Improving Error-Diffused HEVC Intra Prediction

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Abstract — **In our previous work, an error-diffused intra prediction algorithm for HEVC was suggested to improve the coding performance. Tested on HM11.0rec1 the proposed algorithm achieves average 0.5% BDBR reduction with 21% increase in total encoding time, compared to the HEVC intra prediction. In this paper we modify the error-diffused algorithm to further improve its computation efficiency from three aspects. In the proposed algorithm, a smaller error-diffused mask is used and a direct gradient computation and error diffusion is employed to reduce computation instead of from both vertical and horizontal directions. In addition, the error diffusion algorithm is performed in the RMD process instead of RDO process. The experiment is evaluated on HM15.0, and the results reveal that average 0.6% BDBR reduction can be achieved in the proposed algorithm with only average 5% increase in encoding time compared to the HEVC intra prediction, and that is much lower than the original error diffusion algorithm.**

I. INTRODUCTION

The latest High Efficiency Video Coding (HEVC) standard developed by JCT-VC provides much better coding efficiency compared to priori coding standards such as H.264/AVC since more complicated techniques are used. The computational complexity however becomes very high. HEVC extends both inter and intra predictions with block size up to 64x64 for mode decision and uses three hierarchical unit representations (including coding unit (CU), prediction unit (PU) and transform unit (TU)) to optimize the coding performance based on the quad-tree structure. Instead of nine prediction modes used in H.264, the prediction unit in each CU utilizes 35 prediction modes, including DC, planar and 33 angular prediction modes. To reduce computational complexity, the intra mode decision first selects N modes among 35 modes based upon the rough mode decision (RMD) criterion with cost function given as

$$J_{RMD} = SATD + \lambda_{mode}{}^{1/2} \cdot R_{mode}$$
$$\lambda_{mode} = 0.57 \times 2^{(QP-12)/3}$$

The selected mode number N is dependent on block sizes, with N equal to 8 for block sizes of 4×4 and 8×8, and 3 for 16×16, 32×32 and 64×64.

To achieve the best coding performance, the rate distortion optimization (RDO) technique is then used to search the best mode among N modes as well as the most probable modes (MPM) by minimizing the RDO cost function

$$J_{RDO} = SSD + \lambda_{mode} \cdot R$$

Many researches have been investigated to improve coding performance of intra prediction [1-2]. Some algorithms [1] use inpainting techniques such as total variation (TV) model for HEVC intra prediction. It provides better prediction for blocks with narrow broken edges, but high computational complexity makes the inpainting technique impractical. Another algorithm [2] employs error diffusion technique on intra predicted block to improve its coding efficiency. It achieves 0.5% BDBR reduction with 21% increase in encoding time, compared to the HEVC intra prediction.

The computation time is still higher than the original HEVC intra prediction. In this paper, we modify the error diffusion technique to HEVC intra prediction from three aspects to improve its computation efficiency. In the new error diffusion algorithm a smaller error-diffused mask is used; and instead of both vertical and horizontal directions direct gradient computation and error diffusion are used to reduce computation. In addition, the error diffusion algorithm is performed in the RMD process instead of RDO process. The experimental results show that the new error diffusion technique significantly reduces the computational complexity with slightly better coding performance, compared to the original error diffusion technique.

II. REVIEW OF PREVIOUS WORK [2]

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 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, leading to more pleasant images. The HEVC intra prediction preserves good sharp edges, but it performs poor on homogeneous or smooth regions. It also cannot illustrate complex contexts well. To improve the coding efficiency of HEVC intra prediction, in [2] we employed the error diffusion technique on intra predicted blocks with following 3×3 mask modified from Stucki [3]:

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 intra predicted pixel is not error diffused if the absolute value of its gradient is less than a gradient threshold (*GT*=20). Otherwise, it is error diffused. 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 error diffusion algorithm we first perform HEVC intra prediction, and find the best prediction mode based on the rate-distortion optimization (RDO) cost function. 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, based on RDO.

III. PROPOSED ERROR DIFFUSION ALGORITHM

Although the error diffusion algorithm in our previous work is much more efficient in computation than the inpainting technique, the computation time is still higher (with 21% increase) than the original HEVC intra prediction. In this section, we modify the error diffusion technique from three aspects to further reduce its computational complexity. The modified error diffusion algorithm uses a smaller error-diffused mask (2×2 mask) with direct gradient computation and error diffusion to reduce computation. In addition, the new error diffusion algorithm is performed in the RMD process instead of RDO process.

