Journal of Advanced Research (2016) 7, 336–347

Cairo University

Journal of Advanced Research

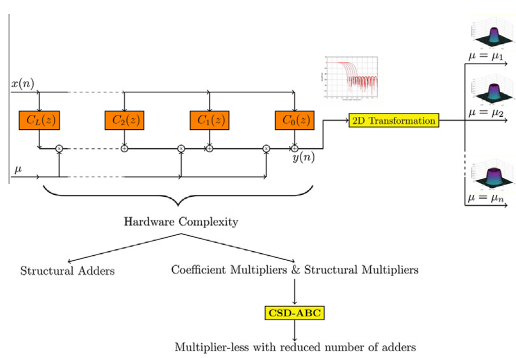
ORIGINAL ARTICLE

Design of efficient circularly symmetric two-dimensional variable digital FIR filters

Thayyil Bindima *, **Elizabeth Elias**

Department of Electronics and Communication Engineering, National Institute of Technology Calicut, Kerala, India

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 11 October 2015
Received in revised form 29 January 2016
Accepted 30 January 2016
Available online 17 February 2016

ABSTRACT

Circularly symmetric two-dimensional (2D) finite impulse response (FIR) filters find extensive use in image and medical applications, especially for isotropic filtering. Moreover, the design and implementation of 2D digital filters with variable fractional delay and variable magnitude responses without redesigning the filter has become a crucial topic of interest due to its significance in low-cost applications. Recently the design using fixed word length coefficients has gained importance due to the replacement of multipliers by shifters and adders, which reduces the hardware complexity. Among the various approaches to 2D design, transforming a

* Corresponding author. Tel.: +91 9495663242; fax: +91 4952287250.
E-mail address: bindima@gmail.com (T. Bindima).

Peer review under responsibility of Cairo University.

ELSEVIER Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.jare.2016.01.005

one-dimensional (1D) filter to 2D by transformation, is reported to be an efficient technique. In this paper, 1D variable digital filters (VDFs) with tunable cut-off frequencies are designed using Farrow structure based interpolation approach, and the sub-filter coefficients in the Farrow structure are made multiplier-less using canonic signed digit (CSD) representation. The resulting performance degradation in the filters is overcome by using artificial bee colony (ABC) optimization. Finally, the optimized 1D VDFs are mapped to 2D using generalized McClellan transformation resulting in low complexity, circularly symmetric 2D VDFs with real-time tunability.

Keywords:
2D circularly symmetric FIR
Variable digital filters
Variable fractional delay filters
McClellan transformation
Canonic signed digit
Artificial bee colony algorithm

Introduction

2D linear filtering has extensive applications in image and video processing, ranging from highly precise medical imaging to low precision industrial imaging and consumer video applications, as these applications often require filters that assure phase linearity and accurate magnitude response in the pass band. As the majority of these applications have tight area and power constraints due to battery lifetime and cost, filters with minimum hardware complexity are desirable. Hence, the development of low power, low complexity, and high-speed digital filters has been a captivating topic of research in the recent past. Again the recent explosive proliferation of the communication standards and the need for arbitrary sampling rate conversion have paved the way for the demand of low complexity VDFs including variable fractional delay (VFD) [1] and variable cut-off frequency [2] (VCF) FIR systems with online tuning. The Farrow structure [3] has been a promising approach for the design of low complexity VDFs.

Similar to 1D, 2D VDFs also have potential applications in multidimensional signal processing fields such as frame interpolation in video processing, sub-pixel interpolation in still images, pattern recognition, robotic vision and communication systems [4–6]. Further, circularly symmetric 2D FIR VDFs are of keen interest in primary applications of image processing especially where there is no preferred spatial frequency axis. For the design of low complexity 2D VDFs, transforming the corresponding 1D VDF to its 2D counterpart using any suitable 1D to 2D transformation such as McClellan transformation [7], would be advantageous. The transformation-based approach gives a drastic reduction in the design and implementation complexity [8]. Moreover, the design of 2D VDFs with infinite precision coefficients has gained wide attention, and several design methods have been proposed [9–12]. However, to the best of our knowledge the design using finite precision coefficients has received less attention [2,8]. Yeung and Chan [8] proposed the design of elliptical and fan type 2D VDFs and Pun et al. [2] proposed the design of circularly symmetric 2D VDFs.

The first part of the paper gives a brief review of the various design methodologies for 2D variable magnitude response FIR filters and in the second part, we present an efficient approach for the design of low complexity circularly symmetric finite precision 2D VCF filters using CSD. VCF filter design using Farrow based polynomial interpolation [2] offers lesser implementation complexity in terms of multipliers than the single stage FIR based design [13]. Further reduction in the implementation complexity is attained in this paper when the sub-filter coefficients are represented using CSD with the minimal number of signed power of two (SPT) terms. The design of 1D filter in discrete space degrades the overall performance of the filters, which necessitates the use of some nonlinear optimization techniques. Since the search space consists of integers, the classical gradient-based methods cannot be used, and meta-heuristic algorithms are preferred. In this paper, artificial bee colony (ABC) optimization has been used to optimize the sub-filter coefficients in the CSD space. The interpolated impulse responses are finally transformed using generalized McClellan transformation to yield the 2D variable impulse responses.

The paper is organized as follows: Section "Overview of 1D variable digital filters and Farrow structure" gives an overview of the Farrow structure for the design of 1D variable digital FIR filter. Section "2D variable digital filter" provides a brief introduction on the 2D VDFs and reviews the different design methods for 2D variable magnitude response FIR filters. Sections "Canonic signed digit representation" and "Overview of artificial bee colony algorithm" give a brief overview of CSD representation and ABC algorithm. The problem statement and the design of continuous coefficient 1D VDF are explained in Sections "Problem statement" and "Design of 1D continuous coefficient variable digital filters", respectively. Section "Design of 2D circularly symmetric VDF" gives the design of 2D circularly symmetric VDFs. Results and conclusion are given in Sections "Results and discussion" and "Conclusion", respectively.

Overview of 1D variable digital filters and Farrow structure

Variable digital filters are a class of digital filters whose spectral characteristics can be varied in real-time, without redesigning the filter and with minimum overhead on complexity. A detailed review of the different methods for 1D VDF design is given by Laakso et al. [1]. The spectral parameter approximation method [3,14,15] is a good approach suitable for the design of general VDFs including VFD filters and variable magnitude response (VMR) filters [9]. Moreover, the VDF obtained by this method can be implemented efficiently using Farrow structure [3], a promising technique for realizing time varying fractional delay filters [1,16]. It enables the filter to be designed offline with easy, accurate online control of its spectral parameters, entirely independent of the filter coefficients. In the spectral approximation method, the impulse response of the VDF is assumed to be a linear combination of some $\phi_k(\mu)$s as in the equation below,