

A Novel CORDIC algorithm for fixed angle rotation

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ABSTRACT: Rotation of vectors through fixed and known angles has wide applications in robotics, digital signal processing, graphics, games, and animation. But, we do not find any optimized coordinate rotation digital computer (CORDIC) design for vector-rotation through specific angles. Therefore, in this paper, we present optimization schemes and CORDIC circuits for fixed and known rotations with different levels of accuracy. For reducing the area- and time-complexities, we have proposed a hardwired pre-shifting scheme in barrel-shifters of the proposed circuits. Two dedicated CORDIC cells are proposed for the fixed-angle rotations. In one of those cells, micro-rotations and scaling are interleaved, and in the other they are implemented in two separate stages. Pipelined schemes are suggested further for cascading dedicated single-rotation units and bi-rotation CORDIC units for high-throughput and reduced latency implementations. We have obtained the optimized set of micro-rotations for fixed and known angles. The optimized scale-factors are also derived and dedicated shift-add circuits are designed to implement the scaling. The fixed-point mean-squared-error of the proposed CORDIC circuit is analyzed statistically, and strategies for reducing the error are given. We have synthesized the proposed CORDIC cells by Synopsys Design Compiler using TSMC 90-nm library, and shown that the proposed designs offer higher throughput, less latency and less area-delay product than the reference CORDIC design for fixed and known angles of rotation. We find similar results of synthesis for different Xilinx field-programmable gate-array platforms.

Index Terms—Coordinate rotation digital computer (CORDIC), digital arithmetic, digital signal processing (DSP) chip, VLSI.

INTRODUCTION:

CORDIC stands for coordinate rotation digital computer. The key concept of CORDIC arithmetic is based on the simple and ancient principles of 2-D geometry. But the iterative formulation of a computational algorithm for its implementation was first described in 1959 by Volder [1], [2] for the computation of trigonometric functions, multiplication, and division. Not only a wide variety of applications of CORDIC have been suggested over the time, but also a lot of progress has taken place in the area of algorithm design and development of architectures for high-performance and low-cost hardware solutions [3]–[12]. Rotation of vectors through a fixed and known angle has wide applications in robotics, graphics, games, and animation [4], [13], [14]. Locomotion of robots is very often performed by successive rotations through small fixed angles and translations of the links. The translation operations are realized by simple additions of coordinate values while the new coordinates of a rotational step could be accomplished by suitable successive rotations through a small fixed angle which could be performed by a CORDIC circuit for fixed rotation [4]. Similarly, interpolation of orientations between key-frames in computer graphics and animation could be performed by fixed CORDIC rotations [14]. There are plenty of examples of uniform rotation starting from electrons inside an atom to the planets and satellites. A simple example of uniform rotations is the hands of an animated mechanical clock which perform one degree rotation each time. There

are several cases where high-speed constant rotation is required in games, graphic, and animation

Existing System:

The rotation-mode CORDIC algorithm to rotate a vector through an angle to obtain a rotated vector is given by [1], [2] In case of fixed rotation, could be pre-computed and the sign-bits corresponding to could be stored in a sign-bit register (SBR) in CORDIC circuit. The CORDIC circuit therefore need not compute the remaining angle during the CORDIC iterations [3]. A reference CORDIC circuit for fixed rotations according to (1a) and (1b) is shown in Fig. 1. and are fed as set/reset input to the pair of input registers and the successive feedback values and at the iteration are fed in parallel to the input registers. Note that conventionally we feed the pair of input registers with the initial values and as well as the feedback values and through a pair of multiplexers. We show here that for rotation of a vector through a known and fixed angle of rotation using a rotation-mode CORDIC circuit, we can find a set of a small number of predetermined elementary angles for θ_i , where θ_i is the elementary angle to be used for the i th micro-rotation in the CORDIC algorithm (1), and N is the minimum necessary number of micro-rotations. Meanwhile, it is well known that the rotation through any angle, can be mapped into a positive rotation through without any extra arithmetic operations [10]. Hence, as a first step of optimization, we perform the rotation mapping so that the rotation angle lies in the range of $[-\pi/4, \pi/4]$. In the The simple pseudo code to optimize a set of micro-rotations is described in Algorithm 1. If the maximum accuracy which is defined as the maximum tolerable error between desired angle and approximated angle is given as an input, the optimization algorithm searches the parameters and that can minimize an objective function $f(\theta_i, N)$. The algorithm starts with the single micro-rotation, i.e., θ_1 , then if the micro-rotation that has smaller angle of deviation than cannot be found, the number of micro-rotations is increased by one and the optimization algorithm is run again. Exhaustive search is employed in the optimization algorithm to search the entire parameter space for all the combinations of θ_i and N .

