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1. Introduction

To achieve the highest coding efficiency, H.264 employs rate distortion optimization (RDO) technique to get the best coding result in terms of maximizing coding quality and minimizing resulting data bits. This means that, in order to achieve RDO, the encoder has to encode the video by exhaustively using all the mode combinations, including different intra and inter prediction modes. As a result, the complexity and computation load of video coding in H.264 increase drastically, which makes it very difficult for practical applications such as real time video communication using state of the art hardware system.

A number of efforts have been made to explore the fast algorithms in motion estimation for H.264 video coding [3-5]. However, no fast algorithm in intra prediction for H.264 has been reported. In this proposal, we present a novel fast mode decision algorithm for H.264 intra prediction based on local edge directional information to reduce the amount of calculations in intra prediction. With the use of edge direction histogram derived from the edge map of the picture, only a small number of most possible intra prediction modes are chosen for RDO calculation. Therefore the fast mode decision algorithm helps to speed up intra coding significantly.

2. Overview of intra coding in H.264

Intra coding refers to the case where only spatial redundancies within a video picture are exploited. The resulting picture is referred to as an I-picture. Traditionally, I-pictures are encoded by directly applying the transform to all macroblocks in the picture, which generates much larger number of data bits compared to that of inter coding. In order to increase the efficiency of the intra coding, spatial correlation between adjacent block/macroblock in a given picture is exploited in H.264, i.e., we can predict the block/macroblock of interest from the surrounding blocks/macroblocks according to their directional information. The difference between the actual block/macroblock and their prediction is then coded.

If a macroblock is encoded in intra mode, a prediction block is formed based on previously encoded and reconstructed blocks. For the luminance (luma) components, intra prediction may be used for each 4×4 sub-block or 16×16 macroblock. There are 9 prediction modes for 4×4 luma blocks and 4 prediction modes for 16×16 luma blocks. For the chrominance (chroma) components, there are 4 prediction modes that are applied to the two 8×8 chroma blocks (U and V). Note that the resulting prediction mode for U and V components should be the same.

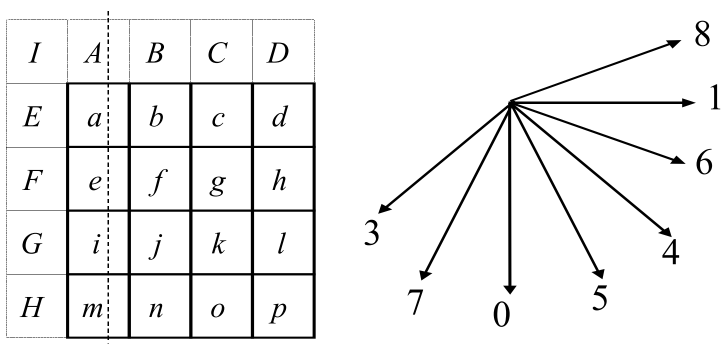

Figure 1. An example of intra prediction

Figure 1 illustrates the intra prediction for a 4×4 luma block. Note that in this figure, *a* to *p* are the pixels to be predicted, and *A* to *I* are the neighboring pixels that are available at the time of prediction. If we choose the prediction mode to be 0, then the pixels *a, e, i,* and *m* are predicted based on the neighboring pixel *A*; pixels *b, f, j* and *n* are predicted based on pixel *B*, and so on. Besides the 8 directional prediction modes shown in the figure, there is the 9th mode, i.e., DC prediction mode, or Mode 2 in H.264.

3.Fast mode decision for intra prediction

As mentioned in Introduction, H.264 video coding is based on the concept of rate distortion optimization, which means that the encoder has to encode the intra block using all the mode combinations and choose the one that gives the best performance in terms of RDO mode. According to the structure of intra prediction in H.264, the number of mode combinations for luma and chroma blocks in an MB is $M8\times(M4\times16+M16)$, where $M8$, $M4$ and $M16$ represent the number of modes for 8×8 chroma blocks, 4×4 and 16×16 luma blocks respectively. This means that, for a macroblock, it has to perform 592 different RDO calculations before a best RDO mode is determined. As a result, the complexity and computation load of the encoder is extremely high.

On the other hand, we observed that the pixels along the direction of local edge are normally of the similar values (this is true for both luma and chroma components). Therefore a good prediction could be achieved if we predict the pixels using those neighboring pixels that are in the same direction of the edge.

There are a number of ways to get the local edge directional information, such edge direction histogram [6], directional fields [7] etc. We have implemented the fast intra-mode prediction algorithm based on both the edge direction histogram and directional fields, and compared their performance in terms of time-saving, average PSNR and resulting bit-rate for all the sequences recommended in [8]. We concluded that the scheme based on edge direction histogram gives better performance. Therefore, the mode decision scheme described in this proposal is based on edge direction histogram.

3.1. Edge map

In order to obtain the edge information in the neighborhood of the intra block to be predicted, we first apply the Sobel edge operators [6] to the intra image to generate the edge map. Each pixel in the intra image will then be associated with an element in the edge map, which is the edge vector containing its edge direction and amplitude. Prior to intra prediction, edge maps are created from the original picture.

