Reduced encoder time complexity using enhanced adaptive multiple transform selection in versatile video coding

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ABSTRACT

When compressing a video, the architecture is provided with the width and height of the frame along with the video as input. The multiple transform selection (MTS) techniques are used to compress video. Traditional discrete cosine transforms (DCT) and other trigonometric (sine and cosine) transforms, such as DCT-8 and DST-7, are included in the pool of transforms. For the best outcomes, two additional transforms DST-2 and DCT-5 were also utilized to compress any remaining video frames. To improve coding effectiveness, peak signal-to-noise ratio (PSNR), and delay, 2D transforms are broken into 1D directional transforms for block sizes ranging from 4×4 to 64×64. The temporal complexity was greatly decreased by adding DST-2 to the existing video test model (VTM). The MTS's adaptive multiple transform (AMT) scheme already included a pool of transforms, but DST-2 was introduced as a fourth transform. Encoder time complexity was reduced by 22% on average without compromising PSNR and bitrate.

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1. INTRODUCTION

Compressing videos is the most demanding research interest mainly in consumer goods of electronics. ultra-high definition (UHD) should be supported in upcoming televisions. High definition (HD) must be supported by high-end smartphones. The trend of this nature continues for next years to come. Because of these efficient codecs will be in demand with video capacities more than high efficiency video coding (HEVC) [1]. Identical situation continuing the last 33 years. The new standard of coding whichever developed so far reduced bitrate to 50% compared to its previous versions maintaining quality peak signal-to-noise ratio (PSNR) [2].

Usage of orthogonal transforms in signal processing done in digital enhanced that led to recognizing patterns [3] and filtering using a wiener filter [4]. Noninvertible transformation enabled with orthogonal transforms that transform from pattern space to feature space with less dimensionality. Orthogonal transforms like walsh-hadamard, discrete-fourier, slant, and Haar were considered for different applications because they have fast computing algorithms [3]–[10] for them. Karhunen-loeve transform (KLT) is optimal with respect to the following: variance distribution [3], Estimation mean-square error criterion [4], [6] and rate-distortion function [6], lacks an algorithm that enables its fast computation [3]. It is here, DCT is introduced with the fast algorithm for its computation whose performance is closer to that of KLT compared to the performance of walsh hadamard transform, discrete fourier transform, and hadamard transform. Coding of high-resolution images done successfully by discrete cosine transform (DCT) [11]–[15]. DCT was implemented using double-size fast fourier transform (FFT) utilizing complex arithmetic conventionally due to the lack of an algorithm which reduced its usage in many scenarios. A more efficient algorithm involving only real operations for computing fast DCT for a set of N points is described.

The algorithm can be prolonged to any number of $N=2^m$, $m\geq2$. The method takes $(\frac{3N}{2}).(\log_2^{N-1})+2$ real summing operations and $(N.log_2^{\left(N-\left(\frac{3N}{2}\right)\right)}+4)$ real product operations: approximately 6 times faster than the customary method using double-size FFT. Versatile video coding (VVC) will be based on transform, quantization, and entropy encoding. Multiple transform selection (MTS) schemes will be applied to versatile video coding also [16].

With MTS, two-D transforms will be computed by enacting first a one-D transform horizontal thenceforth one-D vertical transform. MTS scheme is useful to code both intra and inter-coded blocks [17]. MTS runs in all-intra, low-delay, and random-access configurations. VVC standard was unleashed as a new global standard in 2020 [18]. With VVC, forecasting error transformation is performed, quantized, and finally encoded as stream of bits. Following working draft 4 [19], the DCT-2 max. transform size is 64×64, while the other two max. size is 32×32.

Adaptive multiple transform (AMT) coding is effective at the cost of higher intricacy in computation on side of encoder. Joint video expert team (JVET) established joint exploration test model (JEM) software for testing gained extra coding methods and showed the importance of creating extra coding standards for video. Coding methods created in JEM allow a 30% increment in coding efficacy compared to HEVC [20], [21]. A modern approach namely AMT added by necessitating four extra transform varieties of the DCT/discrete sine transform (DST) family [22], [23]. In Inter coding contours, AMT coding efficiency is up by 7x compared to the reference of HEVC.

Modifications were made to the existing pool of transforms by including DST-2 to assess the time complexity of the video test model (VTM). The variations in encoding time ranged from around 19% to 28%. Efficient representation of energy in motion-compensated or residual images is crucial, and the 2-D DCT is widely utilized due to its ability to compactly represent energy in video compression applications.

