FAST AND EFFICIENT INTRA CODING TECHNIQUES FOR SMOOTH REGIONS IN SCREEN CONTENT CODING BASED ON BOUNDARY PREDICTION SAMPLES

Sik-Ho Tsang, Yui-Lam Chan, and Wan-Chi Siu

Centre for Signal Processing, Department of Electronic and Information Engineering
The Hong Kong Polytechnic University
Hung Hom, Kowloon, Hong Kong

ABSTRACT

This paper presents fast and efficient intra prediction algorithms for screen content coding (SCC). The proposed algorithms focus on smooth regions frequently appeared in screen content videos, which have the characteristics of noiselessness. All the samples in a noiseless smooth region exhibit exactly the same pixel value. We then propose two intra coding techniques for noiseless smooth regions in SCC based on the smoothness of the boundary samples which are used for intra prediction. Our proposed algorithm can reduce computational complexity by at most 26.7% while keeping nearly the same video quality. Moreover, by removing the redundant coding bits for intra prediction modes, computational complexity can be further reduced to at most 53.3% in terms of encoding time with bitrate reduction up to 1.2%.

***Index Terms*—** HEVC, Intra Prediction, Screen Content Coding, Smooth Region

1. INTRODUCTION

With the proliferation of thin-client devices as well as cloud technology, computer screen sharing applications such as remote desktop, virtual desktop, video conferencing with document sharing, slideshows sharing, etc., have become widespread nowadays [1]. As a result, new challenges on screen content coding (SCC) for limited network bandwidth has emerged as one of the hot research topics in the aspect of video coding. SCC has become an extension of High Efficiency Video Coding (HEVC) [2], related call for proposal (CfP) [3] has also been launched by ISO/IEC JTC1/SC29/WG11 and ITU-T SG16 Q6 in January 2014. An SCC test model [4] has also been developed recently, and final draft of the standard will be expected in 2015.

Screen content videos which are mainly generated by computers have different characteristics from natural videos taken by cameras. Natural videos are composed of image blocks which have continuous-tone characteristics, and they usually contain camera noise even in smooth regions. Conversely, screen content videos consist of image blocks, textual blocks and noiseless smooth blocks. For textual blocks, they have discontinuous-tone characteristics which contain a complex structure including sharp edges with high contrast. For noiseless smooth blocks, all the samples have the same value without any noise since they are computer-generated.

Numerous SCC research works have been done but they have been mainly focusing on the coding of textual blocks. Though textual blocks have many complex structures, they have limited number of colors. By making use of this feature, the work in [5-7] proposed a base color and index map (BCIM) or palette mode which divides a textual block into color data and structural data, and encode them separately. The color data consists of few major colors which are predicted from color table or from neighboring block whereas the structural data is represented by an index map. However, it is quite waste of bits to encode a noiseless smooth block by signaling the major colors and index map. Another SCC tool referred to as intra block copy (IntraBC) also proposed in [8-10]. This tool efficiently encodes the repeated patterns appeared within the same frame by performing intra motion estimation and compensation. However it is unreasonable to signal a block vector for noiseless smooth blocks.

In HEVC, 35 intra prediction modes are defined for predicting the block based on the neighboring boundary samples [2,11]. It provides high compression efficiency for image blocks as well as noiseless smooth blocks. However, the one Most Probable Mode (MPM) index or one remaining mode is still required for coding noiseless smooth region. While there were research works [12-14] for coding smooth regions, their purpose is only for natural video coding and depth image coding where smooth blocks always contain camera noise or depth estimation noise which is not the case in SCC.

Therefore, Chen *et. al* [15] proposed a new mode called single color mode recently. If the single color mode is used for a particular coding unit (CU), a sample candidate list is derived from boundary samples. Zhang *et. al* [16] introduced an Independent Uniform Prediction (IUP) mode at CU level, a set of commonly used colors is found out at slice level to derive a candidate list. Both [15-16] choose a sample from the list to fill in the whole CU. The one obtaining the smallest rate distortion (RD) cost is chosen as the optimal candidate. As a consequence, one additional signaling flag and one associated candidate index are coded at CU level to indicate the use of these two modes.