Sobel operator has two convolution kernels. Each pixel in the image is convolved with both kernels. One responds to degree of difference in vertical direction and the other in horizontal. Sobel operator is applied to every luminance and chrominance pixel except those pixels on the borders of luminance and chrominance pictures. This is because the operator cannot apply on those pixels without 8 surrounding pixels. For a pixel $p_{i,j}$, in a luminance (or chrominance) picture, we define the corresponding edge vector, $\vec{D}_{i,j} = \{dx_{i,j}, dy_{i,j}\}$, as,

$$
\begin{aligned}
dx_{i,j} &= p_{i-1,j+1} + 2\times p_{i,j+1} + p_{i+1,j+1} - p_{i-1,j-1} - 2\times p_{i,j-1} - p_{i+1,j-1} \\
dy_{i,j} &= p_{i+1,j-1} + 2\times p_{i+1,j} + p_{i+1,j+1} - p_{i-1,j-1} - 2\times p_{i-1,j} - p_{i-1,j+1}
\end{aligned}
\tag{1}
$$

where $dx_{i,j}$ and $dy_{i,j}$ represent the degree of difference in vertical and horizontal directions respectively. Therefore, the amplitude of the edge vector can be decided by,

$$
Amp\ (\vec{D}_{i,j}) = \left|dx_{i,j}\right| + \left|dy_{i,j}\right| \tag{2}
$$

In fact the amplitude could be obtained more accurately using the rooted sum of the squares of $dx_{i,j}$ and $dy_{i,j}$. However for faster processing, Equation (2) is usually used instead. The direction of the edge (in degree) is decided by the hyper-function,

$$
Ang\ (\vec{D}_{i,j}) = \frac{180^0}{\pi} \times \arctan\left(\frac{dy_{i,j}}{dx_{i,j}}\right), \quad \left|Ang\ (\vec{D}_{i,j})\right| < 90^0 \tag{3}
$$

In the actual implementation of the algorithm, Equation (3) is not necessary, as in H.264 there is only limited number of directions that intra prediction could be applied. In fact, we can use simple thresholding technique to build up the edge direction histogram instead.

3.2 Edge direction histogram

In order to reduce the number of candidate prediction modes in RDO, an edge direction histogram is calculated from all the pixels in the block by summing up the amplitudes of those pixels with similar directions in the block.

3.2.1 4 x 4 luma block edge direction histogram

In the case of a 4×4 luma block, there are 8 directional prediction modes, as shown in Figure 1, plus a DC prediction mode. The border between any two adjacent directional prediction modes is the bisectrix of the two corresponding directions. For example, the border of mode 1 (0^0) and mode 8 (26.6^0) is the direction on 13.3^0. Note that for Mode 8 (Horizontal-Up), interpolation is done at an angle of approximately 26.6^0 above horizontal direction. It is important to note that mode 3 and mode 8 are adjacent due to circular symmetry of the prediction modes. The mode of each pixel is determined by its edge direction $Ang(\vec{D}_{i,j})$.

Therefore the edge direction histogram of a 4 x 4 luma block is decided as,

$$
\begin{aligned}
& Histo(k) = \sum_{(m,n)\in SET(k)} Amp\ (\vec{D}_{m,n}), \\
& SET(k) \in \{\{(i_0, j_0)\}, \{(i_1, j_1)\}, ..., \{(i_u, j_u)\} ..., \{(i_8, j_8)\} \mid Ang\ (\vec{D}_{i_u, j_u}) \in a_u\}, \\
& while \\
& a_0 = (-103.3^0, -76.6^0] \\
& a_1 = (-13.3^0, 13.3^0] \\
& a_3 = (35.8^0, 54.2^0] \\
& a_4 = (-54.2^0, -35.8^0] \\
& a_5 = (-76.7^0, -54.2^0] \\
& a_6 = (-35.8^0, -13.3^0] \\
& a_7 = (54.2^0, -76.7^0] \\
& a_8 = (13.3^0, 35.8^0]
\end{aligned} \tag{4}
$$

Note that *k=1,…,8* refers to 8 directional prediction modes. Note also that in the above equation, the direction has a period of 180^0. Figure 2 shows an example of the edge direction histogram.

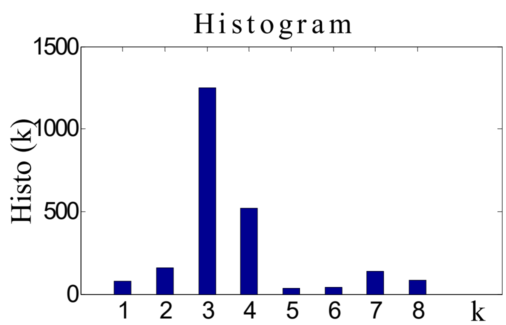

Figure 2. Edge direction histogram

3.2.2 Edge direction histogram for 16 x 16 luma and 8 x 8 chroma block

In the case of 16×16 luma and 8×8 chroma blocks, there are only two directional prediction modes, plus a plane prediction and a DC prediction mode. Therefore, the edge direction histogram for this case will be based on three directions, i.e., horizontal, vertical and diagonal directions, as shown in Figure 3.

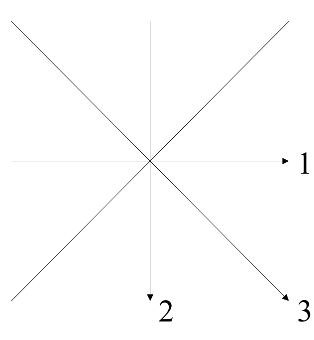

Figure 3. Intra 8x8 and 16x16 prediction mode directions

Their edge direction histogram is constructed as follows,

$$
\begin{aligned}
&Histo(k) = \sum_{(m,n)\in SET(k)} Amp\ (\vec{D}_{m,n}),\\
&SET(k) \in \{\{i_1, j_1\},\ldots,\{i_u, j_u\}\ldots,\{i_3, j_3\} \mid Ang\ (\vec{D}_{i_u,j_u}) \in a_u\},\\
&while\\
&a_1 = [-22.25^0, 22.25^0]\\
&a_2 = (-\infty, -67.5^0) \cup (67.5^0, +\infty,)\\
&a_3 = \Omega - (a_1 \cup a_2)
\end{aligned}
\qquad (5)
$$

where *k=1* refers to the horizontal prediction mode, *k=2* refers to vertical prediction mode, and *k=3* refers to the plane prediction mode.

