Low-Complexity 2-D Digital FIR Filters Using Polyphase Decomposition and Farrow Structure

1.1 Base paper abstract:

This paper proposes a novel realization technique for quadrantally symmetric 2-D finite impulse response filters with a guaranteed reduction in the hardware complexity. Here, the concept of Farrow structure-based interpolation filter design using the polyphase decomposition of the 1-D filter transfer function is effectively utilized in the 2-D domain. The proposed 2-D filter makes use of row-wise polyphase decomposition of the 2-D transfer function or frequency response, followed by the polynomial approximation of the individual polyphase coefficients resulting in Farrow structures corresponding to each row filter. The final coefficients are implemented by varying the delay values in all the Farrow structures, followed by the interpolation of the coefficients obtained from each delay value, which in turn forms the rows in the 2-D kernel. The major highlight of the proposed method is the highly reduced implementation complexity in terms of the number of multipliers and adders, with a low normalized root-mean-square error. Design examples of the circularly symmetric and fan-type filters have been considered to show the efficiency of the approach. The results show a drastic reduction in the implementation complexity of the 2-D filters of upto 20%, with significantly low normalized root-mean-square error lesser than 0.5%.

1.2 Enhancement of this project:

- To implement 2D Polyphase Decomposition FIR Filter using Truncation Multiplier
- To implement 2D Farrow Structure FIR Filter using Truncation Multiplier

1.3 Proposed title:

FPGA Implementation of 2D polyphase Decomposition and Farrow Structure FIR Filter using Truncation Multiplier

1.4 Proposed Abstract:

In this recent digital signal processing applications, will have lot of filter designs in finite impulse response method, in such as it will take more complexity in 2D domain thus it will take more hardware complexity in crucial area and more critical paths, here this proposed work will presents a Farrow structure based interpolation filter design using the polyphase decomposition of 1D filter which effectively utilized in 2D digital domain, here this polyphase decomposition and Farrow structure will implemented using truncation multiplier, this truncation method will reduced the hardware complexity in internal and external part of multiplication and additions, thus it will provide n x n of n output in all sub filters. Finally this work presents in VHDL and synthesized in XILINX FPGA, and compared in terms of area, delay and power.

1.5 Existing system:

THE design and implementation of 2-D filters is a crucial area, widely explored by researchers due to the wide variety of applications they offer. The application areas include pattern recognition systems, computer image processing, seismic signal processing, biomedical systems, and genomic signal processing. Since many critical applications such as real-time medical image analysis, require fast 2-D filtering operations with filter kernels of large size, effective, fast, low complexity and low power implementation approaches for 2D filters, become essential.

Among the different design approaches for 2D filters, the transformation based approach is a widely used design method for circular and fan-type filters. In the transformation-based method, a suitable 1D filter is designed first, followed by mapping the 1D filter coefficients to 2D domain using specific transformation kernels. McClellan transformation was the first transformation introduced for designing circular 2D filters from their 1D counterparts. In, two new multiplierless transformations were introduced, which was a remarkable achievement over McClellan transformation, towards the aim of designing circular 2D filters of improved circularity. Later, with an aim of designing 2D filters of lower implementation complexity and improved circularity, a new P2 transformaton was proposed. The McClellan transformation based design approach was also extended for the design of fan filters in and, where the transformation coefficients were deduced using different optimization algorithms by maintaining a minimum contour deviation error. Bindima et al. have deduced the transformation coefficients for fan-type filters using multi objective artificial bee colony optimization by ensuring the least contour deviation error.

The 2D filter designed using the transformation method has an efficient implementation structure based on Chebyshev recursion formula, which consists of cascaded 2D transformation kernels F(z1,z2), where F(z1,z2) represents the 2D transformation function corresponding to the spectral transformation F(ω1, ω2) used. But the Chebyshev structure based implementation in the z domain has a major disadvantage of increased delay due to the use of cascaded 2D kernels F(z1,z2), which in turn act as a limitation to the high speed filtering. The implementation of a 2D filter of size (2N +1)×(2N+1) requires a cascade of N number of similar F(z1,z2) blocks. This, in turn, introduces an overall delay of z−N 1 z−N 2 for the transformation-based realizations. Moreover, the realization of the transformations such as P2 that provide better contour circularity requires fractional delay filters to realize z−1 2 . An alternative solution to overcome the delays involved in the 2D filter realization is to use the Chebyshev structure for frequency domain-based implementation of the 2D filter. But the realization of the 2D filter in the frequency domain requires larger number of multipliers and thus increases the implementation complexity.

