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Optimized Adaptive Loop Filter in Versatile Video Coding

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Outline

- Introduction
- Optimized Adaptive Loop Filter
- Experimental Results
- Conclusion

Introduction

- In-loop filters in video coding standards

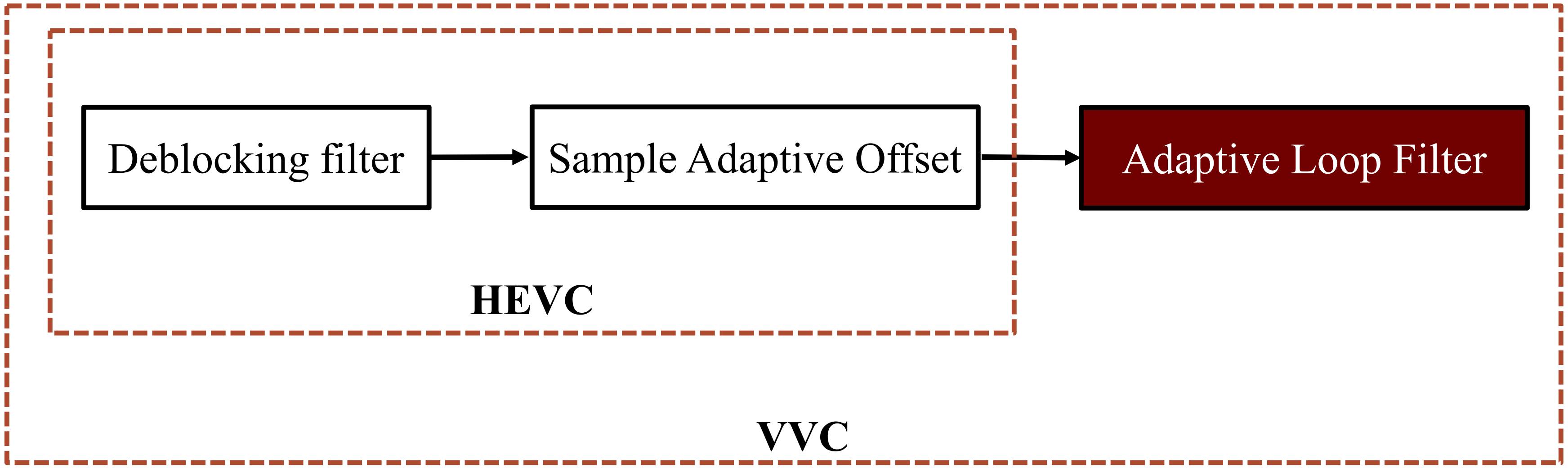

Figure 1: In-loop filters in video coding standards.

Introduction

- Adaptive loop filter (ALF) module in VVC
  - Geometry transformation-based Adaptive Loop Filter (GALF)
  - Cross Component Adaptive Loop Filter (CCALF)

