Error Diffused Intra Prediction for HEVC

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ABSTRACT

HEVC uses up to 35 prediction modes for intra prediction and it can well predict blocks with uni-directional structures or sharp edges, but the intra prediction still suffers from its discontinuous characteristics. To improve coding performance of intra prediction, the inpainting technique has been studied but it is impractical because of its high computational complexity. In this paper, we employ error diffusion technique for HEVC intra prediction to improve its coding efficiency with reasonable increase in computational complexity. The experimental results show that the error diffusion technique outperforms the inpainting technique subjectively and objectively, especially with much lower computational complexity. The results demonstrate that average 0.5% BDBR reduction can be achieved in the proposed algorithm, compared to HEVC intra prediction.

***Index Terms*—**High efficiency video coding (HEVC), Intra prediction, Inpainting, Error diffusion

1. INTRODUCTION

The high efficiency video coding (HEVC) achieves better coding performance, compared to the previous coding standard H.264/AVC. This is due to that more complicated coding techniques are employed in HEVC. For example, HEVC extends intra prediction with block size up to 64x64 for mode decision instead of 16x16 macroblock and uses three hierarchical unit representations (including coding unit (CU), prediction unit (PU) and transform unit (TU)) to optimize the coding efficiency based on the quad-tree structure.

The intra prediction proposed in HEVC utilizes 35 prediction modes, including DC, planar and 33 angular prediction modes, as illustrated in Fig. 1. For DC mode, each predicted pixel $p_{x,y}$ is obtained by averaging both row and column reference pixels

$$p_{x,y} = (R_{0,1} + \cdots R_{0,N} + R_{1,0} + \cdots R_{N,0} + N)/2N$$

where $R_{i,j}$ are the reference pixels. For angular modes (modes 18 to 34), each predicted pixel $p_{x,y}$ is obtained by projecting its location to a row reference pixel using selected prediction direction and interpolating a value for the pixel at 1/32 pixel accuracy

$$p_{x,y} = ((32 - w_y) * R_{i,0} + w_y * R_{i+1,0} + 16) >> 5$$

with

$$c_y = (y * d) >> 5$$
$$w_y = (y * d) \& 31$$
$$i = x + c_y$$

where w_y represents the weighting between reference pixels $R_{i,0}$ and $R_{i+1,0}$, and w_y is calculated based on the projection displacement d for the selected prediction direction. Symbols >> and & denote the right bit shift operator and a bitwise AND operator, respectively. The predicted pixel is derived identically by just swapping the x with y coordinates for angular modes 2 to 17.

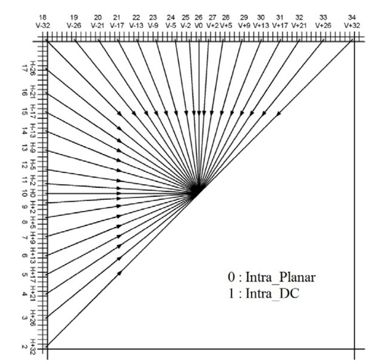


Fig. 1 35 intra prediction modes in HEVC

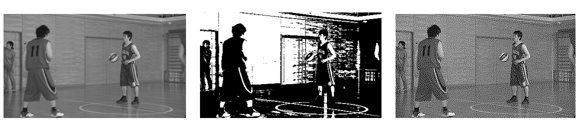
A video sequence usually has various characteristics and the intra prediction in HEVC with 35 prediction modes (including DC, planar and 33 angular prediction modes) predicts blocks well for those with directional structures or sharp edges. Due to its discontinuity property, HEVC intra prediction is not suitable to continuous regions. In addition, the intra prediction cannot perform well for complex contexts. This leads to bit rate increase.

To improve coding performance of intra prediction, the inpainting technique has been studied [1-2]. In [1], Doskkov et al. apply the inpainting technique using partial differential equations (PDEs) and patch-based texture synthesis to H.264/AVC intra to improve the coding performance. Qi et al. [2] uses total variation (TV) model for HEVC intra prediction. It is shown to be superior to PDE-based inpainting, but with much higher high computational complexity. The superiority of TV model over PDEs is that it provides better prediction for blocks with narrow broken edges, while PDE is suitable to predict smooth and homogeneous regions. The high computational complexity makes the inpainting technique impractical when applied to intra prediction.

In this paper, we apply error diffusion technique to HEVC intra prediction to improve its coding efficiency. The experimental results show that the error diffusion technique outperforms the inpainting technique in coding efficiency, especially with much lower computational complexity.

