

JCT-VC B024: Mode-dependent fast separable KLT for block-based intra coding

Chuohao Yeo, Yih Han Tan,
Zhengguo Li, Susanto Rahardja

Institute for Infocomm Research, Singapore

Outline

- Proposal
- Experimental results
- Conclusion

What transform to use in Intra Coding?

- H.264: 2-D separable integer DCT-like transform

$$Y = MXM^T$$

- MDDT: 2-D separable KLT [Qualcomm, VCEG-AG11]

$$Y = C_m X R_m^T$$

- Stores 2 matrices per prediction mode
- KLT computed from training sequences
- Full matrix multiply more expensive than DCT

MDDT Variations

- OMDDT: 2-D separable KLT [TI, VCEG-AM20]


$$Y = C_m X C_m^T$$

- MDDCT: 2-D separable rotated DCT [TI, VCEG-AM20]

$$Y = Q_m M X M^T Q_m$$

Proposal: Fast separable KLT

$$Y = C_m X R_m^T$$

$C_m, R_m \in \{M, C\}$  Proposed Transform

MDDT	Proposal
Requires training to compute KLT	No training required
Needs 18 transforms to be implemented	Needs only 2 transforms
16 muls, 12 adds per tx	8 muls, 10 adds per tx
All modes use KLT	Combination of DCT/KLT

Observation: Intra prediction leads to uneven error distribution

Mode 0 – Vertical

Q	A	B	C	D	E	F	G	H
I	a	b	c	d				
J	e	f	g	h				
K	i	j	k	l				
L	m	n	o	p				

Mode 2 – DC

Q	A	B	C	D	E	F	G	H
I	a	b	c	d				
J	e	f	g	h				
K	i	j	k	l				
L	m	n	o	p				

Mode 3 – Diagonal down-left

Q	A	B	C	D	E	F	G	H
I	a	b	c	d				
J	e	f	g	h				
K	i	j	k	l				
L	m	n	o	p				

27	27	26	32
40	40	41	48
53	54	54	65
72	73	74	86

62	91	93	124
71	100	107	139
89	114	124	160
109	137	154	197

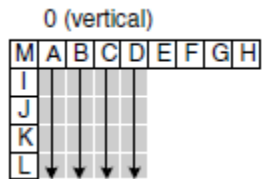
87	88	77	95
131	137	132	150
173	175	172	195
244	225	212	256

Average square error in each 4x4 pixel location

Statistics of prediction residual

Gauss-Markov
Image correlation model

$$E[X_{ij}X_{kl}] = \rho^{|i-k|} \rho^{|j-l|}$$



k_{th} Row-wise

P_1	P_2	P_3	P_4
X_1	X_2	X_3	X_4

k_{th} Column-wise

$$E[R_i R_j] = E[(X_i - P_i)(X_j - P_j)]$$

$$= 2(1 - \rho^k) \rho^{|i-j|}$$

Toeplitz matrix!
DCT is close to optimal

P_0
X_1
X_2
X_3
X_4

$$E[R_i R_j] = E[(X_i - P_0)(X_j - P_0)]$$

$$= 1 + \rho^{|i-j|} - \rho^{|i|} - \rho^{|j|}$$

No longer Toeplitz.
Need to compute KLT.

- KLT has sinusoidal terms
- Do this for 4x4, 8x8 and 16x16
- Fast implementation for 4x4

Fast KLT for N=4

• Forward

$$\begin{pmatrix} y_0 \\ y_1 \\ y_2 \\ y_3 \end{pmatrix} = \begin{pmatrix} 29 & 55 & 74 & 84 \\ 74 & 74 & 0 & -74 \\ 84 & -29 & -74 & 55 \\ 55 & -84 & 74 & -29 \end{pmatrix} \begin{pmatrix} x_0 \\ x_1 \\ x_2 \\ x_3 \end{pmatrix}$$

$$c_0 = x_0 + x_3$$

$$c_1 = x_1 + x_3$$

$$c_2 = 74x_2$$

$$y_0 = 29c_0 + 55c_1 + c_2$$

$$y_1 = 74(x_0 + x_1 - x_3)$$

$$y_2 = 84c_0 - 29c_1 - c_2$$

$$y_3 = 55c_0 - 84c_1 + c_2$$

Backward

$$\begin{pmatrix} x_0 \\ x_1 \\ x_2 \\ x_3 \end{pmatrix} = \begin{pmatrix} 29 & 74 & 84 & 55 \\ 55 & 74 & -29 & -84 \\ 74 & 0 & -74 & 74 \\ 84 & -74 & 55 & -29 \end{pmatrix} \begin{pmatrix} y_0 \\ y_1 \\ y_2 \\ y_3 \end{pmatrix}$$

$$b_0 = y_0 + y_2$$

$$b_1 = 74y_1$$

$$b_2 = y_2 + y_3$$

$$x_0 = 29b_0 + b_1 + 55b_2$$

$$x_1 = 55b_0 + b_1 - 84b_2$$

$$x_2 = 74(y_0 - y_2 + y_3)$$

$$x_3 = 84b_0 - b_1 - 29b_2$$

- 8 multiplies, 10 adds

Proposed separable transforms

- Analysis applied for modes 0,1,2,3,7,8
- Computed KLT very similar to MDDT trained KLTs for modes 4,5,6

Mode	Column	Row	Computation Savings
0	KLT	DCT	63%
1	DCT	KLT	63%
2	DCT	DCT	75%
3	KLT	DCT	63%
4	KLT	KLT	50%
5	KLT	KLT	50%
6	KLT	KLT	50%
7	KLT	DCT	63%
8	DCT	KLT	63%

Experiment Conditions (I)

- KTA2.6r1, High Profile
- 5 QP points
- Full length of all CfP sequences coded as Intra frames
- KTA options:
 - `UseAdaptiveLoopFilter = 1`

Experimental Results

Test Class	KTA+MDDT vs KTA		KTA + Proposed KLT vs KTA	
	BD-Rate (%)	BD-PSNR (dB)	BD-Rate (%)	BD-PSNR (dB)
2560x1600	-6.08	0.34	-6.72	0.38
1920x1080	-5.09	0.22	-5.10	0.22
832x480	-4.60	0.27	-4.68	0.27
416x240	-3.85	0.25	-3.89	0.25
1280x720	-7.74	0.45	-7.75	0.45

Experiment Conditions (II)

- KTA2.6r1, High Profile
- 5 QP points
- Full length of all CfP sequences coded as with Hier-B with GOP size 8
- KTA options:
 - MVCompetition = 1
 - UseAdaptiveLoopFilter = 1
 - UseExtMB = 2

Experimental Results

Test Class	KTA+MDDT vs KTA		KTA + Proposed KLT vs KTA	
	BD-Rate (%)	BD-PSNR (dB)	BD-Rate (%)	BD-PSNR (dB)
2560x1600	-2.85	0.12	-3.02	0.13
1920x1080	-2.58	0.07	-2.50	0.07
832x480	-2.00	0.08	-1.93	0.08
416x240	-1.54	0.07	-1.48	0.06
1280x720	-3.77	0.16	-3.43	0.14

Conclusion

- Proposed fast separable KLT for intra coding
 - No training required to compute transform
 - Only 2 transform matrices needed (DCT, KLT)
 - Some rows/columns can use fast DCT
 - Exploit coefficients in KLT to reduce operations
- Recommend further study in Tool/Core Experiments