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2D DCT Based Motion Recovery Using Fourteen Addition Techniques

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Abstract—Video processing systems such as HEVC requiring low energy consumption needed for the multimedia market has lead to extensive development in fast algorithms for the efficient approximation of 2-D DCT transforms. The DCT is employed in a multitude of compression standards due to its remarkable energy compaction properties. Multiplier-free approximate DCTTransforms have been proposed that offer superior compression performance at very low circuit complexity. Such approximations can be realized in digital VLSI hardware using additions and Subtractions only, leading to significant reductions in chip area and power consumption compared to conventional DCTs and integer transforms. In this paper, we introduce a novel 8-point DCT approximation that requires only 14 addition operations and no multiplications. The proposed DCT approximation is a candidate for reconfigurable video standards such as HEVC. The proposed transform and several other DCT approximations are mapped to systolic-array digital architectures and physically realized as digital prototype circuits using FPGA Spartan 3 and it are implemented by verilog language.

Keywords— Approximate DCT, low-complexity algorithms, image compression, HEVC, low power consumption.

I. INTRODUCTION

This A **discrete cosine transform** (**DCT**) expresses a sequence of finitely many data points in terms of a sum of cosine functions oscillating at different frequencies. DCTs are important to numerous applications in science and engineering,from lossy compression of audio and images (where small high-frequency components can be discarded), to spectral methods for the numerical solution of partial differential equations. The use of cosine rather than sine functions is critical in these applications: for compression, it turns out that cosine functions are much more efficient (as explained below, fewer are needed to approximate a typical signal), whereas for differential equations the cosines express a particular choice of boundary conditions. In particular, a DCT is a Fourier-related transform similar to the discrete Fourier transform (DFT), but using only real numbers. DCTs are equivalent to DFTs of roughly twice the length, operating on real data with even symmetry (since the Fourier transform of a real and even function is real and even), where in some variants the input and/or output data are shifted by half a sample. There are eight standard DCT variants, of which four are common. The most common variant of discrete cosine transform is the type-II DCT, which is often called simply "the DCT"; its inverse, the type-III DCT, is correspondingly often called simply "the inverse DCT" or "the IDCT". Two related transforms are the discrete sine transform (DST), which is equivalent to a DFT of real and odd functions, and the modified discrete cosine transform (MDCT), which is based on a DCT of **overlapping** data.

II. DESCRIPTION

Recent years have experienced a significant demand for high dynamic range systems that operate at high resolutions. In particular, high-quality digital video in multimedia devices and video-over-Internet protocol networks are prominent areas where such requirements are evident. Other noticeable fields are geospatial remote sensing, traffic cameras, automatic surveillance, homeland security, automotive industry and multimedia wireless sensor networks, Often hardware capable of significant throughput is necessary; as well as allowable area-time complexity. In this context, the discrete cosine transform (DCT) is an essential mathematical tool in both image and video coding [8]. Indeed, the DCT was demonstrated to provide good energy compaction for natural images, which can be described by first-order Markov signals. Moreover, in many situations, the DCT is a very close substitute for the Karhunen-Loève transform (KLT), which has optimal properties [9]. As a result, the two-dimensional (2-D) version of the 8-point DCT was adopted in several imaging standards such as JPEG, MPEG1, MPEG-2, H.261, H.263, and H.264/AVC.

Additionally, new compression schemes such as the High Efficiency Video Coding (HEVC) employs DCT-like integer transforms operating at various block sizes ranging from 4*4to 32*32 pixels. The distinctive characteristic of HEVC is its capability of achieving high compression performance at approximately half the bit rate required by H.264/AVC with same image quality. Also HEVC was demonstrated to be especially effective for high-resolution video applications. However, HEVC possesses a significant computational complexity in terms of arithmetic operations. In fact, HEVC can be 2 to 4 times more computationally demanding when compared to H.264/AVC. Therefore, low complexity DCT-like approximations may benefit future video codec includes emerging HEVC/H.265 systems.

Several efficient algorithms were developed and a noticeable literature is available. Although fast algorithm scan significantly reduce the computational complexity of computing he DCT, floating-point operations are still required. Despite their accuracy, floating-point operations are expensive in terms of circuitry complexity and power consumption.