Apart from transformation-based methods, different optimization based methods were also introduced for the design of 2D filters, where the entire (2N + 1) × (2N + 1) number of 2D filter coefficients for specific contours, are obtained by minimizing the contour deviation error. The realization of these 2D filters relies upon the direct form implementation of the 2D transfer function. Thus, the realization of a 2D filter of size equal to (2N + 1) × (2N + 1) requires 2N delays both in the z1 and z2 space. On the other hand, the frequency domain realization of the filters increases the implementation complexity. Recently, a computationally efficient 2D filter design approach using sampling-kernel based interpolation and frequency transformation is proposed for the design of sharp 2D FIR filters [13], which focusses on reducing the implementation complexity of the 2D filters. The major drawback of this approach is the design complexity in yielding the optimal lengths of the different sub-filters.

This paper proposes a novel implementation structure for 2D filters of reduced hardware complexity in frequency domain. The proposed implementation structure makes use of the theory of the design of interpolation filters using 1D Farrow structure. The proposed implementation structure realizes the polyphase components corresponding to each row in the filter kernel using the Farrow structure, and the overall 2D filter is realized using a set of parallel Farrow structures, all tunable with the same fixed set of fractional delays. The coefficients obtained from each Farrow structure using the different fractional delays are suitably interpolated to realize the individual rows in the 2D kernel. The total delay involved in the realization of the individual row filters reduces to K, where K represents the order of each polyphase subfilter. The proposed low complexity implementation of the 2D filter has been demonstrated for circular 2D filters and fan-type filters, and can be extended to other types such as elliptical and diamond filters. The quadrantal symmetry of the 2D circular and fan-type filter kernels, which are designed using the existing transformation based approaches, ensure the filter coefficients h(n1, n2) to satisfy the condition h(n1, n2) = h(N − n1, n2) = h(n1, N − n2) for a 2D filter of order equal to N×N. This can also be effectively utilized in reducing the hardware complexity. The proposed method offers effective hardware implementation and better complexity reduction than the state of art methods.

1.6 Disadvantage:

- More complexity in Crucial area
- More power dissipation
- More delay

1.7 Proposed system:

In this recent digital signal processing applications, will have lot of filter designs in finite impulse response method, in such as it will take more complexity in 2D domain thus it will take more hardware complexity in crucial area and more critical paths, here this proposed work will presents a Farrow structure based interpolation filter design using the polyphase decomposition of 1D filter which effectively utilized in 2D digital domain, here this polyphase decomposition and Farrow structure will implemented using truncation multiplier, this truncation method will reduced the hardware complexity in internal and external part of multiplication and additions, thus it will provide n x n of n output in all sub filters. Finally this work presents in VHDL and synthesized in XILINX FPGA, and compared in terms of area, delay and power.

