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Title: Core Experiment results on Low Complexity Loop Filtering

Purpose: Information / Proposal

1 Introduction

This document reports the results of the Core Experiment on Low Complexity Loop Filtering (defined in VCEG-L40).

2 Results

Six experiments were carried out according to the common test conditions (VCEG-L38). Complexity and coding efficiency of the following were measured and are reported later in this document:

1. Loop filter in TML 5.9 software
2. As 1 but with software optimizations not affecting the bitstream syntax.
3. As 2 but with combined filtering of the edge pixels (applying the same difference for both pixels as in TML-5).
4. As 2 but with direct calculation of the differences prior to clipping (as in TML-5).
5. As 2 but with removal of dependencies on 'chrominance strengths'.
6. TML 5.9 with all the optimizations above.

Full simulation results and additional PSNR curves comparing Experiments 1 and 6 can be found in the accompanying spreadsheet [VCEG-M21.xls](#).

2.1 Experiment 1: TML 5.9 Loop Filter

Following table summarises the complexity of the TML 5.9 loop filter:

Table 1: TML 5.9 Loop Filter complexity (operations per Macroblock)

QP	Cont	Fore	News	Sile	Pari	Mobi	Temp	Average	Worst case
16	2247	7071	2807	2985	3110	6330	6306	4408	28544
20	1455	6657	2548	2751	2754	5947	5289	3914	28544
24	1050	6098	2207	2362	2310	4902	4014	3278	28544
28	814	5739	1951	2059	1993	4030	3227	2830	28544
Average	1392	6391	2378	2539	2542	5302	4709	3608	28544

2.2 Experiment 2: Software optimizations

In this experiment TML 5.9 loop filter software was optimized. Optimizations included reshuffling the source code and simplifying some calculations. This did not have any effect on the bitstreams syntax or compression performance. Results are given in the two tables below.

Table 2: Optimized TML 5.9 Loop Filter complexity relative to TML 5.9 complexity

QP	Cont	Fore	News	Sile	Pari	Mobi	Temp	Average	Worst case
16	0.88	0.90	0.88	0.89	0.88	0.80	0.85	0.87	0.95
20	0.89	0.92	0.90	0.92	0.89	0.83	0.87	0.89	0.95
24	0.90	0.94	0.91	0.93	0.91	0.86	0.89	0.90	0.95
28	0.91	0.95	0.92	0.95	0.92	0.89	0.92	0.92	0.95
Average	0.89	0.93	0.90	0.92	0.90	0.85	0.88	0.90	0.95

Table 3: Summary of Experiment 2 results

Average Complexity Reduction	10%
Luma PSNR improvement (sweet spot)	0.00
Luma PSNR improvement	0.00
Chroma PSNR improvement (sweet spot)	0.00
Chroma PSNR improvement	0.00

2.3 Experiment 3: Combined filtering of the edge pixels

This experiment is exactly as the one above except instead of separately filtering the edge pixels they are jointly filtered as in TML 5. A common difference is calculated and applied to both edge pixels on the 4x4 grid boundary (C, D, E, F are used to denote neighboring pixels, the boundary being between D and E):

```
Difference = clip( 32*(E-D) + 10*(C-F)+32) >> 6 );
filtered D = clip0to255( D + Difference);
filtered E = clip0to255( E - Difference);
```

Two additional clipping operations are needed to keep the filtered values in 0 to 255 range, but as seen on the tables below the overall complexity is reduced and some gains are achieved in compression efficiency.

Table 4: Experiment 3 complexity relative to Experiment 2 complexity

QP	Cont	Fore	News	Sile	Pari	Mobi	Temp	Average	Worst case
16	0.89	0.90	0.90	0.89	0.89	0.91	0.89	0.90	0.96
20	0.91	0.89	0.90	0.90	0.90	0.90	0.89	0.90	0.96
24	0.92	0.90	0.91	0.92	0.91	0.89	0.90	0.91	0.96
28	0.89	0.90	0.90	0.91	0.90	0.87	0.89	0.89	0.96
Average	0.90	0.90	0.90	0.90	0.90	0.89	0.89	0.90	0.96

Table 5: Experiment 3 PSNR differences with respect to TML 5.9

	Cont	Fore	News	Sile	Pari	Mobi	Temp	Average
Luma Sweet Spot	-0.01	0.08	-0.02	0.04	0.02	0.06	0.04	0.03
Luma Total	-0.01	0.07	-0.02	0.04	0.02	0.06	0.05	0.03
Chroma Sweet Spot	N/A	0.13	N/A	0.10	0.22	0.16	0.15	0.15
Chroma Total	N/A	0.14	N/A	0.11	0.21	0.15	0.15	0.15

Table 6: Summary of Experiment 3 results

Average Complexity Reduction	10%
Luma PSNR improvement (sweet spot)	0.03
Luma PSNR improvement	0.03
Chroma PSNR improvement (sweet spot)	0.15
Chroma PSNR improvement	0.15

2.4 Experiment 4: Direct calculation of all differences prior to clipping

In TML filter the difference applied to input values is limited by a clipping function. In the current design the difference was evaluated by first calculating an intermediate filter output and taking a difference between this and the input value. The same result can be obtained by directly calculating the differences for the pixels not on the 4x4 grid boundaries as follows (B, C, D, E, F, G are used to denote neighboring pixels, the boundary being again between D and E):

```
Difference1 = clip( 21*(B+D)-42*C + 32) >> 6);
filtered C  = C + Difference;
Difference2 = clip( 21*(E+G)-42*F + 32) >> 6);
filtered F  = F + Difference;
```

This saves 2 operations every time pixels C and F are being filtered this way.

