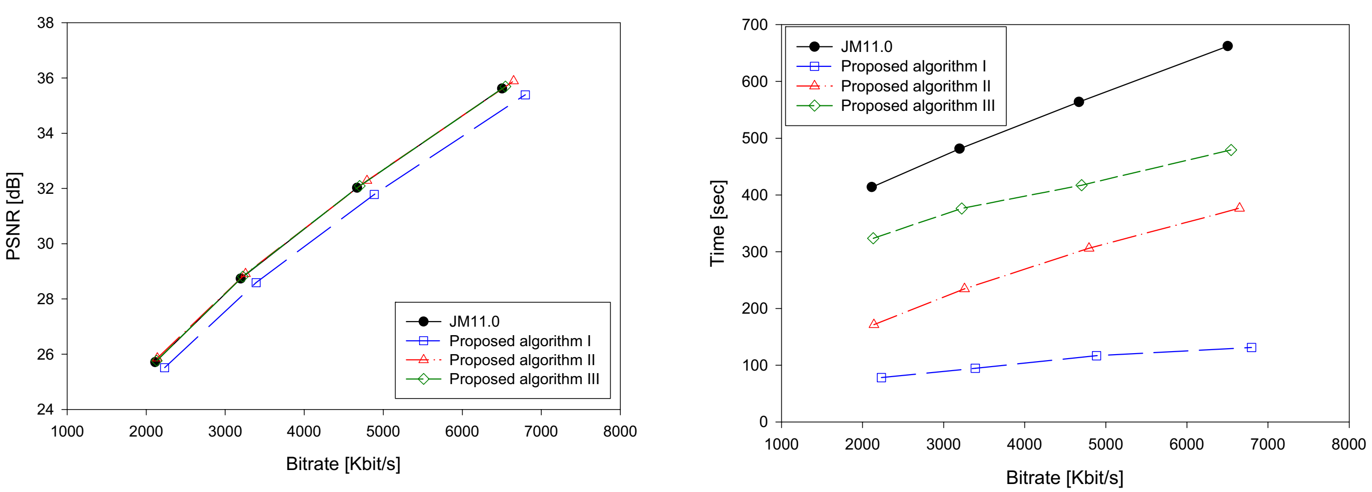
Test sequence	Proposed algorithm I*			Proposed algorithm II			Proposed algorithm III		
	ΔPSNRY [dB]	ΔBitrate [%]	ΔTime [%]	ΔPSNRY [dB]	ΔBitrate [%]	ΔTime [%]	ΔPSNRY [dB]	ΔBitrate [%]	ΔTime [%]
Coastguard (QCIF)	-0.05	+5	-85.06	+0.03	+4.78	-70.73	+0.07	-0.26	-34.72
Bike (CIF)	-0.05	+2.94	-81.44	+0.06	+4.33	-50.97	+0.07	+0.7	-28.36
Coastguard (CIF)	+0.02	+3.52	-82.37	-0.14	+7.1	-70.01	+0.08	-0.31	-35.95
Football (CIF)	-0.02	+4.83	-81.65	0	+3.07	-55.31	+0.06	+0.85	-21.41
Mobile (CIF)	-0.2	+5.21	-80.24	+0.21	+2.01	-49.69	+0.07	+0.74	-24.32
Silent (CIF)	-0.04	+5.95	-81.99	+0.02	+5.21	-63.44	+0.04	+0.99	-35.23
AVERAGE	**-0.06**	**+4.58**	**-82.13**	**+0.03**	**+4.42**	**-60.03**	**+0.07**	**+0.45**	**-30**

* Proposed algorithms I, II, and III denote fast intra prediction mode decision using an unconditional DC mode, a condition of block boundary to select the DC mode, and the ratio of the variance along the horizontal direction to the variance along the vertical direction, respectively.



(a) Rate-distortion curves (b) Time consumption

Fig. 8. No significant rate-distortion degradation and time saving of "Coastguard" (QCIF) sequence for intra-mode decision.



(a) Rate-distortion curves (b) Time consumption

Fig. 9. No significant rate-distortion degradation and time saving of "Mobile" (CIF) sequence for intra-mode decision.

In the proposed algorithm III, we obtain a small bitrate reduction as 0.45%. This is the best result in terms of bit savings among the three proposed algorithms. However, we obtain a small reduction of the entire encoding time and a slight increment in PSNR.