In this paper, we propose to encode noiseless smooth CUs in a faster and efficient way. We start by introducing the conventional intra prediction modes in HEVC. We then proceed to present how we encode noiseless smooth CUs with faster encoding speed and redundant rate removal. Finally, experimental results for our proposed scheme are shown followed by conclusions.

2. INTRA PREDICTION IN HEVC

In HEVC [2,11], there are 1 DC, 1 planar, and 33 directional prediction modes which form 35 intra predictions modes in total. In addition, 2N×2N and N×N prediction are supported for each CU size in order for more flexible intra prediction. Nevertheless, for each sample s_j in CU, it is predicted by boundary samples p_i shown in Fig. 1.

To reduce the computational complexity of testing all 35 intra prediction modes by RD optimization (RDO), rough mode decision (RMD) [17] is applied to select a subset of candidate modes with lower RD costs by sum of absolute differences of Hadamard transformed coefficients. Then RDO is performed for that subset of candidate modes to choose the optimal one.

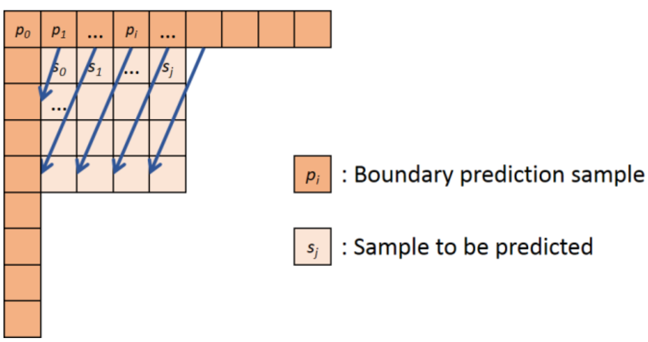

Fig. 1. Illustration of intra prediction for an CU in HEVC using boundary samples.

3. PROPOSED SIMPLE INTRA PREDICTION WITH REDUNDANT BITS REMOVAL

Intra prediction in HEVC is a very efficient intra coding tool for natural videos as there is high spatial correlation between pixels. Nevertheless, considering the case of coding noiseless smooth CUs in SCC, it is found that all boundary samples, p_i, are exactly having the same value, i.e.:

$$p_i = p_{i-1} \quad \forall p_i \in \{P \mid i \geq 1\} \tag{1}$$

where P is the set of boundary samples for CU. Then, all 35 intra prediction modes provides the same predicted samples for that particular CU. Thereby, RMD and RDO processes are totally redundant. Moreover, the MPM index or the remaining mode coded for that CU is also redundant. It is noted that a block candidate is defined as B_{SB}, if condition (1) is satisfied.

3.1. Analysis of noiseless smooth regions

As intra prediction in HEVC depends on the size of transform unit (TU) and the range of TU size is from 4x4 to 32x32, the percentage of noiseless smooth non-overlapping rectangular blocks of different sizes from 4x4 to 32x32 are shown in Fig. 2. Herein we define a block candidate as noiseless smooth blocks, B_{SC}, if the following condition is satisfied:

$$s_j = s_{j-1} \quad \forall s_j \in \{S \mid j \geq 1\} \tag{2}$$

where s_j and S are the samples to be predicted and the corresponding set respectively. In Fig. 2, "BasketballDrillText" and "ChinaSpeed" are the sequences with large amounts of natural videos and computer graphic respectively, the probability of containing noiseless smooth blocks within the sequence, $P(B_{SC})$, are very low. Whereas, for the other sequences, $P(B_{SC})$ are relatively much higher which can be up to 65%. The reason is that these sequences are captured screen contents, which comprise map, document or slideshow, and they contain large amount of noiseless smooth regions. From Fig. 2, another observation is that, higher $P(B_{SC})$ is obtained in the smaller block size.

Furthermore, the conditional probability of all samples within the blocks are equal (i.e. condition in (2)) given that all boundary samples are equal (i.e. condition in (1)), $P(B_{SC}|B_{SB})$, is also investigated and depicted in Fig. 3. It is observed that there are very high correlations between pixels within the block and boundary pixels even for large block size in which $P(B_{SC}|B_{SB})$ can be achieved up to 99%.