2.5 Experiment 5: Removal of dependencies on 'chrominance strengths'

In this experiment the dependencies on chrominance strengths were removed and luminance strengths were used in filtering process for all the components. Reasonable complexity reductions were achieved especially on color rich sequences as seen below.

Table 7: Experiment 5 complexity relative to Experiment 2 complexity

QP	Cont	Fore	News	Sile	Pari	Mobi	Temp	Average	Worst case
16	1.14	0.97	0.99	1.00	0.92	0.95	0.98	0.99	1.00
20	1.09	0.95	0.97	0.99	0.93	0.88	0.94	0.96	1.00
24	1.06	0.94	0.94	0.98	0.91	0.76	0.87	0.92	1.00
28	1.01	0.93	0.92	0.96	0.87	0.67	0.81	0.88	1.00
Average	1.08	0.95	0.95	0.98	0.91	0.82	0.90	0.94	1.00

Table 8: Experiment 5 PSNR differences with respect to TML 5.9

	Cont	Fore	News	Sile	Pari	Mobi	Temp	Average
Luma Sweet Spot	0.00	0.01	0.00	0.00	0.00	0.04	0.01	0.01
Luma Total	-0.01	0.01	0.00	0.00	0.00	0.06	0.01	0.01
Chroma Sweet Spot	N/A	-0.01	N/A	-0.03	0.03	0.10	0.02	0.02
Chroma Total	N/A	-0.01	N/A	-0.05	0.02	0.09	0.01	0.01

Table 9: Summary of Experiment 5 results

Average Complexity Reduction	6%
Luma PSNR improvement (sweet spot)	0.01
Luma PSNR improvement	0.01
Chroma PSNR improvement (sweet spot)	0.02
Chroma PSNR improvement	0.01

2.6 Experiment 6: All the optimizations combined

In this experiment all the optimizations mentioned above were integrated to the TML 5.9. Results are listed in the tables below. More exact simulation results and PSNR curves can be found in [VCEG-M21.xls](#).

Table 10: Experiment 6 complexity (operations per Macroblock)

QP	Cont	Fore	News	Sile	Pari	Mobi	Temp	Average	Worst case
16	2041	5612	2207	2389	2275	4471	4780	3396	25856
20	1287	5224	2002	2255	2072	3951	3921	2959	25856
24	923	4831	1711	1997	1746	2938	2852	2428	25856
28	676	4547	1481	1699	1458	2181	2180	2032	25856
Average	1232	5054	1850	2085	1888	3385	3433	2704	25856

Table 11: Experiment 6 complexity relative to TML 5.9

QP	Cont	Fore	News	Sile	Pari	Mobi	Temp	Average	Worst case
16	0.91	0.79	0.79	0.80	0.73	0.71	0.76	0.78	0.91
20	0.88	0.78	0.79	0.82	0.75	0.66	0.74	0.78	0.91
24	0.88	0.79	0.78	0.85	0.76	0.60	0.71	0.77	0.91
28	0.83	0.79	0.76	0.83	0.73	0.54	0.68	0.74	0.91
Average	0.88	0.79	0.78	0.82	0.74	0.63	0.72	0.77	0.91

Table 12: Experiment 6 PSNR differences with respect to TML 5.9

	Cont	Fore	News	Sile	Pari	Mobi	Temp	Average
Luma Sweet Spot	-0.02	0.08	-0.02	0.04	0.01	0.08	0.04	0.03
Luma Total	-0.02	0.07	-0.02	0.04	0.01	0.09	0.05	0.03
Chroma Sweet Spot	N/A	0.14	N/A	0.08	0.14	0.18	0.12	0.13
Chroma Total	N/A	0.15	N/A	0.05	0.14	0.17	0.11	0.12

Table 13: Summary of Experiment 6 results

Average Complexity Reduction	23%
Luma PSNR improvement (sweet spot)	0.03
Luma PSNR improvement	0.03
Chroma PSNR improvement (sweet spot)	0.13
Chroma PSNR improvement	0.12

3 Summary

Results obtained suggest that very reasonable complexity reductions can be achieved by optimizing the TML 5.9 loop filter. They also show that the compression efficiency can be maintained or even slightly improved with these optimizations. A visual demonstration comparing the optimized filter and the original TML 5.9 filter will be provided in the Austin meeting.

Given the promising results, authors of this contribution would like to ask Video Coding Experts Group to adopt the proposed optimizations to the next version of TML.