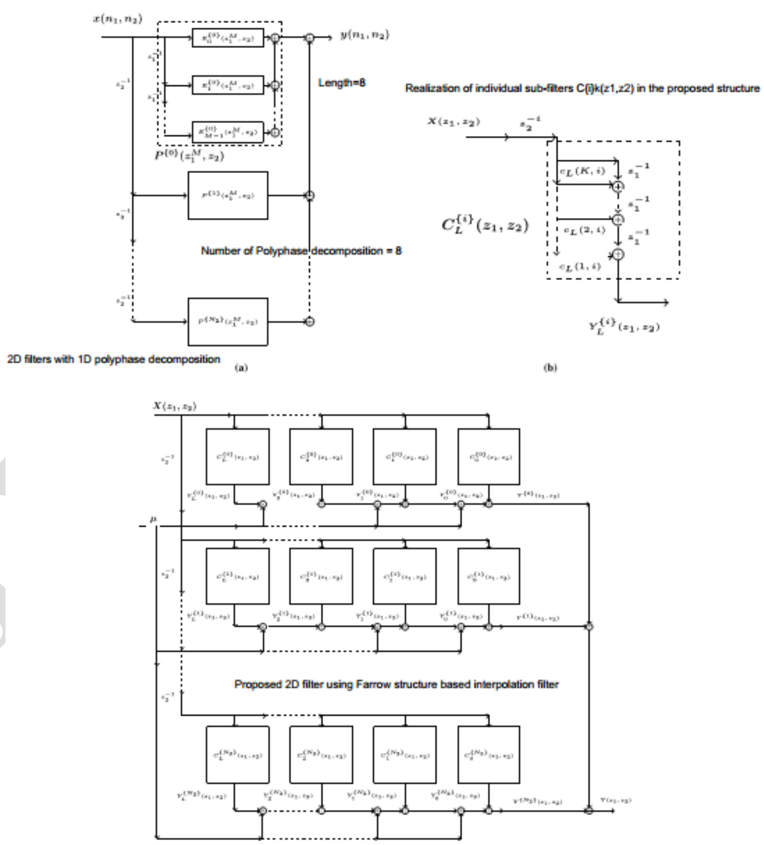

Figure 1: Proposed 2D filter (a) 2D filters with 1D polyphase decomposition (b) Realization of individual sub-filters C{i} k (z1,z2) in the proposed structure (c) Proposed 2D filter using Farrow structure based interpolation filter.

The 2D filter coefficients for any given specifications are obtained using any of the existing design approaches. On obtaining the filter coefficients, the filters designed using the optimization based methods as in are realized using direct form structure and those designed using the transformation based methods are realized using the Chebyshev structure either in frequency domain or time domain. Eventhough the time domain realization of the 2D filter based on Chebyshev recursion formula as in provides a low complexity implementation structure, the delay involved in the 2D filtering operation using this structure is very high. A suitable solution is to make use of the frequency domain realization using the Chebyshev structure as detailed, where delay can be reduced due to direct multiplication of the incoming 2D signal with the coefficients of the 2D transformation kernel and the 1D filter coefficients. But, on the other hand, the implementation complexity of this approach is very high. A trade-off between the implementation complexity and delay is to be maintained, which is ensured by the proposed low complexity implementation structure in frequency domain. The major highlight of the proposed technique is that it is compatible for time-domain as well as frequency-domain based realization. The proposed method utilizes the concept of polynomial approximation based interpolation filter design for realizing the individual row filters in the 2D frequency response. In general, the frequency response of a 2D filter is given by

H(ω1, ω2) = N1 n1=0 N2 n2=0 h(n1, n2)exp(− jn1ω1)exp(− jn2ω2)

where h(n1, n2) represents the 2D filter coefficients of the filter of size (N1 + 1) × (N2 + 1). The proposed filter structure is based on the 1D polyphase decomposition of each row of the 2D filter after the coefficients in the filter kernel are derived using any of the existing design methods. The filter coefficients of each row in the 2D filter kernel, obtained by transformation method, corresponds to a linear phase 1D FIR row filter.

A. 1D Polyphase Decomposition

The proposed approach starts with the polyphase decomposition of the transfer function corresponding to the individual rows of the 2D filter kernel as shown in Fig. 1a. Here, first we consider the case of 2D filters of order N1 × N2 with even N1. The 2D transfer function is expressed using Mth order polyphase decomposition of each of the individual ith row in the 2D filter kernel (for i = 0, 1..N2) as

$$\begin{aligned} H(z_1, z_2) &= \sum_{i=0}^{N_2} z_2^{-i} P^{\{i\}}(z_1, i) \\ &= \sum_{i=0}^{N_2} z_2^{-i} \Big(\sum_{m=0}^{M-1} z_1^{-m} E_m(z_1^M, i) \Big) \qquad (6) \end{aligned}$$

The polyphase components Em(z1,i) corresponding to each of the ith row in (6) can be represented in a generalized form as E{i} m (z1,z2). In the case of even order row filters, the interpolation order M for polyphase decomposition is to be chosen such that N1 = M N0, for any integer N0. The polyphase components of each of the ith row filter can be expressed as

$$E_m^{\{i\}}(z_1, z_2) = \sum_{n_1=0}^{\infty} h(m + n_1 M, i) z_1^{-n_1} \qquad (7)$$