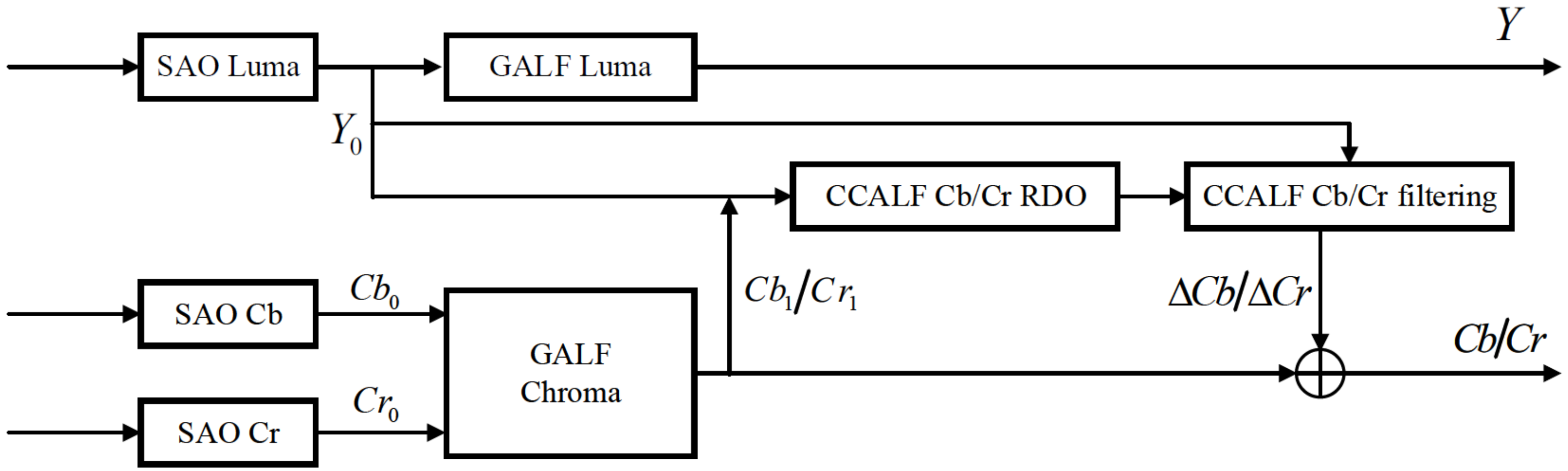

Figure 2: Framework of ALF module in VVC encoder.

Introduction

- Limitations of ALF module
  - High encoding complexity of GALF
    - Unpractical in the fast preset of real-time encoders
  - Parallel-unfriendliness of GALF and CCALF
    - Makes the ALF module more difficult for the real-time encoder design
  - Multi-pass CCALF process
    - One encoding pass requires an access of picture buffer
    - CCALF needs up to 152 picture buffer accesses for the **distortion calculation**
    - Massive external memory bandwidth, much more power consumption and latency

Optimized Adaptive Loop Filter

- Optimized adaptive loop filter
  - Optimized GALF for luma component
    - An adaptive parameter training and selection scheme based on the resolution and QP
  - GALF and CCALF encoder parallel design
  - One-pass CCALF encoding scheme
    - An efficient distortion estimation method

Optimized Adaptive Loop Filter

- Optimized GALF for luma component

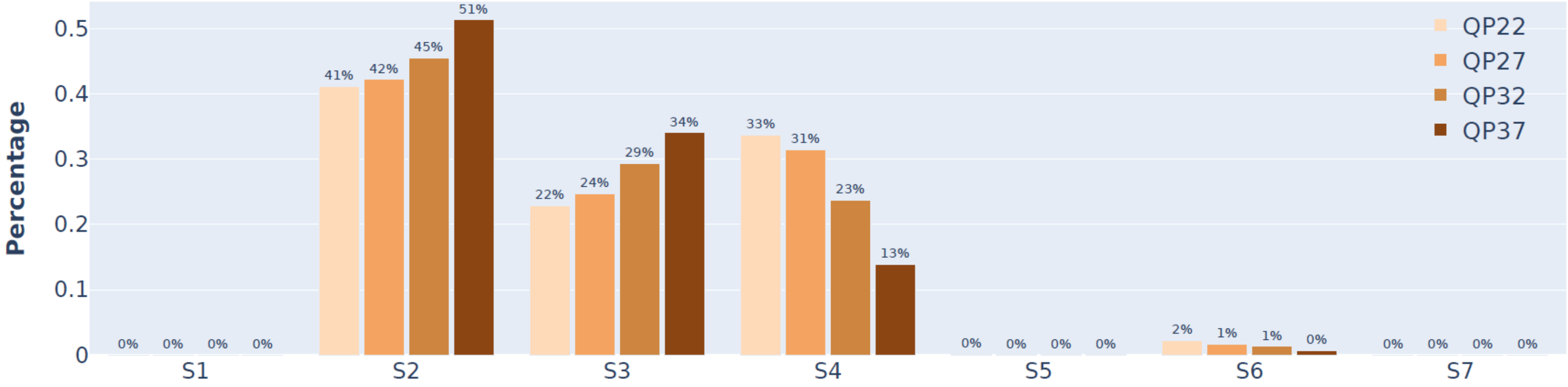

Figure 3: Percentage of the encoding time for each step in the ALF module.