Remnants of this paper are collocated as below. In section-2 deals with method followed by MTS of VVC. In section-3 discusses results of transform selection in MTS algorithm of VVC. In section 4 concludes the paper. MTS already contains DCT-2, DCT-8, and DST-7 as distinct transformations in it. Results were obtained by introducing DST-2 as the fourth transform.

2. METHOD

The flowchart in Figure 1 shows algorithm for the selection of transforms works as follows. The test video sequence is given as input. Video sequence may consist of three types of content. (i) smooth and continuous motion, (ii) complex and fast motion, (iii) discontinuous and sharp edges. If the video has smooth and continuous motion and MTS_CU_flag=0 then DCT-2 will be selected as a transform to compress the coding unit. If the video is having smooth and continuous motion and MTS_CU_flag=1 and MTS_Hor_flag=1 then DCT-8 is selected for horizontal and DST-2 is selected for vertical direction as transforms. If the video is having smooth and continuous motion and MTS_CU_flag=1 and MTS_Hor_flag=0 then DST-2 is selected for vertical and DST-7 is selected for horizontal direction as transforms.

Video may contain complex and fast motion. In this case, if MTS_Hor_flag=0 then DST-2 is selected for vertical and DST-7 is selected for horizontal direction as transforms. The content of the video may have discontinuities and sharp edges. If MTS_Ver_flag=0 then DCT-8 is selected for horizontal and DST-2 is selected for vertical direction as transforms. Test sequence video may have discontinuities and sharp edges. If MTS_Ver_flag=1 and MTS_Hor_flag=0 then DST-2 selected for vertical and DST-7 selected for horizontal direction as transforms. Video sequence may contain discontinuities and sharp edges. If MTS_Ver_flag=1 and MTS_Hor_flag=1 then DST-2 selected for vertical and DCT-8 selected for horizontal direction of transforms. Transforms selected are DST-2 and DCT-8 for this case. These transforms provide optimum compression to the selected block.

Video sequences are given as input to VTM's latest version for encoding without compromising the quality of video for evaluating PSNR, Bitrate, and encoding time. Transformation along with quantization performed before encoding. Multiple transforms are used to transform the frames of a given video sequence. DST-2 was added as the fourth transform to a pool of transforms existing in the AMT scheme of the MTS algorithm used in VVC. The average time difference after adding DST-2 varied from 19 % to 28.6% compared to the existing MTS.

Studies [24]–[27] in recent years reveal the usage of more than one transform allows the usage of different transforms for each block. This enhances the potential of the performance of the system for compressing videos. Many one-D arrangements emerge regularly in residuals of reparated motion and these arrangements are well characterized by group of one-D-DCTs (directional) [24]. Simulations in Biatex *et al.* [24]

manifest that rate-distortion attainment of H.264 enhances remarkably with the help of added 1D-DCTs. Figure 2 shows the concept of separable selection of transforms.

