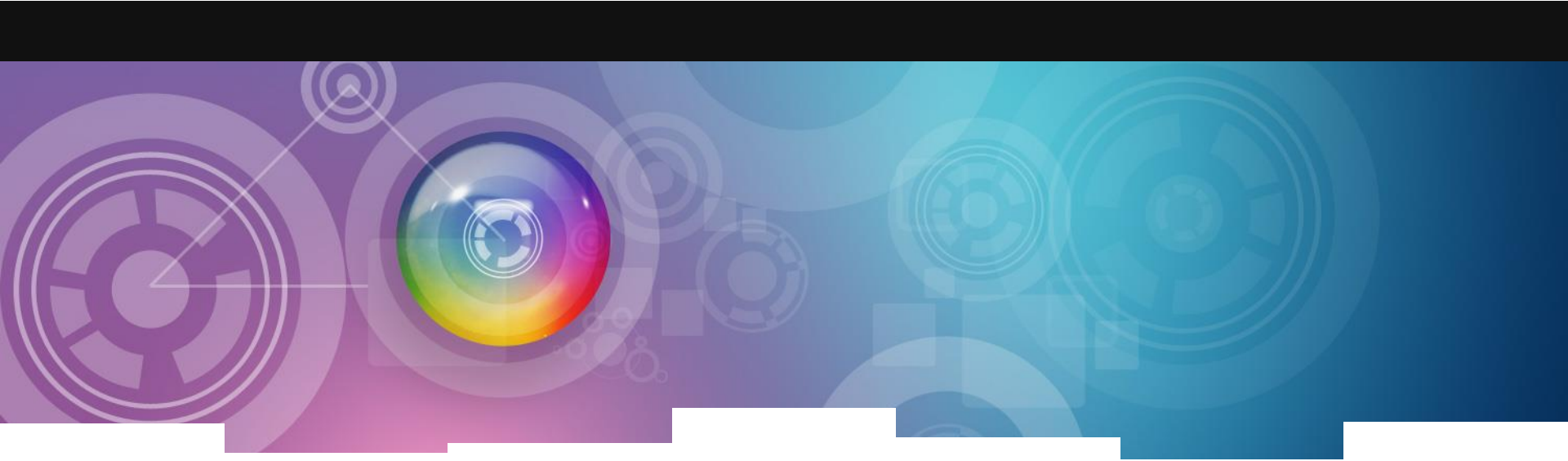


JVET-L0379 - CE6-related: Further Simplification on top of tests

CE6-2.2 (Fast DST-7/DCT-8 based on DFT and matrix multiplication)



Problem

- MTS of VTM3 comprises DST7 / DCT8
- Cannot be decomposed into partial butterfly representation

Proposed solution in CE6.2-2

- inspired from JVET-K0096 proposing DFT-based implementation of DST7
- Main difference: JVET-L0421/M0372 performs matrix multiplication instead of specific implementation of each DFT stage

Approach

- decompose the MTS transforms basis into smaller matrices then
 - perform matrix multiplication to implement the transforms
-
- Proposed solution is generic, independent from the transform size, and SIMD implementation friendly

N-DST7/DCT8 implemented via $(2N+1)$ -DFT

$(2N+1)$ -DFT implemented using prime factor algorithm

- $2N+1=N_1 \times N_2$, with N_1 and N_2 relatively prime

- $2N+1$ DFT implemented by a 2 stages DFT:
 1. N_2 DFTs of size N_1
 2. N_1 DFTs of size N_2

- 16-DCT8 using 33-DFT, decomposed into 3-DFTs and 11-DFTs
- 32-DCT8 using 65-DFT, decomposed into 5-DFTs and 13-DFTs

Generic design requiring 3 functions

- N_2 calls of **DFT_RI** involving N_1 -DFTs
- 1 call of **DFT_RI_IO** involving N_2 -DFTs
- $(N_1+1)/2$ calls of **DFT_IO** involving N_2 -DFTs
- Plus permutations of input/output

