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A Generalized Algorithm and Reconfigurable Architecture for Efficient and Scalable Orthogonal Approximation of DCT

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Abstract: This proposed paper presents architecture of generalized recursive function to generate approximation of orthogonal function DCT with an approximate length N could be derived from a pair of DCTs of length (N/2) at the cost of N additions for input preprocessing. Approximation of DCT is useful for reducing its computational complexity without impact on its coding performance. Most of the existing design for approximation of the DCT target only the small transform lengths DCT, and some of them are non-orthogonal. Proposed method is highly scalable for hardware and software implementation of DCT of higher lengths, and it can make use of the present approximation of 8-point DCT to obtain DCT approximation of any power of two length, N>8. It is shown that proposed design involves lower arithmetic complexity compared with the other existing design. One uniquely interesting feature of the proposed method is that it could be composed for the calculation of a 32-point DCT or for parallel calculation of two 16-point DCTs or four 8-point DCTs. The proposed method is found to offer many advantages in terms of hardware regularity, modularity and complexity. The design is implemented in Xillinx IES 10.1 design suite and synthesized using Cadence Encounter.

Keywords: Algorithm-Architecture Codesign, DCT Approximation, Discrete Cosine Transform (DCT), High Efficiency Video Coding (HEVC).

I. INTRODUCTION

The need of approximation is more important for higher-size DCT since the computational complexity of the DCT grows nonlinearly. On the other hand, modern video coding standards such as high efficiency video coding (HEVC) uses DCT of larger block sizes (up to 32x 32) in order to achieve higher compression ratio. But, the extension of the design strategy used in H264 AVC for larger transform sizes, such as 16-point and32-point is not possible .Besides, several image processing applications such as tracking and simultaneous compression and encryption require higher DCT sizes. In this context, Cintra has introduced a new class of integer transforms applicable to several block-lengths. Cintra *etal.* have proposed a new 16 x16 matrix also for approximation of 16-pointDCT, and have validated it experimentally recently, two new transforms have been proposed for 8-point DCT approximation: Cintra*etal.* have proposed a low-complexity 8-pointapproximate DCT based on integer functions and Potluri*etal.* have proposed a novel 8-point DCT approximation that requires only 14 addition. On the other hand, Bouguezel*etal.* Have proposed two methods for multiplication-free approximate form of DCT. The first method is for length N = 16 and32; and is based on the appropriate extension of integer DCT.

Also, a systematic method for developing a binary version of high-size DCT (BDCT) by using the sequence-ordered Walsh-Hadamard transform (SO-WHT) is proposed in [5]. This transform is a permutated version of the WHT which approximates the DCT very well and maintains all the advantages of the WHT. Some of the existing methods are deficient in terms of scalability, generalization for higher sizes, and orthogonality. This proposed design try to maintain orthogonality in the approximation of DCT for two reasons. Firstly, if the transform is orthogonal, then find its inverse, and the kernel matrix of this inverse transform is obtained by transposing the kernel matrix of the forward transform. This feature of inverse transform could be used to compute the inverse and forward DCT by similar computing structures. Moreover, in case of orthogonal transforms, similar fast algorithms are relevant to both inverse and forward transforms. This paper proposes an algorithm to derive approximate form of DCTs which satisfy all the three features. This paper obtain the proposed approximate form of DCT by recursive decomposition of sparse DCT matrix. It shows that proposed method involves lower arithmetic complexity than the existing DCT approximation algorithms. The proposed DCT approximation form of different lengths are orthogonal, and result in lower error-energy compared to the existing system.

The decomposition process gives generalization of a proposed transform for higher-size DCTs and proposed algorithm is easily scalable for hardware and software implementation of higher lengths DCT. Based on the proposed algorithm, paper has proposed a fully scalable, reconfigurable, and parallel architecture for the computation of approximate DCT. One unique feature of proposed design is that the structure for the computation of 32-point DCT could be used for the parallel exicution of two 16-point DCTs or four 8-point DCTs. The proposed method is more usefull than the existing methods in terms of hardware complexity and energy compaction.

II. LITERATURE REVIEW

A. Approximation of algorithms

The discrete cosine transform (DCT) is popularly used in image and video compression. Since the DCT is computationally intensive, several algorithms have been proposed in the literature to compute it efficiently. Recently, significant work has been done to derive approximate of 8-point DCT for reducing the computational complexity. The main objective of the approximation algorithms is to get rid of multiplications which consume most of the power and computation-time, and to obtain meaningful estimation of DCT as well.

