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FPGA Implementation of 1-D Discrete Tchebichef Transforms

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Abstract: Advances in the regions of image coding have created a creating eagerness for discrete transform. The enthusiasm of high gauge with a limited usage of computational resources and improved costs benefits has lead to experimentation with change coding procedures. This paper deals with Discrete Tchebichef Transform (DTT) which is a polynomial-based orthogonal transform. DTT is chosen for its effortlessness. The image compressing potential is better in DTT than compared other transforms. And also its computational efficiency is high. The performance of the transform is compared with the existing transform like Discrete Cosine Transform (DCT).

Key words: Discrete Tchebichef Transform · Discrete Cosine Transform · Image Compression

INTRODUCTION

Discrete transforms have received much attention owing to their applications in various classes of problems such as feature extraction, image/ video/ speech enhancement, pattern recognition, adaptive techniques, watermarking and image/ video/ speech Compression [1]. These algorithms are used in a variety of applications such as data archival, surveillance and security applications, image transmission on the internet, medical and entertainment applications

Many application and techniques deal with bulky data, video, image, speech or text during real-time. Hence, compression plays a crucial role in storage and transmission of data. Techniques such as predictive coding and transform coding are typically used in image compression. The latter uses discrete transforms for spatial to frequency domain, followed by coding methods such as Huffman coding

The transform kernel of the widely popular Discrete Cosine Transform (DCT) originates from the trigonometric representation of the tchebichef polynomials [2-10]. The main three key points which is need for DTT are: firstly, the need for application of DTT in an image compression scheme that is comparable to the available schemes, Secondly, a detailed analysis of compression performance of DTT and thirdly, the design of a fast DTT algorithm with reduced complexity. The performance is compared with the existing techniques.

Image Compression: Recent technological developments have spawned a generation of digital multimedia products applicable to the medical, biological, space, security and geo-physical. The storage and transmission of graphics, video and audio consume a large amount of memory and transmission bandwidth. Compression of images enables us to reduce the storage and transmission requirements [9]. Compression techniques rely on correlation and redundancies in images. Generally, compression also involves coding, which can be useful to encrypt data for security purposes.

Image Compression Scheme: It is a multi-stage process. It finds applications in many areas such as image sharing over the internet, medical purposes, medical image archival and storage of personal multimedia data [1]. For an image compression technique the block diagram is shown in Fig. 1.

Encoding and Decoding Process: The steps mentioned above to obtain the compressed image are explained in detail below:

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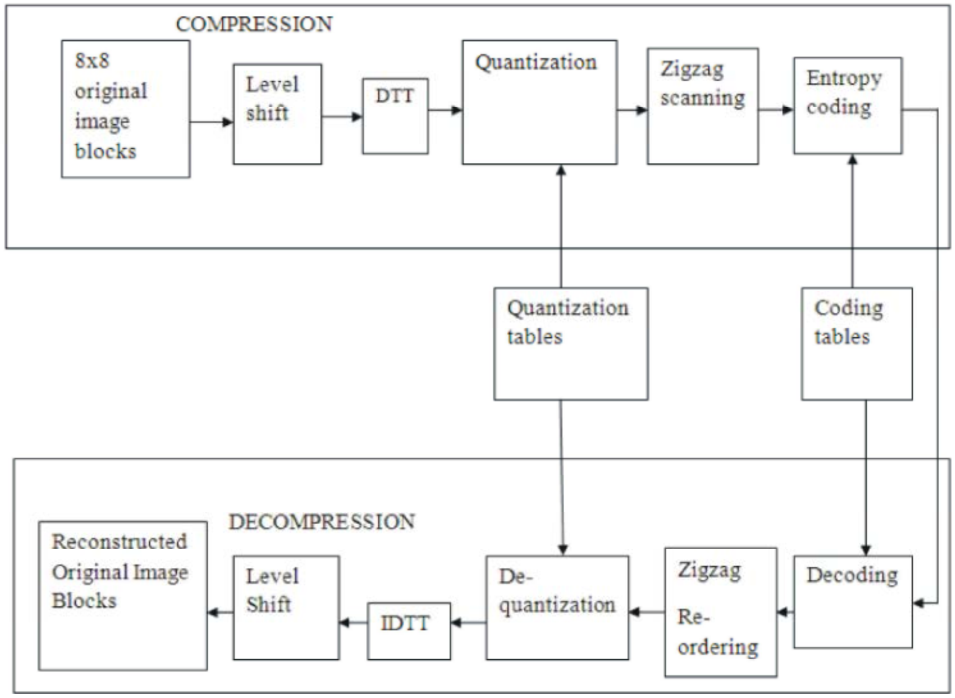