Implemented using matrix multiplications

Process	#Multiplications
N_2 DFT_RI(N_1)	$N_2 * (N_1 - 1)^2/2$
1 DFT_RI_RO(N_2)	$(N_2 - 1)^2/4$
$(N_1-1)/2$ DFT_RO(N_2)	$(N_1 - 1)/2 * ((N_1 - 1)^2/2)$

Process	#Additions
N_2 DFT_RI(N_1)	$N_2 * (N_1 - 1) * (1+N_1/2)$
1 DFT_RI_RO(N_2)	$(N_2-1) * (N_2+5)/4$
$(N_1-1)/2$ DFT_RO(N_2)	$(N_1 - 1)/2 * ((N_2 - 1) * (N_2/2+2) - 1)$

Compared to VTM3.0 implementation

Transform	Adds/VTM_Adds	Mults/VTM_Mults
16x16 DCT8/DST7 (N_1, N_2) = (3, 11)	205/240 = 76%	98/256 = 38%
32x32 DCT8/DST7 (N_1, N_2) = (5, 13)	521/992 = 49%	286/1024 = 28%

Memory

- memory for the core transform (4096 Bytes) unchanged
- For DST7/DCT8, memory reduction is as follows

16-bit DFT	25% of current VTM memory
8-bit DFT	16% of current VTM memory

Further simplifications proposed in this contribution

1. **Odd basis functions of DCT2 for 32x32 and 16x16 are replaced by DCT8 with DFT based implementation**
2. **DCT8/DST7 for 8x8 and 4x4 are replaced by DCT4/DST4 that can be inherited from DCT2**

Benefits

- implementation of DCT8/DST7 for all sizes are embedded in DCT2
- further reduction of the overall memory
- reduced number of operations for computing DCT2 for large block sizes

1st aspect

- With 8-bit representation, VTM needs $4096+1360=5456$ bytes of memory
- With our proposal

8-bit DFT	Memory requirement (Bytes)
DCT2	256
DCT8/DST7 (4x4 and 8x8)	80
DCT8/DST7 (16x16 and 32x32)	28
Sum	364 (6.6% of current VTM)

16-bit DFT	Memory requirement (Bytes)
DCT2	256
DCT8/DST7 (4x4 and 8x8)	80
DCT8/DST7 (16x16 and 32x32)	56
Sum	392 (7.2% of current VTM)

2nd aspect

- With 8-bit representation, VTM needs $4096+1360=5456$ bytes of memory
- With our proposal

8-bit DFT	Memory requirement (Bytes)
DCT2	256
DCT4/DST4 (4x4 and 8x8)	-
DCT8/DST7 (16x16 and 32x32)	28
Sum	284 (5.2% of current VTM)

16-bit DFT	Memory requirement (Bytes)
DCT2	256
DCT4/DST4 (4x4 and 8x8)	-
DCT8/DST7 (16x16 and 32x32)	56
Sum	312 (5.7% of current VTM)

1st aspect - odd basis functions of DCT2 for 32x32 and 16x16 replaced by DCT8 with DFT based implementation

using 8-bit DFT

All Intra Main10					
Over VTM 3.0					
	Y	U	V	EncT	DecT
Class A1	0.29%	0.19%	0.33%	127%	133%
Class A2	0.30%	0.25%	0.26%	122%	125%
Class B	0.14%	0.20%	0.14%	121%	124%
Class C	0.04%	0.08%	-0.12%	116%	114%
Class E	0.15%	0.16%	0.11%	119%	126%
Overall	0.17%	0.17%	0.13%	121%	123%
Class D	0.05%	-0.10%	0.07%	113%	111%
Class F	0.04%	0.09%	0.03%	115%	110%