2. ERROR DIFFUSION FOR INTRA PREDICTION

The error diffusion algorithm has been widely used in digital halftoning or dithering technique that represents a continuous-tone image on display devices that can only produce finite elements. The algorithm was first proposed by Floyd et al. [3] that the error is diffused to the four neighboring pixels to achieve effects of continuous-tone illusion. Jarvis et al. [4] extended the diffusion mask to neighboring twelve pixels; while Stucki [5] modified the twelve-pixel mask with different weights. The pulling-error-forward and pushing-error-ahead processes in error diffusion can render the illusion of continuous-tone image well on finite-level display devices. Figure 2 shows the original gray-scale image converted into bi-level images using fixed threshold and error diffusion algorithms respectively. As can be seen, the error diffused image looks more pleasant, compared to fixed threshold image.



(a) (b) (c)

Fig. 2 (a) Original gray-scale image (b) Fixed threshold image (c) Error diffused image

Like the fixed threshold algorithm as shown in Fig. 2, HEVC intra prediction can preserve good sharp edges. However it performs poor on homogeneous or smooth regions, even it cannot illustrate complex contexts well. To improve the coding efficiency of HEVC intra prediction subjectively and objectively, in this section we suggest using the error diffusion technique on intra predicted blocks. The intra predicted block is error diffused from vertical and horizontal directions respectively, and the final error diffused predicted block is obtained by averaging these two diffused predicted blocks.

In the followings we only describe the vertical error diffusion algorithm for the intra predicted blocks and the horizontal algorithm is similar to the vertical algorithm. In the vertical error diffusion algorithm we first compute the vertical gradient of each pixel $\tilde{f}(i,j)$ in intra predicted blocks Ω:

$$G_{i,j} = \begin{cases} \tilde{f}(i,j) - \tilde{f}(i-1,j), \ if & \tilde{f}(i-1,j) \in \Omega \\ \tilde{f}(i,j) - UR(j), \ if & \tilde{f}(i-1,j) \notin \Omega \end{cases}$$

where $UR(j)$ represents the upper reference pixel. The intra predicted pixel is not error diffused if the absolute value of its gradient is less than the gradient threshold GT. Otherwise, it is error diffused, and the new pixel value $f(i,j)$ is given as followings:

$$f(i,j) = \begin{cases} \tilde{f}(i,j), & if \ |G_{i,j}| \leq GT \\ \tilde{f}(i-1,j) + \mathrm{sgn}(G_{i,j}) \times GT, & if \ |G_{i,j}| > GT \end{cases}$$

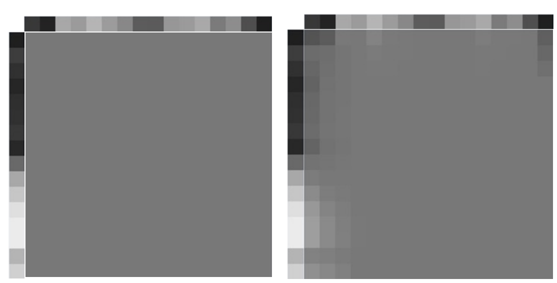
The error $e_{i,j}$ between $f(i,j)$ and $\tilde{f}(i,j)$ is then diffused to the eight neighboring pixels with different weights (modified from Stucki [5], as shown in TABLE I):

$$e_{i,j} = f(i,j) - \tilde{f}(i,j)$$
$$f(i+k, j+l) = f(i+k, j+l) + h(i+k, j+l) \times e_{i,j}$$

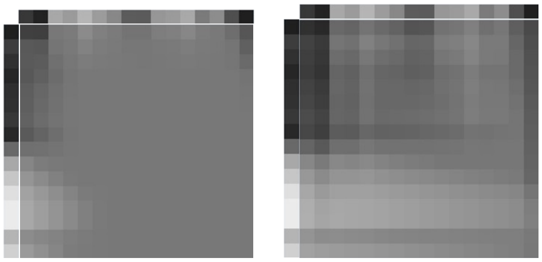
TABLE I ERROR DIFFUSION MASK

$h(i,j)$	8/33	4/33
8/33	4/33	2/33
4/33	2/33	1/33

The gradient threshold GT controls the smoothness of HEVC intra predicted blocks. The smaller the gradient threshold, the more smoothness the intra predicted blocks. The block is not diffused when the gradient threshold becomes infinite (i.e., $GT = \infty$). Figure 3 shows the error diffused predicted blocks for different gradient threshold GT in which the original block is intra predicted using HEVC DC mode. We assume the gradient threshold $GT = 20$ for further study.



