International Journal of Multimedia and Ubiquitous Engineering
Vol.10, No.9 (2015), pp.81-90
http://dx.doi.org/10.14257/ijmue.2015.10.9.09

A Fast Intra Mode Decision Algorithm for HEVC Using Sobel Operator in Edge Detection

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Abstract

As a successor to H.264/AVC, High Efficiency Video Coding (HEVC) standard has an outstanding performance than before. To make the coding efficiency higher, one introduced new coding feature in HEVC is adding intra prediction modes up to 35 instead of 9 in H.264, but it increases calculation complexity. To save the coding time, this paper proposes a fast intra mode decision algorithm based on edge detection technology using sobel operator. Because of the principle that sobel operator can find the texture edge directly, the proposed algorithm can save large numbers of coding time with only a little BD-rate rising. Experimental results show that the proposed fast intra mode decision algorithm can save 38.8% computational complexity on average with a 1.6% BD-rate rise.

Keywords: *HEVC, intra prediction, sobel operator*

1. Introduction

Recently, a completion of the first edition video coding standard, which is referred to as High Efficiency Video Coding (HEVC), has been studied by Joint Collaborative Team on Video Coding (JCT-VC) [1]. Since many new high-level syntax features are adopted in HEVC, compared with the previous video compression H.264/AVC, HEVC promotes the coding efficiency to a high-level. One of these new features is that 33 directional modes, as well as DC and planar prediction modes are used to decide all PU (Prediction Unit) modes in HEVC as shown in Figure 1, which aims to improve intra coding efficiency.

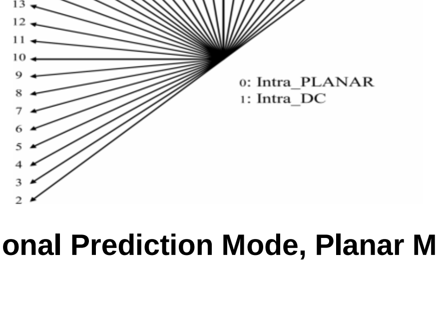


Figure 1. All 33 Directional Prediction Mode, Planar Mode and DC Mode

ISSN: 1975-0080 IJMUE

Edge detection aims at identifying points in an image where the image luma changes sharply. There are lots of operators in edge detection technology; however, different from other operators, one of them is called sobel, which can produce both the corresponding gradient vector and its normal vector at any point in the image. Therefore, we can use this feature of sobel operator in intra coding in HEVC to eliminate other unnecessary intra prediction modes, thus it will save more coding time than original HEVC encoder [2].

In HEVC Model (HM), intra coding composes of the rough mode decision (RMD) stage, the rate-distortion optimization (RDO) stage and the residual quad-tree process (RQT). However, in the first stage, it performs exhaustive search on 35 prediction modes to find the best mode, which introduces so much more computation time.

To solve this problem, many algorithms were proposed as follows. They used an early termination method to reduce the coding time without increasing calculation complexity. Ismail M proposes an adaptive mode selection which employs the prediction modes from the upper layer of coding unit (CU) and neighboring prediction units (PUs) to minimize BD-rate increment with the reduced candidate modes. He also proposes an early termination approach for RDO stage to skip some unnecessary candidate modes based on the average value of rate-distortion costs (RD-costs) that are calculated from the RMD stage [3]. A fast CU size decision algorithm for HEVC intra coding is proposed to speed up the process by reducing the number of candidate in literature [4]. In literature [5], the authors propose a two-stage prediction unit size decision algorithm to speed up the original intra coding in HEVC. Also there are some algorithms which introduce the fast mode decision using edge detection technology. Chen puts forward the pixel gradient statistics (PGS) and mode refinement (MR) to improve prediction efficiency after the RMD [6]. In literature [7], the authors propose an efficient fast algorithm, which is named Extreme Value Detection (EVD), to predict the best directional prediction mode for fast intra mode decision.

But neither of those methods can reduce the number of candidate low enough. Essentially, if the number of candidate can be reduced, for intra directional prediction, calculation complexity will be dropped. Therefore, this paper proposes a fast intra mode decision algorithm based on edge detection technology using sobel operator. We use sobel operator to calculate the gradient direction, according to that the selected predicted directions will be constructed. The experimental result shows that the proposed intra mode decision algorithm computation complexity reduction is up to 38.8%, and BD-rate increased just by 1.6%.

The rest of this paper is organized as follows. We propose a fast intra mode decision algorithm in Section 2, and the experimental results are shown in Section 3. In the end, this paper is concluded in Section 4.