Random Access Main 10					
Over VTM 3.0					
	Y	U	V	EncT	DecT
Class A1	0.20%	0.30%	0.20%	115%	120%
Class A2	0.18%	0.21%	0.36%	110%	111%
Class B	0.12%	0.25%	0.11%	111%	111%
Class C	0.05%	-0.02%	0.23%	108%	109%
Class E					
Overall	0.13%	0.18%	0.21%	111%	112%
Class D	0.05%	-0.25%	-0.23%	107%	103%
Class F	0.06%	0.17%	0.20%	111%	107%

Low delay B Main10					
Over VTM 3.0					
	Y	U	V	EncT	DecT
Class A1					
Class A2					
Class B	0.18%	-0.28%	-0.08%	110%	120%
Class C	0.22%	0.28%	0.39%	108%	113%
Class E	0.25%	0.20%	0.07%	110%	108%
Overall	0.21%	0.03%	0.11%	109%	115%
Class D	0.08%	0.06%	0.41%	105%	102%
Class F	0.30%	0.30%	-0.08%	110%	108%

1st aspect - odd basis functions of DCT2 for 32x32 and 16x16 replaced by DCT8 with DFT based implementation

using 16-bit DFT

	All Intra Main10				
	Over VTM 3.0				
	Y	U	V	EncT	DecT
Class A1	0.30%	0.11%	0.25%	127%	133%
Class A2	0.28%	0.17%	0.19%	121%	125%
Class B	0.13%	0.09%	0.12%	121%	123%
Class C	0.03%	0.05%	-0.11%	116%	114%
Class E	0.15%	0.16%	0.14%	120%	127%
Overall	0.16%	0.11%	0.11%	121%	124%
Class D	0.04%	0.04%	-0.07%	112%	110%
Class F	0.04%	0.05%	0.18%	114%	110%

	Random Access Main 10				
	Over VTM 3.0				
	Y	U	V	EncT	DecT
Class A1	0.24%	0.24%	0.27%	115%	120%
Class A2	0.18%	0.23%	0.26%	110%	110%
Class B	0.13%	0.18%	0.12%	110%	110%
Class C	0.07%	-0.01%	0.25%	108%	108%
Class E					
Overall	0.15%	0.15%	0.21%	110%	111%
Class D	-0.03%	-0.21%	-0.16%	106%	102%
Class F	0.04%	0.08%	0.04%	111%	105%

	Low delay B Main10				
	Over VTM 3.0				
	Y	U	V	EncT	DecT
Class A1					
Class A2					
Class B	0.18%	-0.30%	-0.15%	111%	120%
Class C	0.14%	0.21%	0.26%	108%	113%
Class E	0.25%	0.26%	-0.11%	110%	110%
Overall	0.18%	0.01%	-0.01%	110%	115%
Class D	0.02%	-0.08%	-0.14%	105%	102%
Class F	0.27%	-0.01%	-0.42%	110%	109%

1st+2nd aspects - DCT8/DST7 for 8x8 and 4x4 replaced by DCT4/DST4

using 8-bit DFT

	All Intra Main10				
	Over VTM 3.0				
	Y	U	V	EncT	DecT
Class A1	0.41%	0.34%	0.51%	127%	133%
Class A2	0.37%	0.23%	0.20%	121%	124%
Class B	0.10%	-0.07%	-0.04%	122%	124%
Class C	-0.26%	-0.23%	-0.37%	117%	114%
Class E	-0.15%	-0.20%	-0.27%	121%	126%
Overall	0.08%	-0.01%	-0.02%	121%	124%
Class D	-0.30%	-0.28%	-0.40%	115%	112%
Class F	-0.15%	-0.13%	-0.12%	116%	110%

	Random Access Main 10				
	Over VTM 3.0				
	Y	U	V	EncT	DecT
Class A1	0.28%	0.40%	0.38%	131%	127%
Class A2	0.23%	0.24%	0.41%	123%	115%
Class B	0.12%	0.27%	0.12%	123%	112%
Class C	-0.02%	0.05%	-0.04%	119%	109%
Class E					
Overall	0.14%	0.23%	0.19%	123%	115%
Class D	-0.11%	-0.31%	-0.31%	115%	98%
Class F	-0.05%	-0.11%	0.04%	114%	91%