A. 2×2 *Error Diffusion Mask*

In [4], Ostromoukhov proposed a simple and efficient error diffusion algorithm to generate computer graphics with good visual properties, in which the error is distributed to three instead of four neighbors. The computation is obviously faster than other error diffusion algorithms due to a smaller number of arithmetic operations and memory accesses. In this section we use the three-neighbor algorithm with 2×2 mask (given in TABLE II, modified from [4]) instead of 3×3 mask for the intra prediction.

TABLE II NEW ERROR DIFFUSION MASK

$h(i,j)$	8/20
8/20	4/20

The coding performance is compared on HEVC test model HM15.0 with 100 intra frames coded. The performance is compared based upon Bjontegaard Delta Bit Rate (BDBR) for QP=22, 27, 32 and 37. The results with first video sequences in each class are shown in TABLE III for comparisons. As can be seen the new 2×2 mask (noted as ED W/SM) can saves 5% of computation time compared to the original 3×3 mask [2] with comparable coding performance. The new mask even achieves better coding performance on *Basketball Pass* video sequence. The BDBR (BDPSNR) and computation time is compared to HEVC intra prediction. As shown, the error diffusion algorithm can save 0.6% bit rate.

TABLE III COMPARISON FOR DIFFERENT MASKS

QP=22,27,32,37		BDBR(%)		BDPSNR(dB)		ΔTime(%)	
Sequence		ED[2]	ED W/SM	ED[2]	ED W/SM	ED[2]	ED W/SM
ClassA	PeopleOnStreet	-1.121	-1.041	0.065	0.060	22.61	17.60
ClassB	BasketballDrive	-0.603	-0.571	0.017	0.016	23.89	18.74
ClassC	Keiba	-0.465	-0.391	0.024	0.020	22.81	18.88
ClassD	BasketballPass	-0.428	-0.440	0.025	0.026	23.17	19.40
ClassE	vidyo1	-0.654	-0.604	0.033	0.031	23.84	18.53
Average		**-0.654**	**-0.609**	**0.033**	**0.031**	**23.26**	**18.63**

B. Direct Gradient Computation and Error Diffusion

In the original error diffusion algorithm, the gradient is computed and the error is distributed from both vertical and horizontal directions respectively, and the final error diffused predicted block is obtained by averaging these two diffused predicted blocks. In this paper we calculate the gradient and diffuse the error directly. As a result, only half of computation is required in the proposed algorithm. The gradient is obtained by

$$G_{i,j} = \tilde{f}(i,j) - D(i,j)$$

with $D(i,j)$ defined as the average of the left and up pixels

$$D(i,j) = [\tilde{f}(i-1,j) + \tilde{f}(i,j-1)]/2$$

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. The new pixel value $f(i,j)$ is given by

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

The error $e_{i,j}$ between $f(i,j)$ and $\tilde{f}(i,j)$ is then distributed to neighboring pixels with different weights in the error diffusion mask.

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

We use the same tested video sequences as in TABLE III to investigate the effect of new gradient computation/error diffusion algorithm on both coding performance and computation time. The gradient threshold $GT = 20$ is assumed. The results are displayed in TABLE IV for comparison with same original 3×3 error diffusion mask used in the experiment. The results demonstrate that the direct gradient computation and error diffusion algorithm achieves better time saving with slightly better coding performance. Average 5% of total encoding time can be further reduced.

TABLE IV COMPARISON FOR DIFFERENT GRADIENT COMPUTATION/ERROR DIFFUSION

QP=22,27,32,37		BDBR(%)		BDPSNR(dB)		ΔTime(%)	
Sequence		ED[2]	ED W/DGC	ED[2]	ED W/DGC	ED[2]	ED W/DGC
ClassA	PeopleOnStreet	-1.121	-1.225	0.065	0.071	22.61	16.37
ClassB	BasketballDrive	-0.603	-0.593	0.017	0.017	23.89	18.23
ClassC	Keiba	-0.465	-0.431	0.024	0.022	22.81	17.78
ClassD	BasketballPass	-0.428	-0.513	0.025	0.030	23.17	18.20
ClassE	vidyo1	-0.654	-0.674	0.033	0.035	23.84	17.79
Average		**-0.654**	**-0.687**	**0.033**	**0.035**	**23.26**	**17.68**

C. Error Diffusion Performed in RMD Process

In the original error diffusion algorithm the error diffusion algorithm is performed on the best RDO-based predicted mode and its two neighboring modes, and the final best prediction mode is chosen among these modes, based on RDO process. The algorithm requires three more RDO operations compared to the HEVC intra prediction, in addition to computation in error diffusion process. As the RDO process involves the sum of squared differences (SSD) operation and truly encoded bit rate, it is quite time consuming.