3.3 Histogram based fast mode selection for intra prediction

As mentioned above, each cell in the edge direction histogram sums up the amplitudes of those pixels with the similar directions in the block. Therefore, cell with the maximum amplitude indicates that there is a strong edge presence in that direction, and thus could be used as the direction for the best prediction mode.

3.3.1 4×4 luma block prediction modes

Instead of performing the 9 modes RDO for 4×4 luma block, the fast algorithm only chooses some of the directional prediction modes with higher probability to be the candidate modes for intra 4×4 block prediction according to the edge direction histogram.

Since the pixels along edge direction are likely to have similar values, the best prediction mode is probably in the edge direction whose cell has the maximum amplitude, or the directions close to the maximum amplitude cell. Therefore, the histogram cell with the maximum amplitude and the two adjacent cells are considered as candidates for the best prediction mode. In consideration of the case where all the cells have similar amplitudes in the edge direction histogram, DC mode is also chosen as the fourth candidate.

Thus, for each 4×4 luma block, we will only perform 4 modes RDO calculation, instead of 9.

3.3.2 16×16 luma block prediction modes

Only the histogram cell with maximum amplitude is considered as a candidate of best prediction mode. Similarly as above, DC mode is also chosen as the next candidate.

Thus, for each 16×16 luma block, we will only perform 2 modes RDO calculation, instead of 4.

3.3.3 8×8 chroma prediction modes

In the case of chroma blocks, there are two different histograms, one from component U and the other from V. Therefore the histogram cells with maximum amplitude from the two components are both considered as candidate modes. Same as previously, DC mode will also take part in the RDO calculation. Note that if the direction with the maximum amplitude from the two components is the same, there could only be 2 candidate modes for RDO calculation; otherwise, it will be 3.

Thus, for each 8×8 chroma block, we will only perform 2 or 3 modes RDO calculation, instead of 4.

Table 1 summarizes the number of candidates selected for RDO calculation based on edge direction histogram. As can be seen from Table 1, the encoder with the fast mode decision algorithm would have to perform only 132~198 RDO calculations, which are much less than that of current H.264 video coding (592).

Table 1. Number of selected modes

	Block size	Total No. of modes	No. of modes selected
Luma (Y)	4×4	9	4
Luma (Y)	16×16	4	2
Chroma (U, V)	8×8	4	3 or 2*

*The modes selected from the 2-chroma blocks may be the same.

4. Experimental results

Our proposed algorithm was implemented into JM6.1 provided by JVT. According to the specifications provided in [9], the test conditions are as follows:

a. MV search range is ±32 pels for QCIF, CIF, and ±64 for HDTV.
b. Hadamard transform is used.
c. RD optimization is enabled.
d. Reference frame number equals to 1.
e. CABAC is enabled.
f. MV resolution is ¼ pel.

g. ABT mode is disabled.

h. GOP structure is IPPP or IBBPBB.

A group of experiments were carried out on the recommended sequences with specified quantization parameters by [8]. The PSNR is derived from average PSNRs of luma (Y) and chroma (U, V) based on the equations below:

$$PSNR = 10\log_{10}\left(\frac{255^2}{MSE}\right) \tag{6}$$

Solving (6) for *rms* gives:

$$MSE = \frac{255^2}{10^{\frac{PSNR}{10}}} = \frac{65025}{10^{\frac{PSNR}{10}}} \tag{7}$$

Therefore,

$$MSE_Y = \frac{65025}{10^{\frac{PSNR_Y}{10}}} \tag{8}$$

$$MSE_U = \frac{65025}{10^{\frac{PSNR_U}{10}}} \tag{9}$$

$$MSE_V = \frac{65025}{10^{\frac{PSNR_V}{10}}} \tag{10}$$

From (8), (9) and (10), we have

$$\overline{MSE} = \frac{4 \times MSE_Y + MSE_U + MSE_V}{6} \tag{11}$$

Substituting (11) into (6), which gives the overall PSNR

$$\overline{PSNR} = 10\log_{10}\left(255^2 \Big/ \overline{MSE}\right) \tag{12}$$

Therefore in our following presentation, we will use the overall PSNR value of all the three components Y, U and V using Equation (12). The comparison results were produced and tabulated according to quantization parameter as below:

CHG_BIT_I: Change of the bits used for the first frame (I frame).

CHG_T_I: Change of coding time for the first frame (I frame).

CHG_BIT_AVG: Change of average bits (per frame) used for the whole sequence.

CHG_T_AVG: Change of average coding time (per frame).

CHG_PSNR: Change of PSNR.

The RD curves are plotted by fitting the testing results with the following equation [10].

$$PSNR = a + b \times bitrate + c \times bitrate^2 + d \times bitrate^3 \quad (13)$$

4.1 Experiments on QCIF test sequences

Tables 2-5 show the tabulated performance comparison of the proposed algorithm with JM6.1 for all the QCIF format test sequences listed in [8]. Note that in these tables positive values mean increases, and negative values mean decreases. Figures 4-7 show the RD curves of the five testing sequences.