(a) $GT = \infty$ (not diffused) (b) $GT = 40$



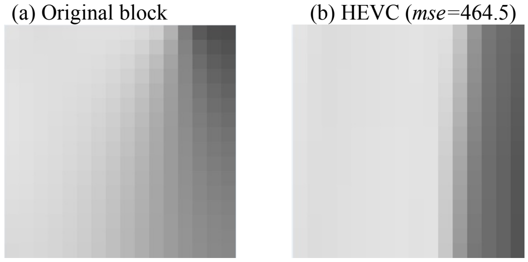
(c) $GT = 20$ (d) $GT = 5$

Fig. 3 Error diffused blocks for HEVC DC predicted block

3. PROPOSED INTRA PREDICTION WITH ERROR DIFFUSION TECHNIQUE

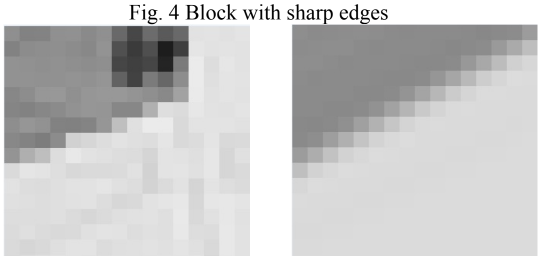
We compare the mean square error (*mse*) between predicted blocks and original blocks, conducted on *BasketballPass* and *Keiba* sequences. The results for blocks with different characteristics are shown in Figs. 4 and 5. For comparison purpose, the PDE-based inpainting technique is also demonstrated. As can be seen, HEVC performs the better for the block with sharp edges and uni-directions while the error diffused technique has the smallest *mse* for block with complex context. In addition, the error diffused block looks more pleasant than the others.

(a) Original block (b) HEVC (*mse*=464.5)

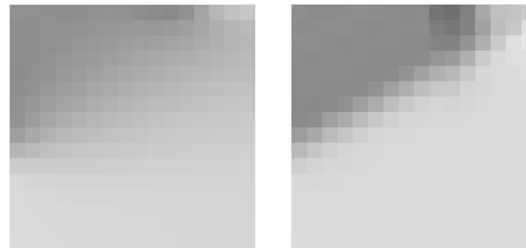


(c) Inpaint. (*mse*=1804.3) (d) Error Diff. (*mse*=1141.9)

Fig. 4 Block with sharp edges



(a) Original block (b) HEVC (*mse*=663.1)



(c) Inpaint. (*mse*=963.7) (d) Error Diff. (*mse*=461.2)

Fig. 5 Original block has complex context

The experimental results reveal following concluding remarks: blocks with smooth edge prefer error diffusion or inpainting technique while HEVC prediction is more suitable for blocks with sharp edge. The experiments also show that a large percentage of the final modes in error diffusion or inpainting are the same as in HEVC intra prediction or its two neighbors. This phenomenon indicates that performing all error diffusion or inpainting on all prediction modes is not necessary, and this can reduce great computation.

Based on these observations, we propose an improved HEVC intra prediction in which the error diffusion technique is incorporated into HEVC intra prediction. In the proposed algorithm we first perform HEVC intra prediction, and find the best prediction mode. Then we perform the error diffusion algorithm to the best predicted mode and its two neighboring modes, and choose the final prediction mode among these modes and that in HEVC, based on the rate-distortion optimization (RDO) cost function. The inpainting technique is incorporated into HEVC intra prediction in a similar way, but only performs on modes of small sizes (below 16x16) due to its high computational complexity.

4. EXPERIMENTAL RESULTS

We implement these algorithms into HEVC test model HM11.0rec1 to evaluate their performance. The experimental settings are summarized in TABLE II.

TABLE II EXPERIMENTAL SETTINGS

Software	HM11.0rc1
Configurations	Intra-only main
Internal bit depth	8
GOP structure	IIII. . . .
Frame number	100
Entropy coding	CABAC
QP	22,27,32,37
Test sequences	ClassA、ClassB、ClassC、ClassD、ClassE

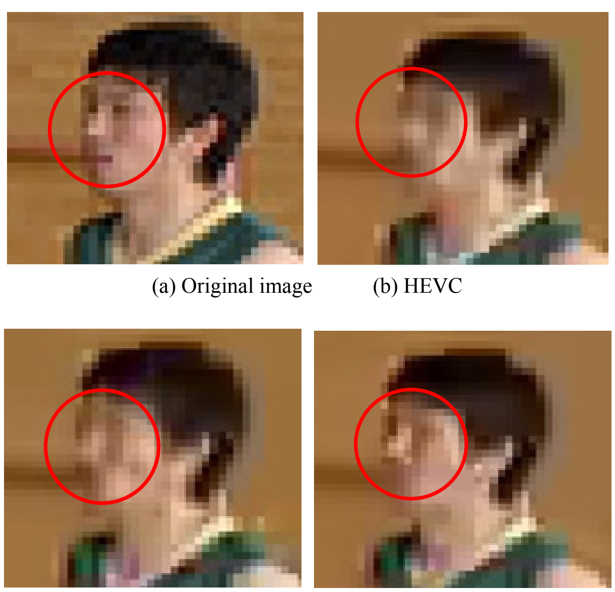
The performance is compared based upon Bjontegaard Delta Bit Rate (BDBR) for QP=22, 27, 32 and 37. TABLE

III displays the BDBR and BDPSNR results. The encoding time is also shown in the table for comparison. As demonstrated, both inpainting and error diffusion methods achieve average 0.25% and 0.5% bit rate reduction respectively, compared to HEVC intra prediction. The computational complexity of the inpainting technique is extremely high (17 times higher than HEVC) while the error diffusion technique only has 21% increase of encoding time, compared to HEVC.

