www.ijecs.in
International Journal Of Engineering And Computer Science ISSN:2319-7242
Volume 4 Issue 5 May 2015, Page No. 11941-11944

A Survey on Different Methods for Design of Sparse FIR Filter

Navreet Kaur [1] **, Ankur Singhal** [2]

[1] Kurukshetra University, Geeta Institute of Management and Technology,
Kurukshetra, Haryana, India
reetkaurvirk9991@gmail.com

[2] Geeta Institute of Management and Technology, Kurukshetra University
Kurukshetra, Haryana, India
ankursinghal071987@gmail.com

Abstract: ***Sparsity has been a great issue in the design of FIR filter. The objective of a Sparse FIR filter design is to reduce the implementation complexity as the number of nonzero-coefficients is reduced. By increasing the number of zero-valued coefficients, the implementation of the filter becomes simple as the additions and multiplications corresponding to zero-valued coefficients are omitted. The proposed paper discusses the various techniques used earlier for designing a sparse FIR filter. This paper also presents the comparative study of several filter designing methods used by researchers for this work.***

Keywords: FIR filter, Sparse filter, nonzero-coefficients, zero-valued coefficients.

1. Introduction

Filter removes the harmful constituents from the signal. The unwanted component present in the signal is noise. A Filter is what that removes the noise from the signal and produces a noiseless signal which provides accurate information of the system. FIR filters have a variety of applications in signal processing, communication field, image area, and medical field. Traditional design strategies aim to reduce the implementation complexity of an FIR filter. This includes designing of Fir filter with power -of -two coefficients [1] or making use of special structures such as frequency – response masking technique [2] and subexpressions among coefficients of filter [3] and [4]. With the advancements in Sparse representation of signals, designers pay attention on designing a filter with majority of coefficients being zero. The main concern is on designing Sparse FIR filter. A Sparse FIR filter is a filter which contains as few non-zero valued coefficients as possible. If a Sparse FIR filter is attained, the multiplications and additions corresponding to zero-valued coefficients can be omitted which consequently reduce the implementation complexity.

Various experiments prove that for an FIR filter, the sparsity of filter coefficients is related to the order of the filter. There are several methods available for design of a Sparse FIR filter. The sparsity of filter coefficients is generally evaluated by l_0 (quasi-) norm. The various techniques include Sparse FIR filter design using linear programming, weighted least-square algorithm (WLS), iterative shrinkage/thresh holding (IST), iterative-reweighted-least-squares (IRLS) and genetic algorithm. In this paper we study the merits and demerits of different approaches used to design Sparse FIR filter.

2. Literature Review

There are several techniques have been introduced for the design of a Sparse FIR filter.

Oscar Gustafsson and Linda S. DeBrunner proposed an algorithm in paper [5] to design a Sparse FIR filter by considering filter as half-band. A half-band filter is a symmetric even-order FIR filter with specified constraints. The proposed utilize the fact that by increasing the ripples in the pass band, it is possible to obtain an filter with fewer non-zero multiplications. In this method chebyshev error criterion is used. Design results indicate that on increasing pass band ripple, the number of nonzero-coefficients is affected. The proposed method shows an improvement in sparsity as the number of non-zero multipliers is reduced. Even the results are better as compared classical Parks McClellan approach but this method does not prove to be effective.

Dennis Wei design a Sparse FIR filter within specified specifications in the paper [6]. The algorithm is based on p-norm minimization problem with p gradually decreasing from 1 towards 0. The p-norm minimization is a simple algorithm which possesses a desirable property of being an asymptotically exact measure of sparsity as p approaches zero. However, when $p<1$ there is lack of convexity which is tackled by optimization procedure where p is slowly decreased from 1 to 0. Results obtain from the examples given in [8] indicate that the algorithm is capable of yielding sparse filter design as compared to classical approaches. But the design results are not consistent in terms of number of delays in filter design.