B. Signed DCT and Series of Methods

Haweel [9] has proposed the signed DCT (SDCT) for 8x8sign, i.e., 1. Bouguezel-Ahmad-Swamy (BAS) have proposed a series of methods. They have provided a good estimation of the DCT by replacing the basis vector elements by 0, 1/2, 1. In the same vein, Bayer and Cintra have proposed two transforms derived from 0 and 1 as elements of transform kernel, and have shown that their methods perform better than the previous method, particularly for low- and high-compression ratio scenarios.

C. Integer Transforms

The need of approximation is more important for higher-size DCT since the computational complexity of the DCT grows nonlinearly. On the other hand, modern video coding standards such as high efficiency video coding (HEVC) uses DCT of larger block sizes (up to 32x32) in order to achieve higher compression ratio. But, the extension of the design strategy used in H264 AVC for larger transform sizes, such as 16-point and32-point is not possible. Besides, several image processing applications such as tracking and simultaneous compression and encryption require higher DCT sizes. In this context, Cintra has introduced a new class of integer transforms applicable to several block-lengths. Cintra have proposed a new 16 x16 matrix also for approximation of 16-pointDCT, and have validated it experimentally. Recently, two new transforms have been proposed for 8-point DCT approximation: Cintra *et al.* have proposed a low-complexity 8-pointapproximate DCT based on integer functions and Potluri et al. have proposed a novel 8-point DCT approximation that requires only 14 additions.

D. Multiplication Free Methods

On the other hand Bouguezeletal has proposed two methods for multiplication-free approximate form of DCT. The first method is for length, N = 8, 16 and32; and is based on the appropriate extension of integer DCT. Also, a systematic method for developing a binary version of high-size DCT (BDCT) by using the sequence-ordered Walsh-Hadamard transform (SO-WHT) is proposed in . This transform is a permutated version of the WHT which approximates the DCT very well and maintains all the advantages of the WHT.

III. EXISTING AND PROPOSED SYSTEMS

A. Existing System

1. Scalability and Orhtogonality

The existing methods are deficient in terms of scalability, generalization for higher sizes, and orthogonality .We intend to maintain orthogonality in the approximate DCT for two reasons. Firstly, if the transform is orthogonal, we can always find its inverse, and the kernel matrix of the inverse transform is obtained by just transposing the kernel matrix of the forward transform. This feature of inverse transform could be used to compute the forward and inverse DCT by similar computing structures. Moreover, in case of orthogonal transforms, similar fast algorithms are applicable to both forward and inverse transforms.

2. Arithmetic Complexity

In this paper, we propose an algorithm to derive approximate form of DCTs which satisfy all the three features. We obtain the proposed approximate form of DCT by recursive decomposition of sparse DCT matrix. It is observed that proposed algorithm involves less arithmetic complexity than the existing DCT approximation algorithms. The proposed approximate form of DCT of different lengths are orthogonal, and result in lower error-energy compared to the existing algorithms for DCT approximation. The decomposition process allows generalization of the proposed transform for higher-size DCTs. Interestingly ,proposed algorithm is easily scalable for hardware as well as software implementation of DCT of higher lengths, and it can make use of the best of the existing approximations of 8-pointDCT. Based on the proposed algorithm, we have proposed a fully scalable, reconfigurable, and parallel architecture for approximate DCT computation.

B. Proposed System

1. Approximation of DCT

A scheme of approximation of DCT should have the following Features:

- It should have low computational complexity.
- It should have low error energy in order to provide compression
- Performance closes to the exact DCT, and preferably should be orthogonal.
- It should work for higher lengths of DCT to support
- modern video coding standards, and other applications
- Like tracking, surveillance, and simultaneous compression and encryption.

But the existing DCT algorithms do not provide the best of all the above three requirements one uniquely interesting feature of proposed design is that the structure for the computation of32-point DCT could be configured for parallel computation of two 16-point DCTs or four 8-point DCTs. The proposed algorithm is found to be better than the existing methods in terms of energy compaction and hardware complexity, as well. The remainder of this paper is organized as follows. we derive the proposed algorithm for the generation of kernel matrices for the approximate DCT we provide the proposed configurable parallel architecture and discuss the performance evaluation of the proposed architecture in terms hardware complexity. I the application of the proposed method in image and video compression, and compression performances are discussed.

IV. EXPERIMENTAL VALIDATION

We discuss here the performance of the proposed DCT approximation algorithm in terms of energy compaction characteristics compared to the DCT approximations suggested in and. Note that the method in was proposed for a fixed size N = 16 The method in was defined for N = 8, 16, 32compared with the SDCT method . Although the SDCT method is the first one related to the approximation of DCT algorithms, its reconstruction capabilities are significantly lower than others.