For the case of a 2D low pass filter (LPF) having quadrantally symmetric response, the individual row filters should ideally represent an ideal LPF, so that H(z1,i) ≈ z−i 2 z − N1 2 1 . This implies that the different polyphase components (E{i} m (z1,z2)) of each of the ith row filter closely approximates an all pass function with a delay equal to N1 2M − m M along the z1 direction (m=0,1,...M-1) in the pass band (PB) region, so that

$$E_m^{\{i\}}(z_1, z_2) \approx z_2^{-i} z_1^{-(\frac{N_0}{2} - \frac{m}{M})}, \quad \omega \in [-\frac{\omega_p}{\pi}, \frac{\omega_p}{\pi}] \qquad (8)$$

Hence, in the case of even N1, the zeroth polyphase component E{i} 0 (z1,z2) of each row approximates a fixed integer delay z − N0 2 1 , while the remaining polyphase terms E{i} m (z1,z2) (for m = 1, 2, ..M − 1) closely approximate a fractional delay of z −(N0 2 − m M) 1 . The polyphase components of each ith row filter approximating fractional delays can be expressed in matrix form as

$$
\begin{bmatrix} E_1^{\{i\}}(z_1,z_2) \\ E_2^{\{i\}}(z_1,z_2) \\ \dots \\ E_{M-1}^{\{i\}}(z_1,z_2) \end{bmatrix}
= \begin{bmatrix} h(1,i) & h(M+1,i) & .. & h((K-1)M+1,i) \\ h(2,i) & h(M+2,i) & .. & h((K-1)M+2,i) \\ \dots & \dots & \dots & \dots \\ h(M-1,i) & h(2M-1,i) & \dots & h(KM-1,i) \end{bmatrix}
\times \begin{bmatrix} 1 \\ z_1^{-1} \\ \dots \\ z_1^{-(K-1)} \end{bmatrix} \quad (9)
$$

where K = N0 and the polyphase coefficient matrix corresponding to the ith row of the 2D filter is given by,

$$
\boldsymbol{P}^{\{i\}} = \begin{bmatrix} h(1,i) & h(M+1,i) & .. & h((K-1)M+1,i) \\ h(2,i) & h(M+2,i) & .. & h((K-1)M+2,i) \\ \dots & \dots & \dots & \dots \\ h(M-1,i) & h(2M-1,i) & \dots & h(KM-1,i) \end{bmatrix} \quad (10)
$$

B. Polynomial Approximation of the Polyphase Coefficients

The low complexity 2D filter is derived by polyphase decomposition of the individual row filters of the 2D kernel and by approximation of each of the polyphase coefficients using a polynomial in terms of a set of fractional delays. Filter coefficient implementation using polynomial approximation in terms of the fractional delays is based on the concept of the design of 1D interpolation filters using Farrow structure. The polynomial approximation in terms of the fractional delay, works effectively for the coefficients of the polyphase components E{i} m (z1,z2) for m = 1, 2, ...M − 1, since they approximate a fractional delay equal to m/M. The coefficients in each mth row of the polyphase coefficient matrix P{i} correspond to the coefficients of the polyphase term E{i} m (z1,z2). The polyphase decomposition of the row filters of H(z1,z2) of order N1 using an interpolation order of M, results in M number of polyphase terms corresponding to each row of H(z1,z2). The number of coefficients in each polyphase term is N0, except for the zeroth polyphase term, where it is N0+1. But, since the zeroth polyphase component approximates an integer delay, it is excluded from polynomial approximationThese coefficients in turn, correspond to the coefficients of different filters approximating varying fractional delays equal to m/M. Each coefficient set h j consisting of M-1 coefficients is polynomial approximated to an Lth order polynomial in terms of the delay parameter μ, where μ takes a set of M-1 values equal to m/M for m = 1, 2, ...M−1. Hence, the approximated Lth order polynomial takes the form h j = cL(j,i)μL + cL−1(j,i)μL−1 + ...c1(j,i)μ + c0(j,i), so that the polynomial evaluation with any μ = m/M reconstructs the mth coefficient in h j . The polynomial approximation is done for all h j (j = 1, 2, ..K) so that (9) can be rewritten as