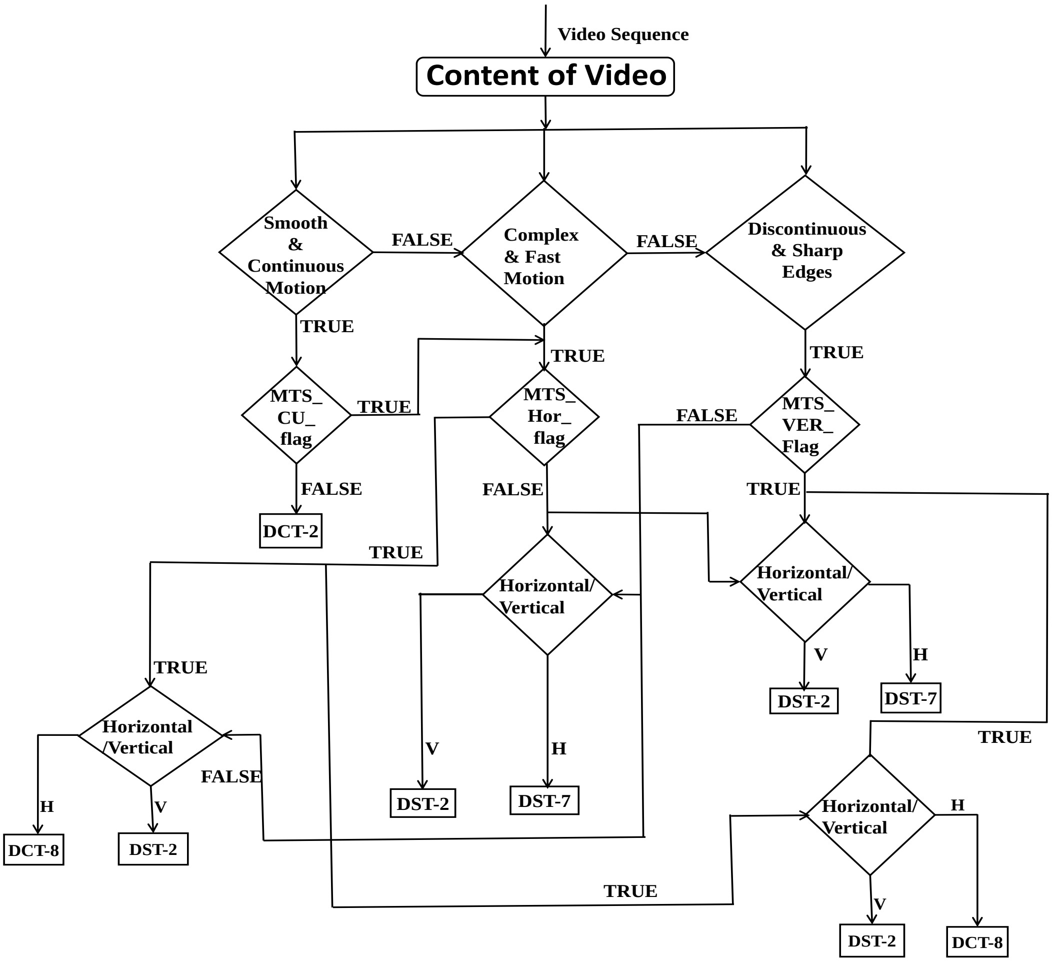

Figure 1. Flowchart for transform selection in MTS algorithm of VVC

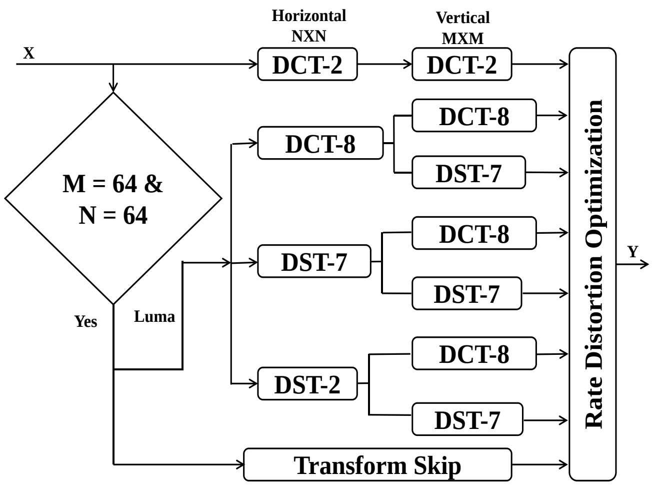

Figure 2. Two-D separable transform selection concept in VVC

In the JVET VVC Document, only horizontal and vertical one-D-DCTs are used instead of many directions. Simulations were performed with three settings: only two-D-DCT, two-D-DCT including all directional transforms, and only horizontal and vertical one-D-DCTs with 2D-DCT. For typical sequences of video, saving in number of bits is mostly because of the usage of horizontal along with vertical one-D-DCTs only. The selection of transforms based on the mode of transform is done in accordance with transform sets seen in Table 1.

Table 1. Pre-defined subsets of transform candidate

Transform set	Transform candidates
0	DST-7, DCT-8
1	DST-7, DST-2
2	DST-7, DCT-2

Perception of dissociable transforms has been broadly studied and scrutinized for HEVC [28], [29] which examines only DCT-2 with DST-7 for luma intra blocks with size 4×4 [30]. The separable transform concept was then integrated into JEM Software [31] which enables 5 trigonometric types of transforms. Five transform types include DCT-2, 5, and 8, and DST-2 and 7. Coding efficiency increased remarkably by around 3% of reduction in bit rate [31]. Gain in coding achieved at cost of large memory for saving coefficients of those transforms and overhead complexity for testing candidates of transform on the encoder side.