Therefore, minimizing the number of floating-point operations is a sought property in a fast algorithm. One way of circumventing his issue is by means of approximate transforms.

The aim of this paper is two-fold. First, we introduce a new DCT approximation that possesses an extremely low arithmetic complexity, *requiring only 14 additions*. This novel transform was obtained by means of solving a tailored optimization problem aiming at minimizing the transform computational cost. Second, we propose hardware implementations for several2-D 8-point approximate DCT.

The approximate DCT methods under consideration are (i) the proposed transform for DCT; (ii) the 2008 Bouguezel-Ahmad-Swamy (BAS) DCT approximation(iii) the Cintra-Bayer (CB) approximate DCT based on the rounding-off function. All introduced implementations are sought to be fully parallel time-multiplexed 2-D architectures for 8 ×8 data blocks. Additionally, the proposed designs are based on successive calls of 1-D architectures taking advantage of the separability property of the 2-D DCT kernel.

III. REVIEW OF APPROXIMATE DCT METHOD

In this section, we review the mathematical description of the selected 8-point DCT approximations. All discussed methods here consist of a transformation matrix that can be put in the following format:

[Diagonal matrix] *[low complexity matrix]

The diagonal matrix usually contains irrational numbers in the $1/\sqrt{m}$ form , where m is a small positive integer. In principle, the irrational numbers required in the diagonal matrix would require an increased computational complexity. However, in the context of image compression, the diagonal matrix can simply be absorbed into the quantization step of JPEG-like compression procedures. Therefore, in this case, the complexity of the approximation is bounded by the complexity of the low-complexity matrix. Since the entries of the low complexity matrix comprise only powers of two in$\{0, \pm 1/2, \pm 1, \pm 2\}$, null multiplicative complexity is achieved.

A. *Proposed Transform*

The aim at deriving a novel low-complexity approximate DCT. For such end, we propose a search over the 8× 8 matrix space in order to find candidate matrices that possess low computation cost. Let us define the cost of a transformation matrix as the number of arithmetic operations required for its computation. One way to guarantee good candidates is to restrict the search to matrices whose entries do not require multiplication operations. Thus we have the following optimization problem:

$$T_P = \arg\min_{T} \text{cost}(T)$$

B. *Arithmetic Complexity*

The arithmetic complexity as figure of merit for estimating the computational complexity.The arithmetic complexity consists of the number of elementary arithmetic operations (additions/subtractions, multiplications/divisions, and bit shift operations) required to compute a given transformation. In other words, in all cases, we focus our attention to the low-complexity matrices:T_1, T_2 , and the proposed matrixT_P.

For instance, in the context of image and video compression, the complexity of the diagonal matrix can be absorbed into the quantization step [15]; therefore the diagonal matrix does not contribute towards an increase of the arithmetic complexity [8], [9].Because all considered DCT approximations have null multiplicative complexity, we resort to comparing them in terms of their arithmetic complexity assessed by the number of additions/subtractions and bit-shift operations. Table I displays the obtained complexities. We also include the complexity of the exact DCT calculated (i) directly from definition [10] and (ii) according to Arai fast algorithm for the exact DCT [13]. We derived a fast algorithm for the proposed transform, employing only 14 additions. This is the same very low-complexity exhibited by the Modified CB-2011 approximation [9]. To the best of our knowledge these are DCT approximations offering the lowest arithmetic complexity in literature.

IV. DCT METHODS

1)Bouguezel-Ahmad-Swamy Approximate DCT

In [10], a low-complexity approximate was introduced byBouguezel*et al.* We refer to this approximate DCT as BAS-2008 approximation. The BAS-2008 approximation C_1has the

following mathematical structure:

$$C_1 = D_1 . T_1 \quad (1.1)$$

$$C_1 = D_1.\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 0 & 0 & 0 & 0 & -1 & -1 \\ 1 & \frac{1}{2} & \frac{-1}{2} & -1 & -1 & \frac{-1}{2} & \frac{1}{2} & 1 \\ 0 & 0 & -1 & 0 & 0 & 1 & 0 & 0 \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\ 1 & -1 & 0 & 0 & 0 & 0 & 1 & -1 \\ \frac{1}{2} & -1 & 1 & \frac{-1}{2} & \frac{-1}{2} & 1 & -1 & \frac{1}{2} \\ 0 & 0 & 0 & -1 & 1 & 0 & 0 & 0 \end{bmatrix} \quad (1.2)$$

where $D_1 = \text{diag}\left({}^{1}/_{\sqrt{8}}, {}^{1}/_{\sqrt{4}}, {}^{1}/_{\sqrt{5}}, {}^{1}/_{\sqrt{2}}, {}^{1}/_{\sqrt{8}}, {}^{1}/_{\sqrt{4}}, {}^{1}/_{\sqrt{5}}, {}^{1}/_{\sqrt{2}}\right)$. A fast algorithm for matrix T_1can be derived by means of matrix factorization. Indeed, can be written as a product of three sparsematrices having $\{0, \pm {}^{1}/_{2}, \pm 1\}$elements as shown below:$T_1 = A_3 . A_2 . A_1$, where

$$A_1 = \begin{bmatrix} I_4 & \bar{I}_4 \\ \bar{I}_4 & I_4 \end{bmatrix} \quad (1.3)$$

$$A_2 = \begin{bmatrix} 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 \\ 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1 & 1 \\ 1 & 0 & 0 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 \end{bmatrix} \quad (1.4)$$

$$A_3 = \begin{bmatrix} 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{2} & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 0 & \frac{1}{2} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \quad (1.5)$$

Matrices $\bar{I}_n$ andI_n denote the identity and counter-identity matrices of order, respectively. It is recognizable that matrixis the well-known decimation-in-frequency structure present inseveral fast algorithms.

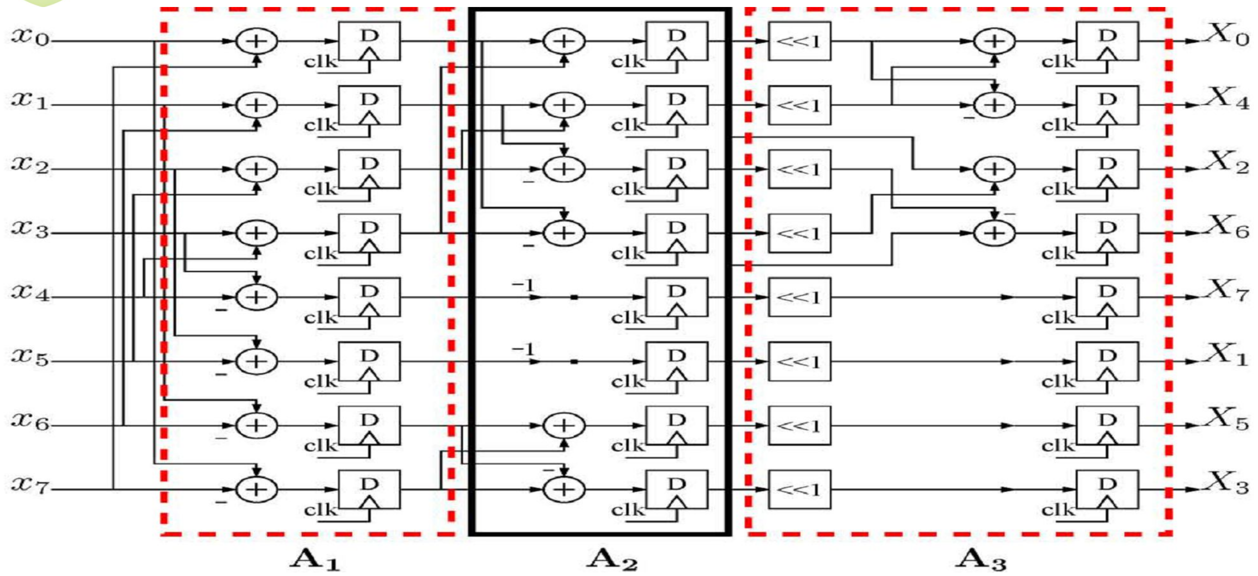

Fig.1.1. Digital Architecture for BAS 2008 Approximation DCT

This diagram represents the digital signal flow graph for BAS 2008 approximation. It contain 18 addition and 2 shift operations. There is no multiplication is performed here.