Table 2. QP = 28, Comparison results

Sequence	CHG_BIT_I (%)	CHG_T_I (%)	CHG_BIT_AVG (%)	CHG_T_AVG (%)	CHG_PSNR (dB)
Container	1.46	-69.44	-0.52	-24.16	-0.020
News	3.16	-60.56	0.65	-24.47	-0.028
Foreman	2.31	-66.67	0.51	-23.57	-0.008
Silent	2.74	-66.67	0.67	-24.57	0.005
Coastguard	1.05	-55.00	0.36	-21.03	-0.018

Table 3. QP = 32, Comparison results

Sequence	CHG_BIT_I (%)	CHG_T_I (%)	CHG_BIT_AVG (%)	CHG_T_AVG (%)	CHG_PSNR (dB)
Container	2.30	-60.00	0.89	-22.92	-0.066
News	3.31	-55.74	0.34	-22.40	-0.012
Foreman	2.54	-63.93	0.68	-22.15	-0.032
Silent	4.64	-63.93	0.89	-22.66	0.009
Coastguard	1.52	-60.00	0.52	-19.46	-0.001

Table 4. QP = 36, Comparison results

Sequence	CHG_BIT_I (%)	CHG_T_I (%)	CHG_BIT_AVG (%)	CHG_T_AVG (%)	CHG_PSNR (dB)
Container	3.52	-60.00	0.86	-21.91	0.013
News	3.37	-63.33	0.94	-20.92	-0.007
Foreman	4.45	-69.09	1.11	-20.98	-0.026
Silent	4.82	-60.00	1.08	-20.81	0.020
Coastguard	3.36	-55.10	0.05	-19.05	-0.058

Table 5. QP = 40, Comparison results

Sequence	CHG_BIT_I (%)	CHG_T_I (%)	CHG_BIT_AVG (%)	CHG_T_AVG (%)	CHG_PSNR (dB)
Container	3.44	-55.10	1.67	-20.99	-0.078
News	4.85	-60.00	2.27	-20.31	0.044
Foreman	4.83	-69.09	1.55	-19.84	-0.016
Silent	4.55	-60.00	0.41	-20.83	0.040
Coastguard	5.12	-50.00	1.33	-17.65	-0.034

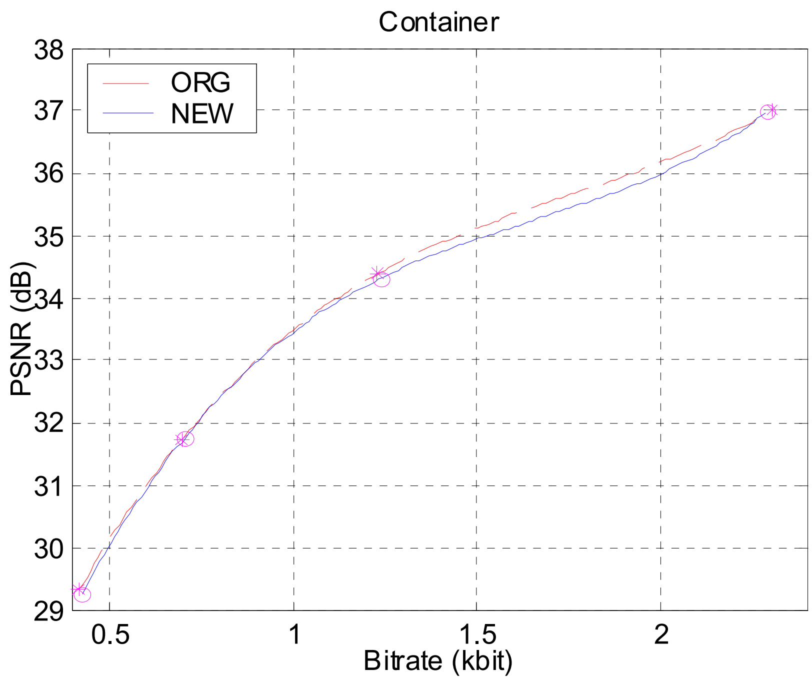

Figure 4.

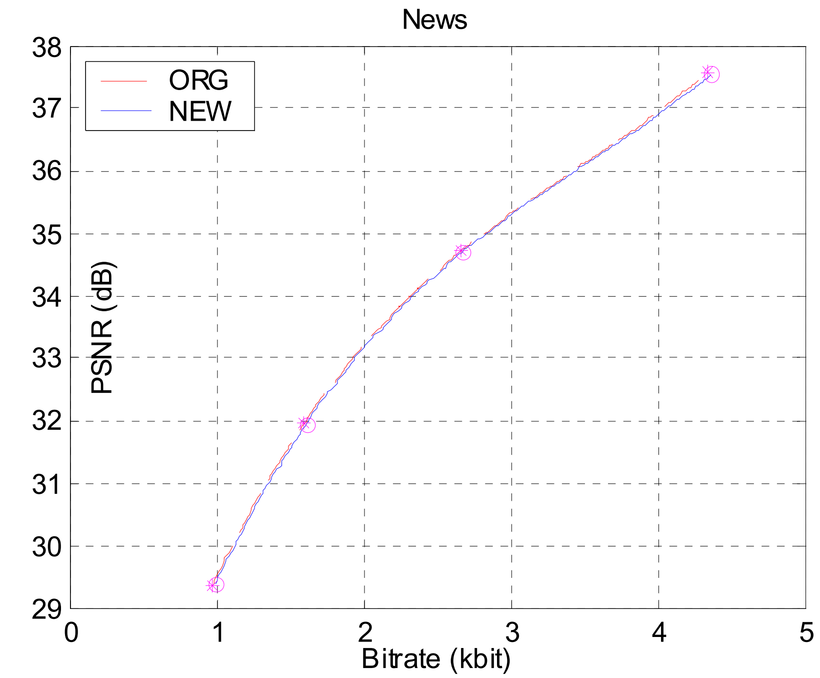

Figure 5.

