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A Review on FPGA based Polynomial Matrix Multiplication for MIMO Communications

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ABSTRACT: Hardware implementation of polynomial matrix techniques such as eigenvalue decomposition (EVD), second order sequential best rotation (SBR2), SBR2P and QR decomposition algorithms are receiving growing interest for real-time applications such as MIMO communications and broadband sensor array signal processing (SASP). In this proposed system polynomial matrix computations are implemented on FPGA with two types of polynomial matrix multiplication (PMM) operations that is polynomial's matrix-vector and matrix-matrix product. The proposed system can verify the recursive accuracy of the architecture through double-precision counterpart running in MATLAB for both real and complex valued data. The proposed architecture requires low execution times while utilizing limited FPGA resources with good approximation as it focuses on SBR2P algorithm. This architecture is scalable in terms of the order of the input polynomial matrices, which is designed using the Xilinx system generator tool. Rather than only SBR2P, the proposed architecture is meant as a generic tool for polynomial matrix operations. This architecture could be used with a future FPGA implementation of other polynomial matrix methods, such as the polynomial matrix QR decomposition algorithm.

KEYWORDS: Polynomial matrix computations, PMM, SBR, SBR2P, QR decomposition, MIMO communication, Xilinx system generator for DSP tool.

I.INTRODUCTION

Wireless communication is a widely used technology used in recent days. In to wireless communication broadband sensor array signal processing, broadband adaptive beamforming, broadband blind signal separation, designing of filter banks, and MIMO communications are vast applications. These involves the transmission and reception of signals in space within a noisy environment accurately. In applications where narrowband signals have been convolutively mixed with noise, it is difficult to represent the received signal in the form of phase and amplitude of the respective signal. There decorrelation comes into picture. But instantaneous decorrelation using unitary matrix is not sufficient to separate the received signal. For that it is necessary to impose strong decorrelation for specified range of signal. To achieve strong decorrelation needs a matrix of finite impulse response (FIR) filters. Here if these filters are represented in terms of z-transform then it is equal to a polynomial matrix [1]. For many signal processing applications the problems of narrowband signals mixing is extended to broadband signals. For that SVD, EVD, PEVD tools are used, in which polynomial eigen value decomposition (PEVD) can factorize the para-Hermitian polynomial matrix into a product of diagonal polynomial matrix and Para-Unitary (PU) matrix. PU matrix can preserve the total signal power at every frequency [2].

SBR2 is one of the methods used to generate FIR PU matrix to diagonalize the polynomial matrix. For high speed real time applications polynomial matrix manipulations becomes difficult as diagonalization method is less efficient at high speeds. For that parallel SBR2 i.e. SBR2P is used which produces the diagonalized para-Hermitian polynomial matrix and related FIR PU filter bank. This paper shows that SBR2P algorithm can be implemented in hardware with the help of highly pipelined field-programmable gate array (FPGA) architecture.In this paper focus is on the multiplication of the polynomial matrices, as various signal processing tasks can be realized in real systems with the help of PMM in conjunction with PEVD. Polynomial matrix play an important role in realization of MIMO systems which are used in the context of Digital Signal Processing (DSP) and communications [1].

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II.LITERATURE SURVEY

As discussed polynomial matrices have been used for many years in the area of control. They play an important role in the realization of multi-variable transfer functions associated with multiple-input multiple-output (MIMO) systems. Over the last few years they have become more widely used in the context of digital signal processing and communications. Some algorithms are specially designed for this purpose, some of the algorithms broadly used forPMM are second order best sequential rotation (SBR2) and SBR2 algorithm used in parallel (SBR2P).

John G McWhirter *et al.* described a generalization of the EVD for conventional Hermitian matrices to para-Hermitian polynomial matrices. This technique will be called as Polynomial Eigenvalue Decomposition while the underlying algorithm is known as the SBR2 algorithm. The number of iterative steps requiredto be reduced for the respective operation, and also to prevent unnecessary growth in the order of the polynomial matrix being diagonalized, the namegiven for the algorithm was SBR [3].The first stage in developing a polynomial singular value decomposition (PSVD) algorithm based on the SBR philosophy, is to generate an SBR algorithm for the case of conventional matrices. For that, it is necessary to merge the QR decomposition stage of the SVD algorithm, into the iterative Kogbetliantz process. A algorithm of this type is developed by John G McWhirter for complex and scalar matrices both. The complex case is more involved than its real counterpart because of the need to ensure that the diagonal elements remain real throughout the process. This algorithm avoids 'squaring' the matrix to be factorized, uses only unitary and paraunitary operations, and therefore exhibits a high degree of numerical stability.