2)CB 2011 Approximate DCT

By means of judiciously rounding-off the elements of theexact DCT matrix, a DCT approximation was obtained and described in [11]. The resulting 8-point approximation matrix is orthogonal and contains only elements in $\{0, \pm 1\}$. Clearly, itpossesses very low arithmetic complexity [11].

The matrix derivedtransformation matrixC_2 is given by:

$$C_2 = D_2.T_2 \quad (2.1)$$

$$C_2 = D_2.\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & -1 \\ 1 & 0 & 0 & -1 & -1 & 0 & 0 & 1 \\ 0 & 1 & -1 & 0 & 0 & 1 & 0 & 0 \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\ 0 & -1 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & -1 & 1 & 0 & 0 & 1 & -1 & 0 \\ 0 & 0 & 0 & -1 & 1 & 0 & 0 & 0 \end{bmatrix} \quad (2.2)$$

Where $D_2 = diag\left(1/\sqrt{8}, 1/\sqrt{6}, 1/2, 1/\sqrt{6}, 1/\sqrt{8}, 1/\sqrt{6}, 1/2, 1/\sqrt{6}\right)$.An efficientfactorization for the fast algorithm for $T_2$was proposed in [11] as described below:$T_2 = P_2.A_6.A_5.A_1$,where

$$A_5 = diag\left(\begin{bmatrix} 1 & 0 & 0 & 1 \\ 0 & 1 & 1 & 0 \\ 0 & 1 & -1 & 0 \\ 1 & 0 & 0 & -1 \end{bmatrix}, \begin{bmatrix} -1 & 1 & -1 & 0 \\ -1 & -1 & 0 & 1 \\ 1 & 0 & -1 & 1 \\ 0 & 1 & 1 & 1 \end{bmatrix}\right) \quad (2.3)$$

$$A_6 = diag\left(\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}, -1, I_5\right) \quad (2.4)$$

Matrix P_2corresponds to the following permutation: (1)(2 58)(3 7 6 4).