$$
\begin{bmatrix} E_1^{\{i\}}(z_1, z_2) \\ E_2^{\{i\}}(z_1, z_2) \\ \cdots \\ E_{M-1}^{\{i\}}(z_1, z_2) \end{bmatrix} = \begin{bmatrix} \mu_1^L & \mu_1^{L-1} & .. & \mu_1 & 1 \\ \mu_2^L & \mu_2^{L-1} & .. & \mu_2 & 1 \\ \cdots & \cdots & \cdots & \cdots & \\ \mu_{M-1}^L & \mu_{M-1}^{L-1} & .. & \mu_{M-1} & 1 \end{bmatrix}
$$

$$
\times \begin{bmatrix} c_L(1,i) & c_L(2,i) & .. & c_L(K,i) \\ c_{L-1}(1,i) & c_{L-1}(2,i) & .. & c_{L-1}(K,i) \\ \cdots & \cdots & \cdots & \cdots \\ c_0(1,i) & c_0(2,i) & .. & c_0(K,i) \end{bmatrix} \begin{bmatrix} 1 \\ z_1^{-1} \\ \cdots \\ z_1^{-(K-1)} \end{bmatrix} \tag{11}
$$

or

$$
\boldsymbol{E} = \boldsymbol{\mu}^T \boldsymbol{C} \boldsymbol{z}_I^T \tag{12}
$$

which can be diagrammatically demonstrated using Fig. 1a-1c. The polyphase decomposition of the individual row filters of the 2D kernel is shown in Fig. 1a. The overall structure of the proposed low complexity 2D filter of size N1 × N2 is shown in Fig. 1c and the realization of the individual sub-filters in the proposed 2D structure is shown in Fig. 1b. The proposed structure consists of N2 levels, where each level corresponds to each row filter. In each level, the row filter is implemented using polynomial approximation. The polynomial coefficients of each μk for k = 0, 1, ..L, together form the sub-filters in the proposed 2D structure. Hence, each level consists of L +1 number of linear phase sub-filters which are 1D FIR filters. In each level, the filter coefficients reconstructed from the Farrow structure for each value of μ are suitably interpolated by an order equal to M to reconstruct the coefficients of the row filter. For the case of 2D filters of order N1 × N2 with odd N1, the interpolation order M for polyphase decomposition is chosen in such a way that N1 + 1 = N0M. In this case, the zeroth polyphase term are also considered for polynomial approximation, since these terms also correspond to fractional delay filters.

1.1.1 Reduction of Parallel Tree Multiplier

A parallel tree multiplier design consists of three steps, i.e., PP generation, PP reduction, and final carry propagate addition. PP generation produces PP bits from the multiplicand and the multiplier. The goal of PP reduction is to compress the number of PPs to two, which is to be summed up by the final addition. The two most famous reduction methods are Wallace tree and Dadda tree reductions. Wallace tree reduction manages to compress the PPs as early as possible, whereas Dadda reduction only performs compression whenever necessary without increasing the number of carry-save addition (CSA) levels.

Here we achieve around 33% area optimization and 20% Fmax enhancement with the same performance. The two most famous reduction methods are Wallace tree and Dadda tree reductions. Wallace tree reduction manages to compress the PPs as early as possible, where as Dadda reduction only performs compression whenever necessary without increasing the number of carry-save addition (CSA) levels. Here we design a multiplier based on Wallace tree only.