The SVD is a very important tool for narrowband adaptive sensor array processing. Thisalgorithm finds application in areas as diverse as high resolution direction finding, stabilized adaptive beamforming and also in blind signal separation [4]. The SVD decorrelates the signals received from an array of sensors by applying a unitary matrix of complex scalars which serves to modify the signals in phase and amplitude. The respective singular values represent the true energy associated with each of the decorrelated components so the signal and noise subspaces may sometimes be identified and separated because the transformation is unitary.In [4], J G McWhirter and P D Baxter generalize the SVD to broadband adaptive sensor arrays by requiring the strong decorrelation to be implemented using a paraunitary polynomial matrix.

A paraunitary polynomial matrix represents a multi-channel all-pass filter and accordingly, it preserves the total signal energy at every frequency. Scientist also present a technique for computing the required paraunitary matrix and show how the resulting broadband SVD algorithm i.e. SBR2 which can be used in practice to identify broadband signal and noise subspaces. The algorithm, being highly generic in nature, has potential application to a wide range of important problems. These include broadband adaptive beamforming, broadband blind signal separation, multi-channel adaptive noise cancellation, the analysis of MIMO communication channels and the design of filter banks for optimal data compaction.In [4] the approach used is quite distinct from other methods reported to date. One important technique is to reduce the broadband problem to narrowband form using a DFT or FFT to split the data into narrower frequency bands. A conventional SVD can then be used to decorrelate the sensor signals within each band. The SVD will arrange the uncorrelated output channels in order of decreasing energy. In the context of blind signal separation this means that the original signals are likely to be assigned to a different channel in each frequency bin and so the reconstituted broadband signals may be remixed in an arbitrary manner.

If there is problem in realizing the PU of the system then it affects the computation process of EVD of a Para-Hermitian system. Hence, more emphasis has been on extracting an approximate eign value decomposition (AEVD) using realizable Para-Unitary functions, such as finite impulse response Para-Unitary systems. Andre Tkacenkopresents an AEVD algorithm for Para-Hermitian systems by successive degree-1 FIR Para-Unitary transformations. This algorithm show how to select the parameters of such a FIR Para-Unitary system to make the zeroth order diagonal energy (ZODE) of the resultant Para-Hermitian system non-decreasing. The Para-Hermitian system approximately becomes more diagonal as the transformations are applied [5].

Server Kasap and SoydanRedif developed a parallelized version of the SBR2 algorithm for polynomial matrix EVD. The proposed algorithm is an extension of the parallel Jacobi method to para-Hermitian polynomial matrices. It is the first architecture developed to findoutPEVD. Hardware implementation of the algorithm is achieved via a highly pipelined, nonsystolic FPGA architecture. The hardware solution is achieved using the coordinate rotation digital computer

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algorithm. This calculates the trigonometric functions and vector multiplications that are performed by the algorithm. An important difference between SBR2 and SBR2P is that SBR2 performs a type of multiobjective optimization per algorithm step, whereas SBR2 does optimization based on a single objective at each step [2].

III. PROPOSED ARCHITECTURE

The proposed system for optimized hardware implementation of PMM contains the hardware implementation of algorithm for parallely computing matrix-matrix and matrix-vector product. It also has the facility to cross check the outputs with the MATLAB code for the same algorithm as described in Fig. 1. The proposed architecture gives low execution times while utilizing limited FPGA resources as it uses a parallel architecture. It yields a good approximation to the polynomial matrix computation provided by its double-precision counterpart running in MATLAB for both real and complex valued data [1]. The architecture has been developed using the Xilinx system generator for DSP tool, which offers a visual interface and a number of standard modules for speedy design.

