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Design and Implementation of CORDIC-based 8-point 1D DCT

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ABSTRACT: CORDIC or CO-ordinate Rotation Digital Computer is a fast, simple, efficient and powerful algorithm used for diverse Digital Signal Processing applications. Primarily developed for real-time airborne computations, it uses a unique computing technique which is especially suitable for solving the trigonometric relationships involved in plane co-ordinate rotation and conversion from rectangular to polar form. It comprises a special serial arithmetic unit having three shift registers, three adders/sub-tractors, Look-Up table and special interconnections. A CORDIC-based processor for sine/cosine calculation was designed using VHDL programming in Xilinx ISE 14.1i. The CORDIC module was tested for its functionality and correctness by test-bench analysis.

KEYWORDS: Discrete Cosine Transform (DCT), Inverse discrete Cosine Transform (IDCT), VHDL

I. INTRODUCTION

For a long time the field of Digital Signal Processing has been dominated by Microprocessors. This is mainly because they provide designers with the advantages of single cycle multiply-accumulate instruction as well as special addressing modes. Although these processors are cheap and flexible they are relatively slow when it comes to performing certain demanding signal processing tasks e.g. Image Compression, Digital Communication and Video Processing. Of late, rapid advancements have been made in the field of VLSI and IC design. As a result special purpose processors with custom-architectures have come up. Higher speeds can be achieved by these customized hardware solutions at competitive costs. To add to this, various simple and hardware-efficient algorithms exist which map well onto these chips and can be used to enhance speed and flexibility while performing the desired signal processing tasks [1][2][3].

One such simple and hardware-efficient algorithm is CORDIC, an acronym for Coordinate Rotation Digital Computer, proposed by Jack E Volder [4]. CORDIC uses only Shift-and Add arithmetic with table Look-Up to implement different functions. By making slight adjustments to the initial conditions and the LUT values, it can be used to efficiently implement Trigonometric, Hyperbolic, Exponential functions, Coordinate Transformations etc. using the same hardware. Since it uses only shift-add arithmetic, VLSI implementation of such an algorithm is easily achievable. DCT algorithm has diverse applications and is widely used for Image compression. Implementing DCT using CORDIC algorithm reduces the number of computations during processing, increases the accuracy of reconstruction of the image, and reduces the chip area of implementation of a processor built for this purpose. This reduces the overall power consumption.

II. CORDIC OVERVIEW

CORDIC or Coordinate Rotation Digital Computer is a simple and hardware-efficient algorithm for the implementation of various elementary, especially trigonometric, functions. Instead of using Calculus based methods such as polynomial or rational functional approximation, it uses simple shift, add, subtract and table look-up operations to achieve this objective. The CORDIC algorithm was first proposed by Jack E Volder in 1959. It is usually implemented in either Rotation mode or Vectoring mode. In either mode, the algorithm is rotation of an angle vector by a definite angle but in

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variable directions. This fixed rotation in variable direction is implemented through an iterative sequence of addition/subtraction followed by bit-shift operation. The final result is obtained by appropriately scaling the result obtained after successive iterations. Owing to its simplicity the CORDIC algorithm can be easily implemented on a VLSI system.

Advantage:-

- Hardware requirement and cost of CORDIC processor is less as only shift registers, adders and look-up table (ROM) are required
- Number of gates required in hardware implementation, such as on an FPGA, is minimum as hardware complexity is greatly reduced compared to other processors such as DSP multipliers
- It is relatively simple in design
- No multiplication and only addition, subtraction and bit-shifting operation ensures simple VLSI implementation.
- Delay involved during processing is comparable to that during the implementation of a division or square-rooting operation.
- Either if there is an absence of a hardware multiplier (e.g. uC, uP) or there is a necessity to optimize the number of logic gates (e.g. FPGA) CORDIC is the preferred choice.

Disadvantage:-

- Large number of iterations required for accurate results and thus the speed is low and time delay is high
- Power consumption is high in some architecture types
- Whenever a hardware multiplier is available, e.g. in a DSP microprocessor, table look-up methods and good old-fashioned power series methods are generally quicker than this CORDIC algorithm.

Application:-

The algorithm was basically developed to offer digital solutions to the problems of real-time navigation in B-58 bomber.

