Enhanced HEVC Intra Prediction with Ordered Dither Technique

Chien-Hung Chen and Yinyi Lin
Department of Communication Engineering
National Central University, Taiwan 32054, R.O.C.
Email: yilin@ce.ncu.edu.tw

ABSTRACT

In the previous work [2], we proposed an error diffused intra prediction for HEVC to improve its coding performance. The proposed algorithm can achieve average 0.5% BDBR reduction with 21% increase of encoding time, compared to the HEVC intra prediction. To further improve the computation efficiency, in this paper, we suggest incorporating ordered dither technique into HEVC intra prediction to reduce computational complexity, instead of error diffusion. The experimental results reveal that average 0.5% BDBR reduction can be achieved in the proposed algorithm and it brings out only an increase of average 4% of total encoding time compared to the HEVC intra prediction, and that is much lower than the error diffused intra prediction.

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

1. INTRODUCTION

As compared with H.264/AVC, 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 [1]. The prediction unit in each CU utilizes 35 prediction modes, including DC, planar and 33 angular prediction modes, as shown in Fig. 1.

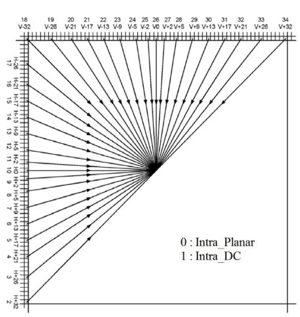


Fig. 1 35 intra prediction modes in HEVC intra prediction

To reduce computational load, in intra mode decision N modes among 35 modes are first selected based upon a rough mode decision (RMD) criterion with cost function given as

$$J_{RMD} = SATD + \lambda_{mode}^{1/2} \cdot R_{mode}$$

$$\lambda_{mode} = 0.57 \times 2^{(QP-12)/3}$$

where λ_{mode} is the Lagrange multiplier for mode decision and $SATD$ represents the sum of absolute Hadamard-transform differences between the current block and its constructed block. R_{mode} is the required bit number for each prediction mode; while QP is the quantization parameter. 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

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

where SSD is the sum of squared differences between the current block and its constructed block while R is the truly encoded bit rate. The final residual quad-tree (RQT) is eventually determined based on RDO procedure. The intra mode decision is summarized in Fig. 2.

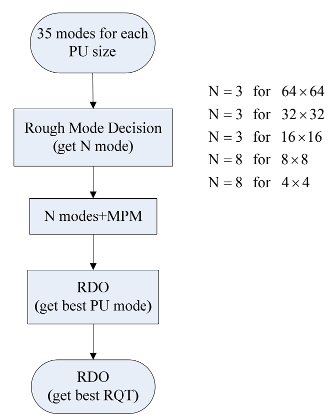


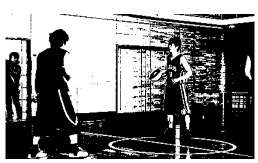
Fig. 2 HEVC intra mode decision

Although HEVC uses up to 35 prediction modes for intra prediction and well predict blocks with uni-directional structures or sharp edges, the intra prediction cannot perform in a good way for blocks with complex contexts, leading to bit rate increase. To improve coding performance of intra prediction, the inpainting technique has been investigated, using partial differential equations (PDEs) [3] or total variation (TV) model [4] for intra prediction. The inpainting technique becomes impractical due to its high computational complexity when applied to intra prediction. In the previous work, we have applied error diffusion technique to HEVC intra prediction to improve its coding efficiency. The experimental results demonstrated that the error diffusion technique outperforms the inpainting technique in coding efficiency, especially with much lower computational complexity. The error diffused algorithm implemented in HM11.0rec1 can achieve average 0.5% BDBR reduction with 21% increase of encoding time, compared to the HEVC intra prediction. In this paper, instead of error diffusion we suggest incorporating ordered dither technique into HEVC intra prediction to greatly reduce computational complexity, while maintaining good coding efficiency.