S1 block-based classification
S2 calculation of auto-correlation matrix and cross-correlation vector
S3 filter coefficient training
S4 CTU-level filter selection
S5 GALF filtering process with the selected parameters
S6 CCALF coefficient training and CTU-level decision
S7 CCALF filtering process with the selected parameters

can be conducted in parallel for each CTU row

bottlenecks of the ALF encoding process

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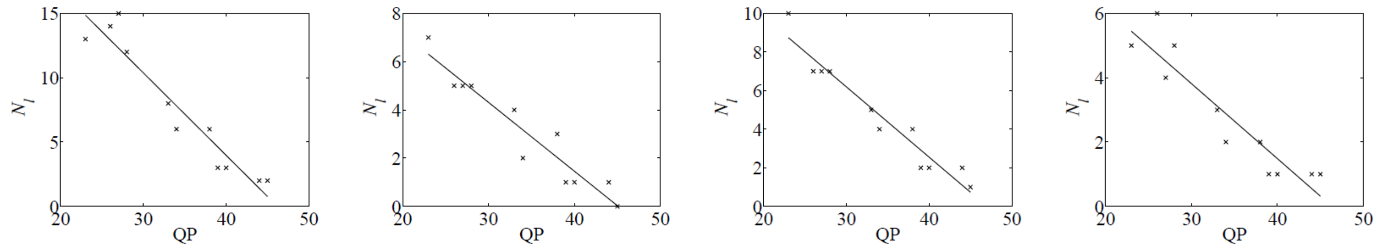
Optimized Adaptive Loop Filter

- Optimized GALF for luma component
  - Predict the initial N based on the resolution and QP



(a) 1920x1080 (b) 1280x720 (b) 832x480 (b) 416x240

Figure 5: Relationship between N_l(the number of GALF filters decided by the encoder) and QP

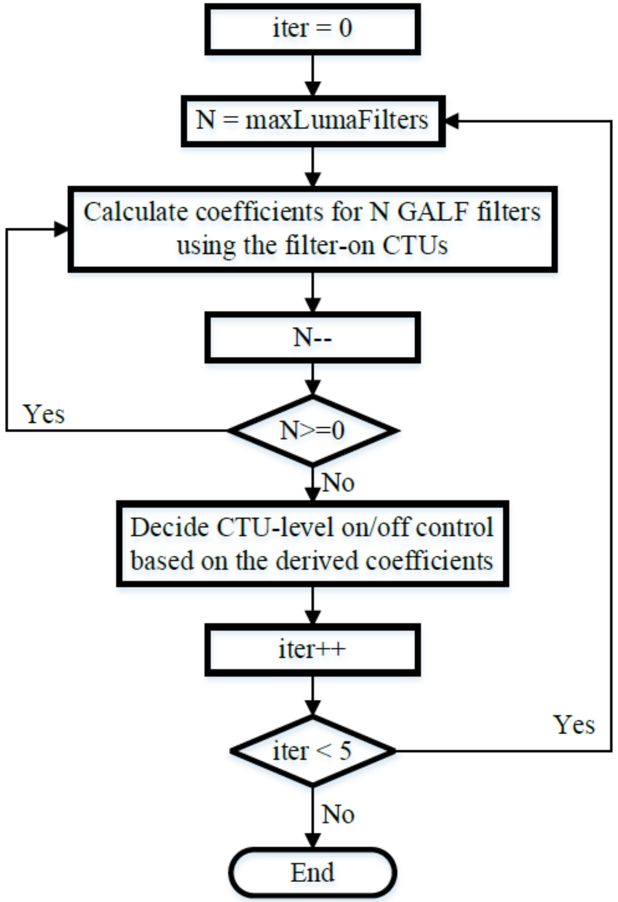


Figure 4: Filter coefficient training (S3).

Optimized Adaptive Loop Filter

- Optimized GALF for luma component
  - Stage 1: CTU-level filters are selected from fixed and temporal filter sets (f_{s1}, selected filter sets)
  - Stage 2: CTU-level filters are selected from fixed, temporal and new filter sets derived in S3 (f_{s2}, selected filter sets)
  - Conduct the Stage2 process based on the results of Stage1.