- John Walther extended the basic CORDIC theory to provide solution to and implement a diverse range of functions.
- This algorithm finds use in 8087 Math coprocessor, the HP-35 calculator, radar signal processors, and robotics.
- CORDIC algorithm has also been described for the calculation of DFT [4], DHT [4], Chirp Z-transforms, filtering, Singular value decomposition, and solving linear systems [9].
- Most calculators especially the ones built by Texas Instruments and Hewlett-Packard use CORDIC algorithm for calculation of transcendental functions.

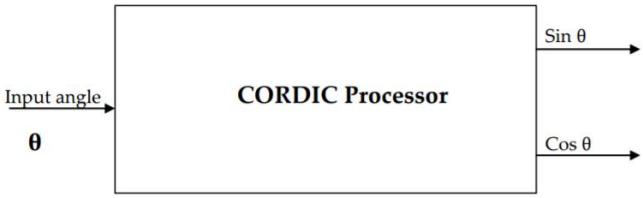

Figure 1: Block Diagram of a CORDIC processor

III. DISCRETE COSINE TRANSFORM

A discrete cosine transform (DCT) expresses a finite sequence of 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 (e.g. MP3) and images (e.g. JPEG) (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 for compression, since it turns out (as described below) that fewer cosine functions are needed to approximate a typical signal, whereas for differential equations the cosines express a particular choice of boundary conditions.

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Fundamental Properties of Discrete Cosine Transformation:-

Decorrelation:-

The neighboring pixels of an image are generally correlated. As a result of which using alternate methods of image compression, coding techniques, introduces redundancy. DCT reduces the correlation between neighboring coefficients, thus, enabling the uncorrelated transform coefficients to be encoded independently.

Energy Compaction:-

DCT provides excellent energy compaction for uncorrelated images. It packs input data into as few coefficients as possible allowing removal of coefficients with relatively less amplitudes during quantization, without introducing visual distortion in the reconstructed image. It is observed that the uncorrelated image exhibits sharper energy variations, unlike the correlated one, showing that it has got higher frequency content.

IV. CORDIC BASED DCT

Although the Loeffler DCT achieves good quality transformation results, it needs floating point multiplications which are significantly slow in both software and hardware implementation. It should be noted that hardware implementation of floating-point multiplication needs more area and power consumption than integer-point approximation. In this regard, Jeong et al. [3] have proposed an 8-point Cordic based DCT with six Cordic Rotations to realize multiplier-less approximation which requires 104 add and 84 shift operations. In addition, it has a very regular structure which is suitable for VLSI design.

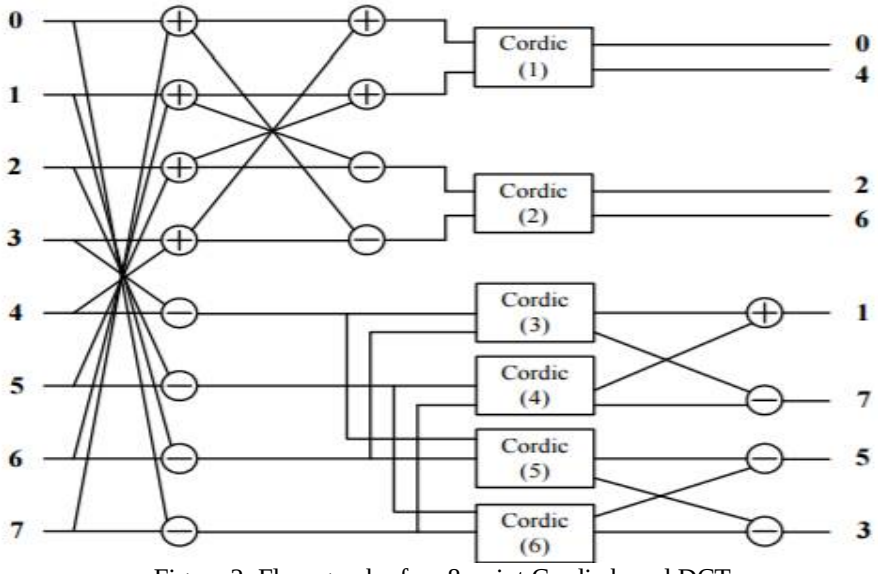

Figure 2: Flow graph of an 8-point Cordic based DCT

Therefore we can replace the multiplications with circulate rotation to carry out the Cordic based DCT as shown in Figure 2. When using the Cordic to replace the multiplications of the 8-point DCT whose rotation angles θ(x) are fixed. We can skip some unnecessary iteration without losing accuracy. Table I shows the detailed number of iterations and compensations for the Cordic based algorithm [3]. Although the Cordic based DCT reduces the number of computations in image/video compression, it still needs more operations than the bin DCT.

