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A Sample Adaptive Offset Early Termination Method for HEVC Parallel Encoding

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Abstract

We propose a slice-level SAO on-off control method that can be applied in the parallel HEVC encoding scheme. To be applied in the parallel encoding scheme, our method does not use any information from the previous encoded frames. Our method uses the GOP level and slice quantization parameter, which are given before starting the current frame encoding. Our experimental results shows that our method can control SAO on-off in the slice level with very small amount of loss than the method that is hardly employed in the parallel encoding scheme.

Introduction

High Efficiency Video Coding (HEVC/H.265) [1] is a new video coding standard that is followed by advanced video coding (AVC/H.264) [2] standard. Since HEVC is known as high compression ratio compared to the previous standard, multimedia market players are interested in applying the HEVC technique to their products. Although HEVC has achieved a half bit rate reduction, the encoding complexity has significantly increased compared to AVC. For example, the average time to encode one frame of the 4K resolution video, “ReadySetGo”, is 265 second. The high time complexity causes a high barrier to be adopted in the multimedia market and many researchers focus on fast encoding while maintaining the minimum distortion. To achieve the goal, exploiting thread-level parallelism is widely chosen mechanism since multi-threading is commonly supported based on the multi-core computer architecture.

Many parallelism approaches for video codecs have been published [3, 4, 5, 6]. In general, the video codec parallelism uses the encoding unit such as IDR (instantaneous decoding refresh) period, GOP (group of picture), frame-level, slice-level, and tile-level.

Sample adaptive offset (SAO) is a newly-added in-loop filter tool in HEVC to reduce the various artifacts [7]. Since SAO is designed to perform right before the end of frame-level encoding, SAO is not applied in many frame-level parallel encoding schemes. In this paper, we propose a fast SAO method that can be used with frame-level parallel encoding scheme.

Background

SAO is a tool to reduce the distortion caused from the encoding process. SAO is known as a tool to enhance visual quality and remove ringing artifact [7]. The key idea of SAO is signaling the distortion between the original image and the reconstructed image to the decoder. To reduce the side information to signal, the representative distortion of CTB is sent. To obtain the efficient representative, the CTB (Coding tree block) is categorized. Fig 1 illustrates the HEVC encoding process. SAO is performed after the deblocking filtering process.

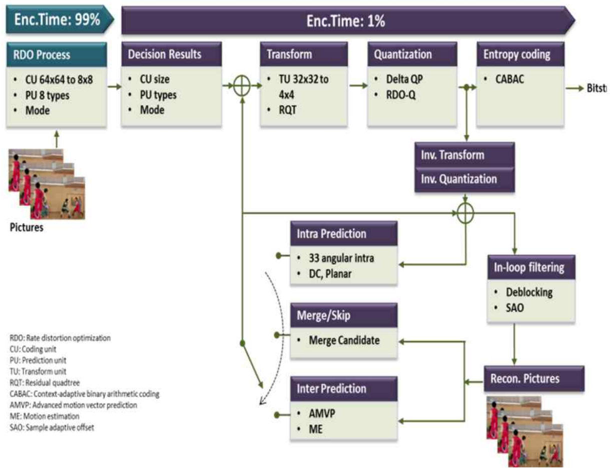

Figure 1. Block diagram of HEVC encoder.

Two SAO Types

Note that the unit of SAO is CTB. For a given CTB, the rate-distortion is calculated among three SAO modes: EO, BO, and none SAO coding. SAO uses two types of offset, edge offset (EO) and band offset (BO). Edge offset categorizes the given CTB by comparison between the current sample and the neighboring samples. Band offset categorizes the given CTB by the sample values.

Edge Offset

EO has four classes based on the sample direction to examine: horizontal, vertical, 135° diagonal, 45° diagonal. Fig. 2 presents the direction of the classes. For a given CTB, one class is selected based on a rate-distortion optimization. For one class, each sample in CTB is fall into five categories: four categories and none as shown in Table 1 and Fig. 3.