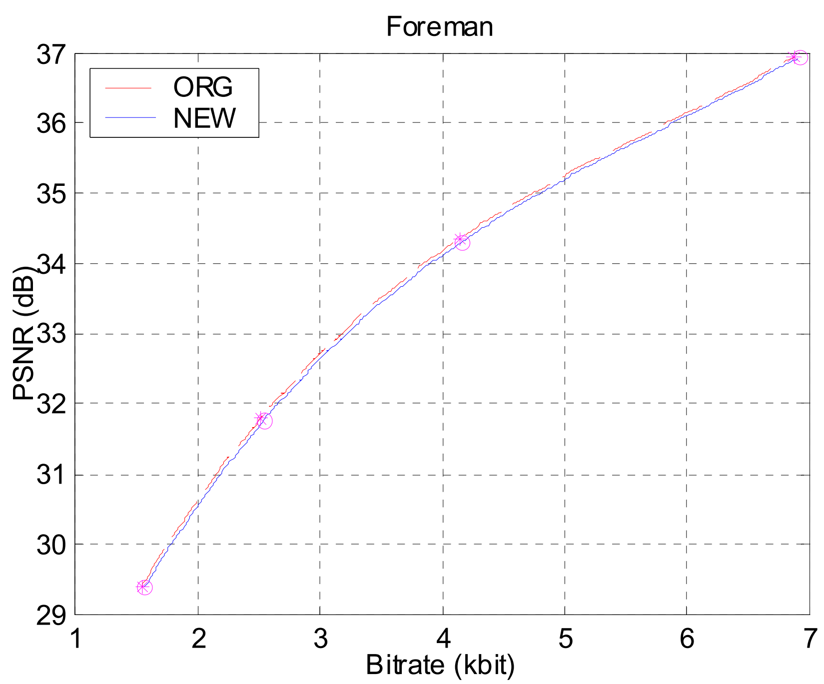

Figure 6.

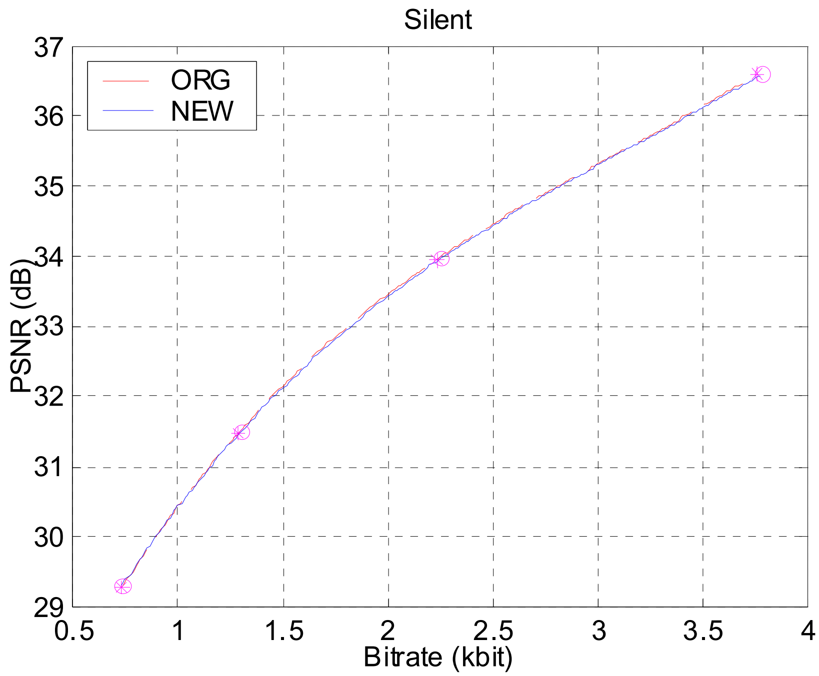

Figure 7.

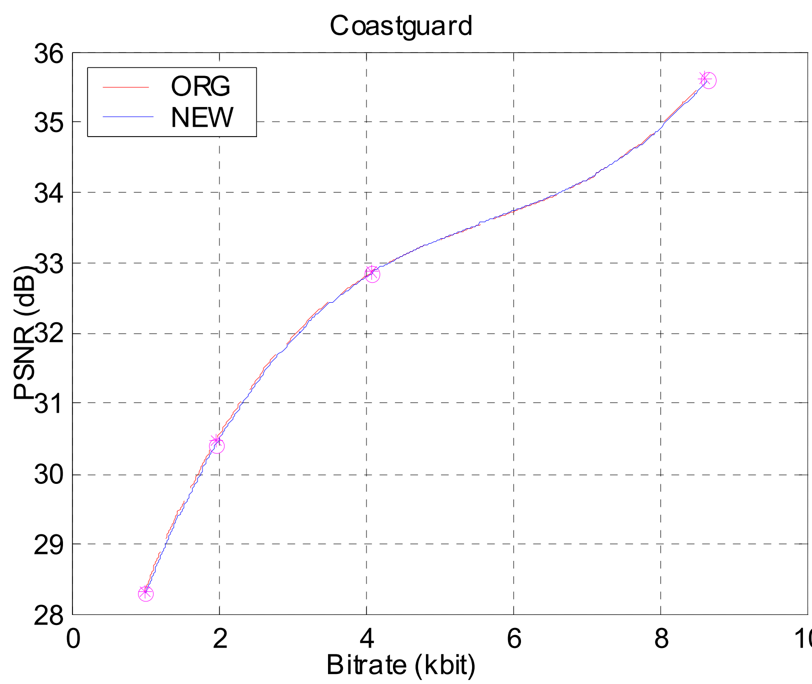

Figure 8.

4.2 Experiments on CIF test sequences

Tables 6-11 show the tabulated performance comparison of the proposed algorithm with JM6.1 for all the CIF format test sequences listed in [8]. Note that in these tables positive values mean increases, and negative values mean decreases. Figures 8-14 show the RD curves of the five testing sequences.