Table 1: Percentage of the filter set in f_{s2} belonging to the f_{s1}

	Class B	Class C	Class D	Class E	Average
I frame	96.50%	99.14%	99.69%	98.04%	97.41%
B frame	100%	100%	100%	100%	100%

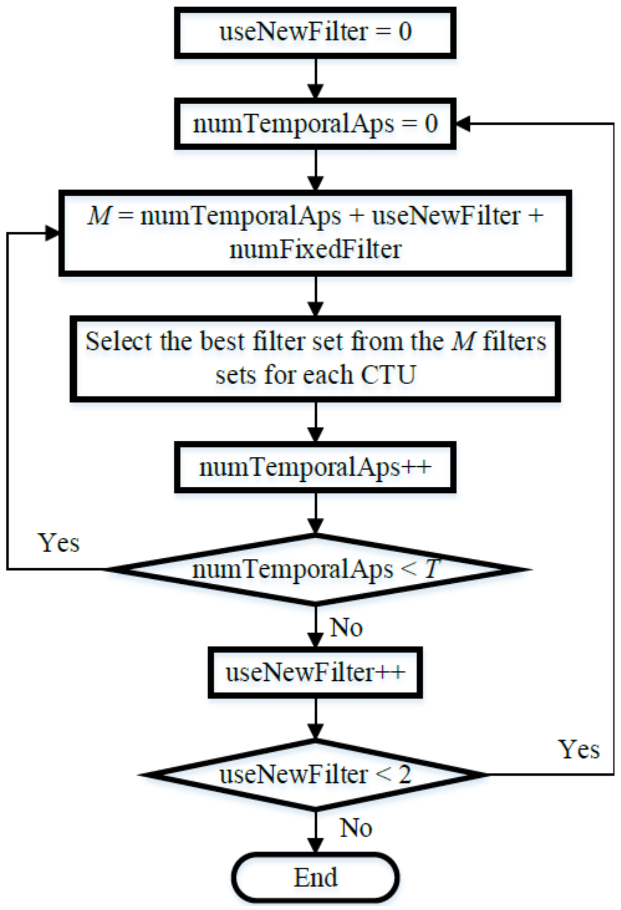


Figure 6: CTU-level filter selection (S4).

Optimized Adaptive Loop Filter

- GALF and CCALF encoder parallel design
  - Utilize the Cb_0/Cr_0 before GALF as the input of CCALF
  - Reason for this design
    - CCALF contributes to almost 70% coding gain on chroma components of ALF module
    - We assume that the GALF process has less impact on chroma signal.

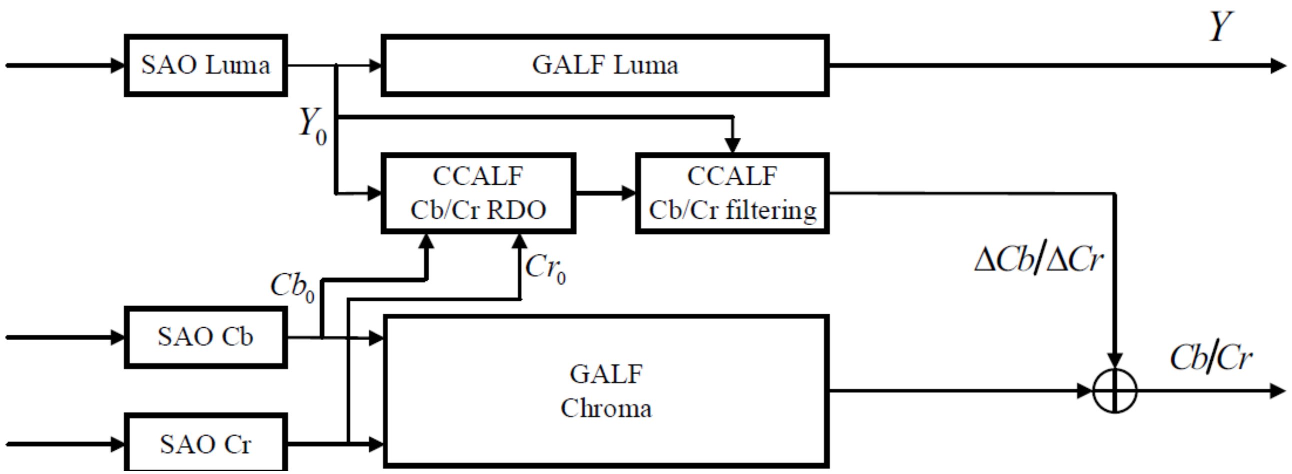


Figure 7: The framework of the proposed ALF module.