In this research [7], Thomas Baran and Dennis Wei pay attention on designing FIR filter with fewest nonzero-coefficients subject to set of frequency domain constraints which is a difficult optimization problem traditional design approaches like Parks McClellan algorithm. Several approximate polynomial-time algorithms are used to design Sparse FIR filter using linear programming. In this approach, two techniques are employed. Firstly, the impulse response of non-sparse filter is iteratively thinned within frequency domain constraints. In second step, the *l*-norm of the impulse response of the filter is minimized to determine the coefficients that are constrained to zero. The technique used in this paper gives better results than the classical Parks McClellan approach. However the problem of nonconvex design still remains means the positions of zero coefficients are not specified in [7].

Wu-Shen Lu and Takao Hinamoto describe a design technique in [8] which attempts to address issues related to design of Sparse FIR filter. The proposed method pays attention on the fact that how a digital filter can be designed to have sparse configuration while improving performance in comparison to its non-sparse counterpart. Two phase design algorithm is introduced in this paper. The non-convexity design problem is due to l_0-norm which is solved by convex design using l_1-norm regularization term. Then the coefficients with small magnitude are forced to zero by applying hard thresh holding algorithm. Finally, to refine the results further a post-processing technique is employed. Earlier design methods consider the design of filter by considering peak-error constraints imposed on the magnitude response. The proposed method employs approximation error mixed with l_0-norm of filter coefficients as the objective function. Results obtained are better but they are not appropriate to understand the effectiveness of proposed algorithm.

Aimin Jiang and Hon Keung Kwan proposed a technique of designing a Sparse FIR digital filter in minimax sense in [9]. In this approach, the l_0-norm is replaced by its l_1 -norm to convert the non-convex design problem to convex optimization problem. The proposed design algorithm consists of two steps method. Firstly, the iterative procedure is followed to find the sparsity pattern and this obtained sparsity pattern is solved to attain a real minimax design by employing iterative procedure. Numerical examples presented in [9] demonstrate the effectiveness of the proposed design algorithm. Design results obtain through the examples are better in performance than results obtain from previous research [7]. The proposed algorithm improves the sparsity of the filter at a cost of slight increase in filter order.

Aimin Jiang and Hon Keung Kwan proposed a new technique in the paper [10] to overcome the non-convexity design problem of the filter. This paper consists of an iterative design algorithm for designing a Sparse non-linear phase FIR filter under the weighted least-squares (WLS) sense. The proposed design method is inspired by iterative shrinkage/thresh holding (IST) algorithm. The design problem is cast as a constrained l_0-norm which is then followed by the iterative procedure. To evaluate the performance of the proposed design method, weighted least-square (WLS) approximation errors are also employed. The design results obtained in this paper [10] in terms of sparsity and WLS approximation error are improved in comparison to minimum l_{0-} norm [7]. This design method can be used to design Sparse FIE filter with high order and overall the algorithm is computationally efficient. But this method is not suitable for designing linear phase Sparse FIR filter.

Aimin Jiang and Hon Keung Kwan proposed a novel algorithm in paper [11] to design Sparse FIR filter. This algorithm is inspired by iterative shrinkage/thresh holding (IST) techniques. The non-convexity design problem which is due to l_0-norm of filter coefficients is tackled in this paper. The iterative procedure is employed to transform a sparse filter design problem into a simpler subproblem. A constrained design problem is constructed in each next iteration. In this work, the linear and non-linear phase FIR filter designs are handled under the same framework of equations which is a great advantage of the proposed method. Numerical examples are presented in paper to demonstrate the performance of the proposed algorithm. The design results in paper [11] reveal better performance in terms of sparsity and also the computation complexity is reduced. The drawback in this method is that this algorithm requires a larger number of core problems and the design results are not consistent.

Chien-Cheng Tseng Su-Ling Lee presents a new approach to design a sparse constrained FIR filter in the paper [12]. The main purpose of this method is to study the design of sparse constrained FIR filter so that the implementation complexity can be reduced. The algorithm used in [12] is orthogonal matching pursuit (OMP) to design the required filter. In this paper, two types of filters are studied. One is design of sparse constrained notch filter and the other is design of sparse constrained low pass filter. The objective of this method is to solve the designing issue by using OMP algorithm in the compressed sense. This method proves to be effective one as the trade-off between sparsity of filter coefficients and magnitude response errors can be made by suitably selecting the prescribed error bound. Numerical in paper [12] demonstrate that the number of zero-valued coefficients is increased on increasing the magnitude response error. But the dependence of result on magnitude response error implies that this method is not computationally efficient as the value of error is to be carefully chosen.