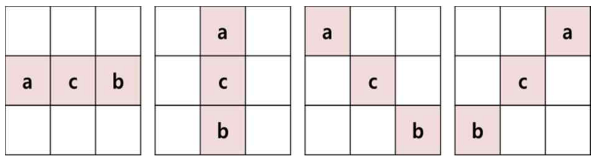

Figure 2. Four EO classes: horizontal, vertical, 135° diagonal and 45° diagonal class.

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Table 1. EO category classification condition

Category	Condition
1	$c < a \;\&\&\; c < b$
2	$(c < a \;\&\&\; c == b) \,\|\|\, (c == a \;\&\&\; c < b)$
3	$(c > a \;\&\&\; c == b) \,\|\|\, (c == a \;\&\&\; c > b)$
4	$c > a \;\&\&\; c > b$
0	None of above

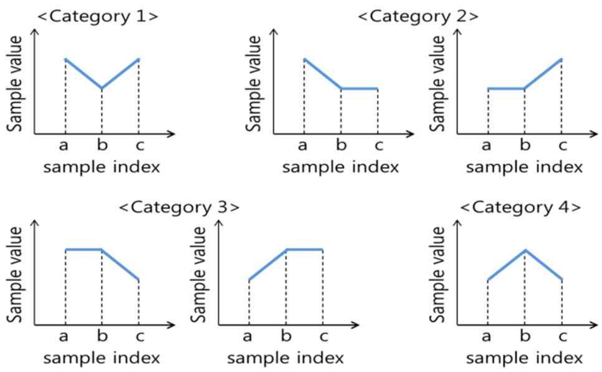


Figure 3. EO categories.

After assigning a category for the given the sample, the representative distortion value for each category is calculated. The representative distortion α:

$$\boldsymbol{\alpha} = \sum (\hat{\boldsymbol{x}} - \boldsymbol{x}).$$

The SAO filtered CTB for the given class, the representative distortion of each category is added to the given sample. The rate-distortion cost can be calculated for the class. For remaining classes, the same process is repeated and the class having the minimal cost is selected.

Band Offset

To obtain the band offset (BO), the samples in CTB is first categorized into 32 sample bands and then the difference is obtained between the original sample and reconstructed sample. The average difference is calculated as through the sample in CTB. As a result, the first band position and the four consecutive bands are signaled to the decoder. BO is selected if the rate-distortion cost is lower than the one of the selected EO class. The example of BO band is shown in Fig. 4.

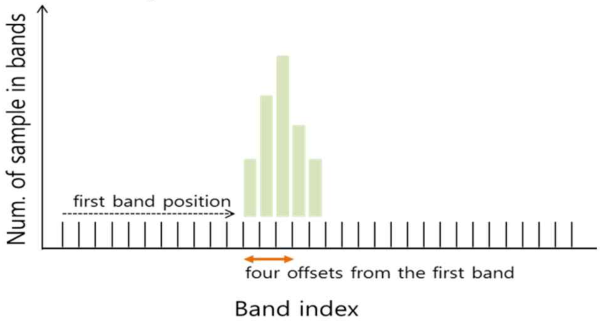


Figure 4. BO offset signals four offset from the first band BO offset.

Proposed Method

Previous SAO on-off control approach

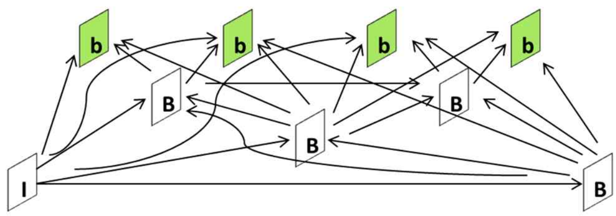
SAO on-off is decided in the CTB level. The luma and chroma can be turned on or off independently. In this paper let the SAO filtered CTB called SAO-CTB.