Based on the analysis of boundary samples for noiseless smooth regions, two techniques are proposed in this paper. One is Simple Intra Prediction (SIP) for speeding up the encoding process, and the other is Redundant Bits Removal (RBR) for improving the coding efficiency.

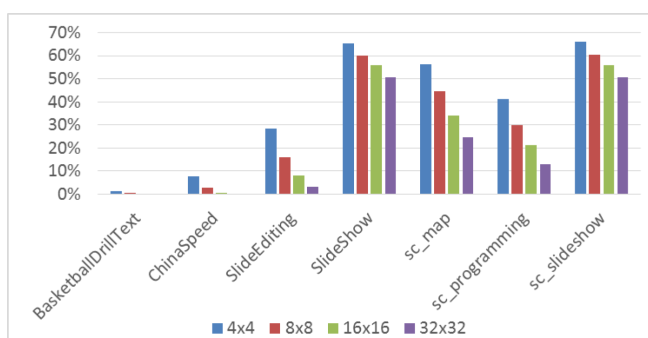

Fig. 2. Percentage of noiseless smooth blocks.

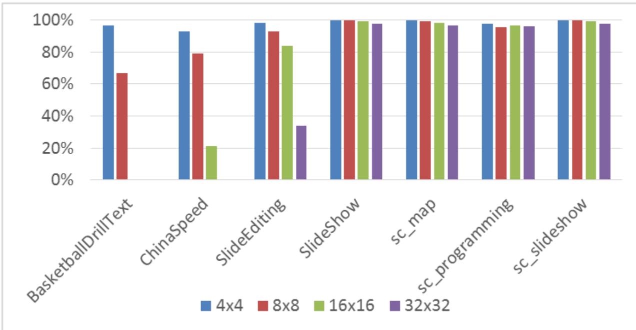

Fig. 3. Percentage of noiseless smooth blocks given that boundary samples are equal.

3.2. Simple Intra Prediction (SIP)

When the boundary samples of the current CU satisfy (1), all samples within the predicted CU can be filled by the boundary samples with the MPM index selected. Therefore, RMD and RDO processes [17] mentioned in Section 2 can be skipped. Besides, intra reference smoothing [2,18] for boundary samples can also be skipped since values of all boundary samples are exactly the same.

When the distortion of predicted CU is equal to zero, the predicted CU is perfectly reconstructed as it is a noiseless smooth CU. Early termination can also be achieved by skipping the testing of the palette mode [7] and the IntraBC mode [8-9] to further reduce the complexity of encoder. Fig. 4 shows the flowchart of our proposed SIP. It is noted that SIP is conformed to the HEVC standard.

3.3. Redundant Bits Removal (RBR)

Since only single intra prediction mode is utilized in SIP, MPM index or the remaining prediction mode are redundant to be coded for noiseless smooth CUs. We propose to skip the coding of MPM index or the remaining prediction mode if boundary samples satisfy (1). Hence, no additional signaling bits are required to code the noiseless smooth CU as compared with [15,16].

Thus, the CU syntax is adaptively changed according to the smoothness of boundary samples. At the decoder side, to decode a CU which is coded by the conventional intra prediction, boundary samples should be reconstructed first in order to determine whether RBR is used for that particular CU. Fig. 5 illustrates the decoding process of CUs in which bitstreams are encoded using RBR.

4. EXPERIMENTAL RESULTS

To evaluate the performance of the proposed algorithms, we perform simulation on the testing sequences “BasketballDrillText” (832x480), “ChinaSpeed” (1024x768), “SlideEditing” (1280x720), and “SlideShow” (1280x720) which belong to Class F YCbCr 4:2:0 standard test sequences for SCC [19], as well as sc_map (1280x720), sc_programming (1280x720), and sc_slideshow (1280x720) which are RGB/YCbCr 4:4:4 standard test sequences for SCC [20]. We have integrated our proposed SIP and RBR into the screen content coding test model of the HEVC reference software HM-15.0+RExt-8.0+SCM-2.0 (Hereby SCM-2.0) [4]. All experiments were conducted with all-intra (AI) SCC configuration with IntraBC with fast search enabled [9] and palette mode enabled [7] using quantization parameters (QP) of 22, 27, 32 and 37. The experiments were performed on a computer with Intel Core i7-4770 3.39GHz CPU and 8GB RAM.