Aimin Jiang and Hon Keung Kwan proposed a technique in paper [13] to design a Sparse FIR filter by reducing the number of nonzero-valued filter coefficients by employing weighted least-square (WLS) approximation error constraints on the frequency domain. Both linear and non-linear phase FIR filter can be designed under this method. It is inspired by iterative shrinkage/thresh holing (IST) algorithm. The proposed design successively transforms the original non-convex problem to a series of subproblems which are simpler. Sparsity is improved effectively which is demonstrated by the numerical examples given in paper [13] as compared to minimum l_{0-}norm algorithm [7]. The design results yield better performance but the effect of filter order on design performance is not taken into account in [13].

Niraja Singh and Pushpraj Tanwar design a Sparse FIR filter in paper [14] by reducing the number of nonzero valued coefficients so that the implementation complexity can be reduced. An efficient algorithm is presented in this research work. To design a Sparse FIR filter an iterative shrinkage/thresh holding (IST) based technique is employed. Many of the design approaches consider an FIR filter designs which are subjected to peak error constraints imposed on magnitude response. However, in this paper weighted least-square (WLS) approximation error constraint imposed on frequency domain is considered on the designing of the filter. The main aim of the proposed algorithm is to transform the original non-convex design problems to a series of subproblems which are simpler. The results obtained from the proposed work show an improvement in sparsity in comparison to earlier approach [7]. The major advantage of this method is that the optimization can be decomposed into a set of scalar optimization problems at each iterative step so that these problems can be efficiently solved. The effect of filter order on the performance is not yet demonstrated in this paper.

Heng Zhao and Wen Bin Ye in paper [15] design Sparse FIR filter by minimizing the number of non-zero coefficients under the required filter order and given frequency domain constraints which is difficult to attain in previous researches. The proposed method consists of Genetic Algorithm for searching the optimal positions of the zero-valued coefficients. This approach is two stage designs where the genes of the chromosomes are encoded as the possible positions of the zero-valued coefficients. After specifying the positions, the chromosome's fitness is evaluated by least squares (LS) error such that higher the chances to survive with smaller error. Efficiency is increased by preliminary optimization stage. Numerical examples demonstrate the sparser results in [15] in comparison to iterative SOCP [11] and smallest coefficient algorithm [7] and minimum order obtained is also effective.

Aimin Jiang and Hon Keung Kwan proposed an efficient algorithm in paper [16] as an attempt to jointly optimize filter as well as sparsity of an FIR filter. Various experiments show that for an FIR filter the sparsity of filter and filter order are highly related. Traditional design methods overlook the impact of filter order on design performance. Such methods only focus on reducing the number of nonzero-coefficients. The proposed design method cast the original design problem as a weighted l_0-norm optimization problem. Then an efficient numerical method iterative –reweighted-least-squares (IRLS) algorithm is used to solve the design problem. Examples are presented in paper [16] to get the desired results. The design results show that the proposed method is capable of improving the sparsity of an FIR filter while determining an appropriate filter order.

3. Future Enhancement and Conclusion

There are various techniques used for designing of a Sparse FIR filter. Every method and algorithm used has its own merits and demerits. For example linear programming used in [7] does not solve the non-convexity design problem. Some techniques do not take the effect of filter order on design performance. Comparative study of different methods used for designing Sparse FIR filter is shown in table I. The future work is to develop a technique suitable for designing a Sparse FIR filter with optimized filter length to further refine the design results given in table I. An appropriate optimization algorithm is to be used for such designing.

Table I Comparative study of different techniques used for sparse FIR filter.