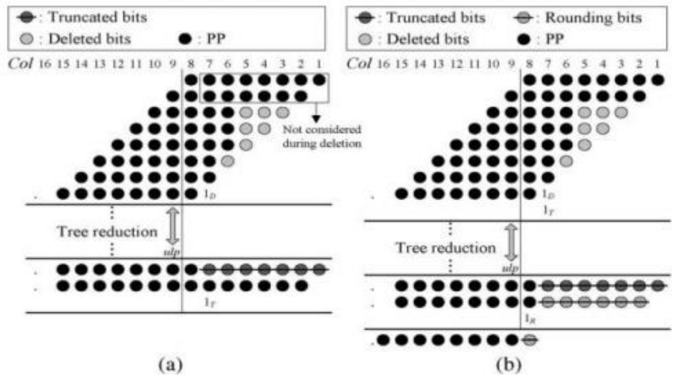

Figure 2 : proposed truncation multiplier

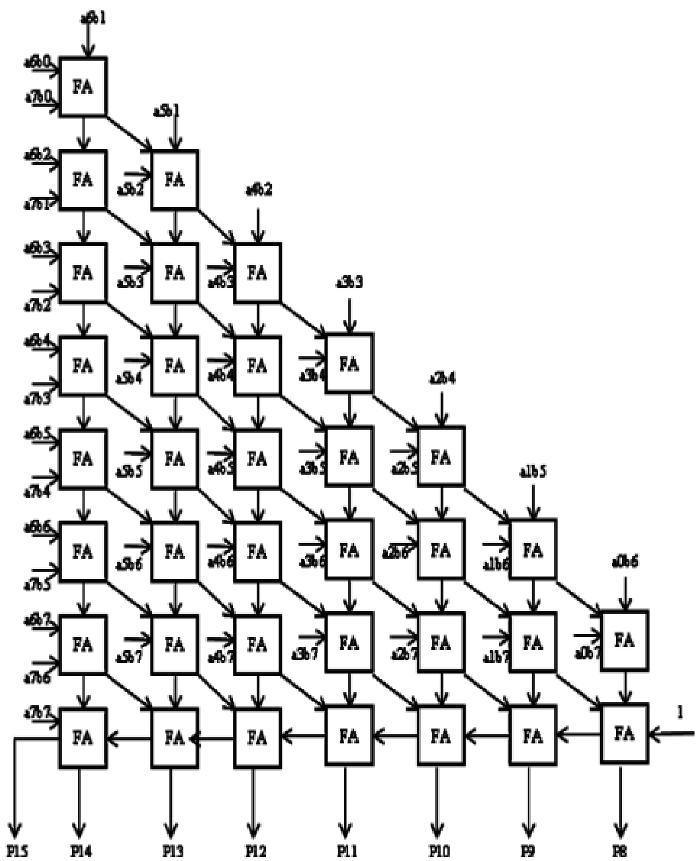

Figure 3 : proposed truncation multiplier

Proposed Truncated Multiplier Design:

PP truncation and compression

The objective of the truncated multiplier design is to compute P MSBs of the product with a maximum truncation error of no more than 1 ulp, where 1 ulp = 2^{-P}.The FIR filter design in this brief adopts the direct form is shown in figure. where the MCMA module sums up all the products $\hat{a}_i \times x[n - i]$. Instead of accumulating individual multiplication for each product, it is more efficient to collect all the PPs into a single PPB matrix with carry-save addition to reduce the height of the matrix to two, followed by a final carry propagation adder. In order to avoid the sign extension bits, we complement the sign bit of each PP row and add some bias constant using the property $\bar{s} = 1$

− s, where s is the sign bit of a PP row, as shown in Figure. All the bias constants are collected into the last row in the PPB matrix. The complements of PPBs are denoted by white circles with over bars.

In the proposed truncated multiplier design in FIR filter implementation, it is required that the total error introduced during the arithmetic operations is no larger than one ulp. compares the two approaches. In the removal of unnecessary PPBs is composed of three processes: deletion, truncation, and rounding. Two rows of PPBs are set undeletable because they will be removed at the subsequent truncation and rounding .

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1.2 Advantage:

- More complexity in Crucial area
- More power dissipation
- More delay

Literature survey:

- " Synthesis and Optimization of 2D Filter Designs for Heterogeneous FPGAs", CHRISTOS-S. BOUGANIS, SUNG-BOEM PARK, GEORGE A. CONSTANTINIDES, and PETER Y. K. CHEUNG Imperial College London, Many image processing applications require fast convolution of an image with one or more 2D filters. Field-Programmable Gate Arrays (FPGAs) are often used to achieve this goal due to their fine grain parallelism and reconfigurability. However, the heterogeneous nature of modern reconfigurable devices is not usually considered during design optimization. This article proposes an algorithm that explores the space of possible implementation architectures of 2D filters, targeting the minimization of the required area, by optimizing the usage of the different components in a heterogeneous device. This is achieved by exploring the heterogeneous nature of modern reconfigurable devices using a Singular Value Decomposition based algorithm, which provides an efficient mapping of filter's implementation requirements to the heterogeneous components of modern FPGAs. In the case of multiple 2D filters, the proposed algorithm also exploits any redundancy that exists within each filter and between different filters in the set, leading to designs with minimized area. Experiments with real filter sets from computer vision applications demonstrate an average of up to 38% reduction in the required area.