Table 6. QP = 28, Comparison results

Sequence	CHG_BIT_I (%)	CHG_T_I (%)	CHG_BIT_AVG (%)	CHG_T_AVG (%)	CHG_PSNR (dB)
Paris	1.47	-61.34	0.37	-30.87	-0.014
Mobile	1.34	-61.28	0.00	-32.49	-0.005
Tempete	1.71	-59.85	0.24	-31.54	0.000
Bus	1.10	-61.54	0.28	-25.54	-0.010
Stefan	1.15	-60.61	-0.31	-25.17	-0.021
Goldfish	5.47	-61.11	1.07	-21.79	-0.065
Bike	1.00	-63.48	0.04	-13.80	-0.059

Table 7. QP = 32, Comparison results

Sequence	CHG_BIT_I (%)	CHG_T_I (%)	CHG_BIT_AVG (%)	CHG_T_AVG (%)	CHG_PSNR (dB)
Paris	2.66	-59.09	0.31	-29.50	0.010
Mobile	2.16	-59.11	0.09	-30.92	-0.002
Tempete	2.37	-60.71	0.02	-29.62	-0.010
Bus	1.57	-58.33	0.55	-23.64	-0.028
Stefan	2.26	-58.05	0.80	-23.94	-0.001
Goldfish	7.20	-57.29	1.49	-21.54	-0.067
Bike	2.32	-61.43	0.41	-12.25	-0.030

Table 4. QP = 36, Comparison results

Sequence	CHG_BIT_I (%)	CHG_T_I (%)	CHG_BIT_AVG (%)	CHG_T_AVG (%)	CHG_PSNR (dB)
Paris	3.52	-59.57	0.58	-28.67	-0.031
Mobile	3.19	-58.23	0.09	-29.24	0.001
Tempete	3.49	-59.82	0.07	-28.53	-0.012
Bus	2.45	-57.58	0.75	-22.76	-0.022
Stefan	2.96	-57.73	1.15	-22.82	-0.010
Goldfish	8.69	-55.61	2.03	-21.06	-0.049
Bike	2.77	-61.06	0.49	-11.41	-0.048

Table 5. QP = 40, Comparison results

Sequence	CHG_BIT_I (%)	CHG_T_I (%)	CHG_BIT_AVG (%)	CHG_T_AVG (%)	CHG_PSNR (dB)
Paris	5.12	-61.68	0.55	-28.00	0.071
Mobile	4.16	-57.73	0.33	-27.82	0.001
Tempete	3.32	-56.86	0.30	-28.04	-0.011
Bus	5.94	-55.02	1.63	-21.68	-0.010
Stefan	4.97	-55.50	1.09	-22.12	-0.016
Goldfish	11.33	-58.60	1.94	-20.83	-0.052
Bike	3.22	-62.11	0.81	-11.45	-0.044

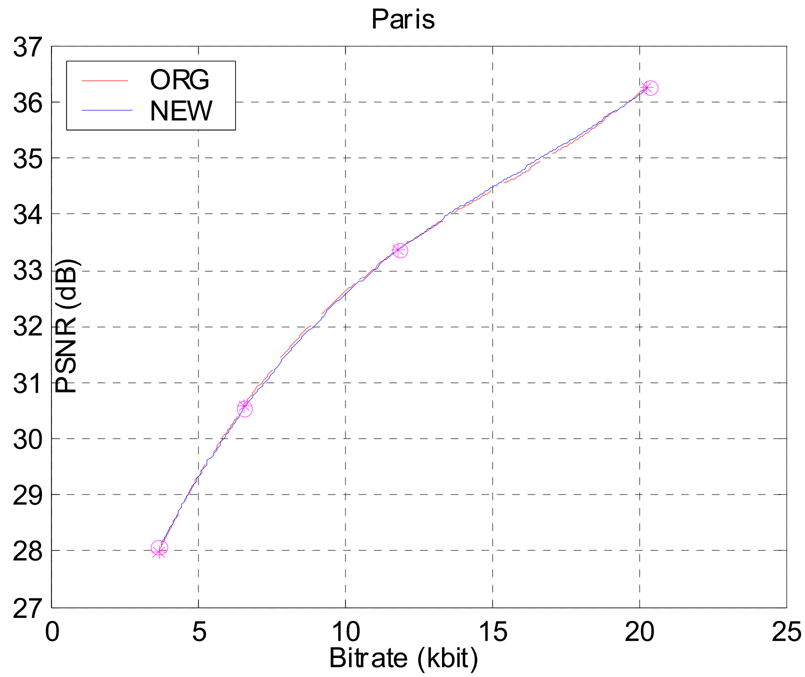

Figure 8.

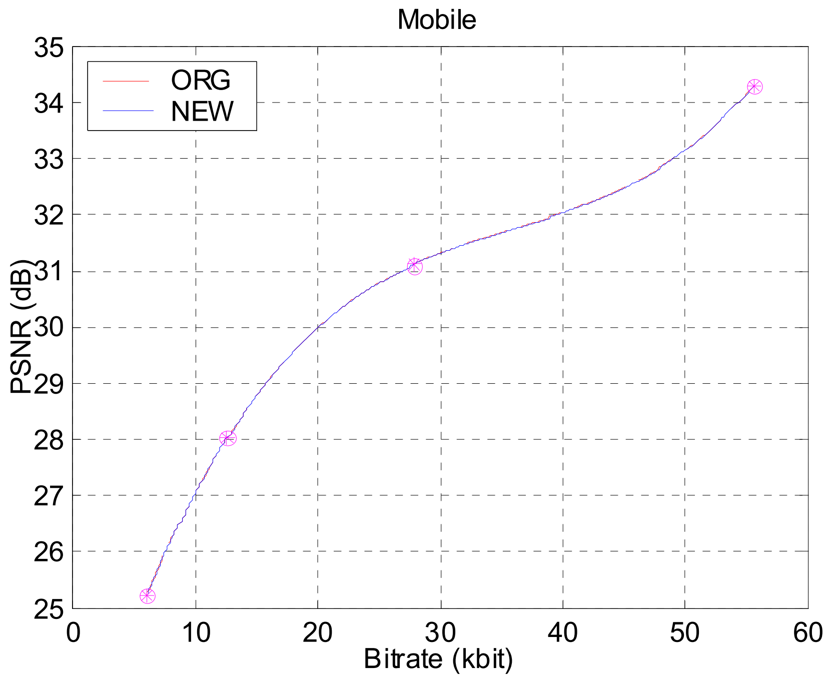

Figure 9.