SAO on-off decision in the CTB level has high time complexities of the rate-distortion optimization (RDO) process.

Fu [7] found that the SAO-CTB is rarely selected in some frames, which results in the encoding time increase without any distortion compensation effect of the SAO. For that reason, a slice-level SAO on-off decision algorithm is proposed [8, 9]. The slice-level SAO on-off is determined by the SAO-CTB statistics of the previous GOP level frame. The GOP level refers the temporal level in the hierarchical GOP structure. As an example, the GOP level in the random access condition of the GOP size of eight in Fig. 5 are:

GOP level 0: POC 0, POC8
GOP level 1: POC 4
GOP level 2: POC 2, POC 4
GOP level 3: POC 1, POC 3, POC 5, POC 7.

For GOP level 0, the slice-level SAO is always turned on. For the next GOP level frames, the luma SAO is turned off if 75% of luma CTB in the previous GOP level frame was disabled, and the chroma SAO is turned off if 50% of chroma CTB was disabled. In the example of Fig 5, the POC 0 and POC 8 are always SAO turned on in the slice level. The SAO POC 4 is depend on the statistics of CTB SAO in the POC 8. The POC 2 and POC 6 are dependent on the statistics of CTB SAO in the POC 4. POC 1 and POC 3 are depended on the statistics of CTB SAO in the POC 2, and POC 5 and POC 7 are dependent on the statistics of POC 6. In this way, the SAO RDO process can be skipped in the slice level and the encoding time reduction can be achieved.



POC	0	1	2	3	4	5	6	7	8
Enc. Order	0	8	4	2	1	3	6	5	7

Figure 5. Example of GOP structure in the random access condition

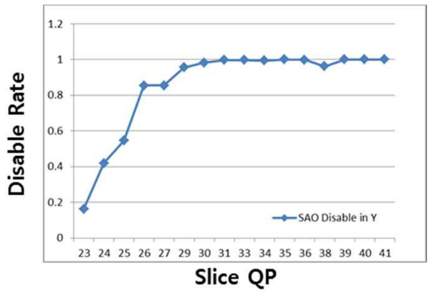
The Fu's method [7] cannot apply for the following scenarios: All-intra frame encoding configuration and frame-level parallel scheme. The slice-level SAO on-off control operates when there is hierarchical GOP level. The algorithm cannot apply if there is only one GOP level such as all-intra configuration. Secondly, the slice-level SAO on-off control is hard to apply to the frame-level parallel encoding scheme because the on-off control is built on the dependencies between frames. In addition, to use the previous statistics, the statistics is required to be stored globally, which results in parallel efficiency decreases. In order to overcome the limitations of the slice-level SAO on-off control algorithm, we propose new slice-level SAO on-off control method.

Proposed Slice-level SAO on-off control

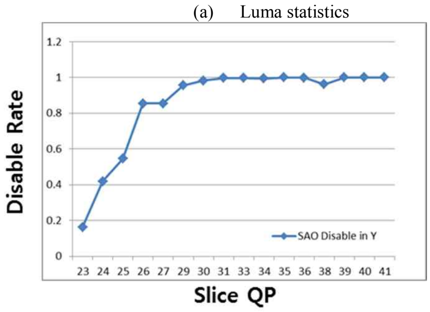
We investigate the statistics of CTB-SAO by the GOP level and slice quantization parameter (QP). The statistic is summarized in Table 2 and Fig. 6, respectively.

Table 2. SAO disable statistics by GOP level.

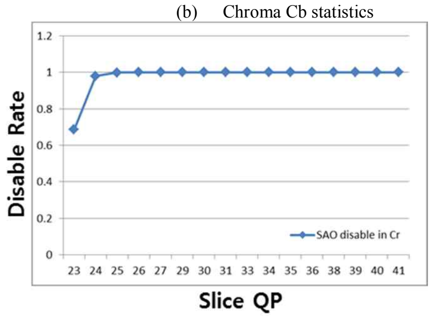
GOP Level	Y	Cb	Cr
0	0.62	0.90	0.90
1	0.84	0.99	0.99
2	0.87	1.00	1.00
3	0.96	1.00	1.00



(a) Luma statistics



(b) Chroma Cb statistics



(c) Chroma Cr statistics

Figure 6. SAO disable statistics by QP.