Reference No.	Algorithm used	Design Results	Compared with	Conclusion
[9]	L1-norm mixed with minimax approximation error	Nmin.=90 Sparsity=52	[7] Nmin.=90 Sparsity=49	Simulation results improved in proposed algorithm
[11]	Iterative SOCP with IST technique	Nmin.=80 Sparsity=48	[7] Nmin.=80 Sparsity=33	Increase in number of zero-valued coefficients with proposed method
[13]	IST based algorithm is used subjected to WLS approximation error	P= 5.0 Sparsity= 20	[7] P=5.0 Sparsity=16	Results improved in terms of sparsity
[15]	Genetic algorithm	Nmin.=44 NZ=29	[11] Nmin.=80 NZ=33	Sparser results than the existing algorithm
[16]	IRLS algorithm	Nmin.=76 NZ=55	[7] Nmin.=80 NZ=57	Improvement in sparsity while determining appropriate filter order

References

[1]D. Li, Y. C. Lim, Y. Lian, and J. Song, "A polynomial-time algorithm for designing FIR filters with power-of-two coefficients", IEEE Trans. Signal Process., vol.50, pp. 1935-1941, Aug. 2002.

[2]W.-S. Lu and T. Hinamoto, "Optimal design of frequency-response masking filters using semidefinite programming",

IEEE Trans.Circuits Syst. I, Reg. Papers, vol.50, no. 4, pp. 557-568, Apr. 2003.

[3] Ya Jun Yu and Yong Chin Lim, "Design of linear phase FIR filter in subexpression Space using mixed integer linear programming", IEEE Trans. Circuits Syst. I, Reg. Papers, vol. 54, pp. 2330-2338, Oct. 2007.

[4] D. Shi and Y. J. Yu, "Design of linear phase FIR filters with high probability of achieving minimum number of adders", IEEE Trans. Circuits Syst.I, Reg. Papers, vol.58, pp. 126-136, Jan. 2011.

[5] O. Gustafsson, L. DeBrunner, V. DeBrunner, and H. Johansson, "On the design of sparse half-band like FIR filters", in Proc. 41st Asilomar Conf. Signal, Syst., pp. 1098-1102, IEEE, 2007.

[6] Dennis Wei, "Non-Convex optimization for the design of sparse FIR filter", in IEEE 15th Workshop Statist. Signal process., pp. 117-120, Sep. 2009.

[7] T. Baran, D. Wei, and A. V. Oppenheim, "Linear programming algorithms for sparse filter design", IEEE Trans. Signal Process., vol.58, pp.1605-1617, Mar. 2010.

[8]W.-S. Lu and T. Hinamoto, "Digital filters with sparse coefficients",in Proc. IEEE Int. Symp. Circuits Syst.,pp. 169-172, May 2010.

[9] Aimin Jiang and Hon Keung Kwan, "Minimax design of sparse FIR digital filters", Acoustics, Speech and Signal Process., IEEE, pp.-3497-3500, March 2012.

[10]Aimin Jiang and Hon Keung Kwan, "Efficient design of sparse FIR filters in WLS sense", Circuits and Systems, IEEE, Int. Symp., pp.41-44, May 2012.

[11] A. Jiang, H. K. Kwan, and Y. Zhu, "Peak-error-constrained sparse FIR filter design using iterative SOCP", IEEE Trans. Signal Process., vol.60, pp. 4035-4044, Aug. 2012.

[12]Chien-Cheng Tseng and Su-ling lee, "Design of sparse constrained FIR filter using Orthogonal matching pursuit method", IEEE ISPACS , pp. 308-313, Nov. 2012.

[13] A. Jiang and H. K. Kwan, "WLS design of sparse FIR digital filters", IEEE Trans. Circuits Syst. I, Reg. Papers, vol.60, pp. 125-135, Jan. 2013.

[14] Niraja Singh and Pushpraj Tanwar, "FIR (sparse) filter design using IST algorithm", IJIET, vol. 2, Issue 2, pp.386-394, April 2013.

[15]Heng Zhao, Wen Bin Ye and Ya Jun Yu, "Sparse FIR filter design based on Genetic Algorithm", in Proc. IEEE Int. Symp. Circuits Syst., pp. 97-100, May 2013.

[16] Aimin Jiang and Hon Keung Kwan, "Efficient Design of Sparse FIR Filters with Optimized Filter Length" , IEEE Circuits and Systems., pp. 966-969, 2014

Author Profile

Navreet Kaur received the Bachelor of Technology degree in Electronics and Communication Engineering from Haryana College of Technology and Management (Kurukshetra University) Haryana, India in 2013.She is pursuing Master of Technology degree in Electronics and Communication from Geeta Institute of Management and Technology (Kurukshetra University) Haryana, India.