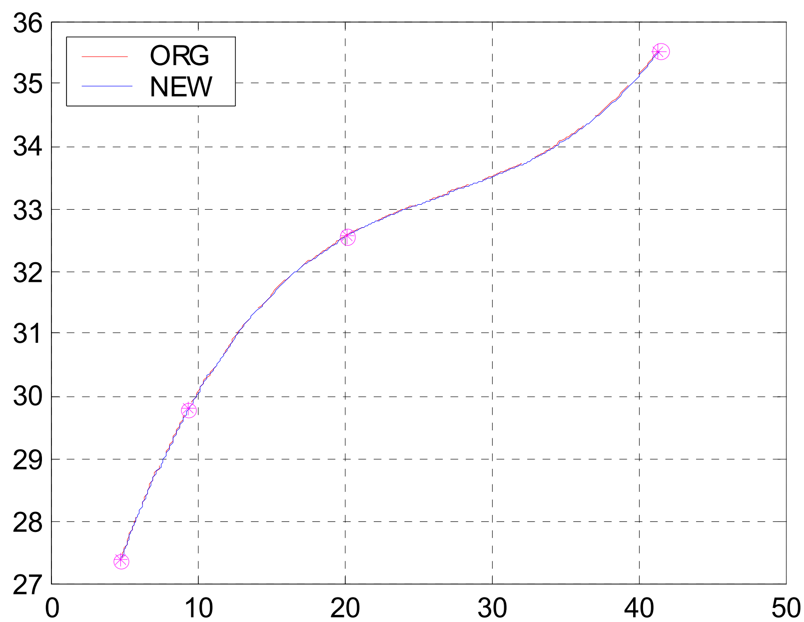

Figure 10.

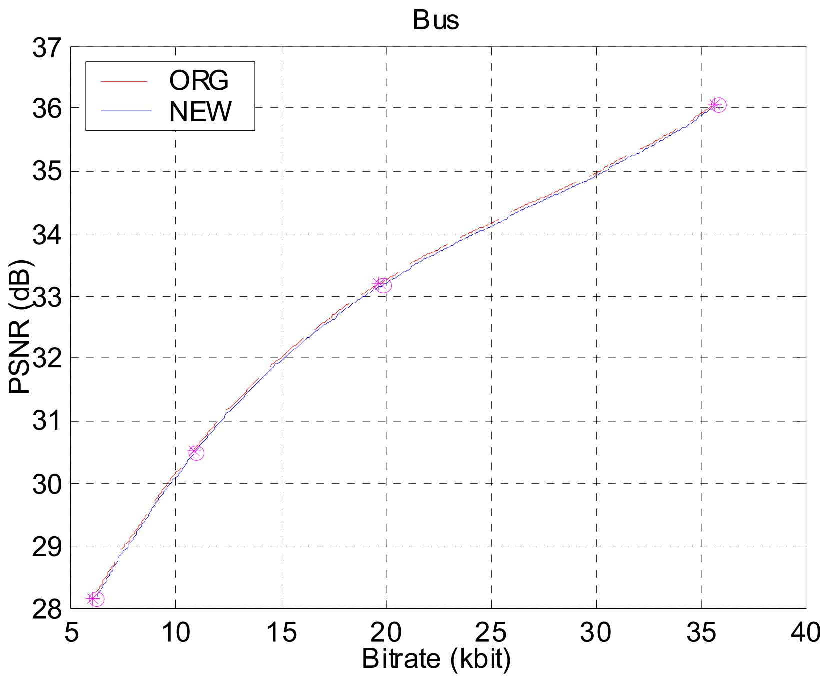

Figure 11.

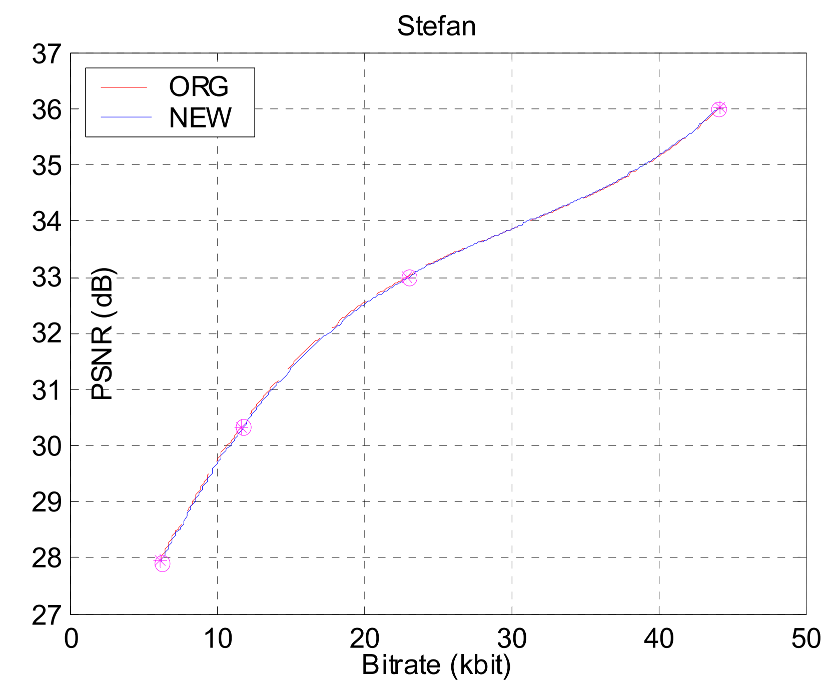

Figure 12.