Based on the investigation, we propose to control the slice-level SAO on-off method using the given QP and GOP level. In our method, the slice-level SAO on-off is determined by the current slice QP and the GOP level not by the statistics of the previous encoded frame. The slice-level luma SAO is turned off if the slice QP is higher than QP_δ and the GOP level is higher than L_δ. The slice-level chroma SAO is turned off if the slice QP is higher than QP_ε and the GOP level is higher than L_ε. Since there is no need to refer the statistics of the previously encoded frames, our algorithm can be applied to the frame-level parallel encoding scheme. Fig. 7 presents an example of frame-level parallel encoding scheme wherein the frames of the same GOP level are processed in parallel.

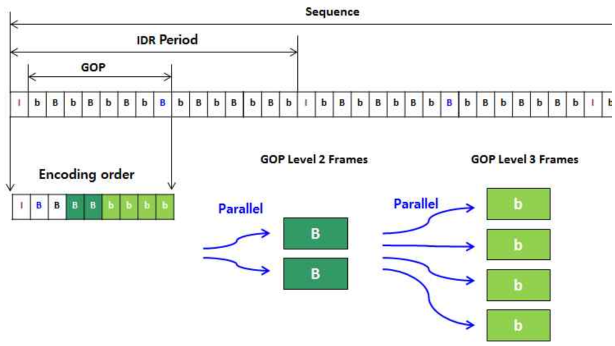


Figure 7. Frame-level parallel encoding scheme.

Experimental Results

We have implemented the proposed method using HEVC reference encoder HM 15. The test sequences used in the experiments are seven 4K UHD (3840x2160, 4:2:0, 10bit) videos of 100 frames (Beauty, Bosphorus, HoneyBee, Jockey, ReadySetGo, ShakeNDry, YachtRide) in Fig. 7, which are from Kvazaar Encoder [10, 11] test sequences. We select Main 10 profile and HEVC common test condition setting [12] with two modifications: AMP is turned off and SAO is selectively turned on as the test condition. Two different encoding configurations are used: random access main 10 (RA) and low delay with P pictures main 10 (LP).

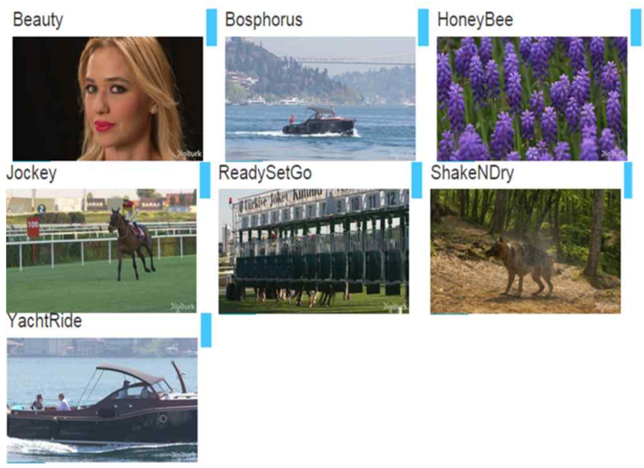


Figure 7. Test sequences.