2. Proposed Fast Intra Mode Decision Algorithm

In HEVC, one largest coding unit (64×64) consists of 341 (including one PU of 64×64, 4 PUs of 32×32, 16 PUs of 16×16, 64 PUs of 8×8 and 256 PUs of 4×4) PUs of sizes varying from 64×64 to 4×4. Each of these prediction units needs to be calculated 35 times (corresponding to 35 intra prediction modes), so for the largest coding unit, it will be calculated 11935 (341×35) times with hadamard transform (HT) and Context-Based Adaptive Binary Arithmetic Coding (CABAC). For some sequences containing large texture complexity region like "Basketball Drive", the summation of small size PUs like 4×4 PUs and 8×8 PUs is much more than the summation of other PUs, because the small size PUs can preserve the detail of an image more effective than other PUs, image quality will not be influenced. So the average of variances is rising with the diminishing of the size of PUs, as shown in Figure 2, the average of variances of different sizes of PUs in sequence "Basketball Drive" (Quantization Parameter, QP=32) [8].

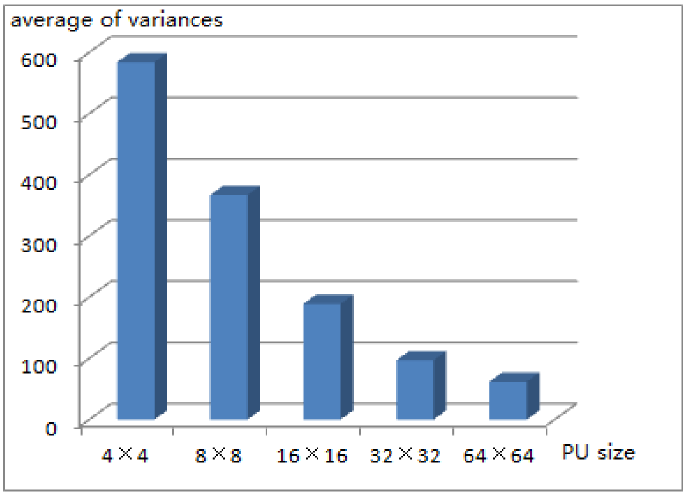


Figure 2. The Average of Variances of different Sizes of PUs in Sequence "Basketball Drive" (QP=32)

In spite of that the larger the number of directions is, the higher the accuracy of prediction improves, enlarging the number of directions means increasing the coding time. Thus we should quit predicting a majority of intra prediction modes without decreasing the coding efficiency as much as possible. Therefore, the unnecessary intra prediction modes will be skipped during the encoding process. In order to skip some unnecessary intra prediction modes in RMD, a fast intra prediction mode decision algorithm based on edge detection using sobel operator is proposed in this paper. As an edge detection operator, sobel is considered in RMD, and we finally utilize it to decide which the best intra mode is among the 33 directional predictions.

As we all know, there are so many operators in edge detection technology, such as roberts operator, sobel operator, prewitt operator and so on. All of them can detect the edge information in an image with different principles. Distinguished from other operators, sobel operator has a feature which is useful to our research, and the feature is that it can detect the edge of an image by being convolved with the image to compute the gradient. What we need is the gradient of the image, and we can use the gradient to decide which prediction directions should be selected. Then our proposed algorithm just needs to calculate the RD-costs of a small number of directions. Entire intra prediction process will be terminated early, so that the large coding time will be saved simultaneously. Figure 3 presents a flowchart of the intra mode decision algorithm proposed in this paper in detail. In the following, we will describe how the sobel operator is used in intra mode decision.