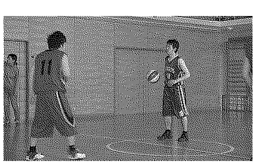
2. IMPROVING HEVC INTRA PREDICTION USING ORDERED DITHER TECHNIQUE

Digital halftoning is a technique that generates bi-level pixels to simulate a continuous-tone image and represents a continuous-tone image on display devices that can only produce finite elements. Current halftoning techniques include error diffusion, ordered dither, dot diffusion, constrained average, and piano curve, etc. [5]. The error diffusion and ordered dither are the two most widely used techniques. In error diffusion each pixel is compared with a threshold that is dependent on weighted errors diffused from previous image pixels; while in ordered dither each pixel is compared with a position-dependent threshold from a threshold matrix that repeats over the entire image. The error diffusion or ordered dither method generates more pleasant images, compared to images using fixed threshold, as can be seen in Fig. 3.

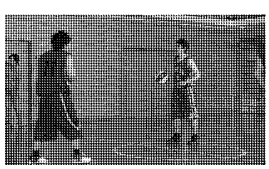
(a) Original image



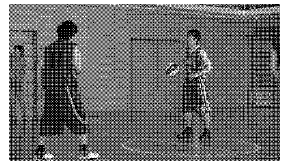
(b)Fixed threshold image



(c) Error diffused image



(d) Clustered ordered dither image



(e) Dispersed ordered dither image

Fig. 3 Subjective comparison on *Basketball* image

The HEVC intra prediction, like the fixed threshold algorithm, preserves good edges, but it cannot perform well on complex textures. To improve the coding efficiency of HEVC intra prediction subjectively and objectively, in previous work we suggested using error diffusion technique on HEVC 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.

The error diffusion is involved about pulling-error-forward and pushing-error-ahead processes and it requires several operations per pixel that cannot be processed in parallel. The ordered dither is a very simple and effective technique with non-recursive nature. Among all halftoning techniques, the ordered dither is perhaps the most efficient one with respect to computation costs and implementation. In this paper we suggest using the ordered dither method instead of error diffusion on HEVC intra prediction to improve its coding performance as well as its computation efficiency.

There are in general two main methods in ordered dither: clustered-dot and dispersed-dot [6]. The clustered-dot ordered dither turns pixels on that are adjacent to one another with thresholds forming a cluster within the threshold matrix. The dispersed-dot ordered dither turns pixels on individually without grouping them into clusters. In this paper for simplicity we only consider 4×4 16-level threshold matrix used in HEVC intra prediction. The two threshold matrices $T(i,j)$ for clustered-dot and dispersed-dot ordered dithers are shown in Fig. 4.

4	8	10	1
11	13	14	5
7	16	15	9
3	12	6	2

(a) Clustered-dot

1	9	3	11
13	5	15	7
4	12	2	10
16	8	14	6

(b) Dispersed-dot

Fig. 4 Ordered dither matrices $T(i,j)$

In the proposed algorithm we first perform HEVC intra prediction, and we use the ordered dither technique to each intra predicted pixel $\tilde{p}(i,j)$ within predicted blocks to improve its video quality. With ordered dither the new predicted pixel value $p(i,j)$ is given as

$$p(i,j) = \begin{cases} \tilde{p}(i,j), & if\ |g_{i,j}| \le GT \\ \tilde{p}(i,j) - \mathrm{sgn}(g_{i,j}) \times t_{i,j}, & if\ |g_{i,j}| > GT \end{cases}$$

where GT is the gradient threshold and $t_{i,j}$ is the position-dependent threshold element in $T(i,j)$, while $g_{i,j}$ represents the gradient which is defined as

$$g_{i,j} = \tilde{p}(i,j) - \tilde{p}(i-1, j-1)$$

The previous work [2] suggested performing the error diffusion on the best prediction mode determined by RDO cost function and its two neighboring modes. The algorithm then decides the best mode based upon RDO technique among these modes. As a result four more RDO procedures have to be performed. Since the RDO procedure involves about computation of truly encoded bit rate and is quite time consuming. To further reduce computational complexity, in the new proposed algorithm we perform the ordered dither algorithm on the *N* best modes determined by the rough mode decision (RMD), and choose the best *N* modes among these 2*N* modes (including *N* original modes and associated *N* ordered dither modes) based upon same RMD criterion. 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, which is the same as that proposed in HEVC intra mode decision, as illustrated in Fig. 2.