Optimized Adaptive Loop Filter

- One-pass CCALF encoding Scheme
  - Distortion estimation

$$f[\boldsymbol{k}] = c[\boldsymbol{k}] + \sum_{n=0}^{N-1} w_n l[\boldsymbol{k}' + \boldsymbol{p}_n]$$

$$\varepsilon = E[(f[\boldsymbol{k}] - s[\boldsymbol{k}])^2] = E[(c[\boldsymbol{k}] + \sum_{n=0}^{N-1} w_n l[\boldsymbol{k}' + \boldsymbol{p}_n] - s[\boldsymbol{k}])^2]$$

$$\varepsilon = \frac{1}{\|K\|}\langle \boldsymbol{w}, (\boldsymbol{R}_{l,l}\boldsymbol{w} - 2\boldsymbol{R}_{l,s-c})\rangle + \frac{1}{\|K\|}\sum_{\boldsymbol{k}\in K}(s[\boldsymbol{k}] - c[\boldsymbol{k}])^2$$

$$\varepsilon = \langle \boldsymbol{w}, (\boldsymbol{R}_{l,l}\boldsymbol{w} - 2\boldsymbol{R}_{l,s-c})\rangle + \sum_{\boldsymbol{k}\in K}(s[\boldsymbol{k}] - c[\boldsymbol{k}])^2$$

$f[\boldsymbol{k}]$	Chroma sample after CCALF
$\boldsymbol{k} = (x, y)$	Sample location
$c[\boldsymbol{k}]$	To-be-filtered chroma sample
$\boldsymbol{w} = [w_0\ w_1\ \dots w_{N-1}]^T$	Filter coefficients
$l[\boldsymbol{k}']$	Collocated luma sample
$\boldsymbol{k}' = (x', y')$	Collocated luma sample location
$\boldsymbol{p}_n$	Sample location offsets to $\boldsymbol{k}'$
$\langle , \rangle$	Inner produce operation
$s[\boldsymbol{k}]$	Original chroma sample
$\boldsymbol{R}_{l,l}$	Auto-correlation matrix of $l[\boldsymbol{k}']$
$\boldsymbol{R}_{l,s-c}$	Cross-correlation vector of $l[\boldsymbol{k}']$ and $s[\boldsymbol{k}] - c[\boldsymbol{k}]$
$\|K\|$	The number of pixels in K

Optimized Adaptive Loop Filter

- One-pass CCALF encoding Scheme
  - Estimation error

$$error = \frac{abs(dist_E - dist_T)}{dist_T} \times 100\%$$

$dist_E$	Estimated distortion
$dist_T$	True distortion

Table 2: Estimation error of the proposed distortion estimation method.

Class	AI		RA		LDB	
	U	V	U	V	U	V
Class A1	0.247%	0.279%	0.929%	1.297%	-	-
Class A2	0.113%	0.089%	0.678%	0.653%	-	-
Class B	0.176%	0.223%	0.227%	0.288%	0.213%	0.282%
Class C	0.110%	0.121%	0.129%	0.146%	0.114%	0.125%
Class E	0.162%	0.177%	-	-	0.195%	0.219%
Average	0.162%	0.178%	0.491%	0.596%	0.174%	0.209%

Experimental Results

- Test condition
  - Anchor: VTM-8.0
  - Test: the proposed optimized ALF
  - QP: 22, 27, 32, 37

Class	AI			RA			LDB		
	Y	U	V	Y	U	V	Y	U	V
Class B	0.01%	0.19%	0.09%	0.06%	-0.51%	-0.30%	0.06%	0.50%	0.15%
Class C	0.00%	0.12%	0.08%	0.02%	0.01%	0.45%	-0.06%	0.48%	-0.42%
Class D	-0.01%	0.13%	0.08%	-0.02%	0.05%	-0.01%	0.06%	0.69%	0.67%
Class E	0.00%	0.10%	0.13%	-	-	-	-0.22%	0.71%	0.00%
Average	0.00%	0.14%	0.09%	0.02%	-0.15%	0.05%	-0.01%	0.58%	0.11%
ΔET_{ALF}	78%			75%			76%		
ΔET_{all}	99%			98%			98%		
ΔDT	100%			100%			100%		

Conclusion

- Optimized ALF module in VVC
- The encoding time of ALF module is reduced by 22%~25% with minor coding performance change
- The off-chip buffer accesses are reduced from up to 152 to 1
- Meaningful for the real-time encoder design

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