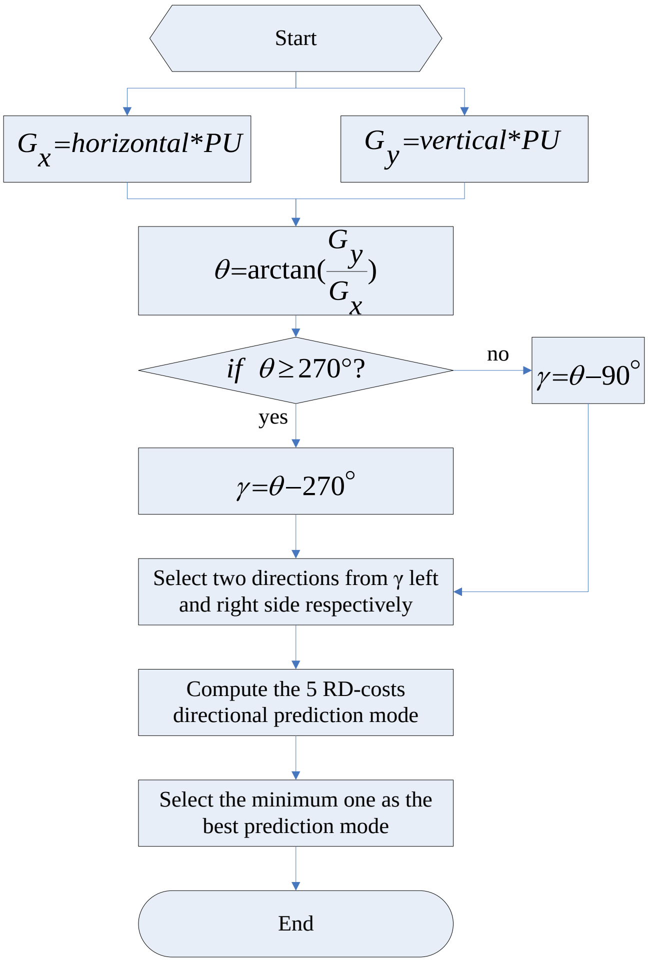


Figure 3. The Flowchart of the Proposed Intra Mode Decision Algorithm

The sobel operator uses two 3×3 matrixes, including horizontal and vertical directions, which are convolved respectively with PU to compute luma difference approximations of the horizontal and vertical directions. It is assumed that PU represents the prediction unit (including from 4×4 to 64×64), as well as G_x and G_y denote the PUs which are convolved with horizontal and vertical operators, respectively. Formula is shown as

$$G_x = \begin{pmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{pmatrix} * PU \quad (1)$$

$$G_y = \begin{pmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{pmatrix} * PU \quad (2)$$

In the PU, the gradient of each pixel can be computed using the formula as follow, which is the horizontal and vertical gradient approximation of each pixel.

$$G = \sqrt{G_x^2 + G_y^2} \quad (3)$$

Then, we can exploit the follow formula to calculate the angular θ of gradient direction.

$$\theta = \arctan(\frac{G_y}{G_x}) \quad (4)$$

Since the gradient expresses the direction of the greatest rate of increase of the function and its value is the slope of the image pixel value in that direction, the angular difference between predicted direction and gradient direction is 90°, no matter what the gradient value is. According to this conception, we can get the selected predicted direction whose angular γ is calculated by formula $\gamma = \theta - 90^{\circ}$. The correlation between prediction direction and gradient direction is shown as Figure 4. However, for intra directional prediction mode in HEVC, we should control the selected predicted direction angular γ from 0° to 180°. Hence, if θ is more than 270°, θ will be subtracted 270°.

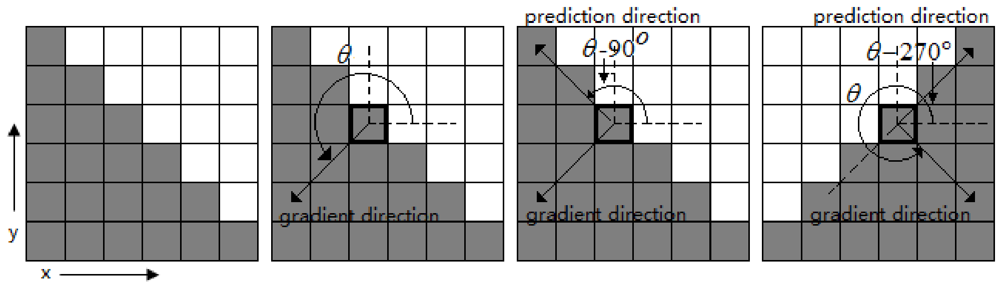


Figure 4. The Correlation between Prediction Direction and Gradient Direction

Once γ is determined, the selected predicted mode is determined. To reduce the error during the calculation, we add 2 modes from left and right side respectively of the best predicted mode into candidate list. Then RD-costs of the 5 candidate modes (including the selected mode) are calculated, and through ranking, the intra prediction mode with minimum RD-cost is chosen as the best mode.

Since the proposed algorithm skips 28 directional prediction modes to cope with just 5 directional prediction modes, the error will be produced during calculation doubtlessly. However, through comparing with the original HEVC encoder under QPs 28, 32 and 37, we know that the proposed algorithm can achieve the accuracy of intra mode decision within an acceptable range, shown as Table 1.