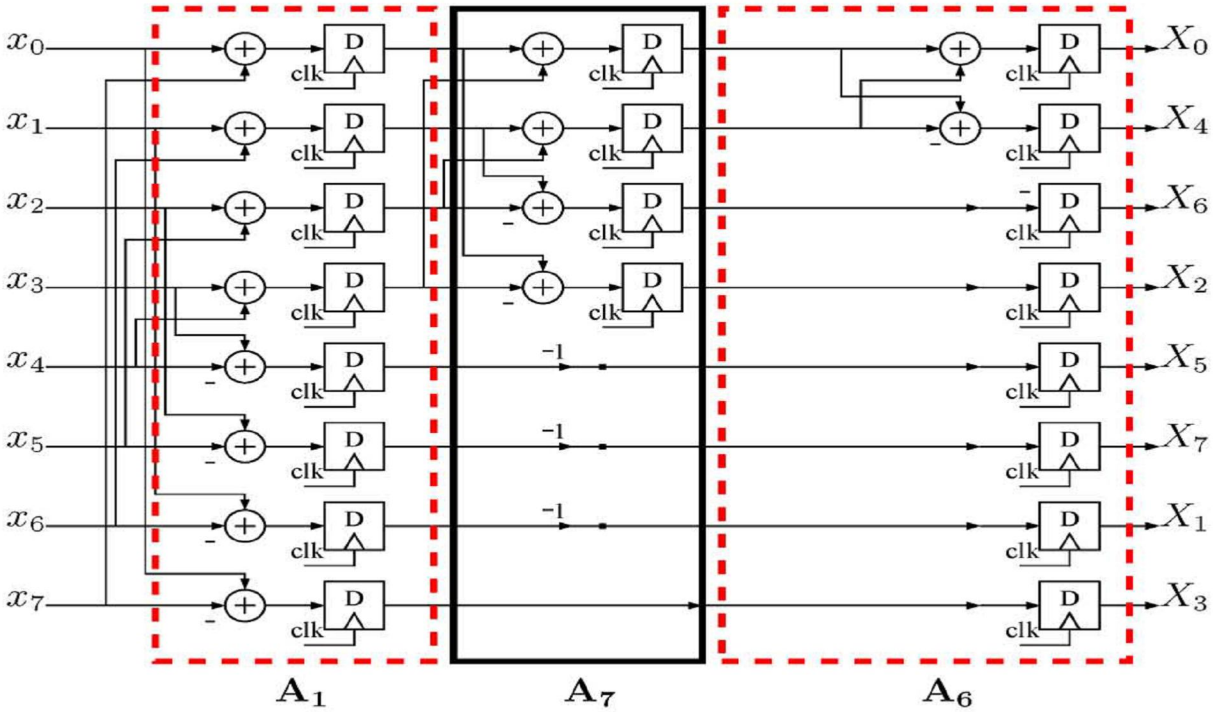

Fig.2.1.Digital architecture for CB2011 approximation

This diagram represents the digital signal flow graph of CB2011approximate DCT.This Transformation matrix contain only 22 additions and there is no shift and multiplications are performed here.

V. DIGITAL ARCHITECTURE AND REALISATION

In this section we propose architectures for the detailed 1-Dand 2-D approximate 8-point DCT. This section explores the hardware utilization of the discussedalgorithms while providing a comparison with theproposed novel DCT approximation algorithm and its fastalgorithm realization. Our objective here is to offer digitalrealizations together with measured or simulated metrics ofhardware resources so that better decisions on the choice of aparticular fast algorithm and its implementation can be reached.

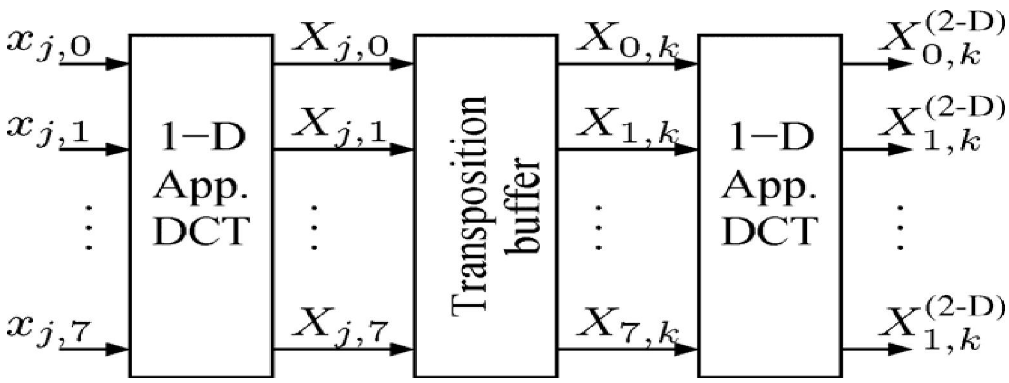

Fig. 1.3Two-dimensional approximate DCT

This is propose digital computer architectures that are custom designed for the real-time implementation of the fast algorithm. The proposed architectures employs two parallel realizations of DCT approximation blocks, as shown in Fig. 1.3..

The 1-D approximate DCT blocks (Fig. 1.3) implement a particular fast algorithm chosen from the collection described earlier in the paper. The first instantiation of the DCT block furnishes a row-wise transform computation of the input image, while the second implementation furnishes a column-wise transformation of the intermediate result. The row- and column-wise transforms can be any of the DCT approximations detailed in the paper. In other words, there is no restriction for both row- and column-wise transforms to be the same. However, for simplicity, Itadopted identical transforms for both steps.