Fig. 1: Block diagram of image compression scheme for Discrete Tchebichef Transform

Sub-Block Extraction: The input image of size M x L is grouped into sub-blocks of size N x N and the subsequent operations are performed on each N x N sub-blocks. Additional samples are added if required to ensure integral number of blocks and further additional samples are mirrored along the existing samples within a block, when the remaining existing samples cannot completely form an N x N block. After decoding, the reverse operation is carried out, i.e., the sub-blocks are re-grouped and the original image is reconstructed.

Level Shifting: To reduce internal precision requirements, the range of the input data is changed from 0 to 2^p-1 to the range -2^{p-1} to 2^{p-1}-1, where p is the precision of the input image, i.e., for p = 8, for an image of size 256 x 256 with unsigned integer values in the range 0 to 255, the level shifted values are unsigned integers in the range -128 to 128. After decoding, the values are level-shifted back to the original unsigned representation.

Discrete Tchebichef Transform: It is performed on the level-shifted image sub-block. The energy compaction property of DTT also ensures that the image information contained in the sub-block is represented by fewer coefficients in the tchebichef domain.

Quantization: It is an irreversible and a lossy process, which contributes to the compression of data [8]. The transform coefficients $Y_{k_1k_2}$ are quantized using uniform quantization with different quantization steps, $Q_{k_1k_2}$ as;

$$T_{k_1k_2} = round\left(\frac{Y_{k_1k_2}}{Q_{k_1k_2}}\right) \quad (1)$$

where k_1, k_2 are the frequency domain indexes, $Q_{k_1k_2}$ corresponds to the entry of the quantization matrix in the position (k_1, k_2).The reverse operation is carried out to de-quantize the values in the decoding process.

Zigzag Scanning: The transform stage results in the concentration of the significance image components in the lower spatial frequencies [5]. The quantized DC coefficient undergoes differential encoding and the quantized AC coefficients are arranged in a zigzag scan order, which sorts the quantized values in the increasing order of spatial frequencies.

Entropy Encoding: Entropy coding techniques such as arithmetic coding and Run Length Coding (RLC) help in further compression of the quantized coefficients by removing statistical redundancies [8]. Huffman coding maps the zigzag ordered quantized coefficients into the shorter symbols depending on the probability of occurrence of the symbols [10].

Parameter Used in Image Compression: The PSNR block computes the peak signal-to-noise ratio, in decibels (dB), between two images. This ratio is often used as a quality measurement between the original and a compressed image. The higher the Peak Signal to Noise Ratio (PSNR), the better quality of the compressed or reconstructed image.

The MSE represents the cumulative squared error between the compressed and the original image. It is the squared norm of the difference between the data and the approximation divided by the number of elements, whereas PSNR represents a measure of the peak error.

To compute the PSNR, the block first calculates the mean-squared error using the following equation [4]:

$$MSE = \frac{\sum_{M,N} \left[I_1(m,n) - I_2(m,n) \right]^2}{M * N} \tag{2}$$

where, M and N are the number of rows and columns in the input images, respectively.

$I_1(m, n)$ and $I_2(m, n)$ represents the original and reconstructed image respectively.

Then the block computes the PSNR using the equation

$$PSNR = 10\log_{10}\left(\frac{R^2}{MSE} \right) \tag{3}$$

where, R is the maximum fluctuation in the input image data type.

Compression Ratio (CR) is defined as the ratio between uncompressed images to compressed image. It means that the compressed image is stored using only CR% of the initial storage size. It is used to measure the ability of data compression by comparing the size of the image being compressed to the size of original image.