Table 1. Accuracy of the Proposed Algorithm

Sequences	QP	Accuracy of proposed algorithm(%)

Traffic (2560×1600)	28	93
	32	91
	37	84
BasketballDrive (1920×1088)	28	94
	32	92
	37	87
FourPeople (1080×720)	28	96
	32	93
	37	88
Average		91

The magnitude of accuracy rate is based on the resolution of the sequence and it depends on the choice of QP. As shown in Table 1， we can see that with the increasing of resolution of the sequence, the accuracy of proposed algorithm decreases inch by inch. It is also obvious that the accuracy rate is high, when QP is small and vice versa. Consequently, the results in Table 1 show that the average accuracy of the proposed algorithm is 91% with the highest accuracy 96% (resolution is 1080×720 on sequence “FourPeople”, QP=28) and the lowest accuracy 84% (resolution is 2560×1600 on sequence “Traffic”, QP=37). For such an average accuracy, the perceived quality of audiences cannot be influenced in comparison with original HEVC encoder.

3. Experimental Result

A number of algorithms about intra prediction mode decision have been proposed, but the coding performance of those methods is not high enough. Here, in order to compare intra coding efficiency of the proposed algorithm to that of other algorithms, the proposed algorithm in this paper is implemented on HEVC test model (HM13.0) and it is also assessed with QPs of 28, 32 and 37 using six sequences with three resolutions (2560×1600, 1920×1088 and 1080×720). The coding efficiency is measured using bitrate and calculation complexity is measured using the consumed coding time. The ΔBD_rate is used to represent the average bitrate difference, and the ΔTC is used to represent the change of the coding time in percentage. We use (6) (7) to express them as follows.

$$\Delta BD\_rate = \frac{BD\_rate_{pro} - BD\_rate_{HM}}{BD\_rate_{HM}} \times 100\% \qquad (6)$$

$$\Delta TC = \frac{Time_{pro} - Time_{HM}}{Time_{HM}} \times 100\% \qquad (7)$$

Where BD_rate_{pro} and BD_rate_{HM} denote DB-rate of proposal and HM13.0 algorithm, respectively. $Time_{pro}$ and $Time_{HM}$ represent coding time of proposal and HM13.0 algorithm, respectively. From Table 2, we can see the result of the comparison of the coding performance with another algorithm.

Since the reduction in the number of candidates, the coding time of the proposed algorithm descends by comparison with the algorithm of [2]. In RDO, the fewer the candidate modes are selected, the more the coding time is saved. The proposed method only choose 5 intra prediction modes to compute the RD-costs, as shown in Table 2, we can find that the proposed fast intra mode decision algorithm can save about 38.8% of coding time, and the BD-rate performance is just 1.6% gain, which is negligible. It is also obvious that the sequence with a minimum of 36.5% coding time reduction is "FourPeople" and a maximum of 40.2% coding time reduction is "PeopleOnStreet". So the proposed method is suitable to reduce the coding time for high-activity sequences like "PeopleOnStreet". Moreover, the average BD-rate increase is only 1.6% with the minimum of 1.3% in "Traffic" and the maximum of 2.0% in "FourPeople". Therefore, it can reduce the coding time of the proposed method significantly while maintain almost the same coding performance as the original HM encoder.

Table 2. Comparison of Coding Performance with HM13.0

Picture Size	Sequence	Algorithm of [2]		Our algorithm	
		ΔBD_rate (%)	ΔTC (%)	ΔBD_rate (%)	ΔTC (%)
(2560×1600)	Traffic	1.6	-37.8	1.3	-38.7
	PeopleOnStreet	2.2	-37.7	1.5	-40.2
(1920×1088)	BasketballDrive	1.6	-38.5	1.6	-39.3
	Cactus	1.9	-37.7	1.7	-38.6
(1080×720)	FourPeople	2.0	-37.1	2.0	-36.5
	Johnny	2.0	-37.6	1.7	-39.6
Average		1.9	-37.7	1.6	-38.8

Table 3. The Variances and standard Deviations of the Two Algorithm

	Variance		Standard deviation	
	Algorithm of [2]	Our algorithm	Algorithm of [2]	Our algorithm
BD-rate	0.048	0.046	0.219	0.214
Coding Time	0.169	1.365	0.411	1.168

To analyze the coding efficiency further, we compute the variances and the standard deviations of the two methods in terms of BD-rate and the coding time as shown in Table 3, the result of which is compared directly between the algorithm of [2] and our algorithm. The variances and the standard deviations are computed by the formulas from (8) to (11) as follows.

$$BD\_rate_{VAR} = \frac{\sum_{i=1}^{n} (BD\_rate_i - BD\_rate_{aver})}{n} \quad (8)$$