Based on the obtained micro-rotations, the parameters for scaling operation can be searched with the different objective function, which is described in Section IV. The sub-optimal set of micro-rotations may be used in some cases, if the optimal set of micro-rotations cannot satisfy the design constraint for scaling. We have used sub-optimal solutions particularly for the rotation with the angle of 31 and 35 in Table I since the scaling requires more terms in these two cases if optimal solutions are used.

Proposed System:

Since the elementary angles and direction of micro-rotations are predetermined for the given angle of rotation, the angle es-

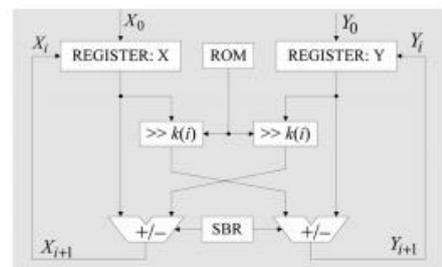


Fig. 2. CORDIC cell for constant complex multiplications.

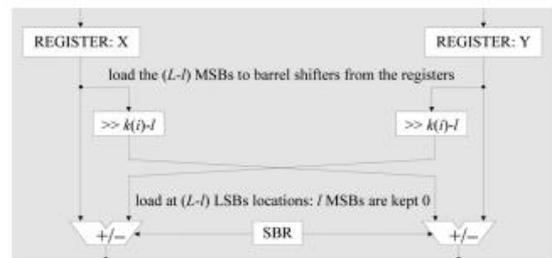


Fig. 3. Hardwired pre-shifting in basic CORDIC module.

timization data-path is not required in the CORDIC circuit for fixed and known rotations. Moreover, because only a few elementary angles are involved in this case, the corresponding control-bits could be stored in a ROM of few words. A CORDIC circuit for complex constant multiplications is shown in Fig. 2. The ROM contains the control-bits for the number of shifts corresponding the micro-rotations to be implemented by the barrel-shifter and the directions of micro-rotations are stored in the sign-bit register (SBR). The major contributors to the hardware-complexity in the implementation of a CORDIC circuit

are the barrel-shifters and the adders. There are several options for the implementation of adders [22], from which a designer can always choose depending on the constraints and requirements of the application. But, we have some scope to develop techniques for reducing the complexity of barrel-shifters over the conventional designs as discussed in the followings.

SCALING OPTIMIZATION AND IMPLEMENTATION

The generalized expression for the scale-factor given by (2) can be expressed explicitly for the selected set of microrotations as

$$K = \prod_{i=0}^{m_1-1} [(1 + 2^{-2k(i)})]^{-1/2}$$

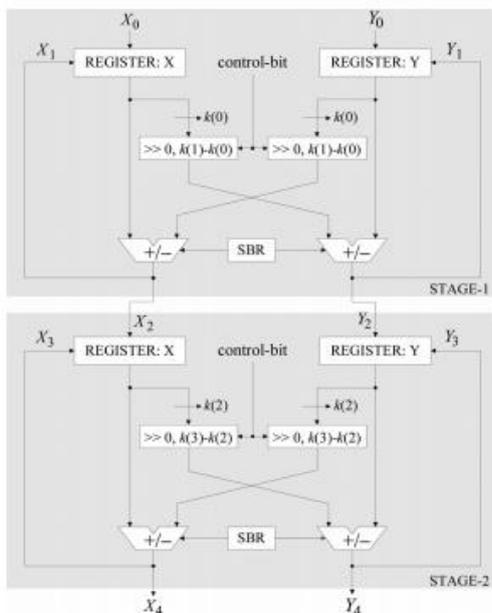


Fig. 6. Two-stage cascaded bi-rotation CORDIC circuit. SBR is sign-bit register of 2-bits size.