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Table 3. Test methods configuration

Test Method	Condition
Test 1	SAO off
Test 2	SAO on; [4]' SAO ET on
Test 3	SAO on; Proposed SAO ET on

Table 4. Bit rate and PSNR of Proposed method (Test 3)

Seq.	Qp	Bit rate	Y psnr	U psnr	V psnr
S01	22	5460.72	39.6982	44.0235	43.321
	27	1368.465	38.8886	43.0654	42.5512
	32	690.045	37.9563	42.0634	41.7919
	37	412.08	36.6059	41.2768	41.053
S02	22	5458.29	43.2545	46.6601	45.3432
	27	2648.925	41.0311	44.7728	43.408
	32	1304.04	38.2979	43.2259	41.8727
	37	660.21	35.5747	42.161	40.8507
S03	22	7152.3	41.1896	44.8809	43.7469
	27	3363.645	39.4255	42.8932	41.8014
	32	1825.875	37.0158	40.9662	40.0354
	37	1045.275	34.332	39.5703	38.705
S04	22	22636.455	36.636	38.774	40.3737
	27	3151.62	34.8329	37.1422	39.2921
	32	521.265	34.3669	36.8104	39.0044
	37	230.055	33.9922	36.7773	38.8824
S05	22	12179.79	39.2516	42.8592	42.4173
	27	5355.975	37.7567	41.6422	41.4462
	32	2572.965	35.4013	40.4872	40.6852
	37	1147.155	32.9551	39.832	40.1504
S06	22	3085.02	42.3693	46.0926	46.1524
	27	932.19	40.8209	44.5514	45.1077
	32	352.17	39.2811	43.2549	44.0543
	37	160.185	37.6248	42.2286	43.1552
S07	22	5635.755	39.1622	43.2507	42.7503
	27	820.635	38.5787	42.0474	42.0526
	32	352.755	37.9552	40.7389	41.3763
	37	210.525	36.956	39.5609	40.6643

We conducted the experiments using three methods. In Test 1 all encoding tools are enabled with SAO turned off; In Test 2 SAO is turned on using [7]' slice-level SAO on-off control algorithm. In Test 3 SAO is turned on using the proposed slice-level SAO on-off control algorithm. Table 4 shows the bit-rate and psnr for four QP of our proposed method. The coding efficiency is measured using the Bjøntegaard delta (BD) bitrate as described in [13].

We compared our proposed method with the one with SAO off option (Test 1). Table 5 – 7 show the comparison results of LP, RA, and All intra configurations, respectively. For three configurations, applying SAO option with our proposed method result in BD-rate gain in 2.14%, 1.1%, and 0.31% average for seven test sequences. The results imply that we should sustain the coding efficiency loss when we should turn off SAO in the frame-level parallel encoding scheme.

Table 5. Comparison to Test 1 (LP main10)

Seq.	BD rate Y	BD rate U	BD rate V	ΔEnc. Time
S01	-1.14%	1.69%	1.58%	-1.24%
S02	-0.55%	-0.36%	0.30%	-0.70%
S03	-3.27%	-1.31%	-1.26%	-0.70%
S04	-1.79%	1.19%	0.18%	0.47%
S05	-0.18%	-0.12%	-0.32%	0.41%
S06	-1.86%	0.21%	0.37%	2.52%
S07	-6.17%	-2.69%	-2.21%	-0.01%
Avg	**-2.14%**	**-0.20%**	**-0.20%**	**0.11%**

Table 6. Comparison to Test 1 (RA main10)

Seq.	BD rate Y	BD rate U	BD rate V	ΔEnc. Time
S01	-0.59%	0.34%	1.25%	0.56%
S02	-0.23%	-0.72%	0.12%	0.94%
S03	-0.81%	0.03%	-0.30%	0.94%
S04	-1.35%	0.68%	1.51%	0.73%
S05	-0.13%	-0.06%	0.09%	1.73%
S06	0.02%	0.59%	-0.34%	1.37%
S07	-4.65%	-0.26%	-1.72%	1.59%
Avg	**-1.10%**	**0.09%**	**0.09%**	**1.12%**

Table 7. Comparison to Test 1 (All-Intra main10)