- " A Unified Approach for the Design of 2-D Digital Filters via Semidefinite Programming", IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS—I: FUNDAMENTAL THEORY AND APPLICATIONS, VOL. 49, NO. 6, JUNE 2002, W.-S. Lu, Fellow, IEEE, This paper attempts to demonstrate that a modern optimization methodology known as semidefinite programming (SDP) can be served as the algorithmic core of a unified design tool for a variety of two-dimensional (2-D) digital filters. Representative SDP-based designs presented in the paper include minimax and weighted least-squares designs of FIR filters with continuous and discrete coefficients, and minimax design of stable separable-denominator IIR filters. Our studies are motivated by the fact that SDP as a subclass of convex programming can be solved efficiently using recently developed interior-point methods and, more importantly, constraints on amplitude/phase responses in certain frequency regions and on stability (for IIR filters), that are often encountered in many filter design problems, can be formulated in a natural way as linear matrix inequalities (LMI) which allow SDP to apply. Design examples for each class of filters are included to demonstrate that SDP-based methods can in many cases be useful in producing optimal or near-optimal 2-D filters with reduced computational complexity.

- " A Novel 2D Filter Design Methodology For Heterogeneous Devices", Christos-Savvas Bouganis, George A. Constantinides and Peter Y. K. Cheung Department of Electrical and Electronic Engineering Imperial College London London, U.K. Email: christos-savvas.bouganis@imperial.ac.uk, In many image processing applications, fast convolution of an image with a large 2D filter is required. Field Programable Gate Arrays (FPGAs) are often used to achieve this goal due to their fine grain parallelism and reconfigurability. However, the heterogeneous nature of modern reconfigurable devices is not usually considered during design optimization. This paper proposes an algorithm that explores the implementation architecture of 2D filters, targeting the minimization of the required area, by optimizing the usage of the different components in a heterogeneous device. Experiments show that the proposed algorithm can achieve a reduction in the required area in a range of 34% to 70% when compared to current techniques.

- " An Analytical Approach for Obtaining a Closed-Form Solution to the Least-Square Design Problem of 2-D Zero-Phase FIR Filters", IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS-]]: ANALOG AND DIGITAL SIGNAL PROCESSING. VOL. 41, NO. 12, DECEMBER 1994, Wei-Ping Zhu, M. Omair Ahmad, Senior Member, IEEE, and M.N.S. Swamy, Fellow, IEEE, A closed-form least-square solution to the design problem of general two-dimensional (2-D) real zero-phase FIR filters is obtained. An in-depth study of the functions and matrices arising from the problem definition reveals some very useful structural properties. It is shown that these properties lead to an optimal analytical solution for the filter coefficients, making it unnecessary to use design procedures involving optimization techniques or matrix inversion operations. The derived closedform expressions for filter coefficients allow their evaluation directly from the filter's frequency response specifications, resulting in a greatly reduced computational complexity. It is confirmed through design examples that the proposed technique enjoys a very short design tie and it rises very slowly as the filter order is increased.