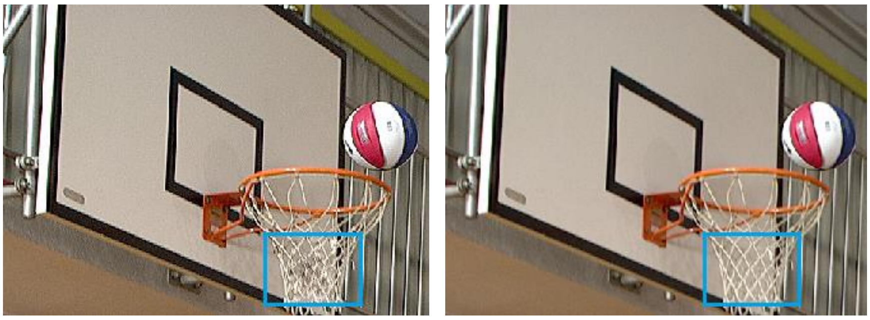
$$BD\_rate_{STD} = \sqrt{BD\_rate_{VAR}} \quad (9)$$

$$CT_{VAR} = \frac{\sum_{i=1}^{n} (CT_i - CT_{aver})}{n} \quad (10)$$

$$CT_{STD} = \sqrt{CT_{VAR}} \quad (11)$$

Where BD_rate_{VAR} and BD_rate_{STD} denote the variance and the standard deviation of BD_rate, respectively, as well as CT_{VAR} and CT_{STD} represent the variance and the standard deviation of coding time. BD_rate and coding time of each sequence are denoted by BD_rate_i and CT_i, as well as the average values of BD_rate and coding time are represented by BD_rate_{aver} and CT_{aver}. We examine the coding performance using 6 test sequences, so the letter "n" in the formulas above equals 6.

In Table 3, we can see, clearly, that whether the variance or the standard deviation, the BD-rate of our algorithm is lower than that of [2], and this result demonstrates that the performance of our algorithm in BD-rate aspect is more stable than that of [2]. However, in the aspect of coding time, both the variance and the standard deviation of coding time of our algorithm are considerably higher than those of [2], because our algorithm is highly-dependent on the content of an image. In the other word, if the texture of an image is complex, the coding time of our algorithm is long accordingly, and if the image has a large homogeneous area, the coding time of our algorithm will decline obviously. Therefore, our algorithm performs on simple sequence considerably higher than that on complex sequence.



(a) (b)

Figure 6. Detail of the Subjective Qualities of the 399th Frame in Sequence "Basketball Drive" (Solution is 1280×720 and QP is 32). (a) Processed by [2] Method. (b) Processed by Our Method

Because the proposed algorithm adopts early termination method which skips some unnecessary directional prediction modes, it is doubtless that the subjective quality of an image processed by our method is worse than that of the original method. But even under this circumstance, the image is still clear without influencing visual sense. Thus, we should compare our method to [2] through watching the result from the subjective quality of the sequence. Figure 5 describes subjective quality of 399th frame processed by our method and by method [2], respectively, on text sequence "Basketball Drive". It is obvious that the detail part, such as net part marked by the blue rectangle, in Figure 5(b) is clearer than that in Figure 5(a). In Figure 5(a), the net part has been distorted and audience cannot find out the lines of it, whereas the net part in Figure 5(b) is almost same as original image. The proposed algorithm takes advantage of the sobel operator in edge detection technology to decide the intra prediction mode, which can find out the best prediction direction accurately, so the detail of an image encoded by our algorithm is close to that of original image.

4. Conclusion

This paper proposes a new fast intra mode decision algorithm for HEVC intra prediction by taking advantages of sobel operator in edge detection technology to terminate the process of intra mode decision early and it only needs to consider 5 candidate modes from 33 angular modes by computing the gradient direction with sobel operator. The proposed algorithm is realized on HEVC test model 13.0 and rises only 1.6% BD-rate whose performance is close to that of original HEVC encoder. Furthermore, the proposed algorithm saves about 38.8% coding time, so it will be more appropriate for real-time application than original HEVC with the aid of specific hardware. Additionally, we consider that the sobel operator can be added from horizontal and vertical directional operators to more directional operators, such as 45° operator and 135° operator, which is aimed at selecting the best intra prediction mode more precisely than our proposed algorithm. Because of improving in this way, the method can speed up intra prediction process.

Acknowledgements

The authors would like to thank the editors and anonymous reviewers for their valuable comments. This work was supported in part by the National Natural Science Foundation of China under grant No. 61302118, 61401404, 61402422, and 61403349, the Scientific and Technological Project of Zhengzhou under Grant No.141PPTGG360, the Scientific and Technological Project of Henan Province under grant No. 14A520034, and in part by the Doctorate Research Funding of Zhengzhou University of Light Industry, under grants No. 2013BSJJ047.

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