Implementation of Scaling

Scaling and micro-rotations could be implemented either in the same circuit in interleaved manner or in two separate stages. The implementation of scaling as well as the micro-rotation would however depend on the level of desired accuracy, and the implementation of scaling also depends on the implementation of micro-rotations. Therefore, we discuss here the

realization of the scaling circuits corresponding to different implementations of micro-rotations.

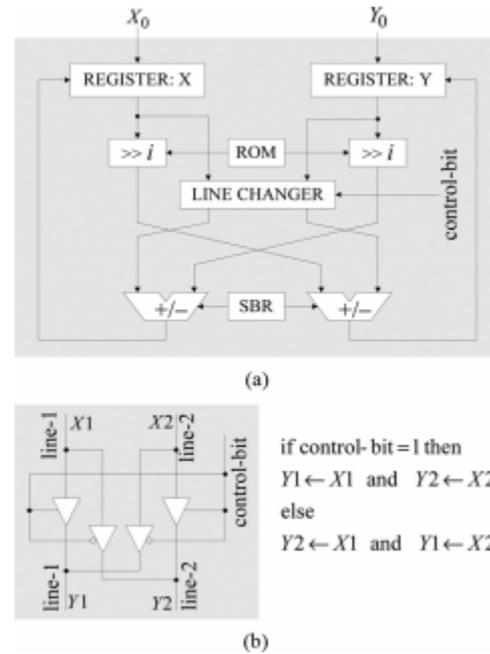


Fig. 8. CORDIC circuit for interleaved implementation of micro-rotations as well as scaling circuit. (a) The CORDIC circuit. (b) Structure and function of line-changer. For control-bit it performs micro-rotations and for control-bit it performs the shift-add operations for scaling.

COMPLEXITY CONSIDERATIONS

We discuss here the hardware and time complexities of the proposed design. In the existing literature we do not find similar work on CORDIC implementation of known and fixed rotations. Therefore, we compare the proposed design with the conventional CORDIC design for the rotation of unknown angle. We have used the basic CORDIC processor in [3, Fig. 2] for the implementation of conventional CORDIC. In addition, we have designed a reference architecture (see Fig. 1) for straightforward implementation of fixed rotations, and we have compared the complexities and speed performance of the proposed design with the conventional and reference design. The maximum deviation of amounting to is assumed to be accuracy level-1 (AL-1) and that amounting to is assumed to be accuracy level-2 (AL-2), so that AL-1 and AL-2 would

correspond to the proposed CORDIC implementations of rotation through four and six micro-rotations, respectively.

CONCLUSION

The number of micro-rotations for rotation of vectors through known and fixed angles are optimized and several possible dedicated circuits are explored for rotation-mode CORDIC processing with different levels of accuracy. The proposed CORDIC cell with interleaved scaling involves more area, but offers more throughput and involves nearly less latency and less ADP, than the reference design for known and fixed rotations. The proposed single-rotation cascade and birotation cascade require, respectively, and times more area over the reference design, but offer nearly 16.3 and 7.0 times more throughput, and involve nearly 4.6 and 2.5 times less ADP with nearly half and two-thirds of the latency of the other. With progressing scaling trends, since the silicon area is getting continually cheaper, it appears to be a good idea to use the cascaded designs for their potential for high-throughput and low-latency implementation. It is found that higher accuracy could be achieved in case of smaller angles of rotation when the same number of micro-rotations are used. The small angle rotators could therefore be very much useful for shape design and curve tracing for animation and gaming devices. The fixed-angle CORDIC rotation would have wide applications in signal processing, games, animation, graphics and robotics, as well.

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