To conquer complexity of MTS JVET presented many contributions [32]–[35]. Solutions reduce complexity in no. of multiplication operations needed per pixel to apply DST-7 and DCT-8. Transform Approximation is not a surprise in literature and is thoroughly inspected for DCT-2 [36]–[45]. Chen *et al.* [36] gave an algorithm for approximation for 8-point DCT-2. This algorithm depends on factorizing matrix of DCT to even and odd and putting back odd with even for minimizing operation count still further. However, approximating DCT roughly of 8-point and utilizing for bigger sizes gives >5% loss in coding with respect to performance of rate-distortion.

Fast methods integrated to VTM-15.0. Experiments conducted are CTC test and QP low test. CTC tests include test condition in common given by JVET for experimenting proposals during VVC standard development. QP-quantization parameter set to 22, 27, 32, 37. Results provided both for inter MTS disabled and enabled. Outputs were provided with DST-2, DCT-8, DST-7, and DCT-2 in the existing AMT scheme in the MTS algorithm of VTM.

3. RESULTS AND DISCUSSION

Modifications were made to the existing pool of transforms in VVC standard to assess the time complexity. This involved disabling either DST-7 or DCT-8 individually to observe their impact on encoding time. Furthermore, the pool of transforms was expanded by appending DST-2. Throughout the evaluations, variations in the time taken to encode frames were observed, ranging from approximately 18% to 28%. To enhance the encoding capabilities of the VTM, the latest version incorporated a simulation with a fourth transform, DST-2, integrated into the MTS algorithm. This expanded the pool of transforms to include DCT-2, DCT-8, DST-7, and DST-2. MTS algorithm utilizes an AMT scheme. To comprehensively evaluate performance of the modified VTM, several parameters were considered, including PSNR, encoding time, and bitrate.

These parameters were assessed across various quantization parameter values for different video sequence categories (B1, B2, and B3). The evaluation also encompassed video sequences with rate of frames-24, 50 (fps) frames per second. Inclusion of DST-2 transforms in the MTS algorithm aimed to improve compression efficiency and overall video quality. By introducing this additional transform, the strike-a-balance between encoding time, achieved compression efficiency could be explored. Different quantization parameter values were examined to determine optimal configurations for specific video categories. The evaluation covered a diverse set of video sequences with varying frame rates, allowing for an in-depth analysis of the VTM's performance across different motion characteristics. This facilitated the identification of potential bottlenecks or areas for improvement in the encoding process. The modifications made to the pool of transforms, particularly the inclusion of DST-2, presented opportunities for optimizing the encoding process for specific video categories and frame rates. The evaluation of performance parameters such as PSNR, bitrate, and encoding time provided valuable insights into the trade-offs involved in achieving higher compression efficiency while maintaining satisfactory video quality. It is important to note that the results obtained from these evaluations are specific to the modifications made in the VTM and the chosen video sequences.

Further research and experimentation are required to validate these findings and explore additional aspects of the VVC standard’s performance. Figure 3 shows RD-curves for B1-category of video sequences in existing (DCT-2, DCT-8, and DST-7) as well as modified (DCT-2, DCT-8, and DST-7 including DST-2). Figure 3 also shows RD-curves for the B2-category of video sequences in existing (DCT-2, DCT-8, and DST-7) as well as modified (DCT-2, DCT-8, and DST-7 including DST-2). Figure 3 also shows RD-Curves for the B3-category of video sequences in existing (DCT-2, DCT-8, and DST-7) as well as modified (DCT-2, DCT-8/DST-7 including DST-2). The average change in encoder time between the original and modified was calculated and shown in the Table 2.

Simulation results for different video sequences are shown in Table 2. Results show that PSNR and bitrate remained the same but encoding time got reduced by 28% (max). This result predicts a significant improvement in compression without compromising for quality of video by maintaining same PSNR and bitrate.