Seq.	BD rate Y	BD rate U	BD rate V	ΔEnc. Time
S01	-0.17%	0.28%	0.28%	-9.13%
S02	-0.12%	0.15%	0.15%	-9.50%
S03	-0.49%	0.15%	0.15%	-9.24%
S04	-1.37%	0.27%	0.25%	-7.62%
S05	-0.05%	0.15%	0.15%	-9.58%
S06	0.15%	0.19%	0.19%	-9.36%
S07	-0.10%	0.07%	0.14%	-9.23%
Avg	**-0.31%**	**0.18%**	**0.19%**	**-9.09%**

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Additionally, we compared our proposed method to Test 2 method, which is hardly applied to the parallel encoder design. Table 8 – 10 show the comparison results of LP, RA, and All intra configurations, respectively. BD-rate loss of 0.16% for LP and 0.33% for RA occurs. But BD-rate gain of 0.06% for All Intra. These results occur because Test 2 method is only based on the GOP level. For RA configuration, there are three GOP level but there are two GOP level for LP and one GOP level for All Intra. Because out method uses both GOP level and slice QP for slice-level SAO on-off control, encoding results with LP and All Intra configurations show better performance than the one with the RA configuration, which has higher maximum GOP level. The average for three configurations is 0.14%. This amount of loss is less than the loss when we disable the SAO tool due to the frame dependency in the parallel encoder.

In terms of speed, our method does not change the encoding time much compared to the Test 2 method. Therefore the encoder adopted our method can be speed up using parallel encoding design with very small amount of loss.

Table 8. Comparison to Test 2 (LP main10)

Seq.	BD rate Y	BD rate U	BD rate V	ΔEnc. Time
S01	-0.03%	0.07%	0.46%	-0.11%
S02	0.25%	0.53%	0.11%	-0.55%
S03	0.15%	-0.53%	0.02%	-0.55%
S04	-0.33%	0.55%	-0.11%	0.85%
S05	0.15%	0.34%	-0.07%	-0.46%
S06	0.69%	0.50%	1.07%	0.65%
S07	0.20%	0.36%	0.67%	0.01%
Avg	**0.16%**	**0.26%**	**0.31%**	**-0.02%**

Table 9. Comparison to Test 2 (RA main10)

Seq.	BD rate Y	BD rate U	BD rate V	ΔEnc. Time
S01	-0.20%	-0.94%	-1.19%	-0.55%
S02	-0.10%	-0.67%	-0.22%	-0.03%
S03	0.26%	0.69%	0.29%	-0.03%
S04	0.38%	0.44%	0.76%	1.60%
S05	0.06%	0.28%	0.16%	2.39%
S06	0.55%	0.60%	0.09%	-0.79%
S07	1.37%	0.40%	0.84%	-0.10%
Avg	**0.33%**	**0.11%**	**0.10%**	**0.36%**

Table 10. Comparison to Test 2 (All Intra main10)

Seq.	BD rate Y	BD rate U	BD rate V	ΔEnc. Time
S01	-0.10%	-0.06%	-0.05%	-0.08%
S02	-0.08%	-0.02%	-0.01%	0.15%
S03	-0.08%	-0.02%	-0.02%	-0.05%
S04	0.03%	0.04%	0.01%	-0.02%
S05	-0.05%	-0.04%	-0.02%	-0.14%
S06	-0.09%	-0.06%	-0.06%	-0.16%
S07	-0.05%	-0.04%	-0.04%	0.04%
Avg	**-0.06%**	**-0.03%**	**-0.03%**	**-0.04%**

Conclusions

We propose a slice-level SAO on-off control method that can be applied in the frame-level parallel encoding scheme. To be applied in the frame-level parallel scheme, our method does not use any SAO statistics from the previous encoded frames. Our method uses the GOP level and slice QP, which are given before starting the current frame encoding, for slice-level SAO on-off control. During working with independent thread, there is no need to communicate between the frame encoding threads, which is very efficient design for the parallel encoding scheme. Our experimental results shows that our method can control SAO on-off in the slice level with very small amount of loss than the method that is hardly employed in the parallel encoding scheme.

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Author Biography

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