CORDIC algorithm, for calculation of sine and cosine values, is of three types. Each of the types has its own advantages and disadvantages depending upon the type of use intended. The three types are:

- Sequential or iterative
- Parallel or cascaded
- Pipelined

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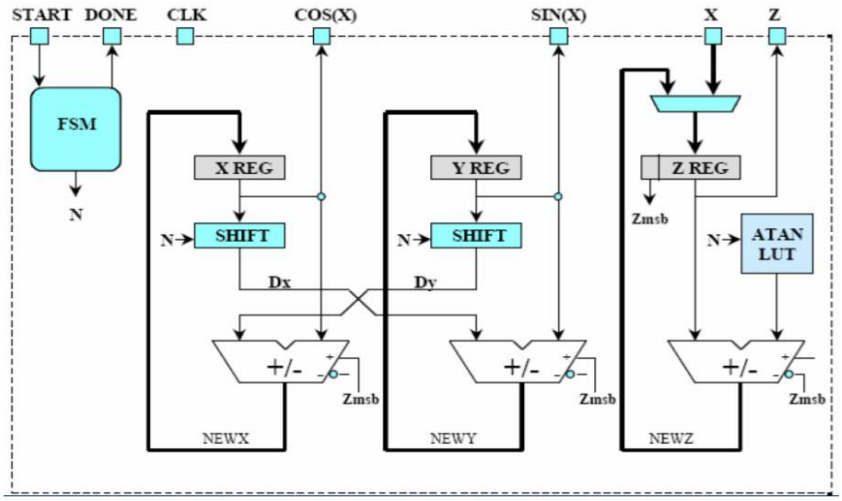

Figure 3: Sequential/Iterative CORDIC structure

V. SIMULATION RESULT

All the designing and experiment regarding algorithm that we have mentioned in this paper is being developed on Xilinx 14.1i updated version. Xilinx 9.2i has couple of the striking features such as low memory requirement, fast debugging, and low cost. The latest release of ISE™ (Integrated Software Environment) design tool provides the low memory requirement approximate 27 percentage low. ISE 14.1i that provides advanced tools like smart compile technology with better usage of their computing hardware provides faster timing closure and higher quality of results for a better time to designing solution. ISE 14.1i Xilinx tools permits greater flexibility for designs which leverage embedded processors. The ISE 14.1i Design suite is accompanied by the release of chip scope Pro™ 14.1i debug and verification software. By the aid of that software we debug the program easily. Also included is the newest release of the chip scope Pro Serial IO Tool kit, providing simplified debugging of high-speed serial IO designs for Virtex-4 FX and Virtex-5 LXT and SXT FPGAs. With the help of this tool we can develop in the area of communication as well as in the area of signal processing and VLSI low power designing. To simplify multi rate DSP and DHT designs with a large number of clocks typically found in wireless and video applications, ISE 14.1i software features breakthrough advancements in place and route and clock algorithm offering up to a 15 percent performance advantage. Xilinx 14.1i Provides the low memory requirement while providing expanded support for Microsoft windows Vista, Microsoft Windows XP x64, and Red Hat Enterprise WS 5.0 32-bit operating systems.

VI. CONCLUSION

CORDIC is a powerful algorithm, and a popular algorithm of choice when it comes to various Digital Signal Processing applications. Implementation of a CORDIC-based processor on FPGA gives us a powerful mechanism of implementing complex computations on a platform that provides a lot of resources and flexibility at a relatively lesser cost. Further, since the algorithm is simple and efficient the design and VLSI implementation of a CORDIC based processor is easily achievable. Although this project primarily deals with the design of 8-point 1D DCT using CORDIC algorithm, the concept and the architecture can be extended to calculate the 8-point 2D DCT. It can be further extended to calculate the higher order DCTs, thus, providing a fast, low cost implementation of processors for Image Processing and other Digital Signal Processing Applications.

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