Table 2. Simulation results for different sequences

Class	Sequence	QP	ΔT%	BD-PSNR	BD-bitrate
A (3,840×2,160)	Bosphorous	22	22.3254	0.0472	0.1010
		27	23.0192	0.1906	0.0010
		32	21.2345	0.1868	0.0090
		37	19.7571	0.0170	0.0080
	Jockey	22	20.7891	0.1743	0.0016
		27	23.4586	0.0169	0.0045
		32	26.5732	0.1826	0.0004
		37	28.7957	0.1710	0.0008
B (1,920×1,080)	Kimono1	22	21.6365	0.0001	0.0000
		27	26.2344	0.0000	0.0000
		32	24.0456	0.0001	0.0000
		37	19.0980	0.0000	0.0001
	Park scene	22	18.9654	0.0001	0.0000
		27	19.5647	0.0000	0.0000
		32	18.2345	0.0000	0.0001
		37	20.9500	0.0000	0.0000
	Cactus	22	22.0147	0.0001	0.0000
		27	18.8209	0.0000	0.0000
		32	18.1236	0.0000	0.0000
		37	22.2900	0.0001	0.0000
C (832×480)	Race horses	22	20.1479	0.0000	0.0000
		27	24.3432	0.0000	0.0000
		32	18.3769	0.0000	0.0001
		37	20.4123	0.0000	0.0000
	BQ mall	22	21.7895	0.0000	0.0000
		27	25.2077	0.0000	0.0000
		32	22.3568	0.0000	0.0000
		37	22.8070	0.0000	0.0000
D (416×240)	Race horses	22	24.5602	0.2305	0.0010
		27	22.1915	0.1725	0.0001
		32	21.0476	0.1073	0.0300
		37	21.3077	0.0850	0.0000
	BQ square	22	27.0077	0.1985	0.0001
		27	20.7731	0.0826	0.0001
		32	23.6547	0.0357	0.0002
		37	23.9852	0.0149	0.0030
E (1,280×720)	Four people	22	22.5421	0.0297	0.0002
		27	21.4653	0.0062	0.0001
		32	20.5689	0.0073	0.0000
		37	20.3214	0.0165	0.0300
	Johnny	22	25.4492	0.0628	0.0001
		27	24.0156	0.0262	0.0000
		32	20.6086	0.0418	-0.0009
		37	24.5687	0.0141	0.0004
	Kirsten and Sara	22	25.7892	0.0551	0.0001
		27	22.8082	0.0217	0.0000
		32	28.1935	0.0152	0.0001
		37	24.0356	-0.0334	0.0030
Average			22.4222	0.0454	0.0040

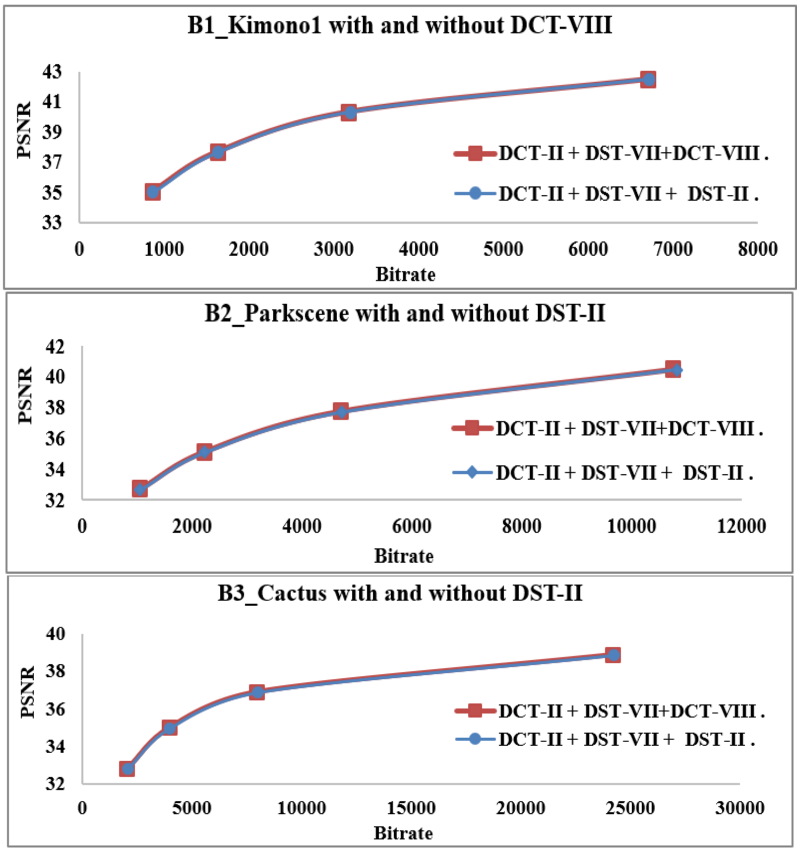

Figure 3. RD-curves of YUV test video sequences

4. CONCLUSION

Video sequences are given as input to VTM's latest version for encoding without compromising the quality of video for evaluating PSNR, Bitrate, and encoding time. Transformation along with quantization performed before encoding. Multiple transforms are used to transform the frames of a given video sequence. DST-2 was added as the fourth transform to a pool of transforms existing in the AMT scheme of the MTS algorithm used in VVC. The average time difference after adding DST-2 varied from 22.7% to 28.6% compared to the existing MTS.

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