TABLE I tabulates the experimental results for all testing sequences using Bjontegaard delta PSNR (BDPSNR), Bjontegaard delta bitrate (BDBR) [21] and delta encoding

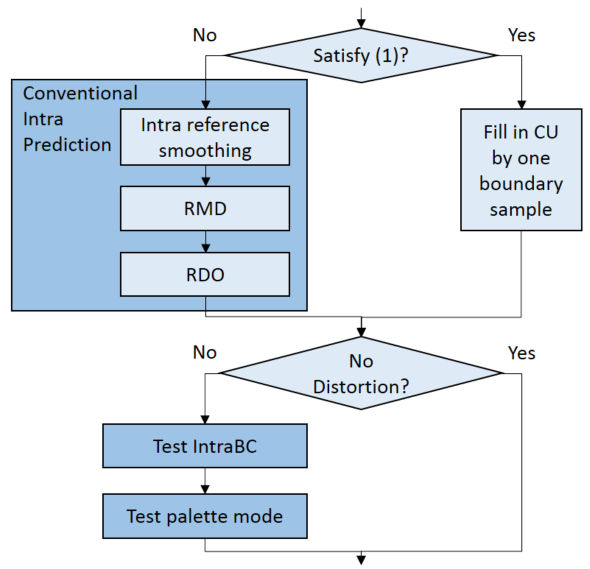

Fig. 4. Flowchart of Simple Intra Prediction (SIP).

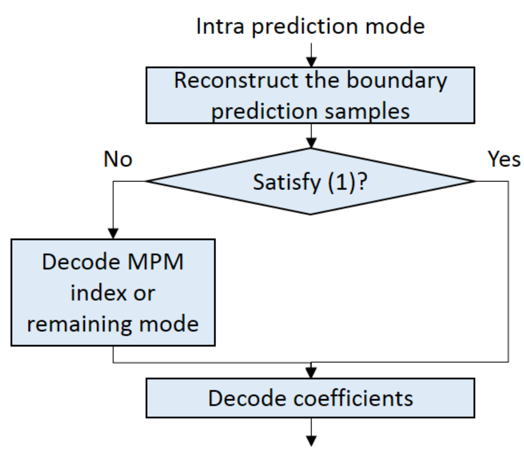

Fig. 5. Flowchart of decoding CU for bitstreams encoded using Redundant Bits Removal (RBR).

TABLE I
BDPSNR, BDBR, and delta encoding time of SIP and SIP+RBR against the conventional SCM-2.0.

Sequences	SIP			SIP + RBR		
	BDPSNR (dB)	BDBR (%)	ΔTime (%)	BDPSNR (dB)	BDBR (%)	ΔTime (%)
YUV 4:2:0						
BasketballDrillText	-0.001	0.022	-1.383	0.013	-0.264	-0.413
ChinaSpeed	-0.004	0.052	-1.181	0.028	-0.412	-0.891
SlideEditing	0.001	-0.013	-2.780	0.038	-0.360	-2.357
SlideShow	-0.016	0.197	-26.683	0.088	-1.241	-26.785
Average	-0.005	0.064	-8.007	0.042	-0.570	-7.612
YUV 4:4:4						
sc_map	-0.021	0.251	-8.068	0.050	-0.558	-7.695
sc_programming	-0.037	0.391	-6.065	0.019	-0.202	-5.570
sc_slideshow	-0.003	0.033	-25.891	0.080	-1.213	-30.149
Average	-0.020	0.225	-13.341	0.050	-0.658	-14.472
RGB						
sc_map	-0.039	0.363	-17.228	0.004	-0.021	-17.347
sc_programming	-0.021	0.195	-17.499	-0.001	0.014	-17.221
sc_slideshow	-0.015	0.193	-47.997	0.016	-0.222	-53.261
Average	-0.025	0.250	-27.574	0.006	-0.076	-29.277