- " An Analytical Least Square Solution to the Design Problem of Two-Dimensional FIR Filters with Quadrantally Symmetric or Antisymmetric Frequency Response", M. OMAIR AHMAD, SENIOR MEMBER, IEEE, AND JIE-DONG WANG, STUDENT MEMBER, IEEE, IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS, VOL. 36, NO. 7, JULY 1989, A closed-form least square solution to the design problem of two-dimensional real zero-phase FIR filters with quadrantally symmetric or antisymmetric frequency response is obtained. An in-depth study of the matrices involved in the development of the design technique reveals a number of useful properties. It is shown that these properties lead to an 3 optimal analytical solution for the filter coefficients making it unnecessary to use either of the time-consuming methods of optimization, matrix inversion, or iteration. Because of the reduced order of the matrices involved, their specific characteristics, and analytical approach, the computational complexity is greatly reduced. Simplicity and efficiency of the design technique is illustrated through examples. The results in terms of error in frequency response compare favorably with those obtained by using other techniques. It is shown that the design time using the proposed technique is significantly smaller than what is required by the I,-optimization technique or weighted least square technique employing Harris' ascent algorithm or modified Lawson's algorithm.

- "Low power 2D finite impulse response filter design using modified artificial bee colony algorithm with experimental validation using field-programmable gate array", Atul Kumar Dwivedi, Subhojit Ghosh ✉, Narendra D. Londhe Department of Electrical Engineering, NIT Raipur, Raipur, India, Motivated by the need of reducing power consumption (PC) in two dimensional (2D) finite impulse response (FIR) filters, in this work, the 2D FIR filter design task is formulated as an optimisation problem that seeks to attain the desired frequency response and reduces PC. The optimisation problem has been solved using the modified version of artificial bee colony algorithm. The applicability of the proposed approach has been evaluated by designing circular shaped 2D FIR filters for a set of specifications in frequency domain. The designed filters have been compared with other reported state of the art techniques. The evaluation is carried out in terms of pass band and stop band ripple minimisation, convergence profile and PC during filter execution in hardware. The proposed technique is found to outperform all other techniques in achieving minimum ripple for a given filter order. To prove the effectiveness of the proposed approach for PC reduction, the designed filters have been implemented in hardware using fieldprogrammable gate array (xc7vx485t-2ffg1761). The PC computed using Xilinx X-power analyser shows that 23.53% power can be saved using the proposed approach as compared with conventional design approaches.

- " Analytical design methods for directional Gaussian 2D FIR filters", Received: 16 December 2015 / Revised: 18 June 2016 / Accepted: 22 September 2016 © Springer Science+Business Media New York 2016, This paper proposes two analytical design methods in the frequency domain for directional Gaussian 2D FIR filters, with a straight directional or an elliptically-shaped frequency response and with a specified selectivity and orientation in the frequency plane. One method relies on the substitution of a frequency mapping into the factored polynomial approximation of the Gaussian, while the other one is based on decomposing the frequency response into Gaussian components along three properly chosen directions in the frequency plane. The frequency response of the 2D directional filter results directly in a factored form, which is a major advantage in implementation. The filters are accurate, efficient and they eliminate the necessity of interpolation. With the mapping substitution method, they result also adjustable in orientation and aspect ratio. Several design examples are given for various specifications, and simulation results of directional filtering on test images are provided, to prove their applicability in image processing.

- " A novel accelerated artificial bee colony algorithm for optimal design of two dimensional FIR filter", Supriya Dhabal, Palaniandavar Venkateswaran, This paper presents a novel approach for the design of two-dimensional (2D) Finite Impulse Response (FIR) filters. The design of FIR filters is generally non-differentiable, multimodal and higher dimensional; especially for 2D filters. A large number of filter coefficients are optimized either using constrained or unconstrained optimization approach. Due to the large number of constraints, traditional design methods cannot produce optimal filters required for some crucial applications. This makes meta-heuristic algorithms as good alternatives for addressing such constraints more efficiently. In order to improve the performance of 2D filters, we propose an Accelerated Artificial Bee Colony algorithm, termed as AABC algorithm. The earlier reported ABC based methods perform the modification of a single parameter of the solution in each cycle. But in this proposed AABC algorithm, we have adopted multiple parameters change of search equation at each step. This in turn improves the convergence speed of the algorithm by three times than the classical ABC algorithm and two times with respect to recently developed CABC method. In order to achieve better exploration behaviour of abandoned bees, we have also introduced a change during the initialization strategy of scout bees in the proposed AABC algorithm. The efficiency and robustness of the proposed algorithm are demonstrated by comparing its performance with classical Genetic Algorithm (GA), Particle Swarm Optimization , ABC and CABC methods.

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