3. EXPERIMENTAL RESULTS

The coding performance and computation efficiency of the proposed algorithm are evaluated and compared on HEVC test model HM15.0. Many widely used test sequences with various formats are used in simulations, covering wide ranges of contexts. Each sequence with 100 frames is encoded using all I frame structures. Context-based adaptive arithmetic coding (CABAC) is employed as the entropy coding method. The performance is compared based upon Bjontegaard Delta Bit Rate (BDBR) for QP=22, 27, 32 and 37.

The optimal gradient threshold GT for ordered dither methods, that determines the smoothness of HEVC intra predicted blocks, is investigated before comparison. TABLE I tabulates BDPSNR performance versus various thresholds for dispersed-dot ordered dither with 4×4 16-level threshold matrix shown in Fig. 4, tested on some video sequences. A similar result is obtained for clustered-dot ordered dither method and omitted here. As shown, the threshold GT=20 gives the best performance and is used for further comparison. Note that the intra predicted block is not dithered when the gradient threshold is greater than 255.

TABLE I BDBR VERSUS GRADIENT THRESHOLD

QP=22,27,32,37		BDPSNR(dB)							
Sequence		GT=0	GT=10	GT=20	GT=25	GT=30	GT=40	GT=80	GT=256
ClassA	PeopleOnStreet	0.019	0.034	0.047	0.046	0.038	0.029	0.000	0.000
ClassB	BasketballDrive	0.001	0.006	0.007	0.009	0.009	0.009	-0.001	0.000
ClassC	Keiba	0.001	0.010	0.014	0.008	0.005	0.007	0.002	0.000
ClassD	BasketballPass	0.012	0.006	0.015	0.017	0.004	-0.003	-0.001	0.000
ClassE	vidyo1	0.009	0.012	0.024	0.024	0.015	0.015	-0.001	0.000
Average		**0.008**	**0.013**	**0.021**	**0.021**	**0.014**	**0.011**	**0.000**	**0.000**

TABLE II demonstrates BDBR results for all test sequences. The encoding time is also shown in the table for comparison. As shown, both error diffusion and ordered dither methods achieve average 0.6% and 0.5% BDBR reduction respectively, compared to HEVC intra prediction. Compared with error diffusion, the ordered dither method significantly improves the computational complexity with a saving of 19% total encoding time. The ordered dither only has average 4% increase of encoding time while 23% for error diffusion, compared to HEVC. The clustered-dot ordered dither achieves a better performance in both BDBR and computation time than the dispersed-dot ordered dither.

Comparisons of both rate-distortion performance and computational complexity are made between these methods for various *QP*s (22, 27, 32 and 37) conducted on *PeopleOnStreet* sequence, and demonstrated in Figs. 5 and 6. The results clearly reveal the superiority of error diffusion and ordered dither methods over HEVC intra prediction in rate-distortion performance. As also shown, more computation time can be saved (19% saving in encoding time) for ordered dither, compared to error diffusion.

To obtain further insight, we also compare their subjective performance, and the results are demonstrated in Fig. 7, tested on *PartyScene* sequence. As shown, all halftoning techniques (error diffusion and ordered dithers) can achieve better subjective performance, compared to HEVC intra prediction.

TABLE II BDBR AND COMPUTATION TIME COMPARISONS

QP=22,27,32,37		BDBR(%)			ΔTime(%)		
Sequence		ED[2]	Clus. OD	Disp. OD	ED[2]	Clus. OD	Disp. OD
Class A (2560x1600)	PeopleOnStreet	-1.121	-0.850	-0.777	23.06	3.90	4.65
	Traffic	-0.626	-0.391	-0.355	22.53	4.84	4.23
Class B (1920x1080)	BasketballDrive	-0.603	-0.523	-0.515	23.90	3.95	3.87
	Tennis	-1.098	-0.836	-0.823	23.47	4.07	4.12
	BQTerrace	-0.387	-0.454	-0.417	25.81	3.60	3.48
	Cactus	-0.599	-0.584	-0.554	22.28	4.04	4.10
	Kimono1	-0.396	-0.047	-0.057	18.16	3.38	3.14
Class C (832x480)	Keiba	-0.465	-0.380	-0.360	21.48	2.53	3.57
	PartyScene	-0.498	-0.621	-0.601	22.42	3.38	3.26
	BasketballDrill	-0.317	-0.325	-0.347	25.05	3.27	3.59
	BQMall	-0.471	-0.448	-0.452	23.67	3.56	3.35
	RaceHorses	-0.515	-0.548	-0.495	21.20	3.94	4.13
Class D (416x240)	BasketballPass	-0.428	-0.547	-0.529	23.46	3.48	3.97
	BQSquare	-0.368	-0.512	-0.512	24.05	4.32	4.15
	Flowervase	-0.441	-0.330	-0.275	20.57	2.73	3.71
	BlowingBubbles	-0.550	-0.639	-0.596	22.58	4.48	3.99
	Keiba	-0.398	-0.361	-0.335	22.02	3.28	3.42
	RaceHorses	-0.536	-0.667	-0.626	20.83	3.18	3.58
Class E (1280x720)	vidyo1	-0.654	-0.573	-0.516	24.66	4.18	5.01
	vidyo3	-0.695	-0.448	-0.444	24.64	3.98	4.61
	vidyo4	-0.509	-0.421	-0.384	22.60	3.79	3.95
Average		**-0.556**	**-0.500**	**-0.475**	**22.78**	**3.71**	**3.90**