In order to illustrate a negligible loss in PSNR values, an increment in bitrate, and significant time saving, we show the rate-distortion (RD) and the running time curves of "Coastguard" (QCIF) and "Mobile" (CIF) sequences. We observe similar improvements in other test sequences.

Fig. 8(a) presents the RD curves of "Coastguard" (QCIF) sequence. The figure indicates that those curves almost overlap especially the RD curve of the proposed algorithm III and that of JM11.0. Fig. 9(a) shows the RD curves of "Mobile" (CIF) sequence. The RD curves of the proposed algorithms II and III overlap that of JM11.0. This means the RD performance of the proposed algorithms is almost similar to that of the reference software JM11.0. Therefore, the proposed algorithms have negligible rate-distortion degradation.

Fig. 8(b) and Fig. 9(b) show the time saving of "Coastguard" (QCIF) and that of "Mobile" (CIF) sequences, respectively. The running time curves of the three proposed algorithms lie bellow that of the original reference software JM11.0 in both test sequences. Fig 8(b) and Fig. 9(b) indicate that the proposed algorithms outperform the original H.264 implemented on the reference software JM11.0 in terms of time saving.

C. Comparison with Other Algorithms

We compare the results of the three proposed algorithms with those of other algorithms in Table III. The results in the table are the average results of four QP values, as shown in Table I.

From Table III, the time saving of the proposed algorithm I lies between 80.24% and 85.06% while those of the other algorithms lie between 55.026% and 76.87%. This means the proposed algorithm I reduces time much better than the other algorithms can. In addition, the bitrate increment resulting from the proposed algorithm III lies between -0.26 and +0.74 while those of resulting from the other algorithms lie between +0.631 and +5.405. From this comparison, we can say that the proposed algorithm III results in much better bitrate saving than the other algorithms.

As shown in Table III, the results of the proposed algorithm I and the other algorithms still ensure a negligible loss in PSNR values. Besides, the PSNR values of the proposed algorithm I are similar to those of the algorithms in [3] and [4], and the bitrates of the proposed algorithm I are slightly higher than those of the other algorithms.

As shown in Tables II and Table III, compared to the existing algorithms, the proposed algorithm I is the best algorithm in terms of the entire encoding time. Therefore, we can say that the proposed algorithm I outperforms the other algorithms for fast intra mode decision. In addition, the bitrate increment of the proposed algorithm III is the smallest value among those values of the other algorithms. Moreover, the proposed algorithm II shows the best improvement in PSNR for "Mobile" (CIF) sequence.

TABLE III
COMPARISON OF CODING PERFORMANCES AND COMPLEXITY REDUCTION WITH OTHER ALGORITHMS

Test sequence	*Algorithm*	*ΔPSNRY [dB]*	*ΔBitrate [%]*	*ΔTime [%]*
Coastguard (QCIF)	Ref. [2]	-0.151	+2.932	-74.91
	Ref. [3]	-0.106	+2.361	-55.026
	Ref. [4]	-0.088	+5.405	-72.29
	Ref. [5]	-0.068	+0.860	-63.90
		-0.047	+0.631	-59.62
	Ref. [6]	-0.036	+2.830	-61.49
	Proposed I	**-0.05**	**+5**	**-85.06**
	Proposed II	**+0.03**	**+4.78**	**-70.73**
	Proposed III	**+0.07**	**-0.26**	**-34.72**
Mobile (CIF)	Ref. [2]	-0.137	+2.260	-76.87
	Ref. [3]	-0.255	+3.168	-59.086
	Ref. [4]	-0.211	+3.321	-72.83
	Ref. [5]	-0.122	+1.163	-64.46
		-0.085	+0.852	-60.59
	Ref. [6]	-0.036	+1.702	-59.58
	Proposed I	**-0.2**	**+5.21**	**-80.24**
	Proposed II	**+0.21**	**+2.01**	**-49.69**
	Proposed III	**+0.07**	**+0.74**	**-24.32**

IV. CONCLUSIONS

We categorized fast intra prediction mode decision into three types as fast intra decision based on mode features, block features, and edge or directional information. For each type, we proposed a fast intra-mode decision algorithm using an unconditional DC mode, a condition of block boundary to select the DC mode, and the ratio of the variance along the horizontal direction to the variance along the vertical direction. Using the proposed algorithms, on average, we either achieved 82.13% time saving with no significant rate-distortion degradation or obtained 0.45% bitrate increment while slightly increasing the PSNR values and saving the entire encoding time.

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