To improve computation efficiency, in the proposed algorithm we perform the error diffusion algorithm on the RMD-based selected modes in which (8,8,3,3,3) modes are selected for block sizes of (4×4 , 8×8 , 16×16 , 32×32 , 64×64) respectively, as shown in Figure 1. The error diffusion algorithm is consecutively performed from the one with smallest RMD cost and only the final best N modes among 2N candidates are selected for next RDO computation. Note that the error diffusion is not performed on those modes not in the first N candidates and at most N error diffusion operation is required.

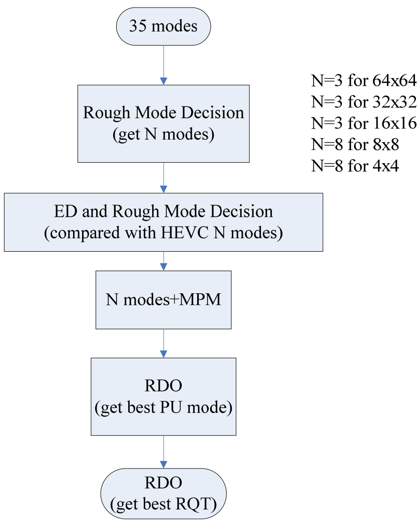


Figure 1 Modified error diffusion Algorithm

We compare coding performance and computation time on the same video sequences for algorithms performed in RDO process (original) and RMD process (proposed). The experimental results are shown in TABLE V. As shown, the proposed algorithm performed in RMD process is superior to the original one performed in RDO process on both coding performance and computation efficiency. The proposed algorithm has 15% increment in computation time while 23% for original algorithm, compared to the HEVC intra prediction. Both algorithms achieve 0.65% and 0.73% bit rate reduction.

TABLE V COMPARISON FOR ERROR DIFFUSION PERFORMED IN RDO PROCESS AND RMD PROCESS

QP=22,27,32,37		BDBR(%)		BDPSNR(dB)		ΔTime(%)	
Sequence		ED[2]	ED on RMD 2	ED[2]	ED on RMD 2	ED[2]	ED on RMD 2
ClassA	PeopleOnStreet	-1.121	-1.325	0.065	0.076	22.61	15.88
ClassB	BasketballDrive	-0.603	-0.624	0.017	0.017	23.89	14.78
ClassC	Keiba	-0.465	-0.485	0.024	0.025	22.81	15.89
ClassD	BasketballPass	-0.428	-0.584	0.025	0.034	23.17	13.41
ClassE	vidyo1	-0.654	-0.635	0.033	0.033	23.84	15.95
Average		**-0.654**	**-0.731**	**0.033**	**0.037**	**23.26**	**15.18**

IV. OVERALL PERFORMANCE COMPARISON

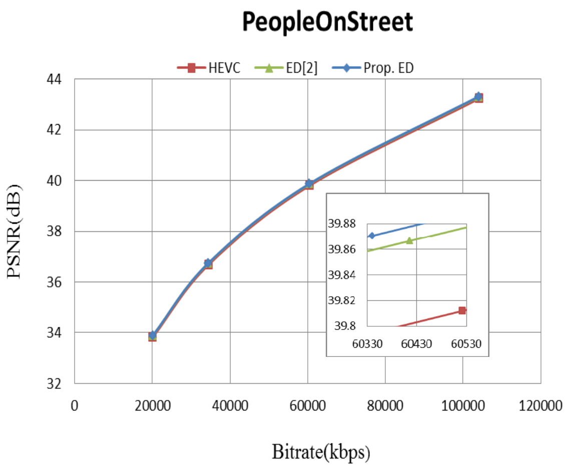
The overall performance for proposed algorithm and the original algorithm are displayed in TABLE VI, which is compared with HEVC intra prediction. All 21 video sequences in the five classes with different formats are tested in test model HM15.0 for QP=22, 27, 32 and 37. As demonstrated, the two error diffusion algorithms achieve average 0.6% and 0.55% bit rate reduction respectively, compared to HEVC intra prediction. The proposed algorithm achieves slightly better coding performance than the original error diffusion algorithm for most tested video sequences. The gain mainly comes from performing error diffusion in RMD process.