	Low delay B Main10				
	Over VTM 3.0				
	Y	U	V	EncT	DecT
Class A1					
Class A2					
Class B	0.20%	-0.16%	0.02%	128%	126%
Class C	0.15%	0.29%	0.03%	123%	120%
Class E	0.25%	0.91%	0.82%	130%	98%
Overall	0.19%	0.26%	0.23%	127%	116%
Class D	0.00%	-0.04%	-0.21%	119%	105%
Class F	0.16%	-0.14%	-0.24%	129%	98%

1st+2nd aspects - DCT8/DST7 for 8x8 and 4x4 replaced by DCT4/DST4

	All Intra Main10				
	Over VTM 3.0				
	Y	U	V	EncT	DecT
Class A1	0.42%	0.23%	0.41%	126%	134%
Class A2	0.32%	0.16%	0.19%	121%	124%
Class B	0.07%	-0.08%	-0.08%	122%	123%
Class C	-0.26%	-0.20%	-0.33%	117%	114%
Class E	-0.14%	-0.24%	-0.24%	121%	125%
Overall	0.06%	-0.04%	-0.04%	121%	123%
Class D	-0.31%	-0.44%	-0.43%	114%	111%
Class F	-0.19%	-0.20%	-0.12%	116%	110%

	Random Access Main 10				
	Over VTM 3.0				
	Y	U	V	EncT	DecT
Class A1	0.27%	0.37%	0.38%	131%	127%
Class A2	0.23%	0.32%	0.33%	123%	116%
Class B	0.11%	0.29%	0.18%	123%	113%
Class C	-0.06%	-0.13%	-0.17%	118%	110%
Class E					
Overall	0.12%	0.20%	0.16%	123%	115%
Class D	-0.10%	-0.21%	-0.12%	115%	98%
Class F	-0.01%	0.06%	0.08%	114%	91%

using 16-bit DFT

	Low delay B Main10				
	Over VTM 3.0				
	Y	U	V	EncT	DecT
Class A1					
Class A2					
Class B	0.21%	-0.09%	0.05%	128%	126%
Class C	0.16%	0.47%	0.24%	123%	120%
Class E	0.27%	0.07%	0.05%	130%	98%
Overall	0.21%	0.14%	0.11%	127%	116%
Class D	0.01%	0.02%	0.24%	119%	104%
Class F	0.14%	0.18%	0.08%	128%	97%

This contribution proposes a fast implementation of MTS transforms using matrix multiplication

Generic process, non-size dependent, SIMD friendly

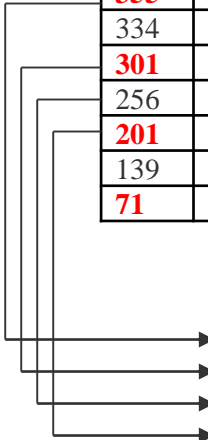
Compared to a full matrix multiplication,

- reduction of memory (5 to 7% of full VTM3 matrices memory need)
- reduction of nb of operations (32x32/16x16 : 76%/49% adds, 38%/28% mults compared to VTM3)

Limited impact on coding performance

256	256	256	256	256	256	256	256
355	301	201	71	-71	-201	-301	-355
334	139	-139	-334	-334	-139	139	334
301	-71	-355	-201	201	355	71	-301
256	-256	-256	256	256	-256	-256	256
201	-355	71	301	-301	-71	355	-201
139	-334	334	-139	-139	334	-334	139
71	-201	301	-355	355	-301	201	-71

8x8 DCT2
transform matrix



71	201	301	355
201	355	71	-301
301	71	-355	201
355	-301	201	-71

4x4 DST4 transform
matrix