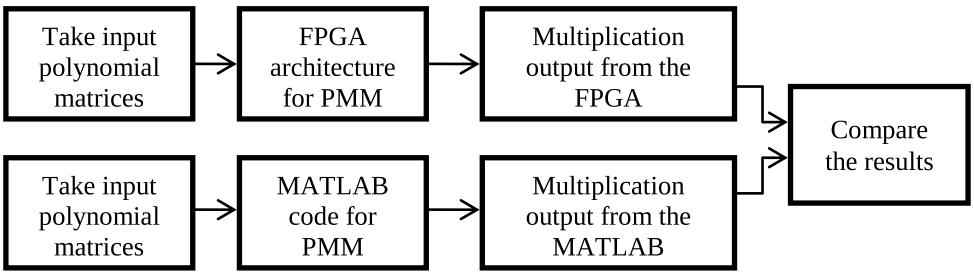

Fig.1: Proposed Block Diagram

The system has operations as follows:

1. Firstly, the input polynomials equations are converted into the polynomial matrices/ vectors.
2. These matrices/ vectors are feeded to two systems i.e. to the FPGA and to the MATLAB.
3. PMM computations are performed on both the systems and outputs are listed for all the parameters like area, time, accuracy,etc.
4. These results are compared for a better solution with high accuracy.

The indetail operational flow for the proposed system can be summaries as shown in Fig. 2

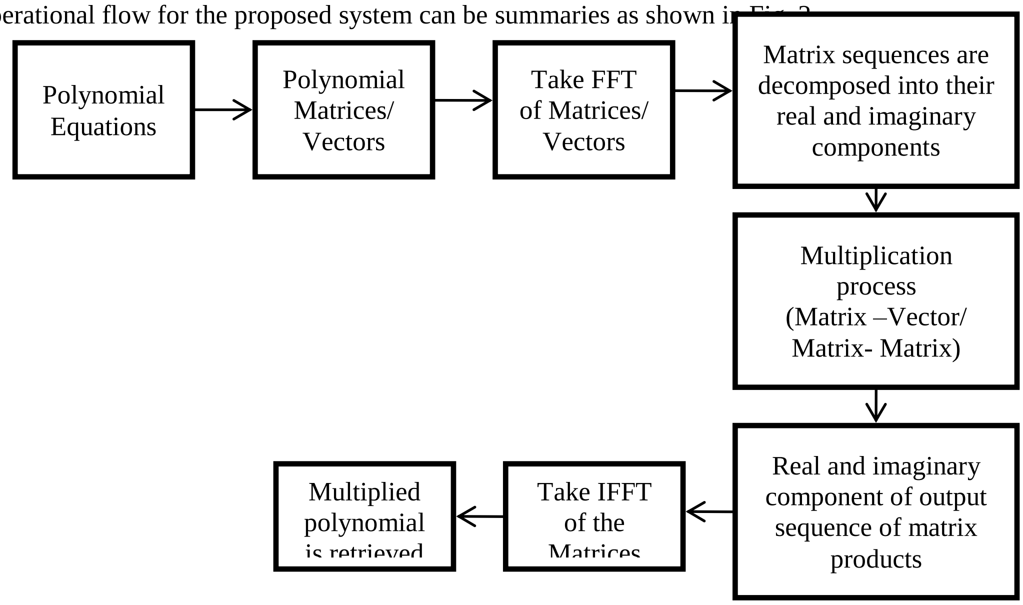

Fig.2: Operational Flow for the proposed system

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Till now, no attention is given to the hardware realization of PMM. The development of such hardware is beneficial for the MIMO communication systems.McWhirter and Redif uses the SBR2-generated FIR PU filter bank to impose strong decorrelation on the set of sensor signals for the problem of broadband SASP. This operation can be viewed as the polynomial matrix multiplication of a polynomial matrix with a polynomial vector (or matrix–vector PMM). To apply the PU filter bank to the para-Hermitian polynomial matrix directly, there is need to realize PEVD factorization without having to run SBR2 each time. This operation can be looked upon as the product of polynomial matrices (matrix–matrix PMM) [1].

VI.CONCLUSION

The proposed system is the first hardware solution to polynomial matrix multiplication, based on the application of the fast convolution technique to MIMO systems with high accuracy. FFT is the technique used to reduce the broadband problem to narrowband form using the concept of split the data into narrower frequency bands. This will increase the hardware accuracy of the system increasing the speed of operation. The proposed architecture uses limited FPGA resources and less execution time. This is achieved by using DSP processor in conjunction with Xilinx system generator tool. Further more accurate implementations of PMM in FPGAs are expected to increase the flexibility of the algorithm considering more no of input signals and also decreasing the dependency on degree of input polynomial.

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