A. Application for Image Compression

Image compression is a typical application to validate the energy compaction capability of DCT. We have used the compression scheme of [9] to compare the performance of the competing DCT approximation schemes. According to this method, in each block of the 2D-transform of size NxN r only coefficients are retained to reconstruct the image according to the zigzag sequence (all the other coefficients were set to zero). For, N = 8 we have used r_{min} =1 and r_{max} = 32, where, which corresponds to compression ratio in the range50% to 98.43%. In order to keep the same compression ratio for different DCT sizes, and are multiplied by 4 when is doubled. Accordingly, the number of retained coefficients is varied in the range [4,128], [16,512], and [64, 2048], respectively, For block-sizes (16x 16), (32 x32), and (64x 64) to vary the compression ratio from 50% to 98.43% equivalently for all block-sizes. In this context, we have introduced the notation of normalized which varies in the range [1,32] for all block sizes. For a given block-size, the normalized is the ratio of to the number of times the block-size is larger than 8x8.Accordingly, normalized remains the same for all block sizes. The idea behind this notation is to have the same compression ratio for different block sizes for the same normalized.

In Fig1 we have plotted the average PSNR of reconstructed image from a set of forty 512 x512 8-bit grey scale images (Miscellaneous and Aerials) obtained from a standard database .For comparison, we have taken the method in with the 0th order approximation which leads to a lower hardware complexity. Note that for N = 8 the DCT matrix given by [7] is the same one used in .Moreover, our algorithm is based on the 8-point DCT approximation given in .For that reason; we find the same PSNR performance of proposed approximation as that of. It is also shown that for high compression ratio method in [7] presents a higher PSNR, and for BAS method outperforms all 8-point approximations.

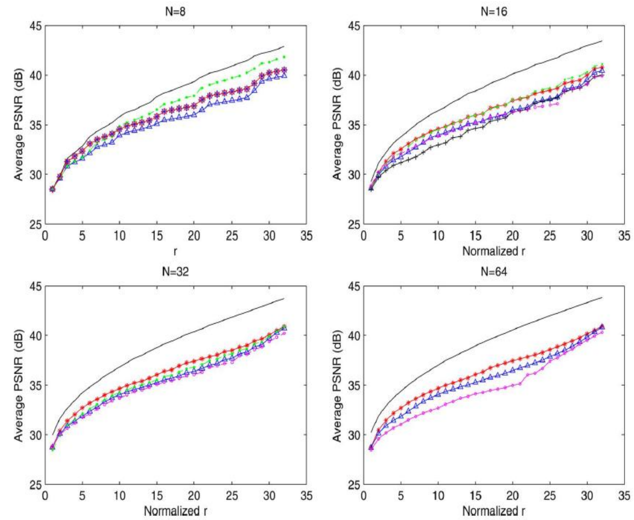

Fig 1. Average PSNR: exact (solid line), proposed ( ), BAS [9] ( ), Cintra ( ), BDCT [5] ( ) and BC ( ) DCT. BAS transform is defined for maximum size of N = 32.

For the proposed method often presents better results especially for normalized. Finally, for and the proposed method has a higher PSNR at all compression ratios. All these results are obtained by Matlab simulations and are in conformity with those presented in [5]where comparison is made between methods in [5]. We have considered the structural similarity (SSIM) index, (which is an improved version of the universal quality index(UQI), and one of the best objective metrics for image distortion). In Fig. 2 we have shown the plot of mean SSIM values obtained for different approximation methods relative to the exact DCT. We have used different compression ratios for and for the same images of PSNR assessment. It is found that the proposed algorithm outperforms existing methods for all and for compression ratios higher than 84.37% . For lower compression ratios, the SSIM values are similar. Finally, subjective evaluation is presented in Fig. 3 for normalized and for . As expected, it is found that the reconstructed images using the proposed algorithm have less blocking artifacts than methods and while method of presents a reconstructed image closely similar to the proposed method.

B. Application for Video Compression

To evaluate the performance of the proposed algorithm for video coding we have integrated the proposed approximated DCT into HEVC reference software HM12.1, in the same way as has been done .Moreover, we have integrated the existing methods to have a comparison in real time video coding. One key feature of HEVC is that it involves DCTs of different sizes such as 4, 8, 16, and 32. Therefore, we select the BDCT in and BAS methods since orthogonal approximate DCTs are implemented in the encoder to produce HEVC-compliant bit-stream. The inverse DCT defined in the HEVC final draft international standard is used in the decoder.