time (ΔTime) of our proposed SIP and SIP+RBR against the conventional SCM-2.0. For the proposed SIP, encoding time can be reduced by up to 48.0% while only negligible loss in PSNR of at most 0.039dB or increase in bitrate of 0.39%. We can observe that SIP is a fast intra coding approach with nearly no loss in video quality. For the proposed SIP+RBR, encoding time can be reduced by up to 53.3% as well as with at most 0.088dB PSNR improvement, or equivalently 1.2% bitrate reduction. As $P(B_{SC}|B_{SB})$ is very high, up to 99%, it is valuable to improve the coding efficiency for noiseless smooth regions. It is noted that for RGB testing sequences, the speed up is much larger than YUV 4:4:4 testing sequences. This is because our proposed algorithms would also skip the additional in-loop color transform [22] in the conventional intra prediction which provides much higher coding efficiency for RGB testing sequences.

5. CONCLUSIONS

In this paper, we presented a fast intra coding approach for noiseless smooth regions in screen content coding. Based on the statistical analysis of the boundary samples and the samples of noiseless smooth blocks, SIP is designed to speed up the encoding process by skipping the RMD and RDO as well as skipping the palette mode and IntraBC mode when distortion of the predicted block is equal to zero. Furthermore, redundant intra coding bits are removed for noiseless smooth blocks using RBR. Experimental results show that the proposed techniques can speed up the encoder while improving the coding performance for SCC. As the computational power is increased at the decoder side nowadays, we believe that making use of statistics of reconstructed data, such as boundary samples in this paper, could be the next stage to further improve the compression efficiency against HEVC.

6. ACKNOWLEDGEMENT

The work described in this paper is partially supported by the Centre for Signal Processing, Department of Electronic and Information Engineering, The Hong Kong Polytechnic University, and a grant from the Research Grants Council of the Hong Kong Special Administrative Region, China (Grant No. PolyU 5119/13E).

7. REFERENCES

[1] Y. Lu, S. Li, and H. Shen, "Virtualized screen: A third element for cloud-mobile convergence," *IEEE Multimedia*, vol. 18, no. 2, pp. 4–11, February 2011.

[2] G. J. Sullvian, J. Ohm, W.-J. Han, and T. Wiegand. "Overview of the High Efficiency Video Coding (HEVC) standard," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 22, no. 12, pp. 1649-1668, December 2012.

[3] "Joint Call for Proposals for Coding of Screen Content," *ISO/IEC JTC1/SC29/WG11*, MPEG2014/N14175, San Jose, U.S.A., January 2014.

[4] R. Joshi, J. Xu, R. Cohen, S. Liu, Z. Ma, and Y. Ye, "Screen Content Coding Test Model 2 Encoder Description (SCM 2)," *JCT-VC of ITU-T SG 16 WP 3 and ISO/IEC JTC1/SC29/WG11*, JCTVC-R1014, Sapporo, Japan, June-July 2014.

[5] Z. Pan, H. Shen, Y. Lu, S. Li, and N. Yu, "A Low-Complexity Screen Compression Scheme for Interactive Screen Sharing," *IEEE Trans. Circuits Syst. Video Technol.*, vol.23, no.6, pp. 949-960, June 2013.

[6] W. Zhu, W. Ding, J. Xu, Y. Shi, and B. Yin, "Screen Content Coding Based on HEVC Framework," *IEEE Trans. Multimedia*, vol.16, no.5, pp. 1316-1326, August 2014.

[7] Z. Ma, W. Wang, M. Xu, and H. Yu, "Advanced Screen Content Coding Using Color Table and Index Map," *IEEE Trans. Image Process.*, vol.23, no.10, pp. 4399-4412, October 2014.

[8] M. Budagavi, and D.-K. Kwon, "Intra motion compensation and entropy coding improvements for HEVC screen content coding," in *Proc. of Picture Coding Symposium (PCS)*, pp. 365-368, San Jose, U.S.A., December 2013.