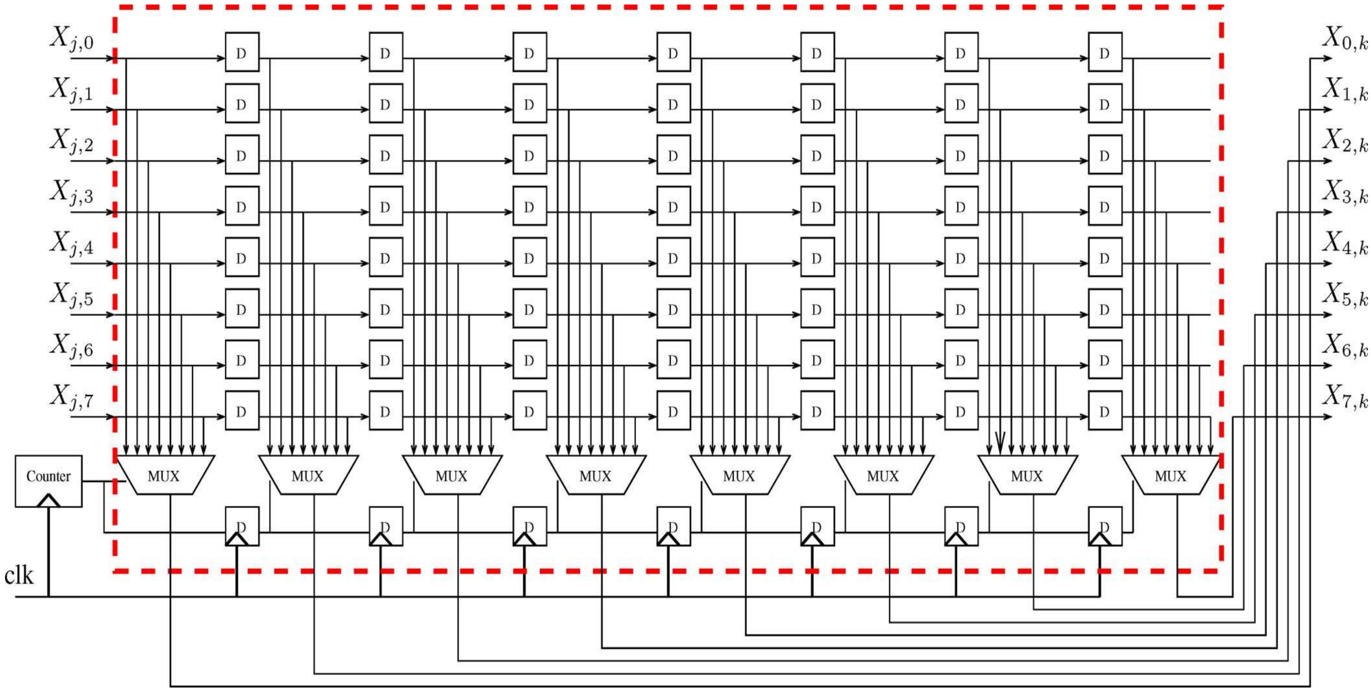

Fig.1.4. Proposed transposition buffer block

Between the approximate DCT blocks a real-time row-paralleltransposition buffer circuit is required. Such block ensuresdata ordering for converting the row-transformed datafrom thefirst DCT approximation circuit to a transposed format as requiredby the column transform circuit. The transposition bufferblock is detailed in Fig. 3.2.The circuitry sections associated to the constituent matrices ofthe discussed factorizations are emphasized in the figures inbold or dashed boxes.

VI. CONCLUSION

In this paper, we proposed a novel low-power 8-point DCTapproximation that require only 14 addition operations to computations and hardware implementation for the pro- posed transform and several other prominent approximate DCT methods, including the designs by Bouguezel-Ahmad-Swamy. We obtained that all considered approximate transforms perform very close to the ideal DCT. However, the modified CB-2011approximation and the proposed transform possess lower computational complexity and are faste than all other approximations under consideration. Interms of image compression, the proposed transform could outperform the modified CB-2011algorithm. Hence the new proposed transform is the best approximation for the DCT interms of computational complexity and speed among the approximate transform examined. Introduced implementations address both1-D and 2-Dapproximate DCT. All the approximations were digitally implemented using bothXilinx FPGA tools and CMOS45nm ASIC technology. The speeds of operation were much greater using the CMOS technology for the same function word size. Therefore, the proposed architectures are suitable for image and video processing, being candidates for improvements in several standards including the HEVC.

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