We also compare their subjective performance, and the results are demonstrated in Figs. 6 and 7, tested on *BasketballPass* sequence. As shown, the error diffusion technique subjectively achieves the better performance, compared to the other algorithms.

TABLE III BDBR, BDPSNR AND TIME COMPARISONS

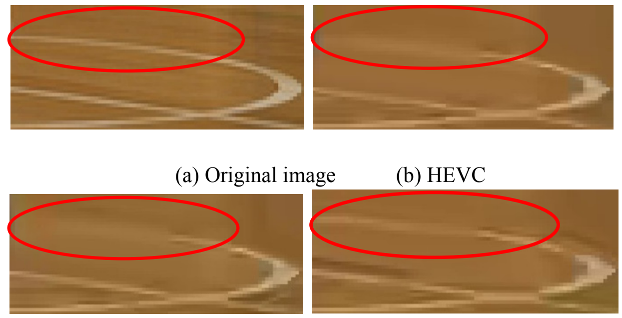
QP = 22, 27, 32, 37		BDBR(%)		BDPSNR(dB)		ΔTime(%)	
Sequence		Inpainting	Diffusion	Inpainting	Diffusion	Inpainting	Diffusion
Class A (2560x1600)	PeopleOnStreet	-0.394	-0.990	0.022	0.057	1804.688	22.248
	Traffic	-0.275	-0.550	0.015	0.030	1752.650	20.303
Class B (1920x1080)	BasketballDrive	-0.276	-0.527	0.008	0.015	1857.829	23.098
	Tennis	-0.533	-1.036	0.017	0.033	2076.602	23.353
	BQTerrace	-0.135	-0.344	0.009	0.021	1744.126	25.129
	Cactus	-0.307	-0.505	0.012	0.019	1641.468	20.513
	Kimono	-0.369	-0.386	0.013	0.014	1519.410	16.612
Class C (832x480)	Keiba	-0.295	-0.414	0.015	0.021	1721.509	21.080
	PartyScene	-0.191	-0.415	0.015	0.033	1342.829	21.537
	BasketballDrill	-0.164	-0.295	0.008	0.015	1403.098	17.135
	BQMall	-0.177	-0.406	0.011	0.024	1685.315	23.263
	RaceHorses	-0.230	-0.469	0.015	0.031	1509.528	20.794
Class D (416x240)	BQSquare	-0.158	-0.322	0.014	0.029	1341.356	20.710
	Flowervase	-0.191	-0.400	0.013	0.026	1775.823	20.000
	BlowingBubbles	-0.224	-0.504	0.014	0.031	1693.011	20.492
	Keiba	-0.160	-0.336	0.011	0.022	1693.01054	21.768
	RaceHorses	-0.242	-0.475	0.016	0.032	1526.821	20.561
	BasketBallPass	-0.217	-0.413	0.013	0.025	1795.183	22.096
Class E (1280x720)	Vidyo1	-0.444	-0.536	0.022	0.027	1984.619	20.344
	Vidyo3	-0.105	-0.580	0.006	0.033	2046.641	24.793
	Vidyo4	-0.336	-0.442	0.015	0.020	1960.111	21.543
Average		**-0.258**	**-0.493**	**0.013**	**0.027**	**1708.363**	**21.303**



(a) Original image (b) HEVC

(c) HEVC+Inpaint. (d) HEVC+Error Diff.

Fig. 6 Subjective comparison on *BasketballPass* sequence



(a) Original image (b) HEVC

(c) HEVC+Inpaint. (d) HEVC+Error Diff.

Fig. 7 Subjective comparison on *BasketballPass* sequence

5. CONCLUSION

In this paper, we propose an improved HEVC intra prediction algorithm using error diffusion technique to enhance the coding efficiency subjectively and objectively. In the proposed algorithm HEVC intra prediction is first performed to find the best prediction mode. Then the predicted blocks with the best mode and its two neighboring modes are error diffused and predicted again. The rate distortion optimization technique is then employed to select the best intra prediction among the original best mode and error-diffused predicted modes. Experimental results demonstrate that the proposed algorithm outperforms the algorithm using inpainting technique. In addition, the computational complexity is much lower than the inpainting technique. The results show that average 0.5% BDBR reduction is achieved with reasonable increase in computational complexity, compared to HEVC intra prediction.

6. REFERENCES

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