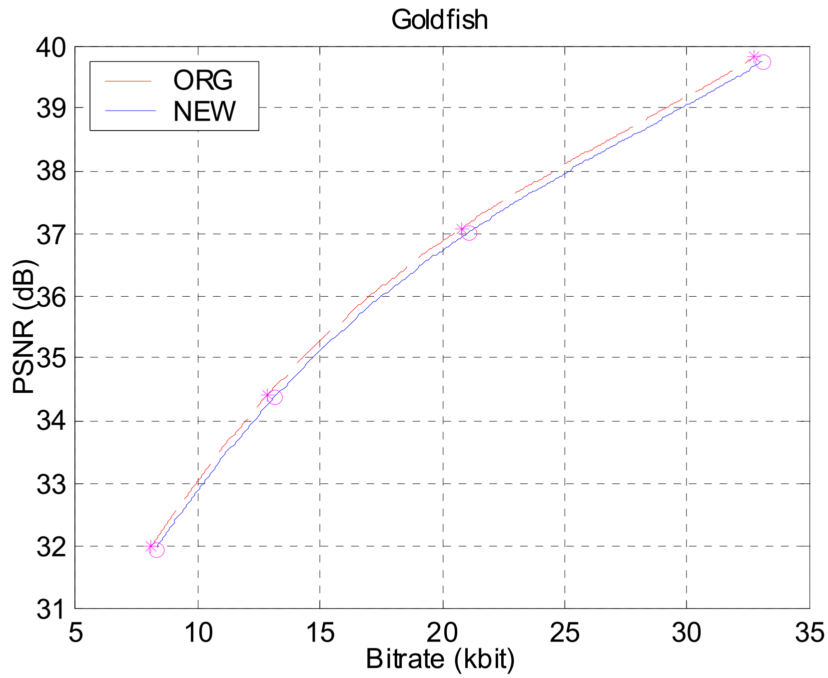

Figure 13.

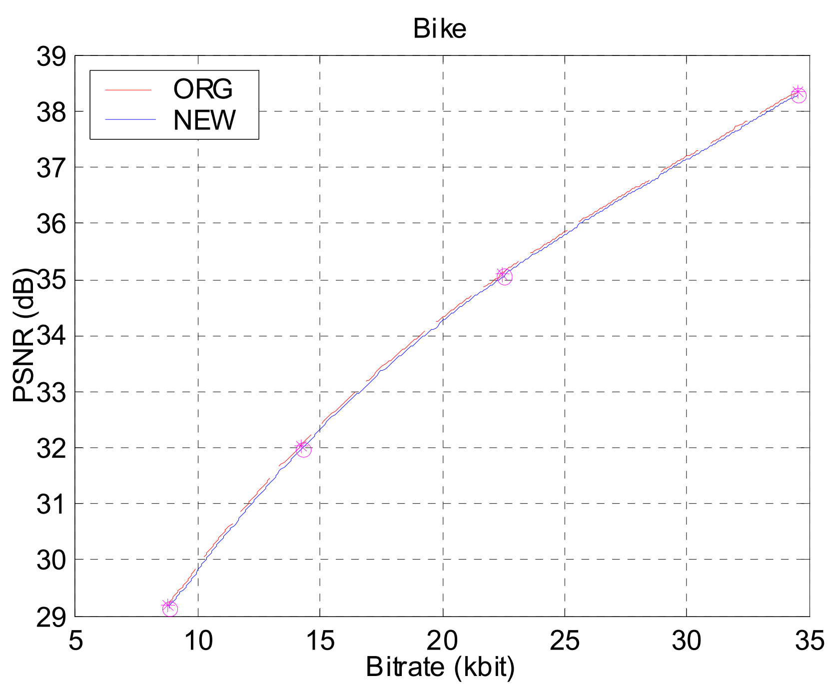

Figure 14.

4.3 Summary of experimental results

From the results above, we can see that the proposed algorithm has outstanding improvement in coding speed of I frame (majority saving time between 55% and 65%) with less than 5% extra bits used. There are also significant increment in average coding speed (majority saving time between

20% and 30%) with less than 2% extra bits used. The sacrifice of PSNR is less than 0.08 dB some cases even have increment in PSNR.

5. Conclusions

This proposal prosented a fast mode decision algorithm for intra prediction in H.264 video coding. By making use of the edge direction histogram, the number of mode combinations for luma and chroma blocks in a MB that take part in RDO calculation has been reduced significantly from 592 to as low as 132. Other techniques such as early termination of RDO mode calculation are also used to further reduce the computation time. This results in great reduction in the complexity and computation load of the encoder. Experimental results show that the fast algorithm has a negligible loss of PSNR compared to the original scheme.

6. References

[1] ITU-T Rec. H.264 | ISO/IEC 14496-10 AVC, “Joint Final Committee Draft (JFCD) of Joint Video Specification,” Klagenfurt, Austria, July 22-26, 2002.

[2] MPEG test group, “Preliminary Results of Subjective Assessment of Responses to Video Call for New Tools to Further Improve Coding Efficiency”, ISO/IEC JTC1/SC29/WG11, N4355, July 2001.

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(Append for Proposal Documents)

JVT Patent Disclosure Form

International Telecommunication Union Telecommunication Standardization Sector	International Organization for Standardization	International Electrotechnical Commission

Joint Video Coding Experts Group - *Patent Disclosure Form*

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