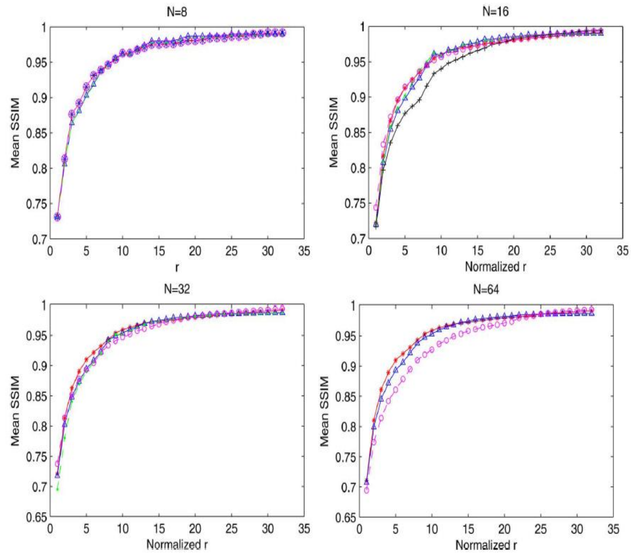

Fig 2. Mean SSIM relative to exact DCT of proposed (—*—), BAS (—●—), Cintra (—o—), BDCT (—Δ—) and BC (—+—) DCT. BAS transform is defined for maximum size of N=32.

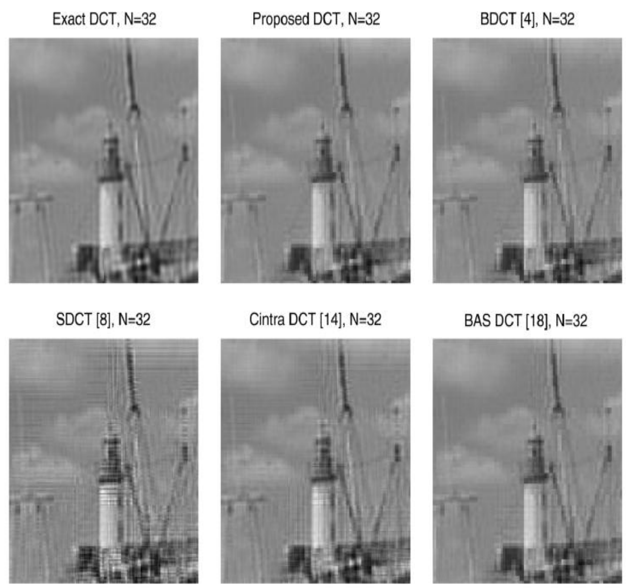

Fig 3. Reconstructed images using several algorithms for N=32 and normalized r=5.

We performed the tests using JCT-VC HM 12.1 for the main profile, and all-intra configuration over Qp values of 22, 27, 32, and 37. We have taken the People on Street 2560 x1600, Crowd Run 1920x 1080, and Old Town Cross 1280x 720 test sequences for comparison. All simulations are performed under Desktop PC switch the Intel Core2 processor family with 2GHzof processor frequency and 1 G bit of RAM. We have measured bit-rate difference (BRD) as the percentage difference of bit rate of each of the methods,(bit rate $_{approx}$)and from the bit rate of the anchor (bit rate $_{org}$)with the same value of PSNR. The values shown in Table I are calculated as:

$$BRD = \frac{(bitrate_{org} - bitrate_{approx})}{bitrate_{org}}$$

Where positive values indicate coding loss compared to the anchor. Note that the bit rate is calculated by taking into account the frame rate of the test sequence, the total number of tested frames and the size of the bit stream. Assessment of video coding performance of approximated transforms compared to HM12.1are summarized in Table I. The approximated DCT algorithms give coding loss between 3.43% and 6.40% for different test sequences. This coding loss can be explained by the entropy coder used after the DCT. The entropy coder is designed for coding the exact DCT coefficients and not approximated coefficients. The coding loss could be reduced by an appropriate modification of context models used in CABAC coder, which we can take up as a future work.

Table I. BRD percentage of approximated transforms for BDCT, BAS, and proposed method.

Test sequence	$Qp = 22$	$Qp = 27$	$Qp = 32$	$Qp = 37$
PeopleOnStreet (2560 × 1600)	6.40	5.83	5.47	4.51
CrowdRun (1920 × 1080)	5.74	5.09	4.62	4.17
OldTownCross (1280 × 720)	5.26	4.96	4.15	3.99

V. CONCLUSION

In this paper, we have proposed a recursive algorithm to obtain orthogonal approximation of DCT where approximate DCT of length N could be derived from a pair of DCTs of length N/2 at the cost of additions for input pre processing. The proposed approximated DCT has several advantages, such as of regularity, structural simplicity, lower-computational complexity, and scalability. Comparison with recently proposed competing methods shows the effectiveness of the proposed approximation in terms of error energy, hardware resources consumption, and compressed image quality. We have also proposed a fully scalable reconfigurable architecture for approximate DCT computation where the computation of 32-point DCT could be configured for parallel computation of two 16-point DCTs or four 8-point DCTs.

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