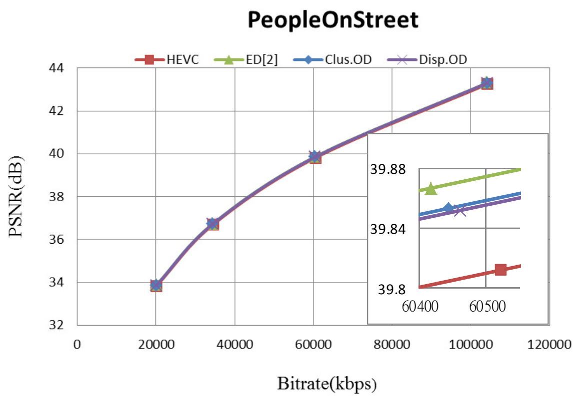


Fig. 5 Rate distortion performance

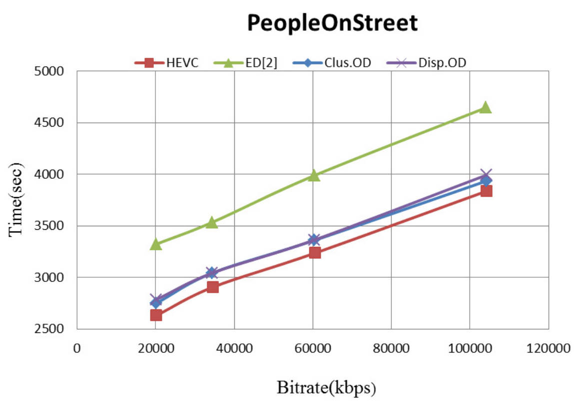
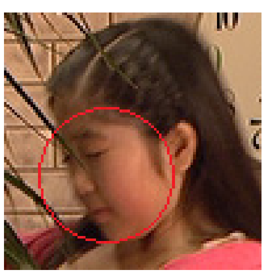
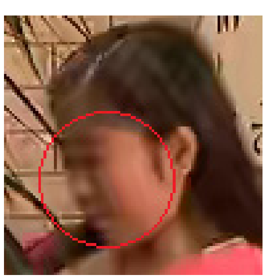


Fig. 6 Computation time

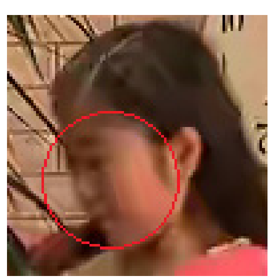


(a) Original image

(b) HEVC



(c) HEVC+Error Diff.



(d) HEVC+Clustered-dot

(e) HEVC+Dispersed-dot

Fig. 7 Subjective comparison on *PartyScene* sequence

4. CONCLUSION

In this paper, instead of error diffusion we suggest using ordered dither technique to enhance the coding efficiency of HEVC intra prediction. The proposed ordered dither method achieve similar improvement in coding performance but with much lower computation time, compared to error diffusion.

The results reveal that the ordered dither methods achieve average 0.5% BDBR reduction (0.6% for error diffusion), compared to HEVC intra prediction. The ordered dither only has average 4% increase of encoding time while 23% for error diffusion, compared to HEVC. The results also demonstrates that the clustered-dot ordered dither method achieves a better performance in both BDBR and computation time than dispersed-dot ordered dither.

5. REFERENCES

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