[9] M. Budagavi, and D.-K. Kwon, "Fast intra block copy (IntraBC) search for HEVC screen content coding," in *Proc. of IEEE International Symposium on Circuits and Systems (ISCAS)*, pp. 9-12, Melbourne, Australia, June 2014.

[10] C.-C. Chen, X. Xu, R.-L. Liao, W.-H. Peng, S. Liu, and S. Lei, "Screen content coding using non-square intra block copy for HEVC," in *Proc. of IEEE International Conference on Multimedia and Expo (ICME)*, pp. 1-6, Chengdu, China, July 2014.

[11] X. Zhang, S. Liu, and S. Lei. "Intra mode coding in HEVC standard," in *Proc. of IEEE Visual Communications and Image Processing (VCIP)*, pp. 1-6, San Diego, U.S.A., November 2012.

[12] D.-Y. Kim, K.-H. Han, and Y.-L. Lee, "Adaptive Single-Multiple Prediction for H.264/AVC Intra Coding," *IEEE Trans. Circuits Syst. Video Technol.*, vol.20, no.4, pp. 610-615, April 2010.

[13] S.-H. Tsang, Y.-L. Chan, and W.-C. Siu, "Efficient intra prediction algorithm for smooth regions in depth coding," *IET Electronics Lett.*, vol.48, no.18, pp.1117-1119, August 2012.

[14] L.-L. Wang, and W.-C. Siu, "Novel Adaptive Algorithm for Intra Prediction With Compromised Modes Skipping and Signaling Processes in HEVC," *IEEE Trans. Circuits Syst. Video Technol.*, vol.23, no.10, pp. 1686-1694, October 2013.

[15] Y.-W. Chen, Y.-C. Sun, Y.-W. Huang, and S. Lei, "SCCE3 Test D.1: Single color intra mode for screen content coding," *JCT-VC of ITU-T SG 16 WP 3 and ISO/IEC JTC1/SC29/WG11*, JCTVC-R0058, Sapporo, Japan, June-July 2014.

[16] X. Zhang, and R. Cohen, "SCCE3 Test D.2: Independent Uniform Prediction (IUP) Mode," *JCT-VC of ITU-T SG 16 WP 3 and ISO/IEC JTC1/SC29/WG11*, JCTVC-R0200, Sapporo, Japan, June-July 2014.

[17] Y. Piao, J. Min, and J. Chen, "Encoder improvement of unified intra prediction," *JCT-VC of ITU-T SG 16 WP 3 and ISO/IEC JTC1/SC29/WG11*, JCTVC-C207, Guangzhou, China, October 2010.

[18] G. Van der Auwera, X. Wang, and M. Karczewicz, "CE6.e: Mode-Dependent Intra Smoothing Modifications," *JCT-VC of ITU-T SG 16 WP 3 and ISO/IEC JTC1/SC29/WG11*, JCTVC-F126, Torino, Italy, July 2011.

[19] C. Rosewarne, K. Sharman, and D. Flynn, "Common test conditions and software reference configurations for HEVC range extensions," *JCT-VC of ITU-T SG 16 WP 3 and ISO/IEC JTC1/SC29/WG11*, JCTVC-P1006, San Jose, U.S.A., January 2014.

[20] H. Yu, R. Cohen, K. Rapaka, and J. Xu, "Common conditions for screen content coding tests," *JCT-VC of ITU-T SG 16 WP 3 and ISO/IEC JTC1/SC29/WG11*, JCTVC-R1015, Sapporo, Japan, June-July, 2014.

[21] G. Bjontegaard, "Calculation of average PSNR differences between RD curves," *Video Coding Experts Group (VCEG)*, VCEG-M33, Austin, Texas, U.S.A., April, 2001.

[22] L. Zhang, J. Chen, J. Sole, and M. Karczewicz, "SCCE5 Test 3.2.1: In-loop color-space transform," *JCT-VC of ITU-T SG 16 WP 3 and ISO/IEC JTC1/SC29/WG11*, JCTVC-R0147, Sapporo, Japan, June-July 2014.