Compression Ratio = uncompressed images/ compressed image.

Discrete Tchebichef Transform: Orthogonal transforms have been vastly explored. DCT, DFT, DWT and DHT have been used in a variety of applications such as image compression, video processing, feature extraction and speech processing [6].

Discrete Tchebichef Polynomials: The Discrete Tchebichef Polynomials (DTP) is the class of hyper geometric orthogonal polynomials associated with distributions of Stieltjes type. It belongs to the family of orthogonal polynomials and has been widely used for data approximation, data fitting and spectral methods. The Tchebichef polynomial of a discrete variable denoted by [3].

The DTP is defined by the difference formula,

$$t_k(x) = k!\Delta^k \left[\binom{x}{k} \binom{x-N}{k} \right]$$

for k = 0, 1…..N-1 (4)

where,

Δ --------- Forward difference operator

$t_k(x)$ --- k Tchebichef Polynomial

Discrete Tchebichef Transform: Tchebichef Transform (DTT) has a polynomial kernel and maps a finite sequence of data to the DTP space. By performing DTT on an image, transform the pixel intensity values in the spatial domain to the frequency domain. But for a certain gray level images, the tchebichef transform provides better reconstruction accuracy and also provides higher gain than the DCT. The performance of DTT is compared with DCT which reflects better coding efficiency and image reconstruction quality of DTT [7].

Formulation of DTT: The orthonormal DTP, denoted by $\tau_k(n)$ is given by;

$$\tau_k(n) = \frac{t_k(n)}{\sqrt{d(k.n)}} \tag{5}$$

The recurrence relation in polynomials $\tau_k(n)$ may be written for orthonormal DTPs in the form;

$$\tau_k(n) = (a_1 n + a_2)\tau_{k-1}(n) + a_3\tau_{k-2}(n) \tag{6}$$

with

$$\tau_0(n) = \frac{1}{\sqrt{N}}, \tau_1(n) = (2n+1-N)\sqrt{\frac{3}{N(N^2-1)}} \tag{7}$$

where, N – Natural numbers and the coefficient of a1, a2 and a3 is given by;

$$a_1 = \frac{2}{k}\sqrt{\frac{4k^2-1}{N^2-k^2}}, a_2 = \frac{1-N}{k}\sqrt{\frac{4k^2-1}{N^2-k^2}}$$

and

$$a_3 = \frac{1-k}{k}\sqrt{\frac{2k+1}{2k-3}}\sqrt{\frac{N^2-(K\_1)^2}{N^2-k^2}} \tag{8}$$

For an DTT domain, the transformed sequence y (k) of an input data sequence x (n) is given by,

$$y(k) = \sum_{n=0}^{N-1} \tau(k,n)x(n),$$

for k, n =0, 1…..N-1 (9)

where, $\tau(k, n)$ is the orthogonal basis of DTP denoted as $\tau_k(n)$ in (5) over an interval [0, N-1].

K and n denotes frequency and time indices.

The inverse DTT restores the input data sequence when applied to the transform coefficients and is given by,

$$x(n) = \sum_{k=0}^{N-1} \tau(k,n)y(k),$$

for k, n=0, 1…..N-1 (10)

Here, n and k represents the time and frequency domain indices respectively.

2-D Discrete Tchebichef Transforms: For a 2-D input sequence $x(n_1,n_2)$ the 2-D DTT of order N x M is defined as;

$$y(k_1,k_2) = \sum_{n_1=0}^{N-1}\sum_{n_2=0}^{M-1} \tau(k_1,n_1)\tau(k_2,n_2)x(n_1,n_2), \tag{11}$$

for k_1, n_1 = 0, 1…..N-1 and k_2, n_2 = 0, 1…..M-1

The inverse 2-D DTT applied to the transform coefficient restores the input data,

$$x(k_1,k_2) = \sum_{k_1=0}^{N-1}\sum_{k_2=0}^{M-1} \tau(k_1,n_1)\tau(k_2,n_2)y(n_1,n_2) \tag{12}$$

For k_1, n_1 = 0, 1…..N-1 and k_2, n_1 = 0, 1…..M-1

Simulation Output

DTT Output: The 1-D DTT architecture was described in Verilog. This Verilog was synthesized into an Altera Cyclone III FPGA family. All the coefficients are determined by integer shift and addition operations. Here the compilation report of 1D-DTT are shown in Fig. 2. This indicates that the total logic elements are 11%; total pins are 49%. The technology schematic view and timing report is shown in Fig. 3 and 4. Here the timing report indicates maximum frequency achieved by 1-D DTT is 89.99MHz. Here the power report of 1D-DTT are shown in Fig. 5. This indicates that the total thermal power dissipation is 80.07mW.