The results also reveal that the proposed algorithm only has 5% increase in encoding time, compared to HEVC; while 23% for the original algorithm. The 18% of computation time can further saved in the proposed algorithm, with 5% from using smaller mask and direct gradient computation/error diffusion respectively, and 8% from performing the error diffusion in the RMD process instead of RDO process.

The rate-distortion performance and computation time is also compared, tested on *PeopleOnStreet* sequence. The results are shown in Figure 2 with three curves compared in each figure, including HEVC, original error-diffused HEVC and proposed error-diffused HEVC. As shown, the proposed algorithm is superior to the original error-diffused HEVC in both rate distortion performance and computation time. The proposed algorithm only requires 7% increment in computation time, but with 1.3% bit rate reduction, compared to HEVC intra prediction.

TABLE VI BDBR, BDPSNR AND TIME COMPARISONS

QP=22,27,32,37		BDBR(%)		BDPSNR(dB)		ΔTime(%)	
Sequence		ED[2]	Prop. ED	ED[2]	Prop. ED	ED[2]	Prop. ED
Class A (2560x1600)	PeopleOnStreet	-1.121	-1.316	0.065	0.076	23.06	6.84
	Traffic	-0.626	-0.648	0.034	0.035	22.53	6.19
Class B (1920x1080)	BasketballDrive	-0.603	-0.593	0.017	0.016	23.90	5.07
	Tennis	-1.098	-0.940	0.035	0.030	23.47	5.77
	BQTerrace	-0.387	-0.593	0.024	0.037	25.81	5.30
	Cactus	-0.599	-0.693	0.023	0.026	22.28	5.31
	Kimono1	-0.396	-0.117	0.014	0.004	18.16	5.08
Class C (832x480)	Keiba	-0.465	-0.416	0.024	0.021	21.48	4.17
	PartyScene	-0.498	-0.651	0.039	0.051	22.42	4.27
	BasketballDrill	-0.317	-0.378	0.016	0.019	25.05	5.43
	BQMall	-0.471	-0.541	0.028	0.032	23.67	4.73
	RaceHorses	-0.515	-0.641	0.034	0.042	21.20	5.88
Class D (416x240)	BasketballPass	-0.428	-0.568	0.025	0.034	23.46	4.29
	BQSquare	-0.368	-0.547	0.033	0.049	24.05	6.05
	Flowervase	-0.441	-0.389	0.030	0.026	20.57	4.97
	BlowingBubbles	-0.550	-0.679	0.035	0.042	22.58	5.65
	Keiba	-0.398	-0.424	0.026	0.028	22.02	4.91
	RaceHorses	-0.536	-0.716	0.036	0.048	20.83	4.31
Class E (1280x720)	vidyo1	-0.654	-0.678	0.033	0.035	24.66	6.20
	vidyo3	-0.695	-0.710	0.039	0.040	24.64	5.72
	vidyo4	-0.509	-0.494	0.023	0.023	22.60	5.13
Average		**-0.556**	**-0.606**	**0.030**	**0.034**	**22.78**	**5.30**



(a) Rate distortion comparison

(b) Encoding time comparison

Fig. 2 Performance comparison on *PeopleOnStreet* sequence

V. CONCLUSION

The previous work suggested using an error-diffused intra prediction algorithm for HEVC to improve its coding performance. In this paper, we modify the previous work and propose an improved error-diffused HEVC intra prediction algorithm to improve the computation efficiency.

We reduce the computational complexity from three aspects: (i) use a smaller error-diffused mask (2×2 mask) instead of 3×3 mask, (ii) use direct gradient computation and error diffusion instead of gradient computation and error diffusion from vertical and horizontal directions respectively, and (iii) perform the new error diffusion algorithm in the RMD process instead of RDO process.

Experimental results reveal that the proposed algorithm outperforms the original error diffusion algorithm in both coding performance and computational complexity. The results show that average 0.6% BDBR reduction is achieved with reasonable increase (with 5% increase) in computational complexity, compared to HEVC intra prediction; while 0.55% bit rate reduction and 23% computation increase for the previous error diffusion algorithm. Improvement in bit rate reduction over the previous work greatly comes from performing the error diffusion in RMD process instead of RDO. The 18% improvement in computation time is with 5% from smaller mask and direct gradient computation/error diffusion respectively, and 8% from performing the error diffusion in the RMD process instead of RDO process.

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