Flow Summary

Flow Status	Successful - Sun May 01 21:27:09 2016
Quartus II Version	9.0 Build 132 02/25/2009 SJ Web Edition
Revision Name	nn
Top-level Entity Name	DTT_algorthm
Family	Cyclone III
Device	EP3C16F484C6
Timing Models	Final
Met timing requirements	N/A
Total logic elements	1,633 / 15,408 (11 %)
Total combinational functions	1,615 / 15,408 (10 %)
Dedicated logic registers	439 / 15,408 (3 %)
Total registers	439
Total pins	171 / 347 (49 %)
Total virtual pins	0
Total memory bits	0 / 516,096 (0 %)
Embedded Multiplier 9-bit elements	0 / 112 (0 %)
Total PLLs	0 / 4 (0 %)

Fig. 2: Compilation Report of 1D-DTT

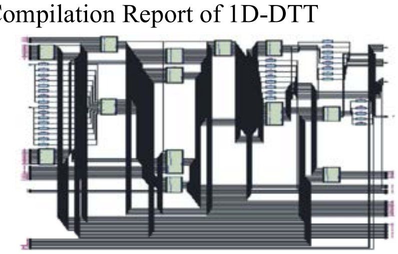
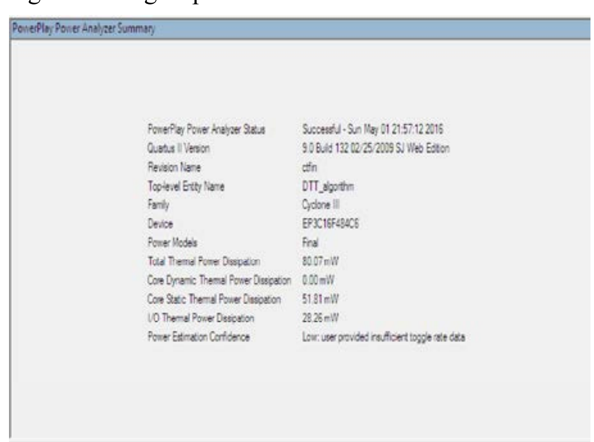


Fig. 3: Technology schematic view of 1D-DTT


Fmax Summary

	Fmax	Restricted Fmax	Clock Name	Note
1	89.88 MHz	89.88 MHz	clk	

Fig. 4: Timing Report of 1D-DTT


PowerPlay Power Analyzer Summary

PowerPlay Power Analyzer Status	Successful - Sun May 01 21:57:12 2016
Quartus II Version	9.0 Build 132 02/25/2009 SJ Web Edition
Revision Name	ctfin
Top-level Entity Name	DTT_algorthm
Family	Cyclone III
Device	EP3C16F484C6
Power Models	Final
Total Thermal Power Dissipation	80.07 mW
Core Dynamic Thermal Power Dissipation	0.00 mW
Core Static Thermal Power Dissipation	51.81 mW
I/O Thermal Power Dissipation	28.26 mW
Power Estimation Confidence	Low: user provided insufficient toggle rate data

Fig. 5: Power Report of 1D-DTT

CONCLUSION

In this project, image compression is performed for images using DCT and DTT techniques and this technique is simulated using MATLAB software. DTT techniques can be implemented using FPGA family and also comparison can be made between DCT and DTT in order to choose better image compression techniques. On Comparing with DCT architecture, the proposed architecture DTT shows an improvement in speed by 2% and delay of 49% reduction on Quartus 2 cyclone III FPGA platforms. Future research direction is to develop a fast 8x8 DTT algorithm for real time image and video compression.

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